No. 126, Original

In the
SUPREME COURT OF THE UNITED STATES

STATE OF KANSAS,
Plaintiff
v.

STATE OF NEBRASKA and
STATE OF COLORADO,
Defendants.

Before Special Master William J. Kayatta, Jr.

Future Impacts of Pumping on Ground Water Consumptive Use

Expert Report of Samuel P. Perkins[1] and Steven P. Larson[2]

[1]Civil Engineer, Interstate Water Issues, Kansas Dept. Of Agriculture, Div. of Water Resources;
[2]S. S. Papadopulos & Associates, Inc., Bethesda, MD.

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Introduction

The RRCA Groundwater Model was used to estimate future impacts of pumping and reductions in pumping on groundwater computed beneficial consumptive use (GWCBCU) and the imported water supply credit (IWS) in Nebraska. These estimates were made as part of the effort to evaluate what level of pumping reduction in Nebraska would be required so that Nebraska would be in a position to maintain compact compliance when dry periods recur in the future, at least over the next several decades. The focus of this effort is to evaluate the impact of dry periods that might occur several decades from now on the ability of Nebraska to maintain compact compliance, at least at that time.

Specifically, the model was used to compute the effect of various levels of reduced pumping in Nebraska on future groundwater consumptive use and on the imported water supply credit. Pumping reductions over several different geographic areas were considered in the calculations. For each pumping reduction that was considered, calculations were made over a 60-year future period by cycling the hydrologic conditions for the historical years 1995 to 2009 four times.

A series of calculations were made for each of several different geographic areas over which reductions in future pumping were considered. The series consisted of different levels of pumping reduction from a baseline amount of pumping within a specific geographic area. The results could then be compiled and used to estimate the amount of future pumping reduction necessary to achieve a specific reduction in GWCBCU and changes in IWS for that geographic area.

Method of Analysis

The first step in the analysis was to select a baseline level of pumping in Nebraska. Under the concept of the Integrated Management Plans (IMP) as we understand them, future pumping in the three natural resources districts (NRD) will be limited to an average value for each NRD. The average value is eighty percent of the average pumping that occurred during the years 1998 to 2002. The 1998 to 2002 average pumping values are defined in the IMPs as 531,763 acre-feet for the Upper Republican NRD (URNRD, 2010), 309,479 acre-feet for the Middle Republican NRD (MRNRD, 2010) and 242,289 acre-feet for the Lower Republican NRD (LRNRD, 2011). Eighty percent of these values yields 425,410 acre-feet for the URNRD, 247,583 acre-feet for the MRNRD, and 193,831 acre-feet for the LRNRD. These average pumping amounts were assumed to apply to irrigated acreage as of 2006.

A further constraint, as we understand the IMPs, is that allocations of water to irrigated acreage are limited, at least as a total over a period of years. Based on this constraint and the limitations on longer term average pumping described above, a sequence of irrigation depths was developed that attempts to follow the pattern of actual irrigation depths over the period from 1995 to 2006 but produces a sequence that is within the aforementioned constraints on irrigation depth and average pumping volume for each NRD. The result of that process is shown on Table 1 for each year and for each of the three NRDs.

Hydrologic conditions such as precipitation and evapotranspiration for the years 1995 to 2009 were used to represent future hydrologic conditions. This 15-year period was repeated four times to yield a 60-year future period of analysis. This 15-year period was selected for several reasons. First, the period contained both wet and dry climatic conditions. Second, the average precipitation within Nebraska for this period was very close to the average precipitation over the past 50 years. Third, the irrigation conditions in terms of measures such as acreage and applied water during this period are likely more representative of current practices. Fourth, the selected conditions produce trends in GWCBCU that are comparable to trends observed in model runs made by Nebraska to estimate potential future increases in GWCBCU.

Several different geographic areas were initially tested to determine the impact of pumping reductions that were limited to these areas. The areas included the so-called 10-2 and 10-5 areas described in various Nebraska documents and nominal 5-mile and 7-mile stream corridors determined from stream cell locations in the Republican River Compact Administration (RRCA) Groundwater Model. These initial tests indicated that the nominal 5-mile corridor would encompass an area where pumping reductions could produce sufficient reductions in Nebraska's GWCBCU for purposes of this analysis. The extent of the nominal 5-mile stream corridor in which pumping was reduced is shown on Figure 1.

Using the conditions outlined above, the RRCA Groundwater Model was used to calculate potential future impacts to Nebraska's GWCBCU and IWS resulting from reduced levels of pumping within the NRDs. The results of those calculations are summarized in the tables below.

Table 1 below shows the estimated future GWCBCU and IWS for Nebraska for each of the years 2010 to 2069 (60 years) for the baseline pumping condition. As described previously, the baseline pumping condition was set so that the average pumping volume over each 15-year future cycle for each of the three NRDs was equivalent to the average pumping limitation described in the IMPs. This average pumping limitation was eighty percent of the historical pumping amounts for 1998 through 2002 listed in the IMPs.

Table 2 below shows the estimated future GWCBCU and IWS for Nebraska for each of the years 2010 to 2069 (60 years) for a pumping condition in which all baseline pumping within the nominal 5-mile stream corridor has been eliminated. In this pumping condition, the overall average annual NRD pumping has been reduced from 867,837 acre-feet in the baseline pumping condition to 607,778 acre-feet.

Table 3 below shows the estimated future GWCBCU and IWS for Nebraska for each of the years 2010 to 2069 (60 years) for a pumping condition in which baseline pumping within the 5-mile stream corridor has been reduced to twenty percent of the baseline amount (an eighty percent reduction in the baseline pumping within the corridor). In this pumping condition, the overall average annual NRD pumping has been reduced from 867,837 acre-feet in the baseline pumping condition to 659,790 acre-feet.

Table 4 below shows the estimated future GWCBCU and IWS for Nebraska for each of the years 2010 to 2069 (60 years) for a pumping condition in which baseline pumping within the 5-mile stream corridor has been reduced to forty percent of the baseline amount (a sixty percent reduction in the baseline pumping within the corridor). In this pumping condition, the overall average annual NRD pumping has been reduced from 867,837 acre-feet in the baseline pumping condition to 711,801 acre-feet.

The results of all of the calculations shown on Tables 1 through 4 are shown graphically on Figure 2.

Based on discussions with Spronk Water Engineers, results for an intermediate pumping reduction between the eighty percent result shown on Table 3 and the 100 percent reduction result shown on Table 2 was also calculated. Table 5 shows the estimated future GWCBCU and IWS for Nebraska for each of the years 2010 to 2069 (60 years) for a pumping condition in which baseline pumping within the 5-mile stream corridor has been reduced to ten percent of the baseline amount (a ninety percent reduction in the baseline pumping within the corridor). In this pumping condition, the overall average annual NRD pumping has been reduced from 867,837 acre-feet in the baseline pumping condition to 633,784 acre-feet.

Sensitivity Tests

The future baseline pumping conditions used in the calculations described above represent a reduction in the amount of water applied per acre from the amount that was actually applied per acre under the historical hydrologic conditions. This reduction was a result of the assumption that future average pumping would be limited to eighty percent of the 1998 to 2002 historical average pumping as described in the IMPs and the assumption that each NRD would not be able to exceed its specific five-year allocation over any five-year period. These constraints on water application could lead to irrigation practices that increase the overall efficiency from the 80 percent value assumed in our analysis. In fact, it is quite probable that current irrigation practices have overall efficiencies that are higher than 80 percent. In any event, higher irrigation efficiencies translate into greater consumptive use and reduced return flows relative to a given amount of applied water. Under these conditions, net pumping (the amount pumped less irrigation return flows) could be higher than the values assumed in our calculations which assumed an efficiency of 80 percent.

To test the impact of the assumed efficiency on the model results described previously, two additional model runs were made using an assumed efficiency of 90 percent rather than 80 percent. The first test run was for the future baseline pumping condition. The results of that analysis are shown on Table 6 and can be compared to the previous baseline results shown on Table 1. The two results are compared graphically on Figure 3.

The second test run was for the pumping condition in which future pumping was reduced to ten percent of the baseline pumping amount within the nominal 5-mile corridor (a ninety percent reduction in pumping within the corridor). The results of that analysis are also shown on Table 6 and can be compared to the previous results shown on Table 5. These two results are also compared graphically on Figure 3.

These sensitivity tests demonstrate that if future pumping reductions lead to more efficient irrigation practices than was assumed in our analysis, estimated future GWCBCU will be higher than the values presented in Tables 1 through 4.

Comparable Future Scenario Model Runs Performed by Nebraska

In the past, Nebraska has conducted and, in some cases, presented, runs of the RRCA Groundwater Model that attempt to estimate future impacts on Nebraska's GWCBCU for various assumed amounts of future pumping and various hydrologic conditions (NE External Hard Drive, 2011). Results of these model runs were compared to the model runs using the repeated cycles of 1995 to 2009 hydrology. These comparisons demonstrate that the 1995 to 2009 hydrology provides a reasonable surrogate for future hydrologic conditions in terms of evaluating potential impacts of reduced pumping on Nebraska's GWCBCU.

In 2006, Nebraska used the RRCA Groundwater Model to make calculations of the future impacts of reducing pumping on GWCBCU in Nebraska. These calculations were summarized in a handout dated July 13, 2006 (Nebraska DNR, 2006) that was prepared for a special meeting of the Upper Republican NRD. The calculations used hydrologic conditions from the historical period from 1981 through 2000 to represent future hydrologic conditions. This 20-year hydrologic period was cycled twice to produce a 40-year study period extending from 2006 to 2045. Using this future study period, the RRCA Groundwater Model was used to calculate Nebraska's GWCBCU assuming various levels of reduced pumping over different geographic areas. The impact of reduced pumping was compared against impacts under a baseline condition on various graphs contained in the July 13, 2006 handout.

The model results for the baseline condition and for many of the reduced pumping conditions show an increasing level of GWCBCU in Nebraska over the 40-year study period. As might be expected, the steepest trend occurs in the baseline condition and trends decrease as the overall amount of pumping is reduced. For example, the trend line for GWCBCU for the baseline condition has a slope of about 1,540 acre-feet/year per year (see Figure 4). The average annual pumping for the three NRDs (UR, MR, and LR) under the baseline condition was about 1,000,400 acre-feet. When pumping in three NRDs (UR, MR, and LR) and in the Tri-Basin NRD was reduced by 15%, the slope of the trend line for GWCBCU decreased to 1,140 acre-feet/year per year. The average annual pumping in three NRDs (UR, MR and LR) under this condition (referred to as RED15 in the handout) was about 853,100 acre-feet. When pumping in the four NRDs (UR, MR, LR and TB) area was reduced by 25%, the slope of the trend line for GWCBCU decreased to 808 acre-feet/year per year. The average annual pumping in the three NRDs (UR, MR, and LR) under this condition (referred to as RED25 in the handout) was about 754,900 acre-feet. When pumping in the four NRDs (UR, MR, LR and TB) area was reduced by 50%, the slope of the trend line for GWCBCU became negative showing a decrease in GWCBCU over the study period. The average annual pumping in the three NRDs (UR, MR, and LR) under this condition (referred to as RED50 in the handout) was about 509,400 acre-feet.

The slope of the trend in Nebraska GWCBCU over the study period in our analysis that used four repeated cycles of hydrologic conditions for the historical years 1995 through 2009 was about 1,000 acre-feet/year per year. The average annual pumping in the three NRDs (UR, MR, and LR) for the baseline condition in our analysis was about 872,000 acre-feet. Thus, the slope of the trend in our analysis is somewhat lower than the trends in Nebraska's 2006 analysis under comparable pumping conditions.

It is also worth noting that the slope of trends for the different Nebraska runs is highly correlated to the amount of pumping. Although this relationship is not unexpected, the correlation shows that a slope of zero would occur when the average annual pumping in the three NRDs was reduced to about 545,000 acre-feet (Figure 5). This level of reduced pumping in the three NRDs is similar to the amount of pumping that Nebraska concluded was necessary to ensure compact compliance in all years as outlined in Option 1 that was presented to the three NRDs in October 2009. This option was not selected for implementation in the IMPs. Another option that was characterized as ensuring compact compliance in most years formed the basis for implementation in the IMPs.

After 2006, Nebraska conducted additional evaluations using the RRCA Groundwater Model to estimate potential future amounts of GWCBCU. One of these evaluations used randomly generated sequences of future hydrologic conditions over a 40-year study period from 2008 through 2047. In one of Nebraska's evaluations, a total of 510 randomly generated sequences of future hydrologic conditions were tested. According to Nebraska, the purpose of this modeling approach "was to get a better handle on the envelope of future possibilities given historic climate data" (Schneider Deposition, October 24, 2011, page 30). This Nebraska analysis was apparently abandoned for unknown reasons but the results of their calculations are instructive with regard to the future hydrologic conditions used in our analysis.

This second Nebraska analysis used pumping conditions that were constant over the 40-year study period. In other words, the pumping conditions were the same during wet years and dry years. In our analysis, the projected future pumping varied from year to year in a manner that attempted to follow how historical pumping occurred within certain limits. However, the average annual pumping for the three NRDs used in our analysis was very close to the comparable pumping in the Nebraska analysis. The average annual pumping for the three NRDs in our baseline analysis was about 872,000 acre-feet. In the Nebraska analysis, the annual pumping for the three NRDs was about 865,400 acre-feet. By this measure, the two analyses are fairly comparable.

Results from the 510 model runs conducted by Nebraska in this second analysis were compiled to evaluate the variation in the slope of the trend in GWCBCU for the 510 random sequences of hydrologic conditions. This compilation produced 510 values of slope corresponding to the trend in GWCBCU for each random sequence. The median slope of the 510 values was about 720 acre-feet/year per year. The 75th percentile slope was about 1,530 acre-feet/year per year. As discussed previously, the slope of the trend in Nebraska GWCBCU over the study period in our analysis that used four repeated cycles of hydrologic conditions for the historical years 1995 through 2009 was about 1,000 acre-feet/year per year. A slope of 1,000 acre-feet/year per year is equivalent to about the 60th percentile slope derived from the Nebraska analysis. This means that the slope of the trend used in our analysis is near the center of the distribution of slope values generated by the Nebraska analysis.

The 510 model runs conducted by Nebraska were also evaluated to characterize conditions that might occur during future dry periods. The sequence of historical years used to generate the random sequences of hydrologic conditions in the Nebraska analysis was from 1918 through 2005. During these years, several dry years stand out as being particularly low in overall precipitation. Four of these particularly dry years (1934, 1936, 1956, and 2002) were selected as indicators of when dry hydrologic conditions were present. In the Nebraska analysis, each future year from 2008 to 2047 had 510 results. Each of these 510 future year results were examined to see when one of the four particularly dry years occurred in the sequence of annual values. The calculated GWCBCU values for each of these particularly dry years were collected for each future year in the analysis and were statistically characterized. The median of the collected values for each year shows an increasing trend of about 700 acre-feet/year per year (see Figure 6). Over the 40-year study period, this trend increased to a GWCBCU of about 218,000 acre-feet after 40 years. Our analysis included one of those particularly dry years, 2002. Each time that dry year occurred in the repeated cycle of hydrologic conditions in our analysis, GWCBCU declined to a local minimum along the generally increasing trend of annual values of GWCBCU. During the third cycle, at the 38th year of the future calculations (with 2002 hydrologic conditions), the GWCBCU was calculated in our analysis at a little less than 222,000 acre-feet. This value is only a few percent greater than the value shown by the trend after 40 years of median values for particularly dry years in the Nebraska analysis.

The comparisons described above demonstrate that the repeated 15-year cycle of hydrologic conditions for the historical years 1995 through 2009 provide a reasonable surrogate for future hydrologic conditions for the purpose of evaluating Nebraska's future GWCBCU and IWS credit using the RRCA Groundwater Model.

Additional Calculations

At the request of David Barfield, we have conducted several calculations of future Nebraska GWCBCU using the RRCA Groundwater Model under various assumptions regarding the nature and duration of future pumping curtailment in Nebraska. Specifically, three different pumping curtailment scenarios were evaluated. The first scenario calculated the impact of reducing the overall pumping in the three NRDs (UR, MR and LR NRDs) to an average of 75% of the historical average pumping during the years 1998 through 2002. In the second scenario, future pumping was removed (100% curtailment) from the Rapid Response Region (the area referred to as the 10-percent/2-year response area) defined in the NRD IMPs for each future year. In the third scenario, future pumping was removed (100% curtailment) from the Rapid Response Region for each future year corresponding to historical years 2002 through 2007 (a 6-year curtailment period during each 15-year future cycle).

Table 7 and Figure 7 tabulate and illustrate, respectively, the calculated future Nebraska GWCBCU results for the first scenario. For convenience, the results for the baseline conditions using an average of 80% of the historical average pumping during the years 1998 through 2002 have been included on the table and figure. The difference in calculated GWCBCU between the baseline using 80% of average pumping for the period 1998 through 2002 and the 75% scenario are tabulated in Table 7 and shown graphically on Figure 7a.

Table 8 and Figure 8 compile the future Nebraska GWCBCU results for scenarios two and three and also include the results for the baseline condition for comparison. Differences between the results for the baseline condition and the results for scenarios two and three are also shown on Table 8 and depicted graphically on Figure 8a.

The impact of future groundwater pumping in Nebraska on stream baseflow conditions is also of interest in evaluating the potential effects of future pumping curtailment. Stream baseflow interaction is a fundamental component of the RRCA groundwater model. Calculations of total stream baseflow were made for some of the future pumping scenarios described previously. Specifically, future total stream baseflows were calculated for the baseline pumping condition (an average of 80% of the average historical pumping for the period 1998 through 2002) and for the scenario in which ninety percent of the baseline pumping within the nominal 5-mile corridor was removed. The results of those calculations are given on Table 9 and shown graphically on Figure 9.

It is also worth comparing the calculated stream baseflow impacts described above with stream baseflow impacts calculated by Nebraska in their analysis of random future sequences of hydrologic conditions that was discussed earlier in this report. The 510 model runs conducted by Nebraska in that analysis were evaluated with regard to total stream baseflow that might occur during future dry periods. Using the same criteria that were used to evaluate Nebraska's median GWCBCU as depicted on Figure 6, the median annual total stream baseflow was compiled from the 510 model run results. Figure 10 is a graph of median annual total stream baseflow as compiled from the results of Nebraska's analysis.

The trend over time in the baseflows shown on Figure 10 is downward at about 1,100 acre-feet/year per year. This downward trend is greater than the downward trend shown on Figure 9 for our analysis (which is about 550 acre-feet/year per year). The upward trend in Nebraska's GWCBCU as shown on Figure 6 was about 700 acre-feet/year per year as compared to an upward trend of about 1,000 acre-feet/year per year in our analysis. The differences in these trends are likely largely related to differences in future hydrologic conditions between the two analyses. The future hydrologic conditions used in our analysis are somewhat wetter than the median hydrologic conditions used in the Nebraska analysis. As a result of this difference, the upward trend for Nebraska GWCBCU in our analysis is greater than the comparable upward trend in the Nebraska analysis and, conversely, the downward trend in total stream baseflow in our analysis is lower than the comparable downward trend in the Nebraska analysis.

References

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2. MRNRD, 2010, "INTEGRATED MANAGEMENT PLAN Jointly Developed by the DEPARTMENT OF NATURAL RESOURCES and the MIDDLE REPUBLICAN NATURAL RESOURCES DISTRICT".
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4. Nebraska DNR, 2006, "Handouts for Upper Republican Natural Resources District – Special Meeting, July 13, 2006".
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    b. Stochastic Simulations: \6-MODFLOW_RUNS_LARGE\Stochastic\2008\A

Table 1: Estimated future Nebraska GWCBCU and IWS credit under baseline pumping conditions.

	Baseline Pumping	
Year	GWCBCU	IWS Credit
2010	219,024	20,114
2011	237,236	27,149
2012	215,901	18,975
2013	210,701	18,392
2014	227,386	18,710
2015	207,407	19,354
2016	220,607	18,018
2017	192,150	14,259
2018	205,713	10,867
2019	214,398	12,227
2020	216,990	15,304
2021	209,699	13,291
2022	230,506	23,099
2023	233,101	25,233
2024	247,268	22,478
2025	236,422	20,418
2026	258,468	26,684
2027	235,544	19,353
2028	229,825	18,643
2029	246,859	18,607
2030	225,741	19,101
2031	238,137	17,287
2032	208,415	14,072
2033	222,002	11,363
2034	232,037	12,025
2035	233,330	14,843
2036	226,775	12,897
2037	248,109	22,658
2038	250,287	25,698
2039	264,810	22,418
2040	255,787	21,739
2041	278,182	26,928
2042	253,308	19,927
2043	244,362	18,890
2044	264,906	18,500
2045	240,710	17,905
2046	253,690	16,992
2047	221,670	13,702
2048	236,904	11,940
2049	246,919	12,372
2050	247,989	14,516
2051	239,965	12,650
2052	264,301	22,499
2053	265,084	26,143
2054	279,990	22,788
2055	270,662	22,259
2056	295,314	27,203
2057	268,139	20,515
2058	256,958	19,101
2059	278,625	18,407
2060	253,551	17,547
2061	266,656	16,822
2062	233,746	13,506
2063	247,751	12,237
2064	259,416	12,742
2065	260,600	14,232
2066	250,927	12,561
2067	276,719	22,091
2068	278,538	26,789
2069	293,501	23,122

Table 2: Estimated future Nebraska GWCBCU and IWS credit with all (100%) baseline irrigation pumping removed from the nominal 5-mile stream corridor.

	100% Pumping Reduction in 5-mile Corridor	
Year	GWCBCU	IWS Credit
2010	200,081	24,331
2011	192,295	27,266
2012	176,412	24,606
2013	163,086	23,156
2014	172,043	27,359
2015	155,622	22,995
2016	157,600	26,267
2017	141,833	20,088
2018	153,961	24,633
2019	158,728	26,918
2020	155,620	25,281
2021	150,798	25,968
2022	161,674	28,073
2023	160,374	28,857
2024	165,094	29,063
2025	162,064	28,517
2026	167,757	29,854
2027	161,531	28,704
2028	155,617	27,560
2029	165,534	29,944
2030	154,456	26,769
2031	157,007	29,075
2032	145,132	23,165
2033	157,853	27,834
2034	162,854	29,319
2035	160,332	27,941
2036	157,120	28,302
2037	168,463	30,588
2038	168,222	31,467
2039	173,517	31,542
2040	171,448	31,141
2041	177,836	32,372
2042	171,362	31,184
2043	164,844	29,847
2044	176,787	32,284
2045	164,645	29,024
2046	167,435	31,182
2047	154,721	25,107
2048	169,494	29,907
2049	173,882	31,158
2050	171,424	29,802
2051	167,593	29,994
2052	180,744	32,610
2053	180,137	33,483
2054	185,875	33,536
2055	182,350	33,043
2056	190,847	34,457
2057	182,876	33,089
2058	175,990	31,624
2059	188,415	34,044
2060	176,276	30,790
2061	178,804	32,892
2062	165,154	26,548
2063	180,268	31,192
2064	185,857	32,681
2065	182,434	31,196
2066	178,046	31,345
2067	191,578	33,983
2068	192,355	35,139
2069	198,254	35,204

Table 3: Estimated future Nebraska GWCBCU and IWS credit with eighty percent of baseline irrigation pumping removed from the nominal 5-mile stream corridor.

	80% Pumping Reduction in 5-mile Corridor	
Year	GWCBCU	IWS Credit
2010	204,461	23,199
2011	201,612	27,525
2012	185,253	23,554
2013	173,043	21,932
2014	185,194	26,685
2015	166,851	21,305
2016	171,621	25,813
2017	155,280	18,909
2018	168,335	21,531
2019	174,054	25,694
2020	169,671	23,920
2021	166,120	25,240
2022	177,808	27,329
2023	175,188	28,267
2024	181,887	28,346
2025	178,516	26,933
2026	185,573	29,459
2027	178,211	27,302
2028	171,783	25,826
2029	184,650	29,384
2030	170,974	24,501
2031	175,685	28,202
2032	162,370	20,981
2033	176,443	25,060
2034	182,205	28,007
2035	178,302	26,017
2036	175,436	27,462
2037	187,645	29,551
2038	185,878	30,633
2039	193,202	30,579
2040	190,442	29,372
2041	198,427	31,742
2042	190,256	29,504
2043	183,141	27,823
2044	198,238	31,565
2045	183,098	26,498
2046	188,038	30,161
2047	173,451	22,330
2048	189,594	26,795
2049	194,975	29,660
2050	190,779	27,706
2051	186,860	28,894
2052	201,236	31,402
2053	199,099	32,535
2054	207,400	32,505
2055	202,638	31,123
2056	213,401	33,743
2057	202,963	31,231
2058	195,187	29,394
2059	210,968	33,169
2060	195,224	28,103
2061	199,789	31,713
2062	183,949	23,408
2063	200,300	27,677
2064	207,624	31,007
2065	202,250	28,930
2066	197,366	30,093
2067	212,485	32,656
2068	211,961	34,099
2069	220,636	34,033

Table 4: Estimated future Nebraska GWCBCU and IWS credit with sixty percent of baseline irrigation pumping removed from the nominal 5-mile stream corridor.

	60% Pumping Reduction in 5-mile Corridor	
Year	GWCBCU	IWS Credit
2010	208,645	22,087
2011	210,866	27,747
2012	193,495	22,296
2013	183,064	20,971
2014	197,731	25,514
2015	177,234	20,427
2016	185,849	24,715
2017	167,718	17,918
2018	179,589	18,029
2019	187,936	20,931
2020	184,195	23,715
2021	180,013	23,588
2022	193,938	26,898
2023	190,082	27,927
2024	199,057	27,525
2025	193,599	24,980
2026	204,052	29,400
2027	194,036	25,519
2028	187,607	24,110
2029	203,459	28,235
2030	186,026	22,317
2031	194,517	27,029
2032	178,450	19,577
2033	191,351	20,248
2034	199,826	23,291
2035	195,847	25,248
2036	192,538	25,732
2037	206,503	28,637
2038	203,452	30,162
2039	213,489	29,552
2040	208,159	27,092
2041	219,647	31,570
2042	208,143	27,402
2043	200,800	25,797
2044	219,018	30,185
2045	199,458	23,902
2046	208,117	28,788
2047	189,295	20,571
2048	204,670	21,466
2049	212,446	24,329
2050	209,422	26,409
2051	203,866	26,846
2052	220,546	30,162
2053	217,508	31,942
2054	229,194	31,347
2055	221,190	28,553
2056	236,018	33,522
2057	221,579	28,844
2058	213,293	27,152
2059	232,503	31,389
2060	211,666	25,313
2061	219,868	30,024
2062	199,666	21,376
2063	214,424	22,084
2064	224,162	25,237
2065	220,499	27,271
2066	213,824	27,707
2067	231,093	31,188
2068	229,844	33,336
2069	241,935	32,631

Table 5: Estimated future Nebraska GWCBCU and IWS credit with ninety percent of baseline irrigation pumping removed from the nominal 5-mile stream corridor.

	90% Pumping Reduction in 5-mile Corridor	
Year	GWCBCU	IWS Credit
2010	202,313	23,759
2011	196,943	27,413
2012	180,903	24,108
2013	168,066	22,495
2014	178,651	27,081
2015	161,361	22,201
2016	164,599	25,997
2017	148,582	19,466
2018	161,347	23,514
2019	166,498	26,373
2020	162,754	24,494
2021	158,531	25,667
2022	169,749	27,665
2023	167,787	28,555
2024	173,428	28,717
2025	170,453	27,788
2026	176,579	29,629
2027	169,972	28,015
2028	163,789	26,729
2029	175,004	29,697
2030	162,886	25,703
2031	166,379	28,573
2032	153,876	21,928
2033	167,315	26,670
2034	172,699	28,824
2035	169,426	27,003
2036	166,318	27,844
2037	178,092	30,056
2038	177,044	31,029
2039	183,283	31,066
2040	181,160	30,326
2041	188,051	32,012
2042	180,938	30,349
2043	174,147	28,873
2044	187,433	31,937
2045	174,095	27,829
2046	177,726	30,621
2047	164,336	23,558
2048	179,966	28,610
2049	184,847	30,629
2050	181,340	28,764
2051	177,416	29,384
2052	191,131	31,994
2053	189,773	32,975
2054	196,634	33,016
2055	192,771	32,158
2056	201,981	34,026
2057	193,083	32,185
2058	185,865	30,541
2059	199,842	33,666
2060	186,037	29,518
2061	189,304	32,269
2062	174,764	24,829
2063	190,788	29,769
2064	197,043	32,089
2065	192,532	30,076
2066	188,013	30,670
2067	202,193	33,320
2068	202,174	34,555
2069	209,290	34,625

Table 6: Estimated future Nebraska GWCBCU under baseline pumping conditions and ninety percent of baseline irrigation pumping removed from the nominal 5-mile stream corridor and with irrigation efficiency increased to ninety percent.

	Baseline Pumping with 90% Efficiency	90% Pumping Reduction in 5-mile Corridor with 90% Efficiency
Year	GWCBCU	GWCBCU
2010	220,951	202,604
2011	242,622	197,698
2012	220,704	181,794
2013	215,818	169,254
2014	231,770	180,457
2015	213,659	163,217
2016	226,295	167,038
2017	197,231	151,224
2018	211,226	164,398
2019	220,207	170,148
2020	223,507	166,613
2021	216,350	162,670
2022	237,717	174,575
2023	240,997	172,866
2024	256,448	179,245
2025	248,749	176,072
2026	270,761	183,082
2027	247,169	176,122
2028	238,512	169,845
2029	255,932	182,245
2030	235,616	169,394
2031	247,722	173,397
2032	217,202	160,668
2033	230,213	174,574
2034	240,687	180,801
2035	243,583	177,526
2036	236,266	174,382
2037	259,174	187,126
2038	261,694	186,272
2039	276,616	193,370
2040	271,908	190,503
2041	292,652	198,603
2042	268,690	190,603
2043	255,100	183,500
2044	276,957	198,479
2045	251,724	183,664
2046	265,691	187,816
2047	232,662	173,463
2048	246,821	189,233
2049	256,984	195,219
2050	260,178	191,832
2051	250,481	187,269
2052	278,098	202,450
2053	278,918	201,264
2054	294,361	209,586
2055	287,686	204,513
2056	312,262	215,466
2057	284,950	205,034
2058	269,861	197,121
2059	292,315	212,999
2060	265,721	197,161
2061	279,888	201,011
2062	245,597	184,665
2063	258,245	200,621
2064	269,754	207,960
2065	273,151	203,735
2066	261,921	198,155
2067	291,958	213,845
2068	293,849	214,432
2069	309,431	224,128

Table 7: Estimated future Nebraska GWCBCU under baseline pumping conditions and 75% of historical average pumping during the period 1998-2002.

Year	Baseline Pumping (80% of Historical 1998-2002) GWCBCU	75% of Historical 1998-2002 GWCBCU	Difference in GWCBCU (80% versus 75% of Historical Pumping 1998-2002) GWCBCU
2010	219,024	218,043	981
2011	237,236	234,390	2,846
2012	215,901	213,457	2,444
2013	210,701	207,893	2,808
2014	227,386	224,934	2,452
2015	207,407	203,774	3,633
2016	220,607	217,694	2,913
2017	192,150	189,613	2,537
2018	205,713	202,802	2,911
2019	214,398	211,535	2,863
2020	216,990	213,725	3,265
2021	209,699	206,307	3,392
2022	230,506	226,947	3,559
2023	233,101	228,381	4,720
2024	247,268	241,421	5,847
2025	236,422	230,435	5,987
2026	258,468	251,617	6,851
2027	235,544	229,608	5,936
2028	229,825	224,666	5,159
2029	246,859	242,263	4,596
2030	225,741	219,825	5,916
2031	238,137	233,132	5,005
2032	208,415	204,057	4,358
2033	222,002	217,833	4,169
2034	232,037	227,304	4,733
2035	233,330	228,315	5,015
2036	226,775	221,806	4,969
2037	248,109	242,728	5,381
2038	250,287	244,381	5,906
2039	264,810	257,962	6,848
2040	255,787	247,543	8,244
2041	278,182	269,714	8,468
2042	253,308	245,654	7,654
2043	244,362	238,486	5,876
2044	264,906	258,546	6,360
2045	240,710	233,985	6,725
2046	253,690	247,452	6,238
2047	221,670	216,034	5,636
2048	236,904	231,730	5,174
2049	246,919	241,398	5,521
2050	247,989	241,649	6,340
2051	239,965	233,964	6,001
2052	264,301	257,512	6,789
2053	265,084	258,022	7,062
2054	279,990	272,662	7,328
2055	270,662	260,942	9,720
2056	295,314	285,988	9,326
2057	268,139	259,175	8,964
2058	256,958	250,381	6,577
2059	278,625	271,397	7,228
2060	253,551	246,356	7,195
2061	266,656	259,541	7,115
2062	233,746	227,342	6,404
2063	247,751	241,971	5,780
2064	259,416	253,626	5,790
2065	260,600	253,308	7,292
2066	250,927	244,462	6,465
2067	276,719	268,720	7,999
2068	278,538	270,614	7,924
2069	293,501	285,100	8,401

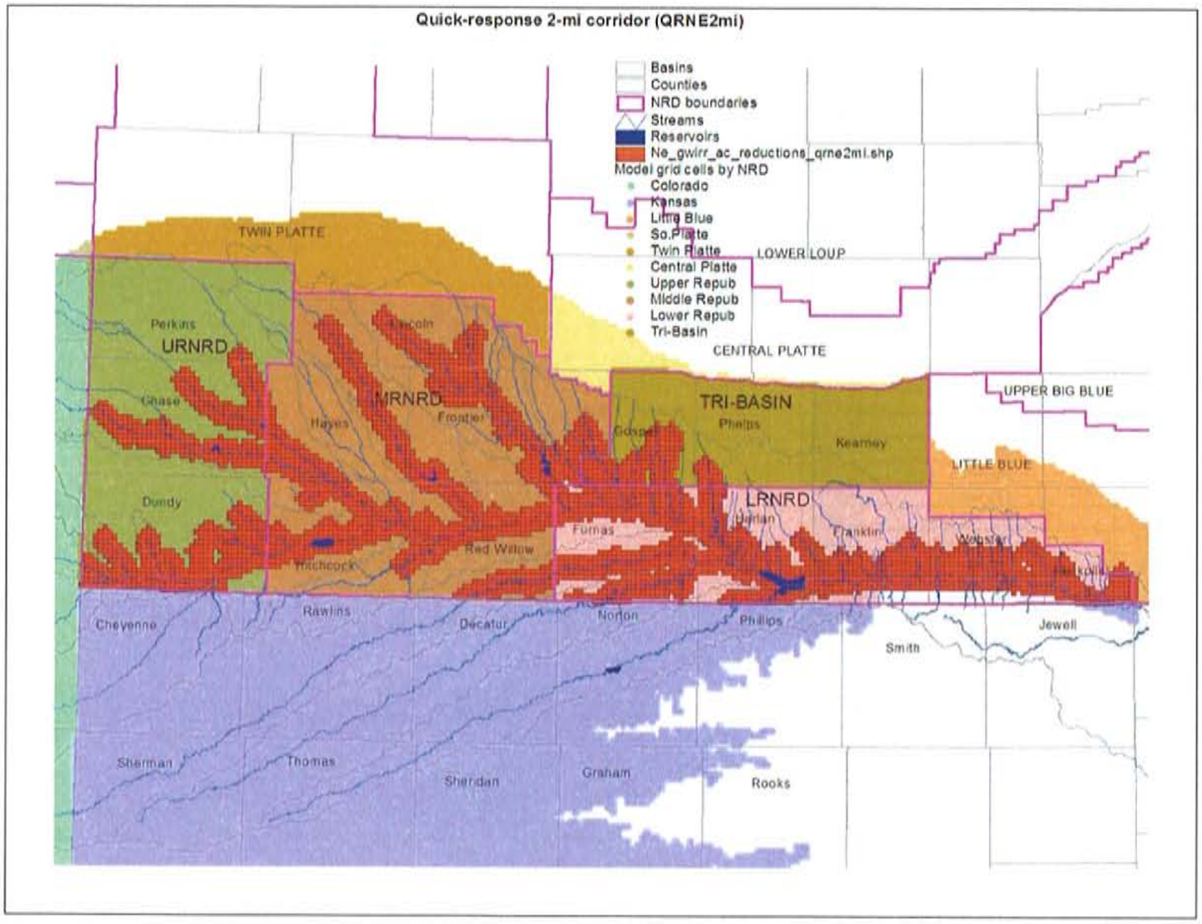
Table 8: Estimated future Nebraska GWCBCU under baseline pumping conditions; 100% curtailment of future pumping from the 10-2 rapid response region; and 100% curtailment of future pumping from the 10-2 rapid response region for each year corresponding to the historical years 2002-2007.

	Baseline Pumping	100% Reduction in RR 10-2 Region	100% Reduction in RR 10-2 Region for Years Corresponding to 2002-2007	Difference in GWCBCU (Baseline versus 100% Reduction in RR 10-2 Region)	Difference in GWCBCU (Baseline versus 100% Reduction in RR 10-2 Region 2002-2007)
Year	GWCBCU	GWCBCU	GWCBCU	GWCBCU	GWCBCU
2010	219,024	201,817	219,024	17,207	-
2011	237,236	201,926	237,236	35,310	-
2012	215,901	188,445	215,901	27,456	-
2013	210,701	177,698	210,701	33,003	-
2014	227,386	194,016	227,386	33,370	-
2015	207,407	174,584	207,407	32,823	-
2016	220,607	181,532	220,607	39,075	-
2017	192,150	163,837	179,171	28,313	12,979
2018	205,713	178,862	185,862	26,851	19,851
2019	214,398	190,152	196,002	24,246	18,396
2020	216,990	186,654	193,700	30,336	23,290
2021	209,699	182,570	186,697	27,129	23,002
2022	230,506	200,186	204,214	30,320	26,292
2023	233,101	200,029	213,368	33,072	19,733
2024	247,268	208,056	239,170	39,212	8,098
2025	236,422	200,923	230,435	35,499	5,987
2026	258,468	213,045	254,046	45,423	4,422
2027	235,544	202,531	232,258	33,013	3,286
2028	229,825	194,585	227,875	35,240	1,950
2029	246,859	212,827	245,392	34,032	1,467
2030	225,741	192,710	224,088	33,031	1,653
2031	238,137	199,771	237,043	38,366	1,094
2032	208,415	180,885	195,720	27,530	12,695
2033	222,002	196,111	202,510	25,891	19,492
2034	232,037	207,858	212,713	24,179	19,324
2035	233,330	204,552	210,765	28,778	22,565
2036	226,775	200,658	204,373	26,117	22,402
2037	248,109	219,681	223,421	28,428	24,688
2038	250,287	219,974	232,406	30,313	17,881
2039	264,810	229,108	257,473	35,702	7,337
2040	255,787	221,581	249,392	34,206	6,395
2041	278,182	235,173	273,769	43,009	4,413
2042	253,308	222,234	249,938	31,074	3,370
2043	244,362	212,308	242,374	32,054	1,988
2044	264,906	233,501	263,074	31,405	1,832
2045	240,710	210,104	238,871	30,606	1,839
2046	253,690	217,172	252,334	36,518	1,356
2047	221,670	194,219	209,133	27,451	12,537
2048	236,904	211,936	218,520	24,968	18,384
2049	246,919	223,013	228,025	23,906	18,894
2050	247,989	220,002	226,279	27,987	21,710
2051	239,965	214,504	218,263	25,461	21,702
2052	264,301	236,109	240,274	28,192	24,027
2053	265,084	235,840	247,950	29,244	17,134
2054	279,990	247,163	273,401	32,827	6,589
2055	270,662	237,014	263,448	33,648	7,214
2056	295,314	254,334	290,914	40,980	4,400
2057	268,139	238,022	264,264	30,117	3,875
2058	256,958	226,577	254,877	30,381	2,081
2059	278,625	248,250	276,679	30,375	1,946
2060	253,551	224,425	251,778	29,126	1,773
2061	266,656	230,944	265,147	35,712	1,509
2062	233,746	206,103	221,205	27,643	12,541
2063	247,751	223,623	230,199	24,128	17,552
2064	259,416	236,922	242,093	22,494	17,323
2065	260,600	233,144	239,194	27,456	21,406
2066	250,927	226,429	230,119	24,498	20,808
2067	276,719	248,604	253,138	28,115	23,581
2068	278,538	249,906	261,765	28,632	16,773
2069	293,501	261,401	287,010	32,100	6,491

Table 9: Future total stream baseflows for baseline pumping condition; and when ninety percent of the baseline pumping within the nominal 5-mile corridor was removed.

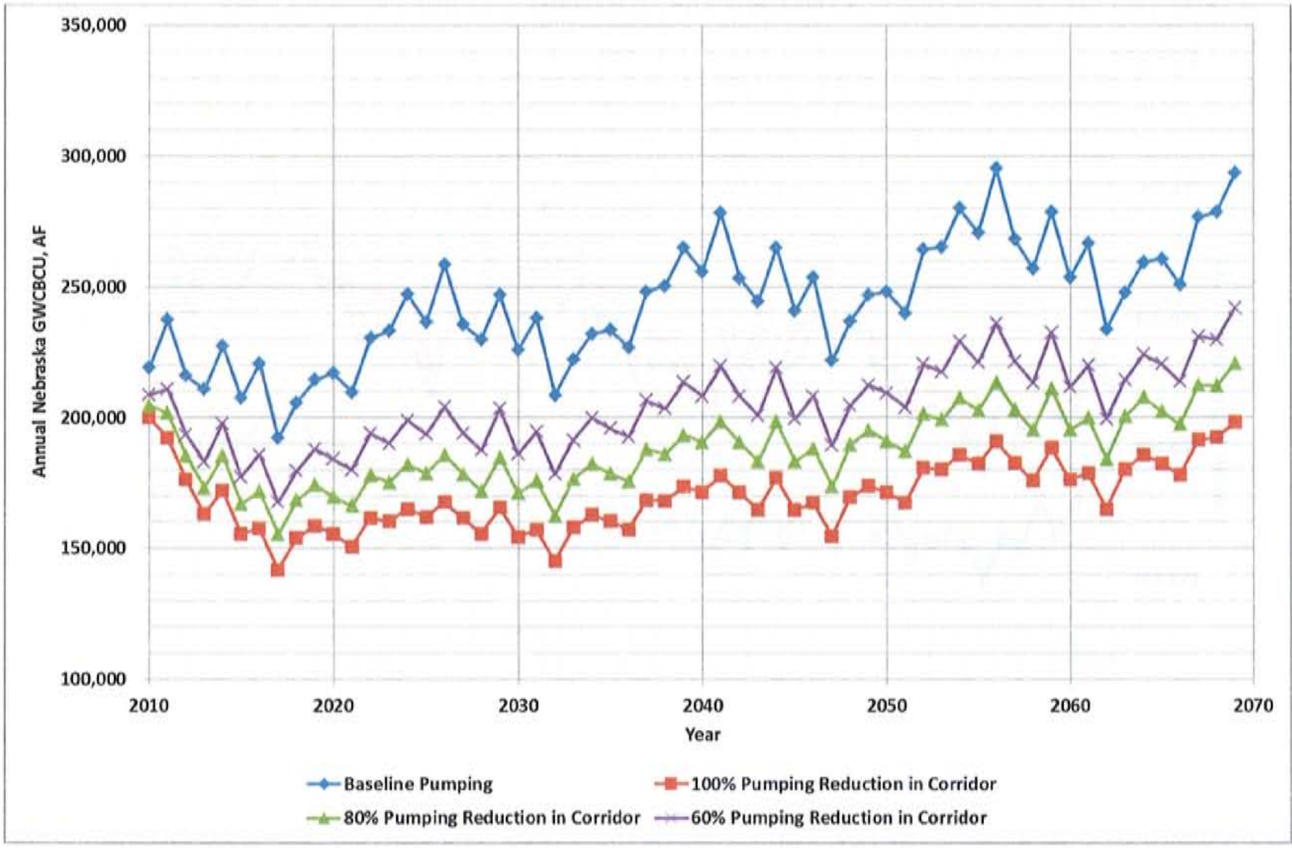
Year	Baseline Baseflow	90% Pumping Reduction in 5-mile Corridor Baseflow
2010	132,291	149,002
2011	144,224	184,516
2012	123,451	158,451
2013	95,177	137,810
2014	102,803	151,538
2015	94,766	140,812
2016	117,389	173,396
2017	80,908	124,474
2018	89,922	134,286
2019	102,520	150,419
2020	105,476	159,711
2021	99,783	150,949
2022	134,538	195,292
2023	148,530	213,847
2024	141,491	215,328
2025	124,788	190,758
2026	131,757	213,646
2027	110,444	176,020
2028	85,597	151,633
2029	90,183	162,036
2030	84,277	147,134
2031	106,413	178,170
2032	73,719	128,260
2033	81,703	136,387
2034	92,647	151,985
2035	94,843	158,747
2036	91,215	151,672
2037	124,379	194,396
2038	138,923	212,167
2039	126,981	208,508
2040	111,904	186,531
2041	117,369	207,498
2042	98,239	170,609
2043	76,293	146,507
2044	79,017	156,491
2045	74,389	141,002
2046	97,256	173,220
2047	65,534	122,867
2048	74,811	131,749
2049	84,134	146,210
2050	85,579	152,231
2051	82,609	145,156
2052	115,467	188,640
2053	130,102	205,414
2054	116,075	199,431
2055	99,047	176,936
2056	106,427	199,760
2057	88,403	163,458
2058	68,979	140,071
2059	68,813	147,602
2060	67,450	134,966
2061	89,304	166,656
2062	58,816	117,801
2063	67,972	124,934
2064	77,993	140,370
2065	77,591	145,661
2066	76,015	138,932
2067	106,196	180,723
2068	122,808	199,172
2069	106,626	190,840

Figure 1: Map showing extent of nominal 5-mile stream corridor where impacts of future irrigation pumping curtailment was evaluated.



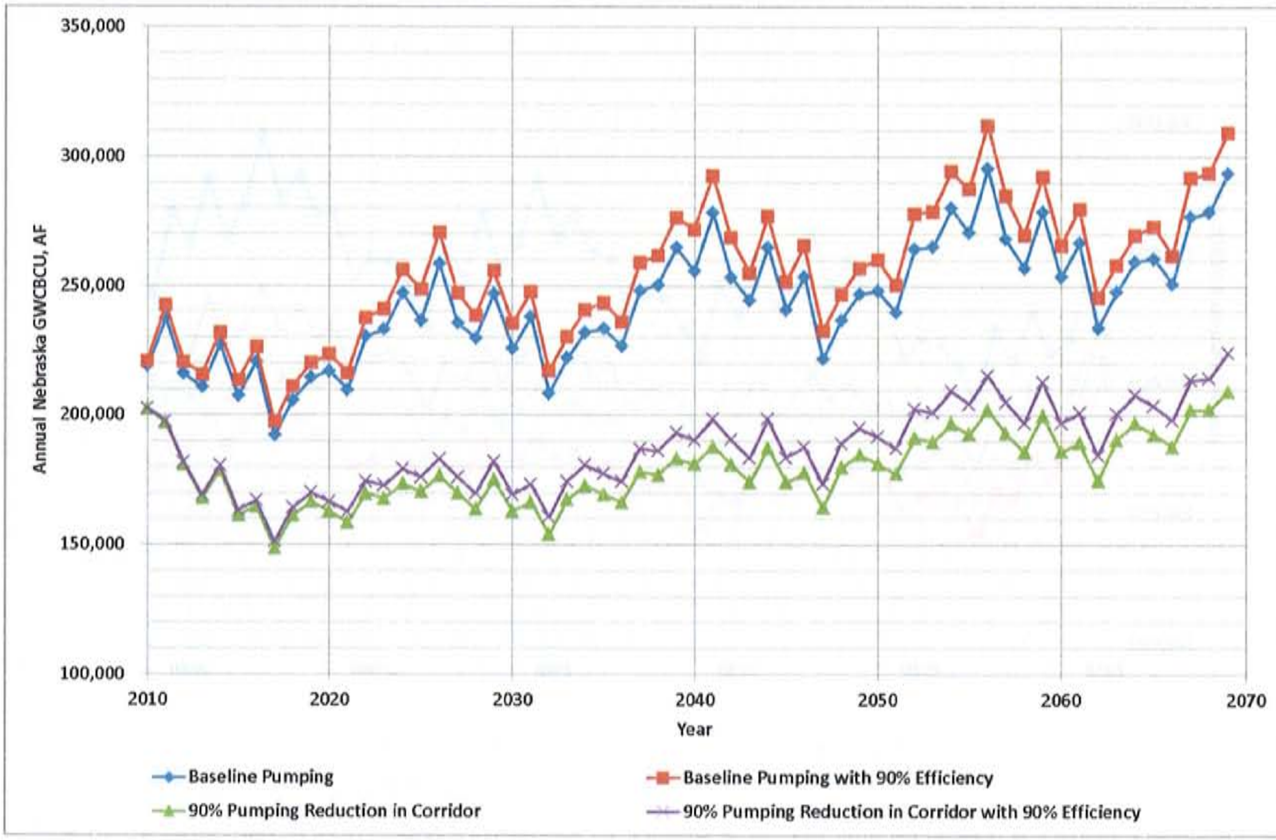
KS000700

Figure 2: Graph comparing estimated future Nebraska GWCBCU under baseline conditions and various levels of irrigation pumping curtailment.



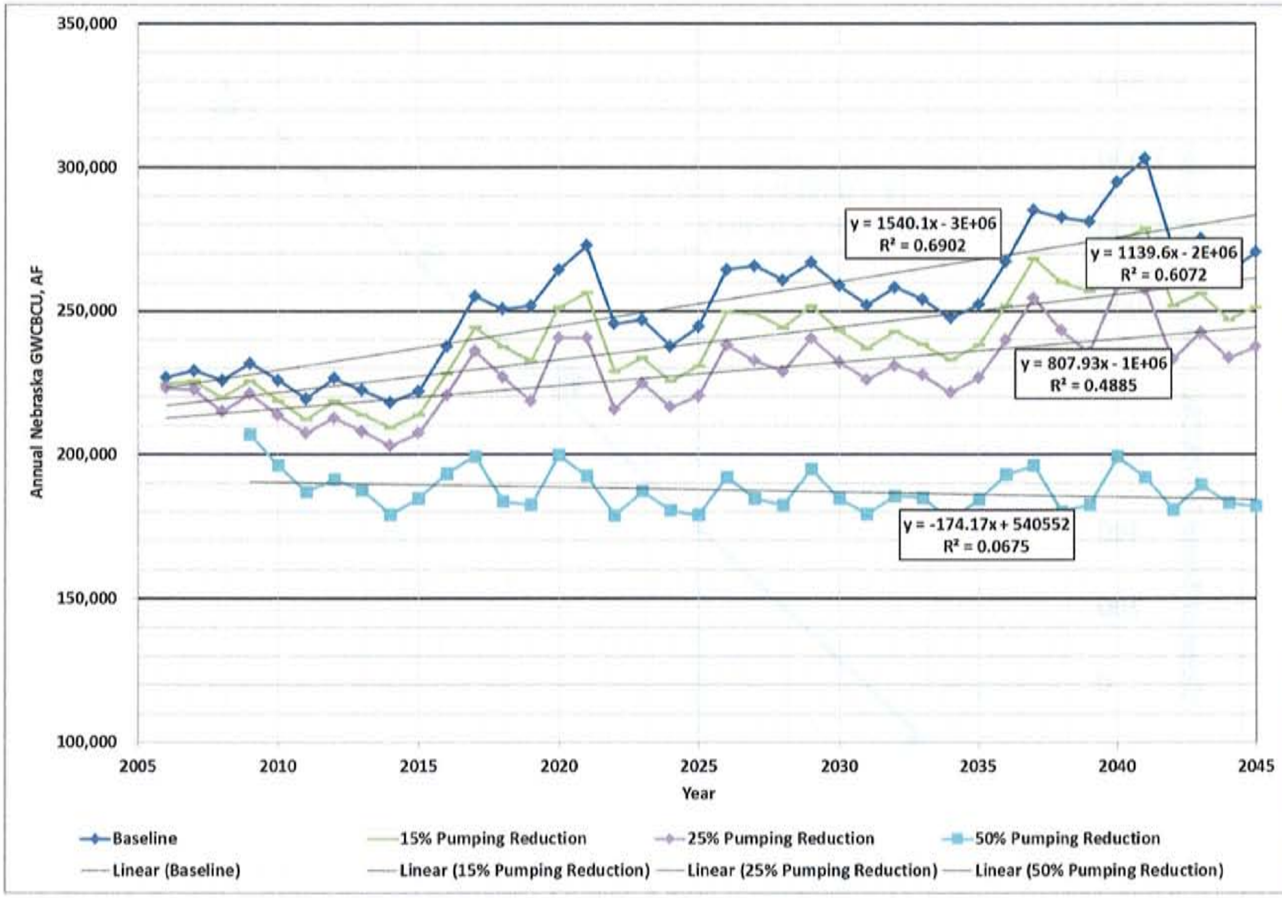
KS000701

Figure 3: Graph comparing estimated future Nebraska GWCBCU under baseline pumping conditions and with ninety percent of baseline irrigation pumping removed from the nominal 5-mile stream corridor and with irrigation efficiency increased to ninety percent.



KS000702

Figure 4: Graph showing estimates of future Nebraska GWCBCU prepared by Nebraska in 2006 under a baseline conditions and several alternative conditions of reduced irrigation pumping.



KS000703

Figure 5: Graph showing correlation of groundwater pumping and estimated future trends in Nebraska GWCBCU derived from Nebraska's 2006 analysis.

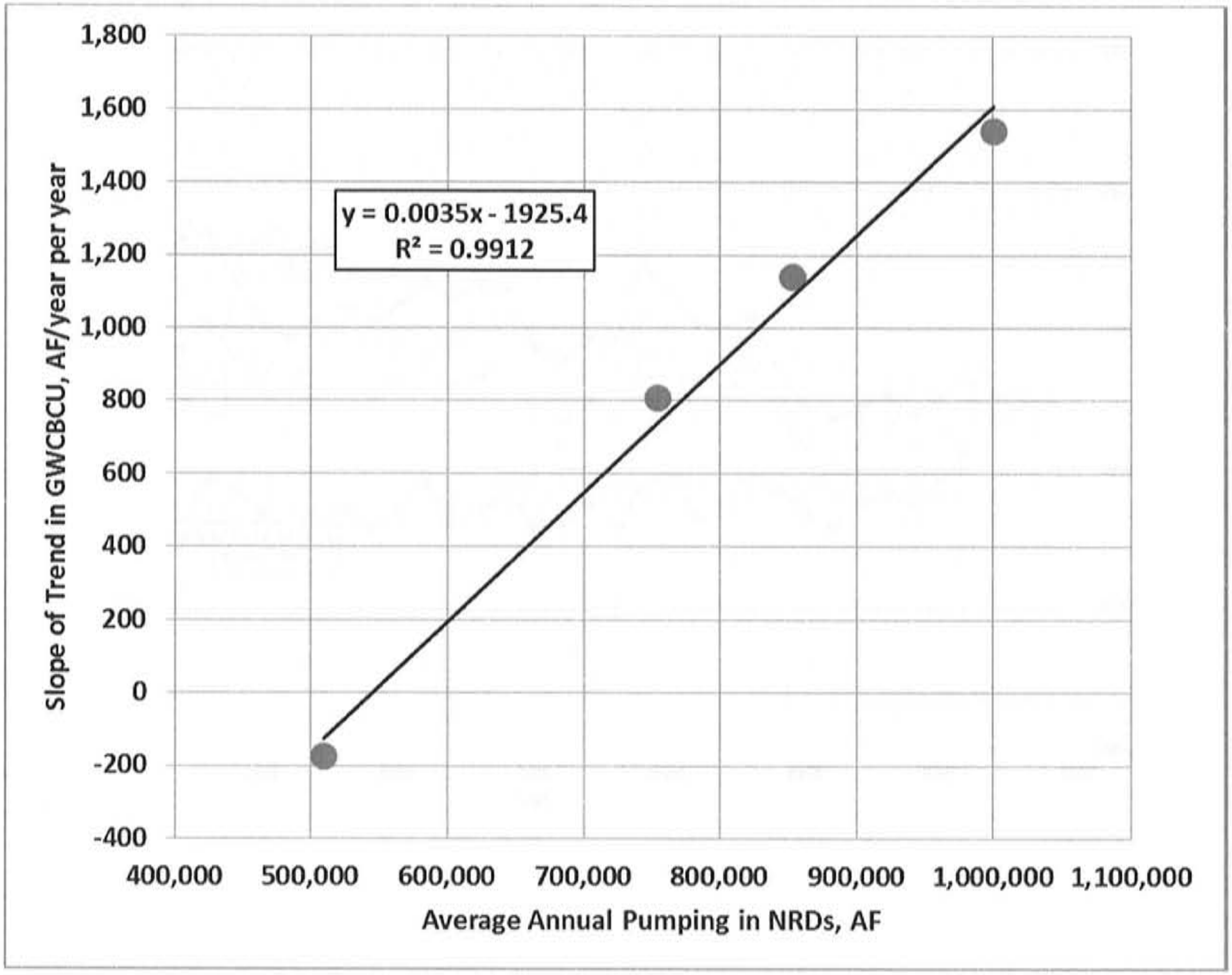
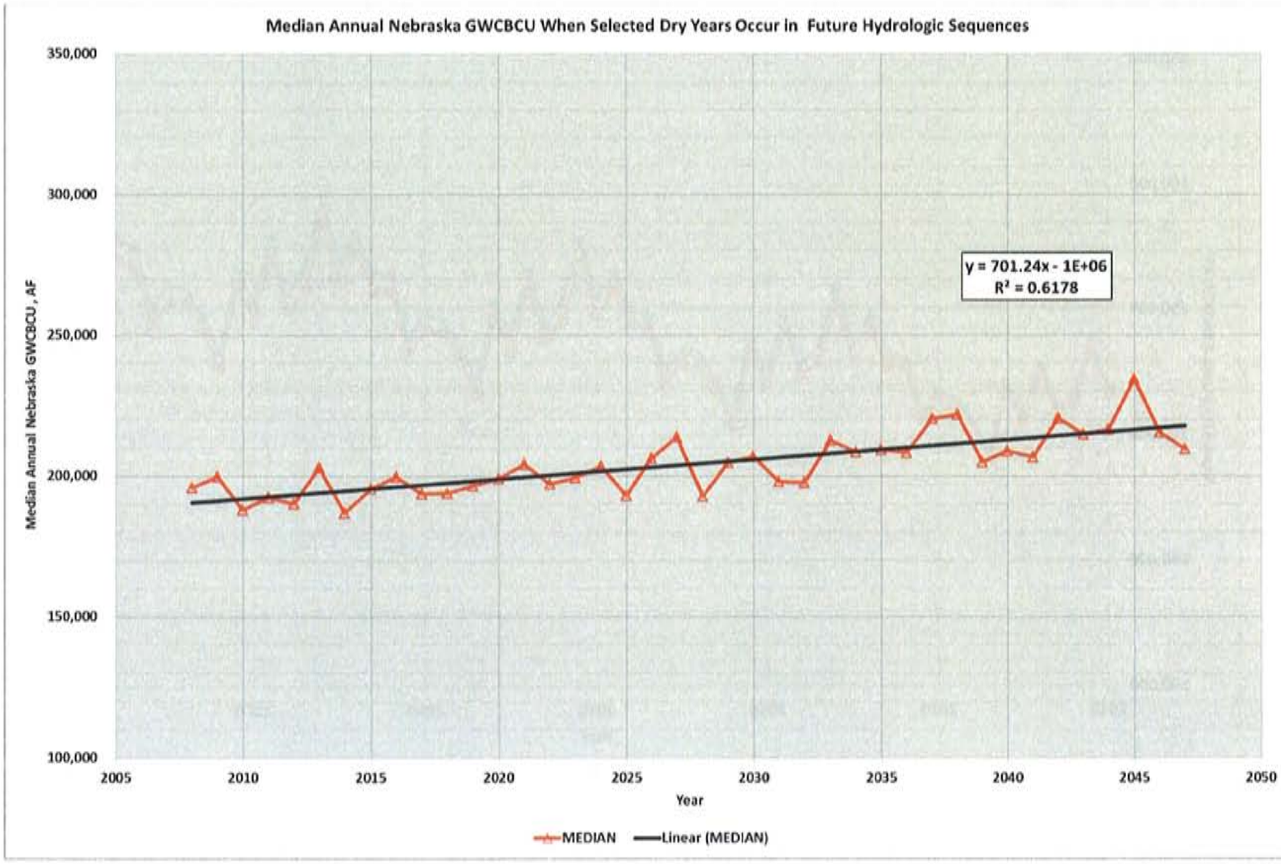


Figure 6: Graph showing annual median estimates of future Nebraska GWCBCU derived from Nebraska's stochastic evaluation of future hydrologic conditions.



KS000705

Figure 7: Graph comparing estimated future Nebraska GWCBCU under baseline pumping (80% of historical pumping during the period 1998-2002) and 75% of historical pumping during the period 1998-2002.

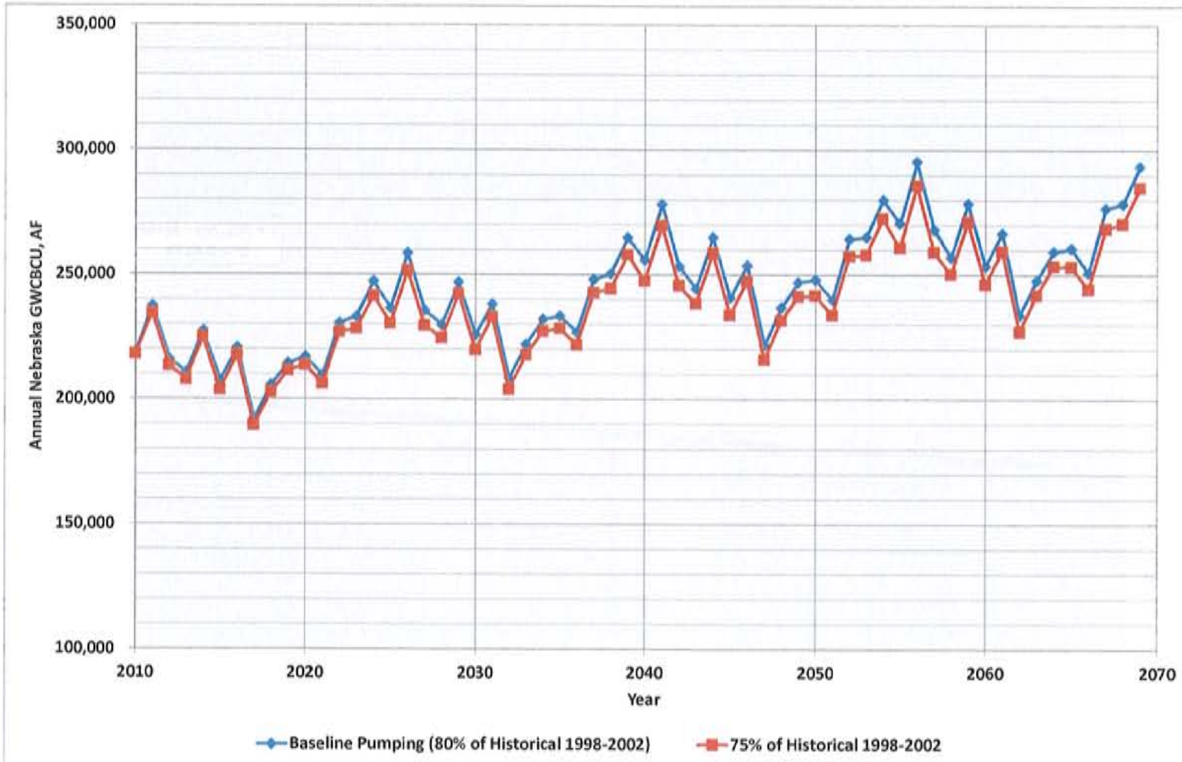


Figure 7a: Graph showing the reduction in estimated future Nebraska GWCBCU due to pumping at 75% of historical pumping during the period 1998-2002.

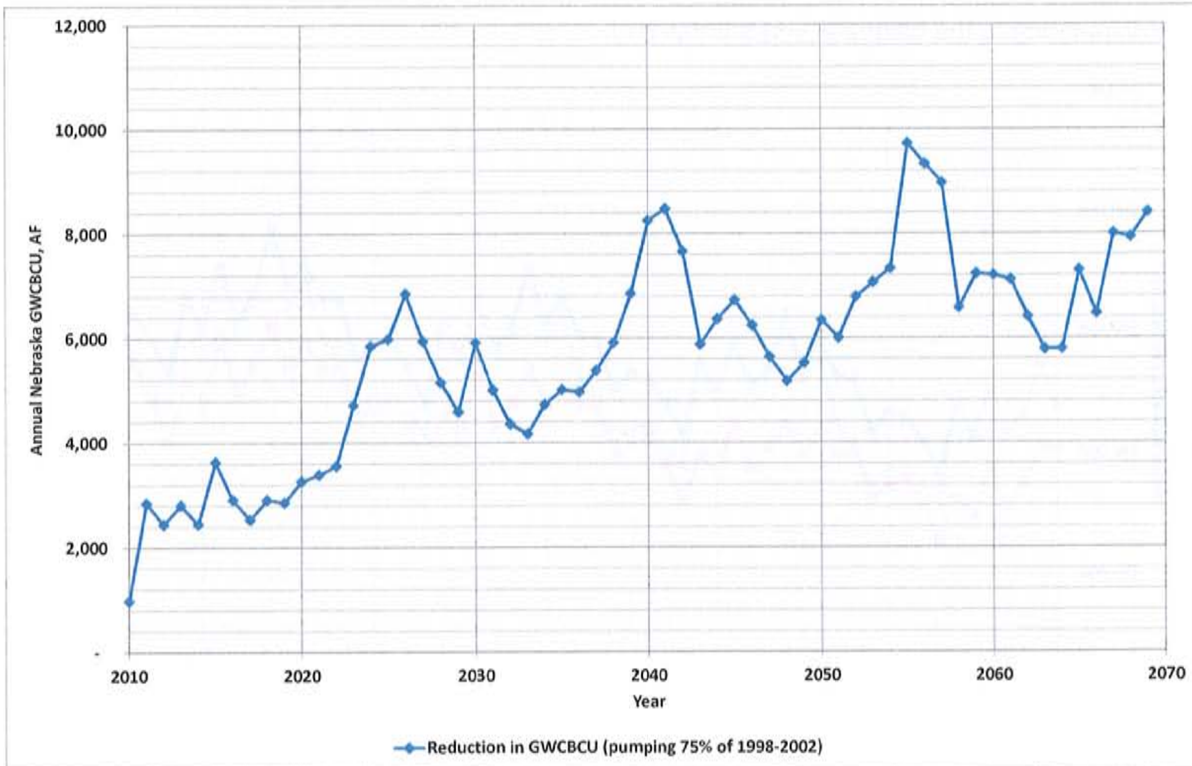
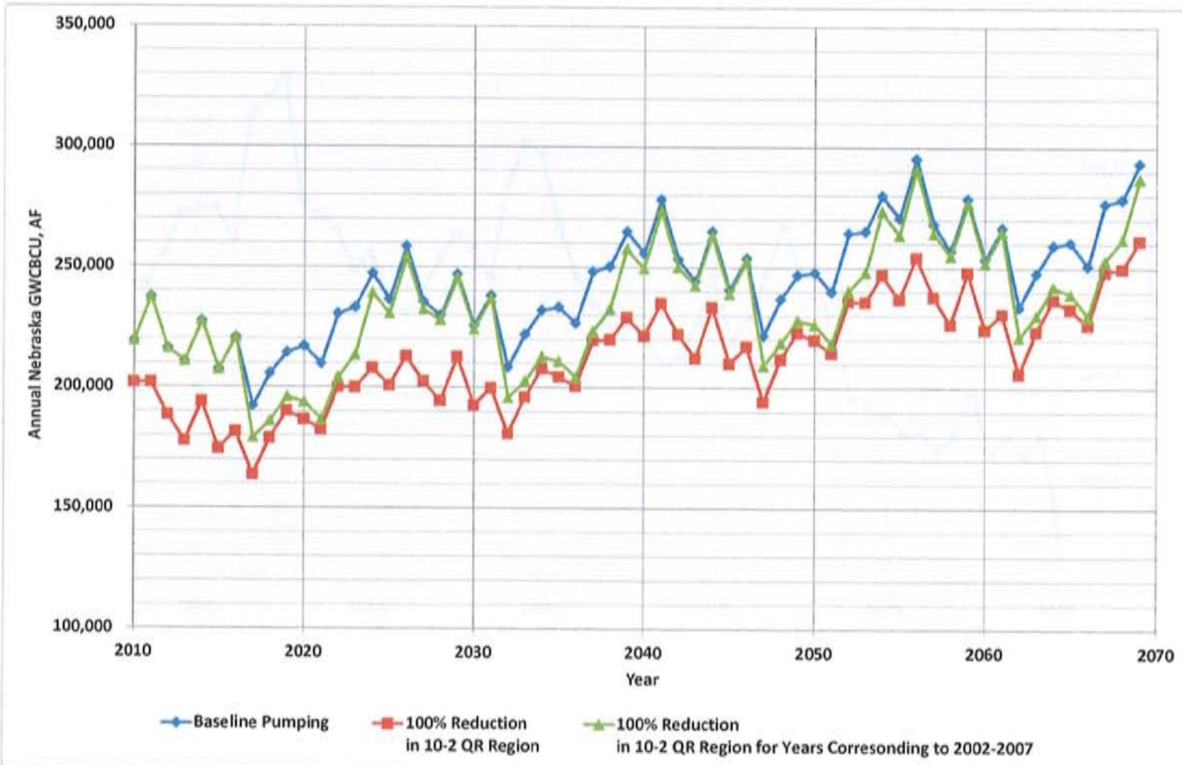
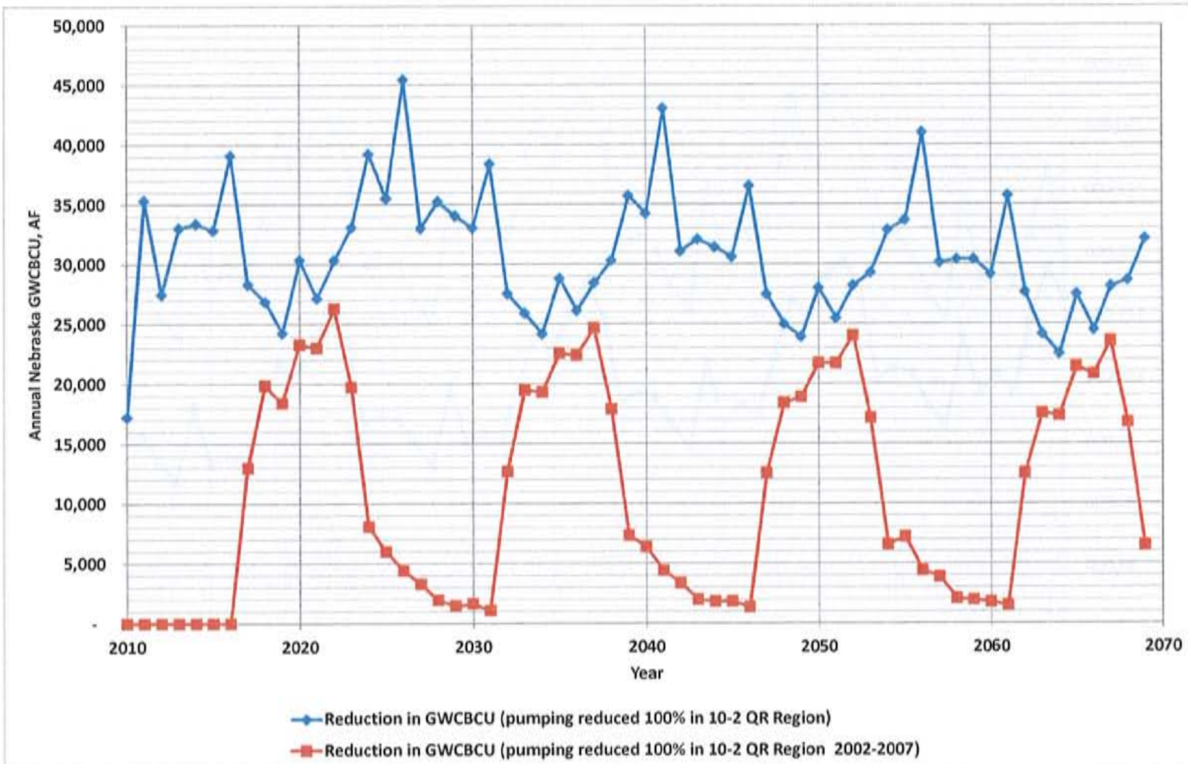


Figure 8: Graph comparing estimated future Nebraska GWCBCU under baseline pumping conditions; 100% curtailment of future pumping from the 10-2 rapid response region; and 100% curtailment of future pumping from the 10-2 rapid response region for future years corresponding to the historical years 2002-2007.



KS000708

Figure 8a: Graph showing the reduction in estimated future Nebraska GWCBCU due to 100% curtailment of future pumping from the 10-2 rapid response region; and 100% curtailment of future pumping from the 10-2 rapid response region for future years corresponding to the historical years 2002-2007.



KS000709

Figure 9: Graph showing future total stream baseflows for baseline pumping condition; and when ninety percent of the baseline pumping within the nominal 5-mile corridor was removed.

Figure10: Graph showing annual median estimates of future total stream baseflows derived from Nebraska's stochastic evaluation of future hydrologic conditions.