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Response to 5-Run

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KANSAS' EXPERT REPORT ON NEBRASKA'S 5-RUN PROPOSAL

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Table of Contents

I. Background

The RRCA Groundwater Model (Model) is used to compute stream depletions caused by groundwater pumping in each of the three States and to compute an imported water supply credit to compensate Nebraska for the effects of seepage associated with water that originates from the Platte River system. Because the Model is not completely mathematically linear, the individual impacts associated with pumping in each of the States and with the imported water supply credit as computed using the procedures described in the Final Settlement Stipulation (FSS) will not always sum to the total impact that would be computed by the model if all of the impacts due to pumping and seepage of imported water were to be considered simultaneously. This latter total impact has been referred to as the "virgin water supply metric" and was used by Kansas to evaluate Nebraska's 2007 proposal to change the method for computing impacts as specified in the FSS. At that time, Kansas criticized Nebraska's proposal because a cursory examination of the proposal indicated that results using the proposed method deviated from the metric to a greater degree than the method specified in the FSS.

In 2012, Nebraska returned to the method that it had proposed in 2007 after advocating an alternative 16-run proposal in the interim. Nebraska's current proposal is now referred to as the 5-Run Proposal. For clarity, the method prescribed in the FSS will be referred to as the RRCA Method. The Special Master has determined that the RRCA Method specified in the FSS includes consumption of imported water in the determination of the computed water supply and that this consumption is contrary to other provisions of the FSS. Nebraska and Colorado have mutually agreed that the 5-Run Proposal should replace the RRCA Method.

II. Kansas' Evaluation of Nebraska's 5-Run Proposal

In the time allotted, Kansas has attempted to evaluate whether the omission of Mound seepage from the baseline of Nebraska's 5-Run Proposal was appropriate. Kansas did so by specifically evaluating: (1) the sufficiency of the calibration of changes in water levels in the Mound as simulated by the Model to changes in water levels in the Mound as measured during the period from 2001 to 2010 and the causes for any discrepancies; and (2) whether it is possible to arrive at a solution that would meet the Special Master's criteria and at the same time (a) eliminate the residuals caused by the hydrologic nonlinearity of the Republican River Basin and (b) assign responsibility for those residuals appropriately.

A. Sufficiency of the Model's Calibration for Purposes of Nebraska's 5-Run Proposal

The 5-Run Proposal changes the baseline condition that is used to calculate groundwater consumptive beneficial use (GW CBCU) with the Model from the historical condition to a condition where seepage from imported water, referred to as "Mound seepage," has been eliminated. This change places greater emphasis on the impact of Mound seepage on the determination of depletions due to pumping. A draft report prepared for the State of Nebraska by McDonald-Morrissey in April, 2006 (McDonald-Morrissey, 2006) recognized this potential impact and initiated a study to evaluate water level conditions in the Mound area and their impact on stream depletions and accretions calculated by the Model. In a subsequent draft report dated January 10, 2007 (McDonald-Morrissey, 2007) that was made available to Kansas, McDonald-Morrissey supplemented their evaluation of the Mound area. This latter report, however, focused on evaluating why imported water supply credits had declined in recent years and did not study or evaluate the impact of high water levels in the Mound area on calculations of stream flow depletions as the 2006 report contemplated it would be.

Kansas has attempted to conduct such a study or evaluation within the time frame it has been allotted to assess the impact of changing the baseline condition from the historical condition to a condition without the effects of Mound seepage. The task involved comparing model results to measured groundwater level data as suggested by McDonald-Morrissey in their 2006 report (McDonald-Morrissey, 2006, page 7).

Kansas compiled available groundwater level data from two sources, the U. S. Geological Survey (USGS) and from the State of Nebraska. In response to discovery requests from Kansas, Nebraska directed Kansas to a website where the Nebraska groundwater level data could be downloaded. Data from the USGS is also available from an online database.

The compiled groundwater level data was compared to historical groundwater levels calculated by the RRCA Model. The purpose of this comparison was to evaluate the nature of overestimation or underestimation of measured groundwater levels and of temporal trends in groundwater levels. This evaluation focused on the period after 2000 because this period is beyond the calibration period that was considered as part of the calibration of the Model at the time of the settlement, is more representative of current hydrologic and institutional conditions, and reflects water use data provided by the States pursuant to the requirements of the FSS.

A comparison of average measured groundwater level elevations for the period 2001-2010 to equivalent Model results shows patterns of consistent overestimation and underestimation. Ideally, differences between Model results and measured groundwater levels would exhibit a random spatial pattern of overestimation and underestimation. When overestimation or underestimation becomes predominant over an area, it can be an indication of bias or error in model inputs. For example, McDonald-Morrissey, on page 7 of their April 2006 report (McDonald-Morrissey, 2006), observed that computed groundwater levels in the Mound area for several Nebraska counties were "consistently too high" and warranted further study.

Figure 1 shows a map of the Model domain and also shows the locations of wells where groundwater level elevation data are available for the period 2001 to 2010. The colors at each of the well locations indicate whether the Model results underestimate or overestimate the measured groundwater levels and depict the degree of overestimation or underestimation. The legend at the lower left corner of the map describes what the individual colors represent. Shades of blue have been used to represent locations where Model results overestimate measured levels and shades of yellow to red represent locations where Model results underestimate measured levels. The intensity of the colors was selected to be greater in relation to the amount of overestimation or underestimation.

As shown on Figure 1, patterns of overestimation are shown in the eastern part of the Nebraska portion of the Model domain. This is an area where Mound seepage is occurring and may be the same area that McDonald-Morrissey was concerned about in their April 2006 report. Other areas of overestimation are also evident in the northwestern part of the Nebraska portion of the Model domain and in parts of the Colorado portion.

While areas of consistent overestimation or underestimation of computed groundwater levels are an indication of potential Model input errors, comparisons of changes in groundwater levels over time are a better indicator of Model input reliability. These comparisons allow for an examination of the Model's ability to track longer term changes associated with Model inputs such as Mound seepage and pumping. Failure of the Model to track these longer term changes can be an indication of bias in the estimated amounts of Mound seepage or pumping.

Figure 2 shows a map of changes in groundwater levels between 2001 and 2010 over the Model domain as measured in numerous wells. The map was constructed from well location data points where groundwater level data were available in both 2001 and 2010 and a change in the measured groundwater level over that period could be determined. The change in measured groundwater level for the individual data points were then contoured using standard computer software to develop the colored map shown on Figure 2. The legend in the lower right corner of the map shows what each of the map colors represent. Areas of groundwater level decline are shown in increasing amounts from yellow to pink to red. Red represents areas of groundwater level declines that exceed 10 feet over the period from 2001 to 2010. Similarly, dark blue represents areas where groundwater levels have increased by 10 feet or more over the period.

As shown on Figure 2, much of the area in the western and north-northwestern parts of the Nebraska portion of the Model domain experienced groundwater level declines over the period from 2001 to 2010. The western area in Nebraska is contiguous with a similar area in Colorado and these are both areas where more intense pumping occurs in both Nebraska and Colorado. These are areas where groundwater levels have been declining for several decades in response to the pumping. The north-northwestern area includes areas where Mound seepage occurs. The general area of Mound seepage extends from this area toward the southeast roughly parallel to and near the northern boundary of Model domain. Over most of this distance, the northern boundary of the Model domain is the Platte River.

Figure 3 shows changes in groundwater levels from 2001 to 2010 as computed by the Model. The same color representations were used on Figure 3 as was used on Figure 2 to allow for a direct visual comparison between the two figures. Two things are readily apparent from visually comparing the two figures. First, the Model results (Figure 3) show two areas of blue and dark blue in the northernmost part of the Model domain near the Platte River. According to the Model results, groundwater levels in these two areas are computed to have increased up to more than 20 feet during the period from 2001 to 2010. In these same areas, the measured groundwater levels (Figure 2) indicate a decline in groundwater levels between 2001 and 2010. Second, measured groundwater levels in the western part of the Nebraska portion of the Model domain and in adjacent parts of Colorado have declined more than 10 feet (red areas on Figure 2) over a much larger area than is shown by the comparable Model results (Figure 3).

The first type of discrepancy between Model results and the measured changes in groundwater levels that appears on Figures 2 and 3 is related to Mound seepage. Figure 4 shows the locations of Model cells where Mound seepage is assumed to occur in the Model domain and depicts the intensity of that seepage in the Model by color gradations. Figure 4a shows the average Mound seepage amounts for the period from 2001 to 2010. The legend in the lower right hand corner of Figure 4a describes the relationship between the colors and the amounts of Mound seepage.

Figure 4b shows the locations of Mound seepage superimposed on the map of computed changes in groundwater levels (Figure 3). The blue and dark blue areas on Figure 3 were noted above as areas where the Model results show a significant increase in groundwater levels from 2001 to 2010, whereas the measured data showed that groundwater levels actually decline. These areas correspond directly to areas of significant Mound seepage during the period from 2001 to 2010 as shown on Figure 4a.

This comparison indicates that Mound seepage is overestimated in these areas and that the overestimation of Mound seepage is the reason that Model calculations show a significant increase in groundwater levels from 2001 to 2010 while the measured groundwater levels show a decline.

The second type of discrepancy that appears on Figures 2 and 3 occurs in the Mound area, but also more broadly, and is most likely related to underestimated amounts of net irrigation pumping. Net irrigation pumping is the difference between the amount of irrigation pumping and the amount of groundwater return flow that is assumed to be associated with that pumping. As described above, the measured groundwater levels show a larger area of groundwater level declines exceeding 10 feet in western Nebraska and adjacent areas in Colorado (Figure 2) than the equivalent area as computed by the Model (Figure 3). To assess the extent of this behavior of the Model, scatter diagrams were prepared to directly compare measured changes in groundwater levels from 2001 to 2010 in wells to what the Model computed the change to be at the location of each of the wells.

First, scatter diagrams were prepared for wells within the geographic area of each State. This allows an evaluation of how well the Model is performing on a State by State basis. Figures 5, 6 and 7 show scatter diagrams for wells in Kansas, Nebraska, and Colorado, respectively. The scatter diagram for Kansas (Figure 5a) will be described generally to illustrate what is portrayed on each of the scatter diagrams. The horizontal axis of the diagram is the change in groundwater level for the period from 2001 to 2010 as measured in various wells. These measured values were the basis for the contour map shown on Figure 2. The vertical axis is the change in groundwater level from 2001 to 2010 as computed by the groundwater Model. The particular values are calculated by interpolating Model results for 2001 and 2010 at each well location and then subtracting the 2010 result from the 2001 result. A negative value indicates that the groundwater level in 2010 was lower than the value in 2001. In other words, a negative value indicates that the groundwater level was computed to have declined between 2001 and 2010. Conversely, a positive value indicates that the ground water level was computed to have risen between 2001 and 2010. The value of groundwater level change computed by the Model at a particular well location is then paired with the measured change in groundwater level between 2001 and 2010 for that same well as shown on Figure 2. If the Model had computed changes in groundwater levels that were exactly the same as the measured change in groundwater level, the point would plot along a 45-degree line on the diagram. The 45-degree line is shown as a bold dark line on the diagrams for easy reference.

The scatter diagram is a diagnostic tool that can be used to examine potential bias in Model results. Generally speaking, an unbiased result is one in which the data points plot along the 45-degree line on the diagram and are randomly distributed above and below the line. If a model was perfect, which models by definition are not, all of the data points would plot exactly along the 45-degree line. Furthermore, as long as the data points are equally distributed above and below the 45-degree line in a random pattern, the Model results would not exhibit bias. If the data points show a pattern but the pattern does not lie along the 45-degree line, this could be an indication of a structural problem with the model. Structural problems could include model input data or the characteristics of the Model itself.

Figure 5a shows the scatter diagram for measured groundwater level data from wells in Kansas. The data points are "scattered" about the 45-degree line in a random pattern. Furthermore, there is no visual predominance of points plotting above the line as opposed to below the line. Consequently, the Model results in Kansas do not indicate a bias or potential structural problem with the Model itself.

Figure 5b is a well series plot that displays the results in a slightly different fashion than the scatter diagram. Rather than plotting the computed result on one axis and the measured result on the other axis as the scatter diagram does, Figure 5b plots both values at a given point along the x-axis. On this figure, each position along the x-axis represents a particular well location. At each position, the computed result and the measured result are plotted with different symbols. The positions have been arranged so that the well with the lowest (in this case, most negative) measured result appears on the left, followed by the next higher (less negative) measured result to the right, and so on across the graph. The results shown on Figure 5b again show computed results plotting above and below the measured result in a random pattern.

Figure 6a shows the scatter diagram for measured groundwater level data from wells in Nebraska. The data points shown on this figure more frequently plot above the 45-degree line than below the line. This bias is particularly evident for the more negative values as seen on Figure 6b which is the well series plot for the Nebraska wells. Negative values represent declines in the groundwater levels between 2001 and 2010. The more negative the value the greater the amount of decline over the period. When a computed value is less negative than the corresponding measured value, it means that the Model is calculating a smaller groundwater level decline than the decline that was measured. Thus the data points on the left side of Figure 6b show that the Model is underestimating the measured groundwater level decline much more frequently than it is overestimating the measured decline.

Figure 7a shows the scatter diagram for measured groundwater level data from wells in Colorado. Figure 7b is the corresponding well series plot. The results depicted on Figures 7a and 7b show the same predominance of underestimating measured groundwater level declines as was seen in the plots for Nebraska.

The bias in results shown on Figures 6 and 7 are even more apparent when data are grouped geographically. For example, Figures 8a and 8b shown the scatter diagram and the well series plot when only wells in Yuma County, Colorado are considered. The scatter plot (Figure 8a) shows that relatively few points plot below the 45-degree line. The bias shown by the scatter plot is significant. As shown on Figure 8b for well locations where the measured groundwater level decline between 2001 and 2010 was more than about 8 to 10 feet, the Model result is always above the measured value indicating that the Model is always underestimating the groundwater level decline over this period of time.

The average measured groundwater level change for the wells shown on Figures 8a and 8b for the period 2001 to 2010 was about negative 10 feet. This means than on average for wells in Yuma County, groundwater levels declined almost 10 feet over the period. The average groundwater level change at these well locations over this period computed by the Model is about negative 5 feet. In other words, the Model is computing an average decline in groundwater levels over this period of just over 5 feet while the measured groundwater level data show an average decline of almost 10 feet. Thus, over this period from 2001 to 2010 the Model is only computing about one-half of the groundwater level decline that actually occurred.

The Model results for western counties in Nebraska show similar bias as that shown for Yuma County in Colorado. For example, Figures 9a and 9b show a scatter diagram and well series plot for well locations in Chase County, Nebraska. The same bias that was evident in the plots for Yuma County, Colorado is evident on these figures. The average measured decline in groundwater levels for wells in Chase County over the period from 2001 to 2010 was over 8 feet. The average decline for that period at those well locations computed by the groundwater Model was less than 6 feet. An evaluation of results for wells in Perkins and Dundy counties in Nebraska showed a similar bias. It is noteworthy that the bias is most acute at well locations where the largest groundwater level declines occurred over the period from 2001 to 2010.

Figures 10, 11 and 12 are groundwater level hydrographs for three well locations, one in Lincoln County, Nebraska (Figure 10), one in Perkins County, Nebraska (Figure 11) and one in Yuma County, Colorado (Figure 12). Each figure shows a hydrograph in the upper pane and a map of the particular well location in the lower pane. Each hydrograph shows three segmented lines. The blue segmented line depicts measurements of groundwater levels taken at different times over a multi-year period as shown on the x-axis. Each blue symbol represents one measurement. Each of the blue symbols has been connected by a straight line to facilitate viewing of the data. The red symbols and red lines depict groundwater levels computed by the groundwater Model at the same locations and times as the measured data. The difference between the red segmented line and the blue segmented line represents the difference in groundwater level elevation between the Model result and the measured value at the well location for each of the times when groundwater levels were measured. Since the bias described earlier dealt with the trends or changes over time in the Model results as opposed to the elevations, a green segmented line was plotted to shift the red segmented line into the range of the measured data (blue segmented line). By comparing the green segmented line to the blue segmented line, the difference in the trends or changes over time computed by the groundwater can be more easily compared to the trends or changes over time shown by the measured data.

The comparisons on Figures 10, 11 and 12 show that the trends in the results from the groundwater Model begin to depart from the trends in the measured data after about 2000. As shown by the red and green segmented lines on Figure 10, the Model results show a sharp increase in computed groundwater levels beginning in about 2007. The measured groundwater levels (blue segmented line) do not show this increase. Furthermore, the change in measured groundwater levels between 2001 and 2010 show a decline of about 10 feet. The change in groundwater level computed by the Model over this period is an increase of about 15 feet. This example hydrograph illustrates the nature of the bias in the area of Mound seepage noted on the comparison of Figures 2 and 3 that was discussed previously.

On Figures 11 and 12, the measured groundwater levels in these wells as shown by the blue segmented line continue to decline after 2000, and the rate of decline appears to increase after 2000. Model results (red and green segmented lines), on the other hand, tend to show less decline and the rate of decline appears to be decreasing. These example hydrographs illustrate the nature of the bias that was noted previously on the comparison of Figures 2 and 3 in the areas of pumping in western Nebraska and eastern Colorado and further defined by the scatter diagrams and well series plots shown on Figures 6 through 9.

The results shown on Figures 6 through 12 for wells in western Nebraska and eastern Colorado indicate that net irrigation pumping may be underestimated in the Model in parts of Nebraska and Colorado. This underestimation may be related to the estimated amounts of return flow associated with irrigation pumping reported by Nebraska and Colorado. Table 1 shows the amounts of return flow associated with irrigation pumping that has been reported by each State for input to the groundwater Model. Also shown on the table are the reported amounts of irrigation pumping and the fraction or percentage of irrigation pumping that is represented by the return flow associated with the pumping.

Figure 13 is a graph that depicts how the return flow fractions or percentages have changed over time. As shown by the values on the table and by the figure, the return flow fraction or percentage has decreased for all of the States over time, corresponding to the use of more efficient irrigation practices over time. The shift from flood irrigation practices to center pivot irrigation systems was likely responsible for much of the increase in efficiency. In addition, irrigation return flows are affected by water management practices. With continuing declines in groundwater levels and potential declines in well yields along with the imposition of more stringent water allocations, irrigators will likely respond with more efficient application of water to meet crop demands, thereby reducing irrigation return flows.

As shown on Figure 13, the fraction or percentage of return flow from irrigation in Kansas over the past 10 to 20 years has continued to decrease to levels between 10 and 15 percent. The increased use of center pivot irrigation systems as well as other system modifications such as low pressure drop nozzles have allowed efficiencies to approach 90 percent and have reduced the fraction of return flow to levels approaching 10 percent. These continued increases in irrigation efficiency and reduced irrigation return flow seen in Kansas are not evident in the reported values for Nebraska and Colorado. As shown on Figure 13, the fraction of irrigation return flow reported by Nebraska has remained at just over 20 percent since 2000. Similarly, the fraction of irrigation return flow reported by Colorado has a slight downward trend over the past 10 to 20 years but remains in the general range of 17 to 18 percent.

Table 2 shows the differences between the percentages of return flow reported by Colorado and Nebraska from the percentages reported by Kansas since 2000. The table also shows the amount of return flow that these differences in percentage represent for Colorado and Nebraska since 2000. For Colorado, this means that net irrigation pumping could be underestimated by 22,000 to 34,000 acre feet per year over these years if irrigation practices in Colorado were actually as efficient as those in Kansas. Similarly, for Nebraska it means that net irrigation pumping could be underestimated by 90,000 to 158,000 acre feet per year over these years if irrigation practices in Nebraska were actually as efficient as those in Kansas. Results from the groundwater Model for changes in groundwater levels from 2001 to 2010 for well locations in Kansas showed no apparent bias when compared to measured changes in groundwater levels (Figures 5a and 5b). Consequently, the most likely explanation for why groundwater Model results for both Colorado and Nebraska show a bias toward underestimation of declines for that period is that irrigation return flows have been overestimated and net irrigation pumping has been underestimated.

B. A More Appropriate Remedy: The Integrated Solution

Although the 5-Run Proposal does not include seepage from imported water when calculating the stream depletions caused by each State's pumping, the sum of the stream depletions or accretions caused by each State's pumping and the imported water supply credit do not equal the total impact of calculating the effects of pumping in each State and seepage of imported water simultaneously. In the discussions below, the sum of the stream depletions caused by each State's pumping and the imported water supply credit calculated separately will be referred to as the "sum of the impacts". The total impact of calculating the effects of pumping in each State and seepage of imported water simultaneously will be referred to as the "total impact".

As discussed above, Kansas criticized Nebraska's 2007 proposal at that time because it departed further from the "VWS metric" than the RRCA Method. The problem that Kansas recognized at that time continues to be a problem with the 5-Run Proposal. Kansas has made evaluations that show that as pumping continues and depletions to stream base flows continue to increase, the departure between the sum of the impacts and the total impact will likely increase over time.

Prior to reaching agreement with Colorado regarding the 5-Run Proposal, Nebraska was advocating a 16-run proposal. One of the features of the 16-run proposal was that the sum of the impacts did equal the total impact. In other words, the 16-run proposal met the "VWS metric". Colorado and Kansas did not support the 16-run proposal for various reasons that are described in expert reports submitted in arbitration proceedings and initially in this matter before the Special Master. In the arbitration proceedings before Karl J. Dreher, the 16-run proposal was presented and evaluated. While the arbitrator did not accept the 16-run proposal, he did make the following conclusion regarding the "VWS metric" that was the foundation for the 16-run proposal.

> 3. Nebraska's proposed procedure for determining VWS, whereby what Nebraska terms VWS_G, determined as $(\theta - CKMN)$, is more consistent with the definition of VWS established in the Compact and adopted in the Accounting Procedures than is summing $CBCU_C$, $CBCU_K$, and $CBCU_N$, less IWS, each calculated in accordance with the existing Accounting Procedures, to compute VWS_G.

From Arbitrator's Final Decision, June 2009, page 61.

The Arbitrator also concluded that under the 16-run proposal, the IWS credit would generally be greater than the credit determined using the RRCA Method. Under the 5-Run Proposal currently proposed by Nebraska and supported by Colorado, the IWS credit would be calculated using the same procedure as that used in the RRCA Method. Thus the 5-Run Proposal would not generally increase the IWS as would have occurred under the 16-run proposal. However, the 5-Run Proposal does not produce a result where the sum of the impacts is equal to the total impact. As will be shown below, the departure of the sum of the impacts from the total impact is expected to increase in the future, and the failure of the 5-proposal to meet this condition has a negative impact on Kansas.

Although Arbitrator Karl J. Dreher did not accept the 16-run proposal, he recommended that the States reconvene the Technical Groundwater Modeling Committee to "thoroughly re-evaluate the non-linear response of the Model when simulated stream drying occurs" and "to re-evaluate the existing procedures for determining CBCU and IWS" (Arbitrator's Final Decision, June 2009, page 71, number 2). Among the reasons that the arbitrator did not accept the 16-run proposal was the fact that the residual or difference between the sum of the impacts and the total impact would essentially be divided among two States without consideration of other factors such as groundwater storage (Arbitrator's Final Decision, June 2009, page 13, number 30). While the Arbitrator recognized the total impact defined by calculating the impact from each State's pumping and IWS seepage simultaneously was an estimate and should not be viewed as a "true" value as was suggested by Nebraska (Arbitrator's Final Decision, June 2009, page 7, number 16), he concluded that it was more consistent with the definition of VWS established in the Compact and adopted in the Accounting Procedures (Arbitrator's Final Decision, June 2009, page 61, number 3).

Given the determinations made by the Special Master in this matter and considering findings of the Arbitrator described above, Kansas has evaluated the 5-Run Proposal in an effort to find a method for computing GW CBCU that would adhere to the determinations by the Special Master and would give a result in which the sum of the impacts would equal or nearly equal the total impact. A method developed by Kansas that would achieve these goals is described below and will be referred to as the Integrated Solution. Subsequently, comparisons between results obtained using the Integrated Solution discussed below and both the RRCA Method and the 5-Run Proposal will be presented and discussed.

Differences between the sum of the impacts and the total impact are related to the non-linear response of the groundwater Model under certain hydrologic conditions. These conditions are primarily associated with what has been referred to as "stream drying". The occurrence of stream drying is variable and can be related to both variations in groundwater pumping and variations in recharge from precipitation. Depletions to stream flow in the future associated with ongoing and historical pumping can be expected to continue to increase. This continuing increase in depletions will increase the prevalence of stream drying and the differences between the sum of the impacts and the total impact will continue to increase.

A preferable alternative approach to addressing the effects of stream drying on the differences between the sum of the impacts and the total impact is to evaluate depletions incrementally over a range of pumping conditions from no pumping to the full amount of pumping at any particular time period. In other words, the approach would be to integrate the depletions with respect to the amount of pumping from no pumping up to the full amount of pumping. The process of integration is a fundamental concept in mathematics and calculus. In practical terms, integration describes the process of determining the total amount of something (a function) that varies over a range of conditions (a variable). In our case, we want to determine the total amount of impact to stream flow associated with a range of pumping conditions. We also want to determine how much each State's pumping contributes to that total impact since each State's pumping will impact stream flows differently. By formulating the total impact as a sum of the partial impacts attributable to each State and integrating over the range of pumping, the portion of each State's contribution to the total impact can be determined.

The integration of partial impacts described above must be evaluated numerically since we do not have a simple function that describes each State's relative capacity to impact stream flows. This means that the integration is accomplished over a series of discrete intervals or increments. The intervals or increments span the range of pumping from no pumping to the total amount of pumping. If the increment of the integration process is made small enough, the resulting estimates of impacts to stream flow or depletions due to pumping in each State will sum to a value that is equal to the total impact. This approach is referred to as the "Integrated Solution" and was developed by Dr. Sam Perkins of the Kansas Department of Water Resources (KDWR). The Integrated Solution is described in more detail in Appendix B to this report.

As described above, the Integrated Solution can be formulated to produce a result where the sum of the impacts is equal to the total impact. In short, the increment of the integration process can be adjusted downward until the sum of the impacts is very close to the result of computing the total impact of pumping and seepage from imported water simultaneously. For purposes of the comparisons to be discussed below, an increment size was selected that produced results that sum to within less than one percent of the total impact.

The Integrated Solution as described herein provides a method that achieves the goals of satisfying the Special Master's determination that GW CBCU must be computed without the inclusion of seepage from imported water and of satisfying the arbitrator's finding that having the sum of the impacts equal the total impact would be more consistent with the definition of VWS in the Compact and the FSS. This latter goal eliminates residual depletions associated with stream drying that would otherwise not be included in the determination of GW CBCU. This residual GW CBCU would then be included in the calculations of the computed water supply, allocations to the States and determinations of compact compliance.

In the following sections, comparisons are presented to illustrate how results using the RRCA Method and the proposed 5-Run Proposal are different from results obtained from the Integrated Solution. Specifically, the comparisons will be presented for the difference in GW CBCU, the difference in the computed water supply (CWS), the difference in the allocation of that computed supply to the States, and the difference in the compliance balance for each State associated with differences in GW CBCU and allocation.

The comparisons were made over a study period extending about 51 years into the future. Two different assumptions were made regarding climatic conditions for the study period. In the first case, an average climatic condition over the study period was assumed to occur in each year of the study period. This condition was the same condition that was developed by Kansas for purposes of illustrating potential future effects of pumping in previous submissions (see Fig. 7, App. C to Kansas' Petition, May 2010) in this case. It is also the same condition that was used by the States of Nebraska and Colorado to illustrate potential future conditions in their prior expert work submitted in this case (see for example Schreüder Report, June 19, 2012).

In the second case, a variable climatic condition was assumed for the study period. This variable climatic condition was the same condition that has been used by Kansas in prior expert work related to the arbitration in 2009 (see Larson and Perkins, January 20, 2009). In summary, the variable climatic condition uses historical climatic data for the years 1990 to 2006, a 17-year period. The sequence of climatic conditions over the 17-year period was repeated three times to create a 51 year study period.

1. Effects on Calculation of GW CBCU

The calculations of GW CBCU using the 5-Run Proposal by Nebraska and using the RRCA Method both produce results where the sum of the impacts may not equal to the total impact. The reason that Kansas did not accept the 5-Run Proposal in 2007 was that the sum of the impacts departed from the total impact to a greater degree than would occur using the method prescribed in the FSS. The departure between the sum of the impacts and the total impact using both the 5-Run Proposal and the RRCA Method can be expected to increase as stream drying becomes more acute in the future.

To illustrate this expectation, Figures 14 and 15 have been prepared to illustrate how the residual GW CBCU could be affected in the future under the RRCA Method and under the 5-Run Proposal. Figures 14a and 14b show differences in GW CBCU between results calculated using the 5-Run Proposal and the RRCA Method and results computed using the Integrated Solution. The differences were computed over the study period assuming the average future climatic condition and the variable climatic condition described previously. The integration interval used in applying the Integrated Solution was selected so the sum of the impacts would be very close to the total impact. Consequently, differences from results using the Integrated Solution are, in effect, differences from the total impact.

A positive value on Figures 14a and 14b indicates that GW CBCU calculated using either the RRCA Method or the 5-Run Proposal would be larger than it would be using the Integrated Solution. In other words, a positive value would indicate that GW CBCU is being overestimated relative to the Integrated Solution. Since the Integrated Solution effectively makes the sum of the impacts equal the total impact, departures from the Integrated Solution are analogous to residual depletions cited by Arbitrator Dreher (Arbitrator's Final Decision, June 2009, page 12, number 27, for example). Conversely, a negative value indicates that either the RRCA Method or the 5-Run Proposal would underestimate GW CBCU relative to the integrated method.

Figures 14a and 14b show an increasing departure over the study period of GW CBCU calculated using the RRCA Method and using the 5-Run Proposal as opposed to the Integrated Solution. This means that under both procedures, residual depletions can be expected to increase over time under the average climatic condition used in the analysis. In his testimony to the Special Master, Dr. Schreüder acknowledged that residual depletions are real and that during the historical period from 1981 to 2006, the residuals associated with the RRCA Method went both ways, "Sometimes we overestimate; sometimes we underestimate" (Transcript of Proceedings, August 2012, page 743). Dr. Schreüder's characterization will be discussed further below. However, as stream drying becomes more acute in the future, one can expect that the residuals will be persistently one way, either overestimating or underestimating, as shown by the results on Figures 14a and 14b.

It is also worth noting that the RRCA Method was based, at least in part, on the adoption of the groundwater Model. The process of adopting the groundwater Model included recognition that certain agreed upon inputs to the Model might overestimate or underestimate depletions from pumping. For example, the extent of increased precipitation recharge on irrigated land was extensively discussed and a compromise agreement reached for purposes of settlement (Final Report of the Special Master, 2003, page 20). If the agreed upon increase in precipitation recharge was overstated, net pumping on the irrigated land would effectively be underestimated and GW CBCU associated with that pumping would also be underestimated. Similarly, groundwater recharge derived from irrigation pumping in Nebraska was assumed to decrease from 30% in 1960 to 20% in 2000 associated with an assumed increase in efficiency from70% in 1960 to 80% in 2000 (Final Report of the Special Master, 2003, page 22). However, since 2000, Nebraska has continued to assume an efficiency of 80% and groundwater recharge of 20% from irrigation pumping. If actual irrigation efficiencies have continued to increase since 2000, groundwater recharge from irrigation pumping in Nebraska would be overstated and net pumping would be understated leading to GW CBCU being underestimated. This issue was discussed in previous sections of this report, but it shows that a tendency for the RRCA Method to overestimate GW CBCU could be partially offset by other factors that would lead to underestimation of GW CBCU.

The same trends in overestimation and underestimation of GW CBCU shown on Figures 14a and 14b can be expected under a variable climatic condition as shown by the results on Figures 15a and 15b. The differences shown on Figures 14a and 14b follow a smooth curved trend going into the future whereas the differences shown on Figures 15a and 15b are more variable. This variability is associated with year to year variations in climatic conditions that were assumed over the study period. Despite the variable nature of the results, the overall trends of the results shown on Figures 15a and 15b are similar to those shown on Figures 14a and 14b. This demonstrates that the trends in overestimation and underestimation of GW CBCU can be expected to persist regardless of variations in future climatic conditions.

2. Effects on Calculations of Computed Water Supply

The differences in GW CBCU described above will produce commensurate differences in the computed water supply (CWS) that is calculated using the accounting procedures. Figures 16 and 17 have been prepared to illustrate how the CWS would be different under the RRCA Method or the 5-Run Proposal as compared the value calculated using the Integrated Solution where the sum of the impacts would essentially equal the total impact.

As shown on Figure 16, the differences between results using the RRCA Method and using the Integrated Solution are positive and are expected to increase in the future under the average climatic scenario. The differences between results using the 5-Run Proposal and using the Integrated Solution are negative and are also expected to increase (become more negative) in the future under the average climatic scenario. Positive differences indicate that the computed water supply is being overestimated relative to the Integrated Solution. Similarly, negative values indicate that the computed water supply is being underestimated relative to the Integrated Solution.

Figure 16 shows that the degree of overestimation in the CWS using the RRCA Method is less than the degree of underestimation using the 5-Run Proposal. Also, the figure shows that the degree of overestimation using the RRCA Method tends to plateau in the future under the average climatic scenario. The degree of underestimation using the 5-Run Proposal, however, continues to increase over the study period. By the end of the study period, the amount of overestimation using the RRCA Method is about 10,000 acre feet per year and the amount of underestimation using the 5-Run Proposal is about 24,000 acre feet per year.

In is worth noting that the difference between the RRCA Method and the 5-Run Proposal at the end of the study period (2059) is about 34,000 acre-feet per year (from

10,000 acre-feet per year overestimated to 24,000 acre-feet per year underestimated). This difference is comparable to what was reported by Dr. Schreüder in his June 19, 2012 submittal in response to a request from the Special Master (Schreüder, June 19, 2012). For example, on the next to last page of that submittal, Dr. Schreüder shows results of his calculations for the year 2059, the last year of his study period. Under the column labeled "Change in CWS", Dr. Schreüder shows a total value of -35,464 acre feet. This represents the difference in the computed water supply in going from the RRCA Method to the 5-Run Proposal. However, as shown by the results on Figure 16, this difference is a result of overestimation of the CWS using the RRCA Method and underestimation of the CWS using the 5-Run Proposal as compared to the Integrated Solution. Furthermore, the degree of underestimation using the 5-Run Proposal is more than twice the degree of overestimation using the 5-Run Proposal. RRCA Method

Figure 17 shows the same type of comparison as Figure 16 except that the variable climatic scenario described previously was assumed rather than the average climatic scenario. As shown on Figure 17, the differences vary from year to year as a result of the varying climatic conditions that were assumed in the analysis as opposed to the relatively smooth lines shown on Figure 16 where an average climatic condition was assumed to occur year after year.

In spite of the varying differences associated with the assumed variations in climatic conditions, the trends shown on Figure 17 are quite similar to the trends seen on Figure 16. Again, the overestimation using the RRCA Method is expected to increase to something on the order of 10,000 acre feet per year but tends to stop increasing near the end of the study period. The underestimation using the 5-Run Proposal, on the other hand, increases over the study period and reaches a level of about 25,000 to 30,000 acre feet per year near the end of the period.

The results depicted on Figures 16 and 17 demonstrate that as stream drying becomes more acute in the future, one can expect that the sum of the impacts using either the RRCA Method or the 5-Run Proposal will become increasingly different from the total impacts. Further, one can expect the 5-Run Proposal to underestimate the CWS relative to what would be calculated using the Integrated Solution where the sum of the impacts would essentially equal the total impact and that the amount of underestimation could increase to as much as 25,000 to 30,000 acre feet per year over a 50-year period.

If the 5-Run Proposal had been implemented rather than the RRCA Method, the CWS and thus the estimated virgin water supply used in the accounting procedures would have been significantly underestimated. In response to questions from the Special Master regarding the impact of not assigning residual depletions on the total estimated virgin water supply, Dr. Schreüder indicated that the "currently approved procedure" or the RRCA Method "goes both ways. Sometimes we overestimate; sometimes we underestimate." (Transcript of Proceedings, August 2012, page 743) Dr. Schreüder went on to indicate that the average impact to Kansas allocation for the period from 1981 to 2006 was a small negative number (page 744). As best he could recall the number was -136 acre feet over the period but that the number was in his report (page 744).

While the number cited by Dr. Schreüder is not apparent from the various reports he has submitted, Dr. Schreüder's characterization that the RRCA Method tended to both overestimate and underestimate the CWS during the period from 1981 to 2006 appears to be accurate. What Dr. Schreüder did not indicate was what the 5-Run Proposal would have shown for the period from 1981 to 2006. If the 5-Run Proposal had been used to compute the CWS for this period, it would have consistently underestimated the CWS relative to the Integrated Solution by an average of over 7,000 acre feet per year. Furthermore, most of this underestimation in the CWS would have translated to reduced allocations to Nebraska and Kansas. The pattern of consistent underestimation of CWS (and consequently consistent under estimation of the total estimated virgin water supply) that would have occurred historically if the 5-Run Proposal had been used rather than the RRCA Method can be expected to continue and become more pronounced in the future as shown by Figures 16 and 17.

3. Effects on Calculation of Allocations to the States

The CWS is used in the accounting procedures as part of the determination of how much of the computed virgin water supply is allocated to each State. These allocations are then compared with computed CBCU and ultimately used to determine compact compliance. Figures 18 and 19 were prepared to illustrate how differences in the CWS described previously would affect the amount of water allocated to each State.

Figures 18a and 18b show how the allocations to each State would be different using the RRCA Method (Figure 18a) or the 5-Run Proposal (Figure 18b) as compared with the Integrated Solution. Results shown on Figure 18 are based on the average climatic scenario and the consequent differences in CWS shown on Figure 16. A positive result on Figure 18 indicates that a State would be allocated a greater amount than it would be allocated using the Integrated Solution where the sum of the impacts would essentially equal the total impact. Conversely, a negative value indicates that a State would be allocated a smaller amount than it would be allocated using the Integrated Solution.

Figure 18a shows that the RRCA Method would allocate more to Kansas and Nebraska and less to Colorado as compared with the Integrated Solution over the study period. This means that under the Integrated Solution Kansas and Nebraska would get less allocation over the years than they would receive under the RRCA Method given the average climatic conditions that were assumed in these calculations. Conversely, Colorado would get slightly more allocation over the years than it would have received under the RRCA Method.

Figure 18b shows that the 5-Run Proposal would allocate less to all the States as compared to the Integrated Solution. This means that under the Integrated Solution all of the States would get more allocation than they would have receive under the 5-Run Proposal given the average climatic conditions that were assumed in these calculations. As shown on the figure, Nebraska would receive the greatest increase in allocation and Colorado would receive the least amount. Kansas would receive an increased amount that is generally midway between the increase for Nebraska and Colorado.

Figures 19a and 19b show the same type of results as was shown on Figures 18a and 18b using the variable climatic scenario described previously. The overall trends in these results are similar to those shown on Figure 18 except that the amounts vary from year to year as influenced by the variable climatic condition as opposed to the average climatic condition that was used for the calculations shown on Figure 18.

4. Effects on Calculation of State Compliance Balances

The differences in GW CBCU, CWS and allocation described above combine to create a difference in the compact compliance balance for each State. For example, if GW CBCU increases, the CWS will be larger and the allocation of the CWS among the States will increase the allocations among the States. The increase in the allocation can be compared to the increase in GW CBCU to determine how each State's compliance balance is impacted. These comparisons of differences in CWS, allocation, and compact compliance balance and are the same types of comparisons that were presented by Dr. Schreüder in his June 19, 2012 report to the Special Master.

Figures 20a and 20b shows how the compact compliance balance for each State would be different considering the differences in GW CBCU, CWS and allocation that were shown on the previous figures. The results shown on these figures were calculated using average climatic conditions for future years. A positive value on these figures means that a State's compact compliance balance would be improved as compared to a result obtained from the Integrated Solution. For example, on Figure 20a, the compact compliance balance for Colorado and Kansas is larger when calculated using the RRCA Method than it would be using the Integrated Solution. Conversely, for Nebraska, the compact compliance balance is smaller when calculated using the RRCA Method than it would be using the integrated method.

Figure 20b shows that Colorado would retain a larger compact compliance balance under the 5-Run Proposal as compared to what would be calculated using the Integrated Solution. For Nebraska and Kansas, the 5-Run Proposal also shows a smaller compact compliance balance than what would be calculated under the Integrated Solution. In other words, the 5-Run Proposal has a negative impact on Kansas and Nebraska and a positive impact on Colorado as compared to the Integrated Solution.

Figures 21a and 21b depict the same type of results as Figures 20a and 20b except the results were calculated using variable climatic conditions for future years. The results shown on Figures 21a and 21b are similar to the results shown on Figures 20a and 20b except that the results are more variable from year to year associated with the year to year variations in the climatic conditions. Under the average climatic conditions, the results for future years follow a relatively smooth curved line whereas the results using the variable climatic condition do not follow a smooth curved line. The overall trend in results using the variable climatic condition is similar to the results using the average climatic condition.

In summary, Colorado receives a benefit to its Compact compliance under either the RRCA Method or the 5-Run Proposal relative to the Integrated Solution. The amount of benefit is approximately the same for the two methods. Kansas receives a benefit under the RRCA Method but is negatively impacted under the 5-Run Proposal relative to the Integrated Solution. Nebraska is negatively impacted under both the RRCA Method and the 5-Run Proposal relative to the Integrated Solution although the amount of negative impact is reduced under the 5-Run Proposal.

III. Conclusions

1. The 5-Run Proposal uses a baseline for determining pumping impacts by each State that does not include Mound seepage. Groundwater level data show that in areas where significant Mound seepage is estimated to occur, Model results for recent years show a bias that indicates Mound seepage rates are overestimated.

2. Groundwater level data for recent years also show a bias in Model results, both in the Mound Area and in western Nebraska and eastern Colorado, that is symptomatic of underestimated net irrigation pumping that, in turn, is likely related to an overestimation of the fraction of irrigation pumping that is assumed for estimating return flow from irrigation pumping.

3. The biases in the estimated amounts of Mound seepage and irrigation return flow indicated by groundwater level data collected from 2001 through 2010

must be resolved in order to reliably determine a baseline condition without Mound seepage, the amount of imported water supply credit, the amount of GW CBCU assigned to the States, the computed water supply and the allocations to the States.

4. An Integrated Solution for determining impacts to stream flow caused by pumping in each of the States is presented that is consistent with the Special Master's determination that the RRCA Method includes consumption of imported water by including Mound seepage in runs of the Model that are used to compute each State's GW CBCU.

5. The Integrated Solution is a mathematical approach for determining each State's impact on stream flow from pumping where the sum of each State's impact would be very nearly equal to the total impact computed by considering all of the pumping simultaneously.

6. The Integrated Solution is also consistent with the arbitrator Karl Dreher's finding that a method where the total impact of all pumping considered simultaneously would equal the sum of each State's impact would be more consistent with the definition of virgin water supply established in the Compact and adopted in the Accounting Procedures in the FSS.

7. The 5-Run Proposal advocated by Colorado and Nebraska is not a method where the total impact of all pumping considered simultaneously would equal the sum of each State's impact and would not be consistent with arbitrator Dreher's finding in this regard.

8. The 5-Run Proposal underestimates the computed water supply as compared with the Integrated Solution and the degree of underestimation is likely to increase in the future as stream drying conditions within the Model become more acute in the future due the effect of historical and ongoing pumping for irrigation.

9. Evaluations of the 5-Run Proposal assuming both an average future climatic condition and a variable future climatic condition show that underestimation of the computed water supply as compared with the Integrated Solution could increase to between 20,000 and 30,000 acre-feet per year over the next 50 years.

10. Residual GW CBCU as described by arbitrator Dreher would occur under the 5-Run Proposal and is also likely to increase in the future as stream drying becomes more acute. The Integrated Solution does not have a residual GW CBCU.

11. Based on the foregoing analysis and conclusions it is apparent that Nebraska's 5-Run Proposal is not an appropriate technical modification to the RRCA Accounting Procedures.

IV. References

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List of Figures

List of Tables

List of Figures

List of Tables

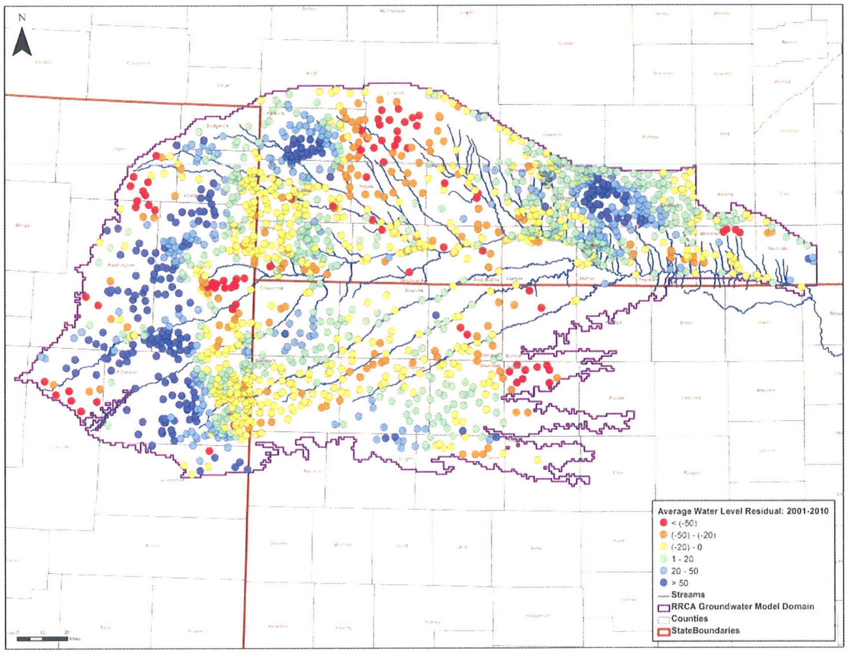

Figure 1: Map of RRCA Model Domain with Water Level Residuals for 2001-2010.

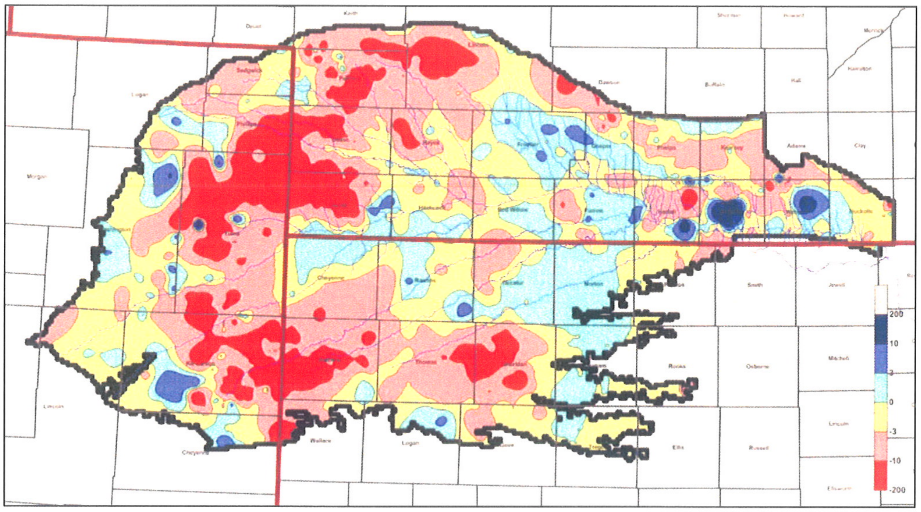

Figure 2: Map of Measured Changes in Groundwater Levels from 2001 to 2010.

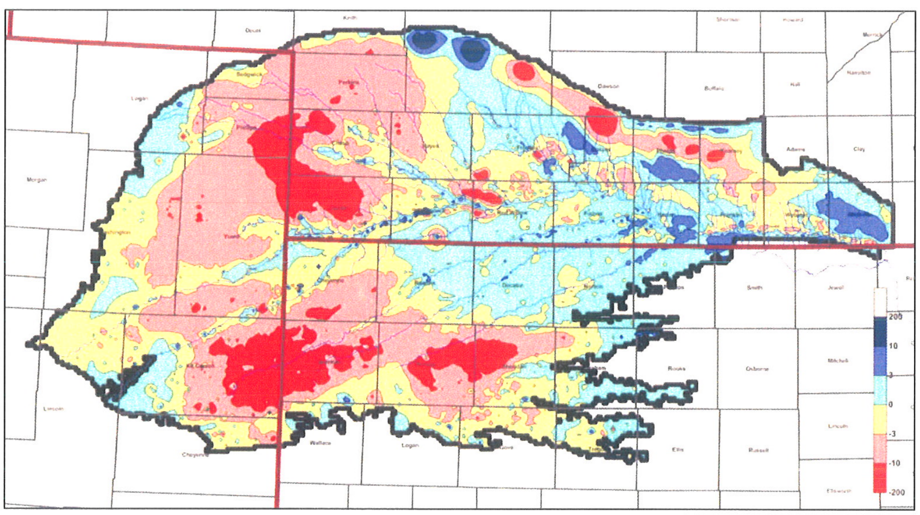

Figure 3: Map of Computed Changes Groundwater Levels from 2001 to 2010.

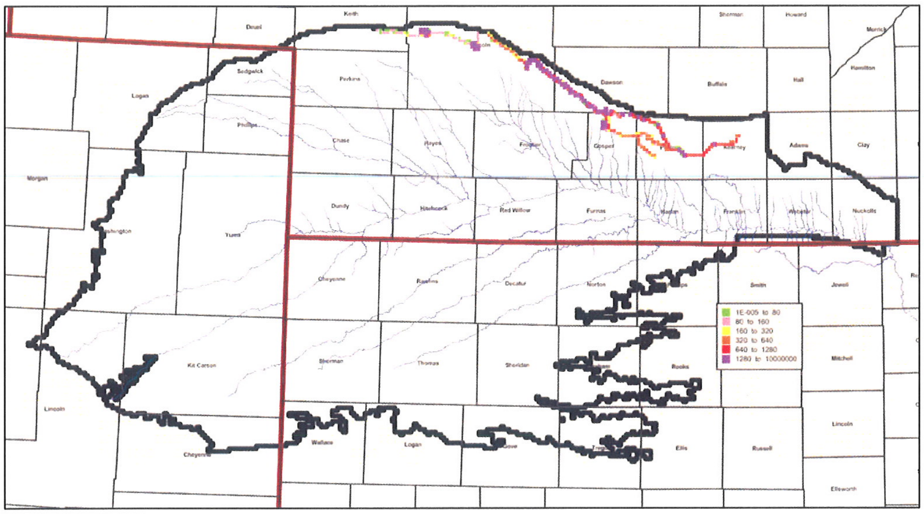

Figure 4a: Map Showing Locations and Amounts of Average Mound Seepage from 2001 to 2010.

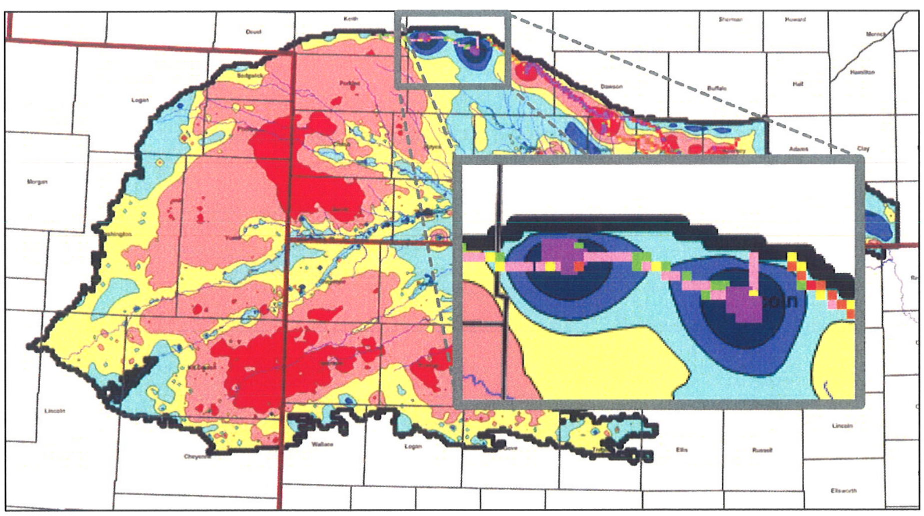

Figure 4b: Map Overlaying Locations and Amounts of Average Mound Seepage for 2001-2010 and Computed Groundwater Level Changes from 2001 to 2010.

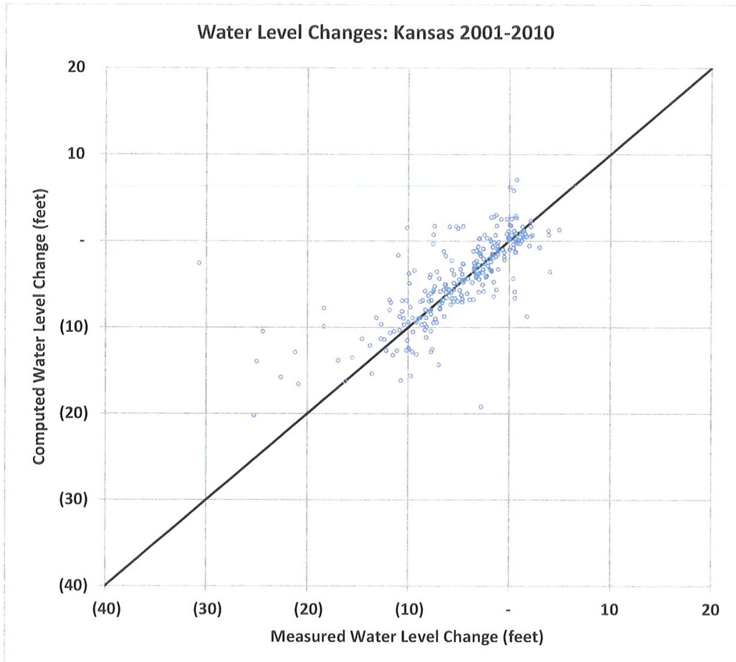

Figure 5a: Scatter Diagram of Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Kansas.

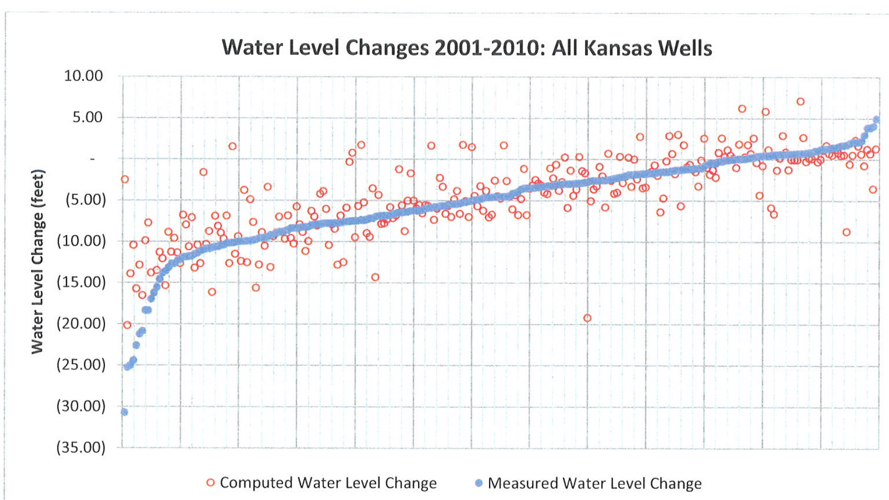

Figure 5b: Alternative Plot Comparing Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Kansas.

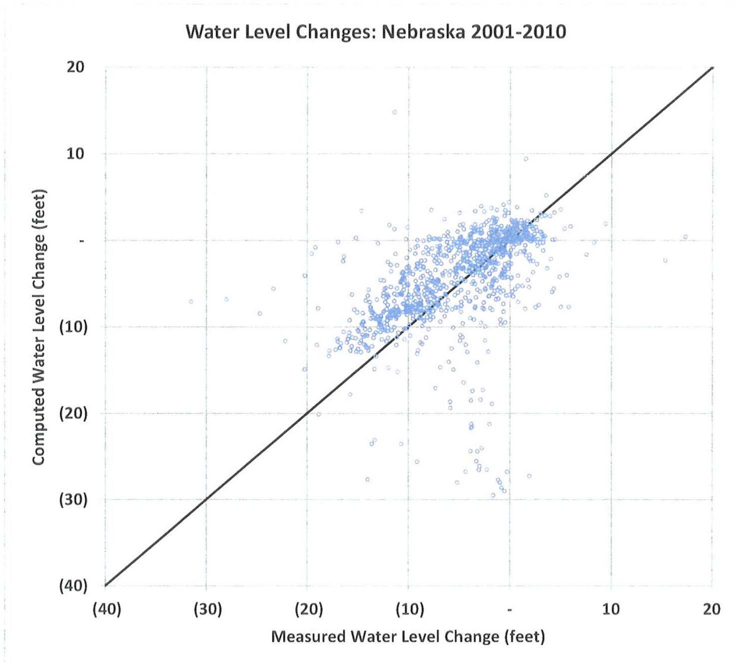

Figure 6a: Scatter Diagram of Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Nebraska.

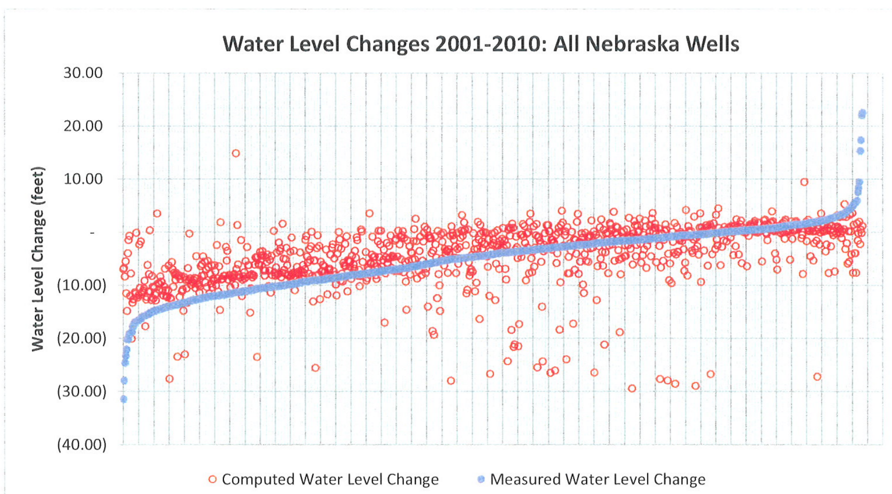

Figure 6b: Alternative Plot Comparing Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Nebraska.

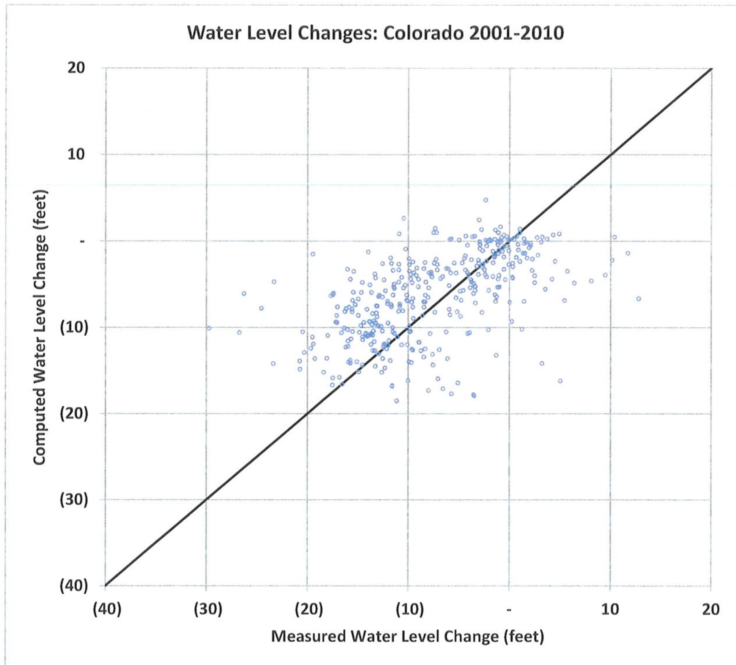

Figure 7a: Scatter Diagram of Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Colorado.

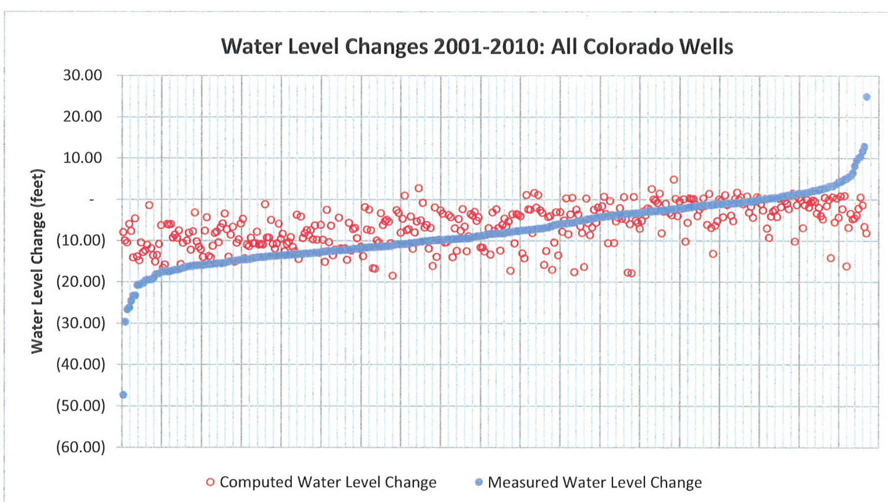

Figure 7b: Alternative Plot Comparing Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Colorado.

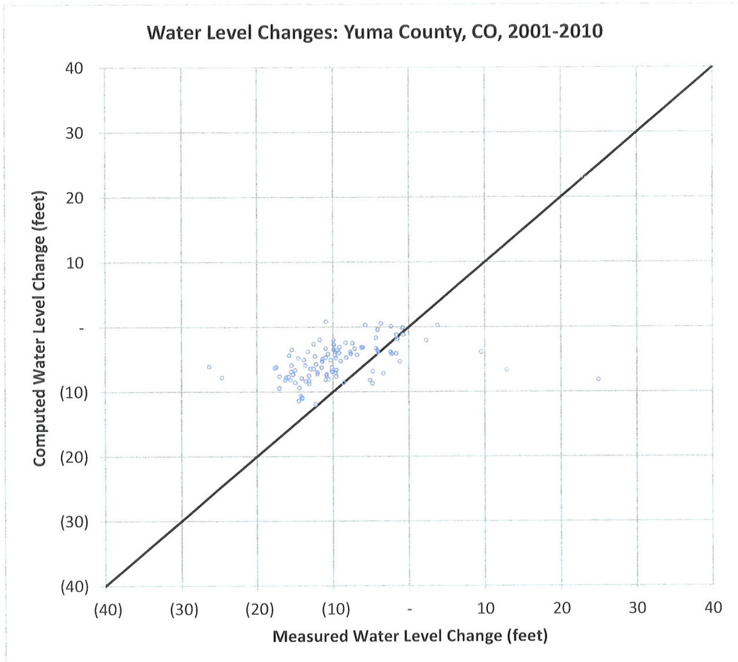

Figure 8a: Scatter Diagram of Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Yuma County, Colorado.

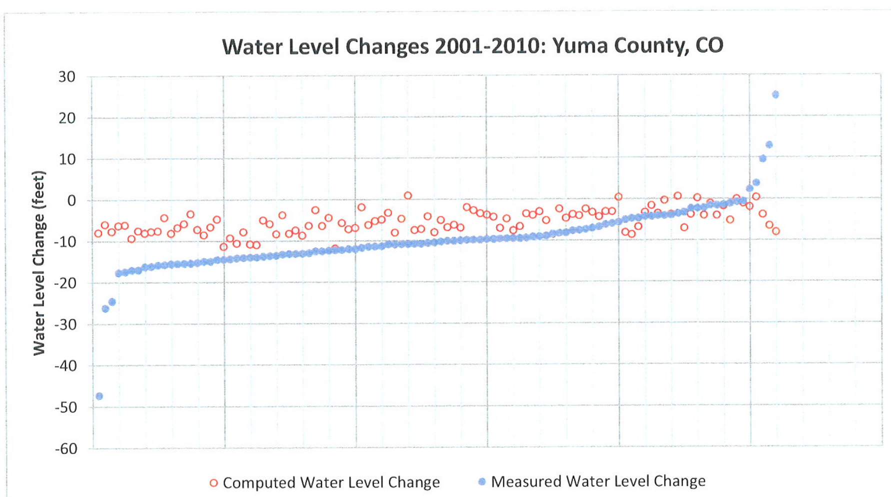

Figure 8b: Alternative Plot Comparing Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Yuma County, Colorado.

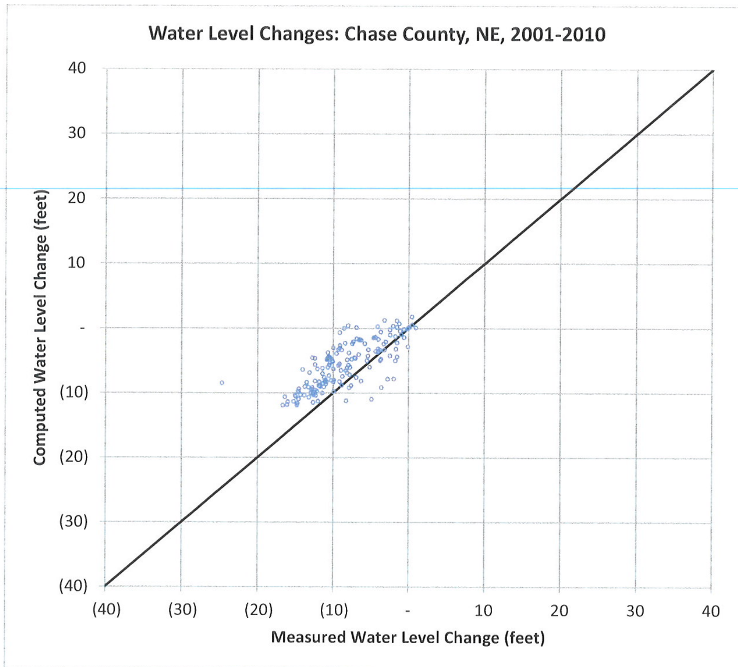

Figure 9a: Scatter Diagram of Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Chase County, Nebraska.

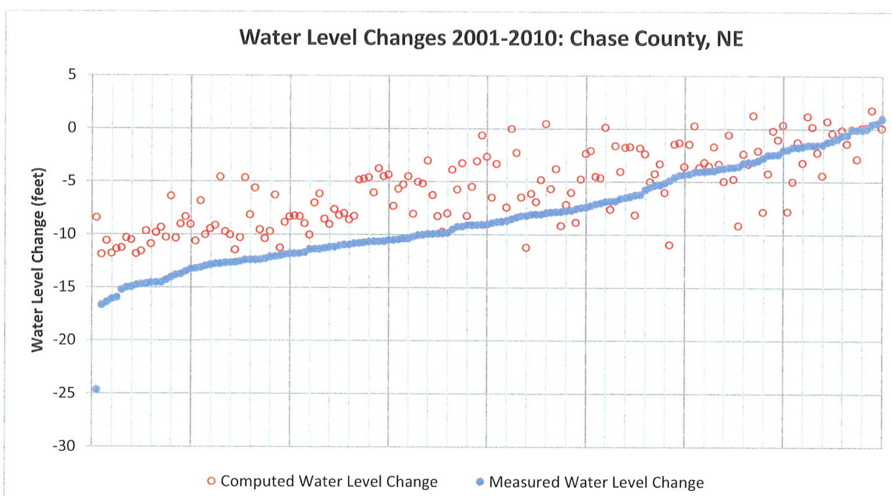

Figure 9b: Alternative Plot Comparing Computed and Measured Groundwater Level Changes from 2001 to 2010 for Wells in Chase County, Nebraska.

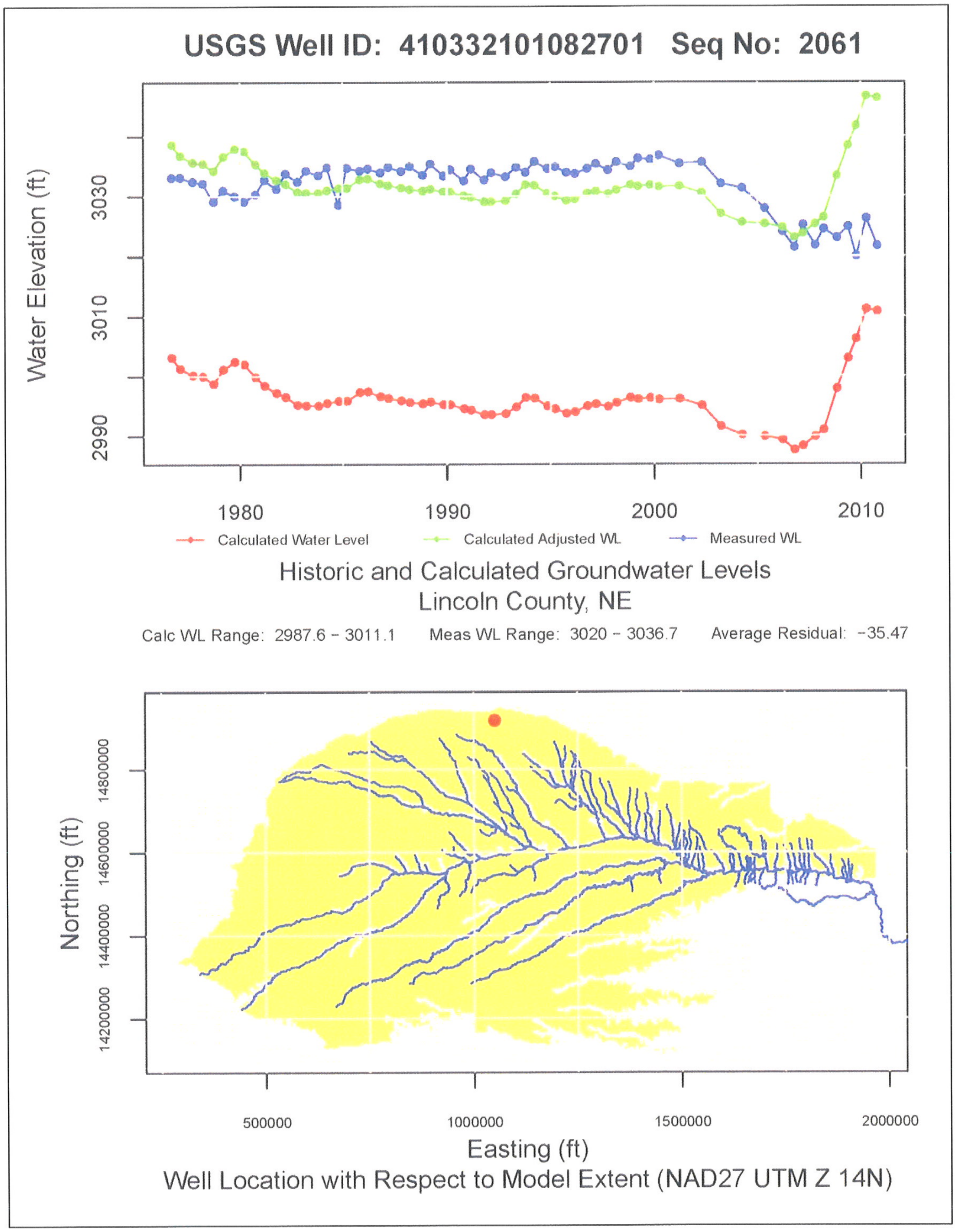

Figure 10: Example Hydrograph Comparing Computed and Measured Groundwater Levels for Well 410332101082701 located in Lincoln County, Nebraska.

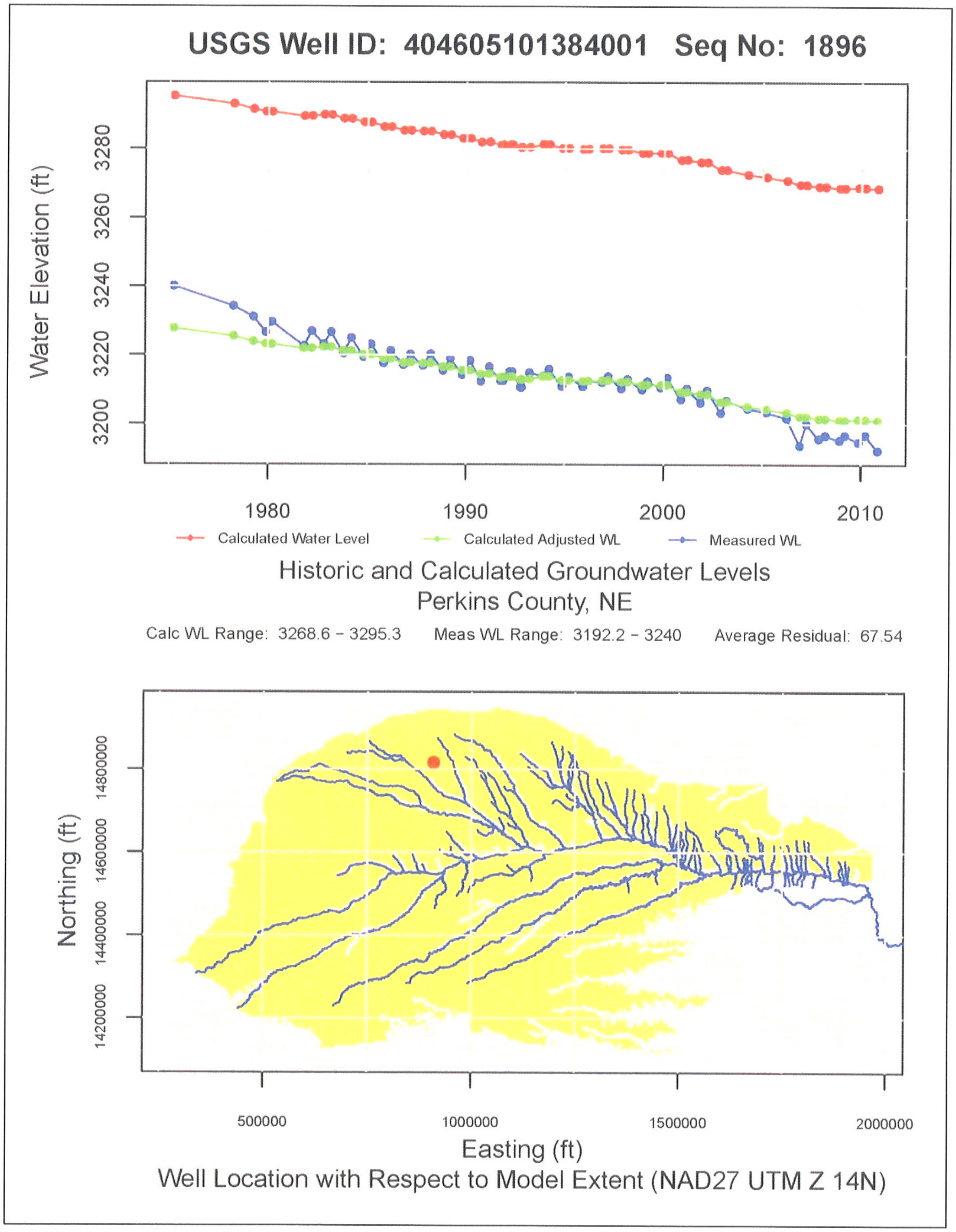

Figure 11: Example Hydrograph Comparing Computed and Measured Groundwater Levels for Well 404605101384001 Located in Perkins County, Nebraska.

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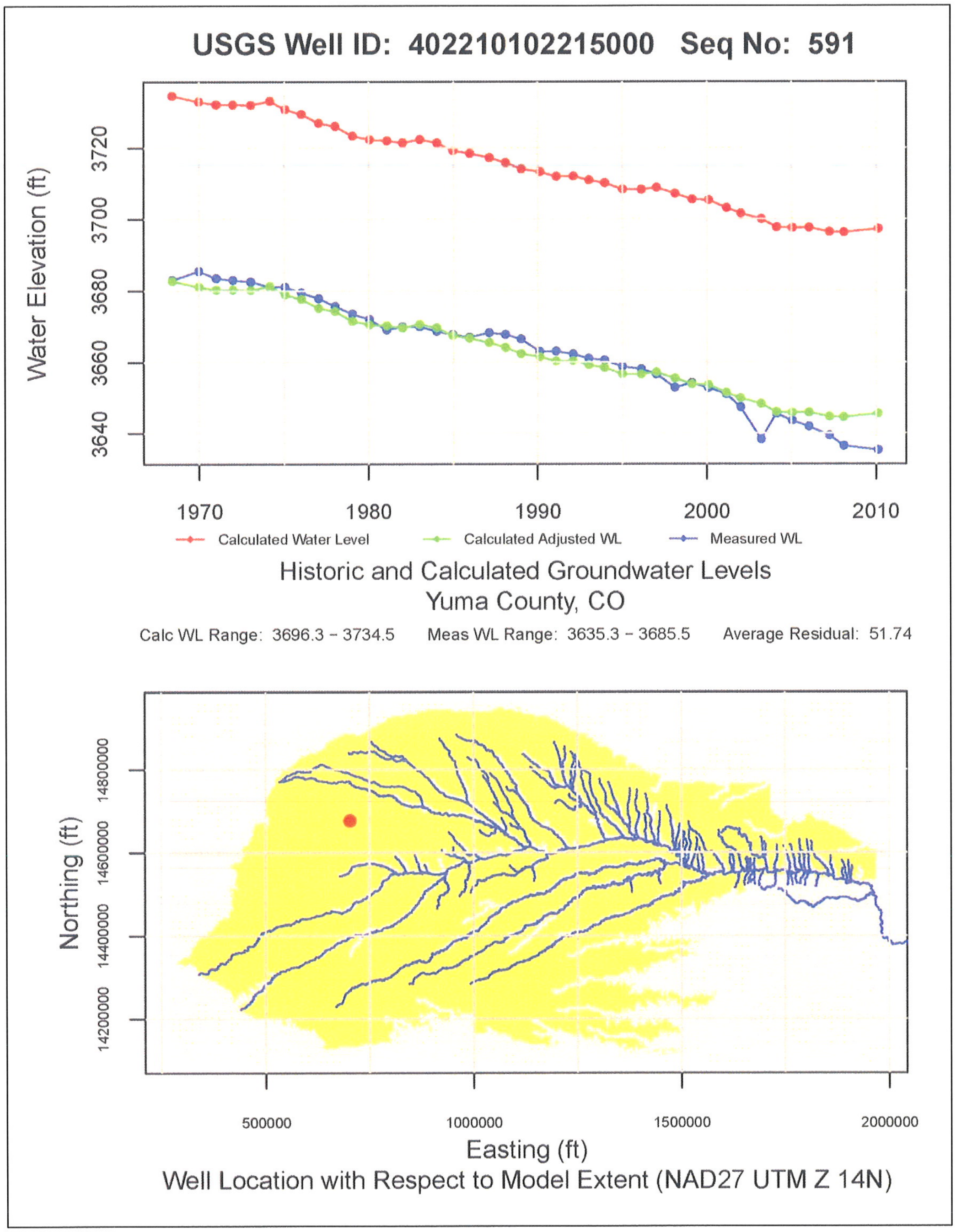

Figure 12: Example Hydrograph Comparing Computed and Measured Groundwater Levels for Well 402210102215000 Located in Yuma County, Colorado.

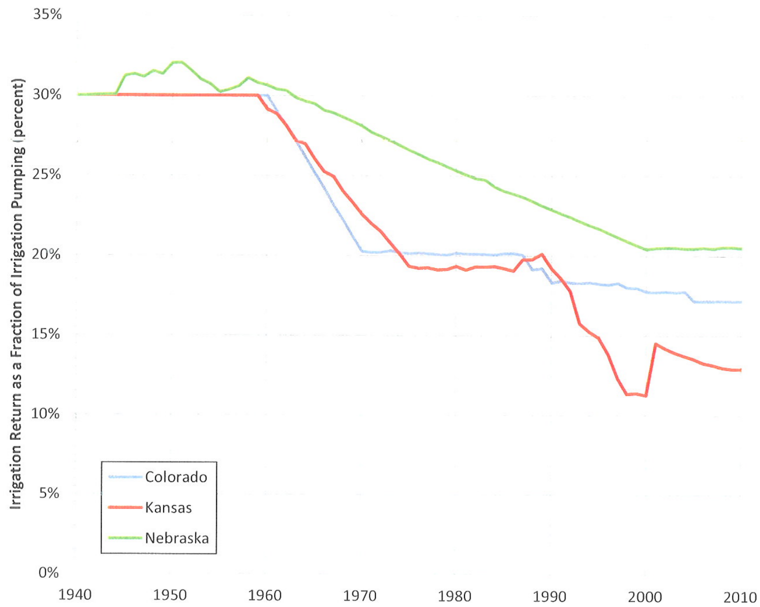

Figure 13: Graph Showing Irrigation Return Flows in Kansas, Nebraska, and Colorado as a Fraction of Irrigation Pumping.

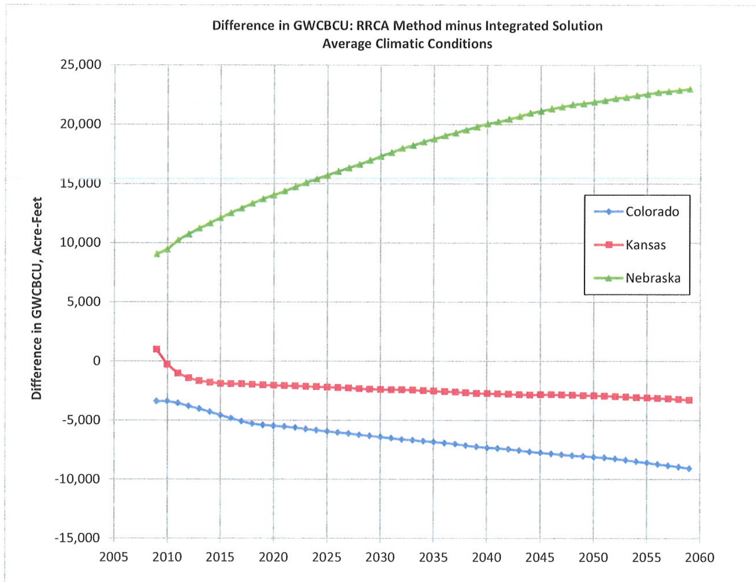

Figure 14a: Difference in GWCBCU – Average Climatic Conditions: RRCA Method minus Integrated Solution.

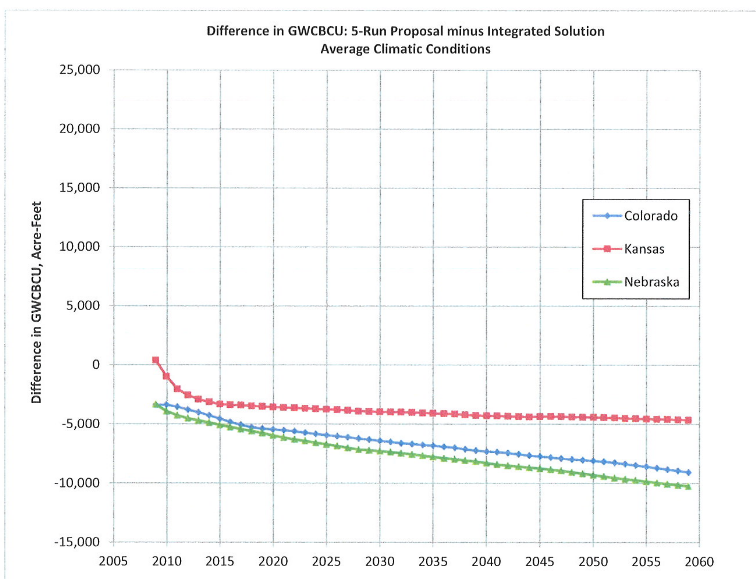

Figure 14b: Difference in GWCBCU – Average Climatic Conditions: 5-Run Proposal minus Integrated Solution.

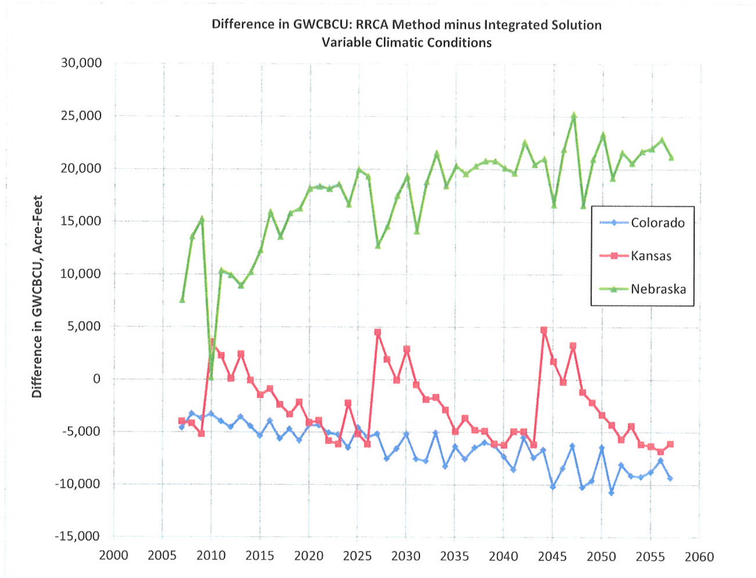

Figure 15a: Difference in GWCBCU – Variable Climatic Conditions: RRCA Method minus Integrated Solution.

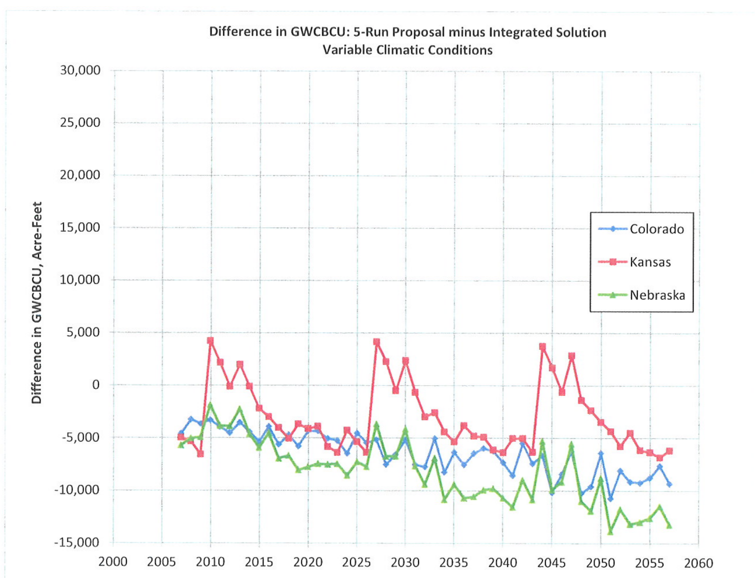

Figure 15b: Difference in GWCBCU – Variable Climatic Conditions: 5-Run Proposal minus Integrated Solution.

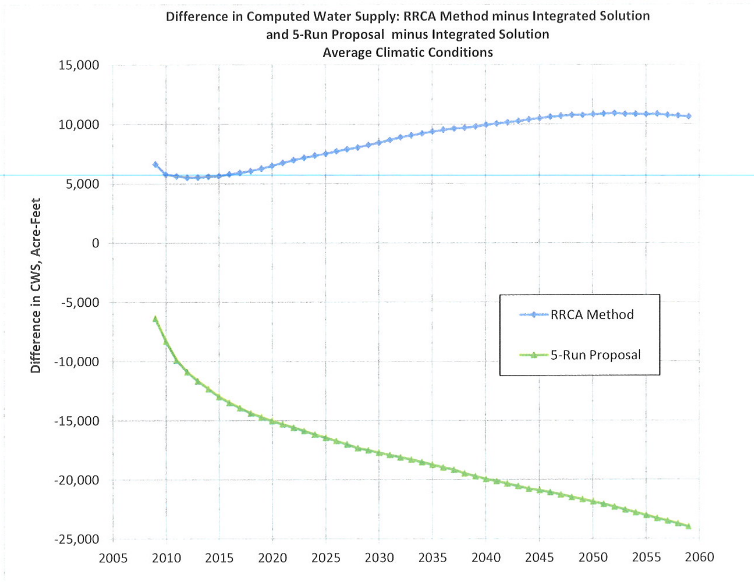

Figure 16: Difference in Computed Water Supply – Average Climatic Conditions:
RRCA Method minus Integrated Solution and 5-Run Proposal minus Integrated Solution.

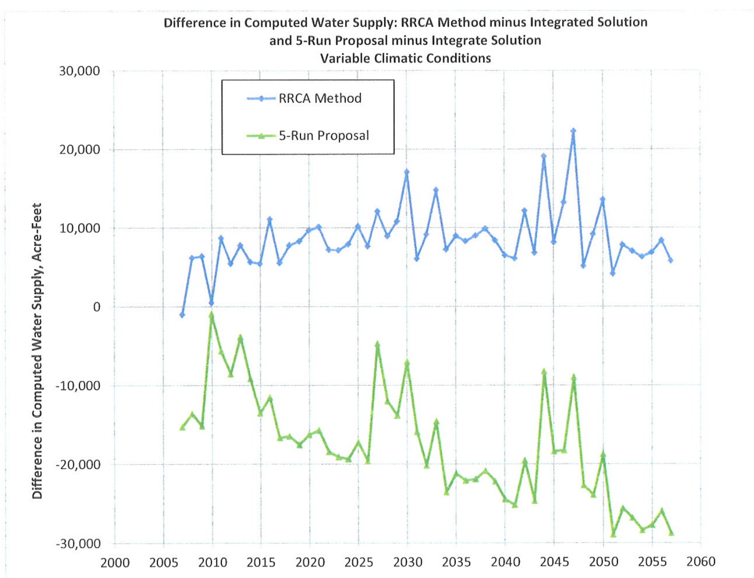

Figure 17: Difference in Computed Water Supply – Variable Climatic Conditions:
RRCA Method minus Integrated Solution and 5-Run Proposal minus Integrated Solution.

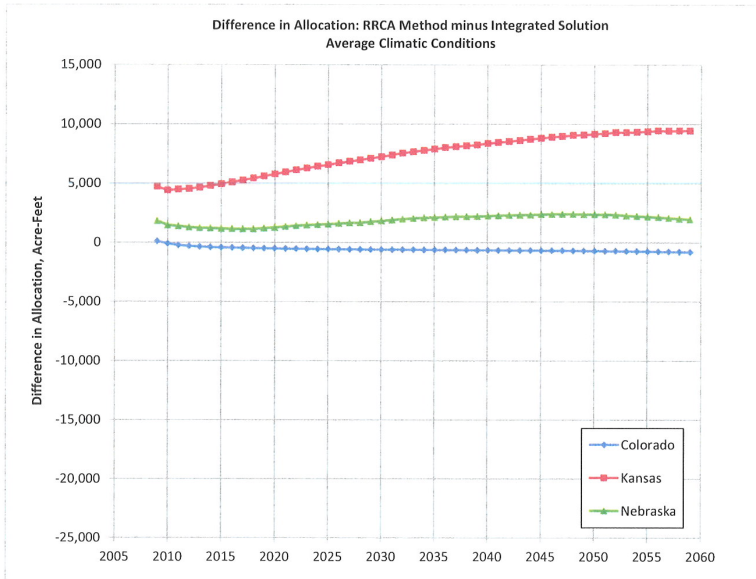

Figure 18a: Difference in Allocation – Average Climatic Conditions:
RRCA Method minus Integrated Solution.

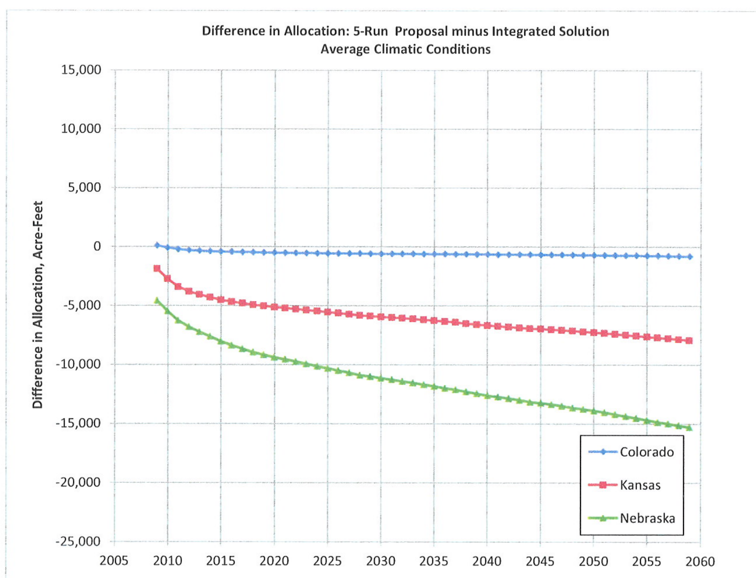

Figure 18b: Difference in Allocation – Average Climatic Conditions:
5-Run Proposal minus Integrated Solution.

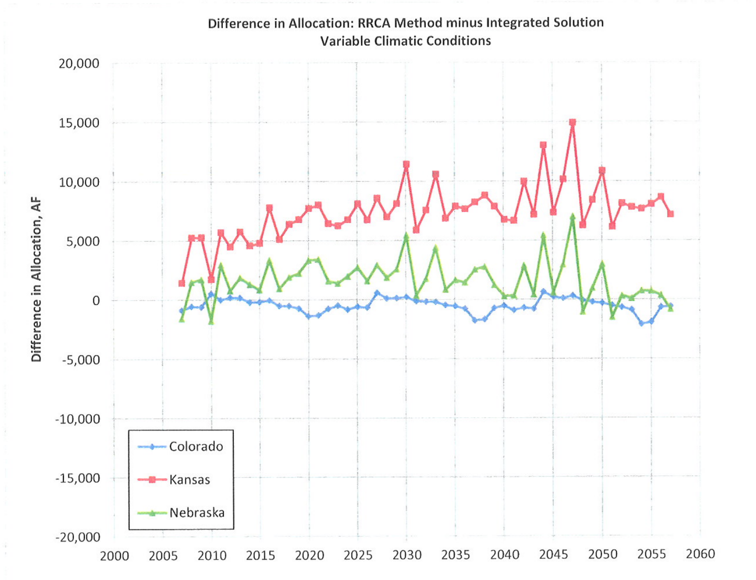

Figure 19a: Difference in Allocation – Variable Climatic Conditions: RRCA Method minus Integrated Solution.

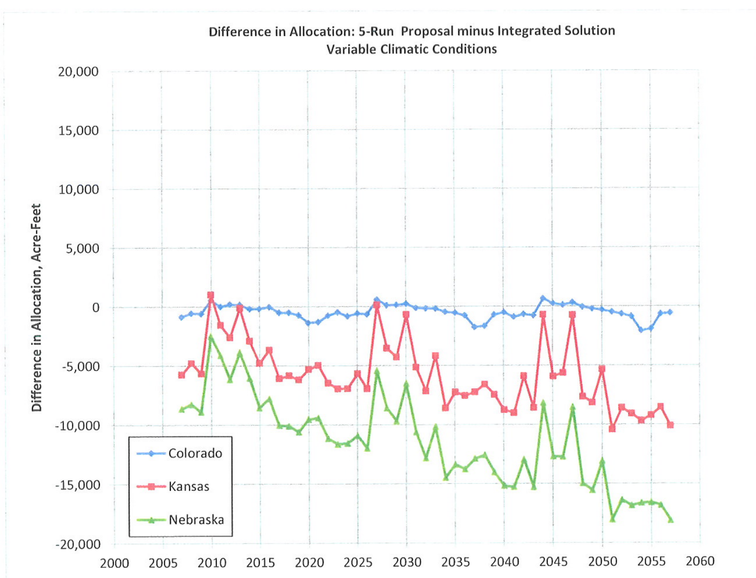

Figure 19b: Difference in Allocation – Variable Climatic Conditions: 5-Run Proposal minus Integrated Solution.

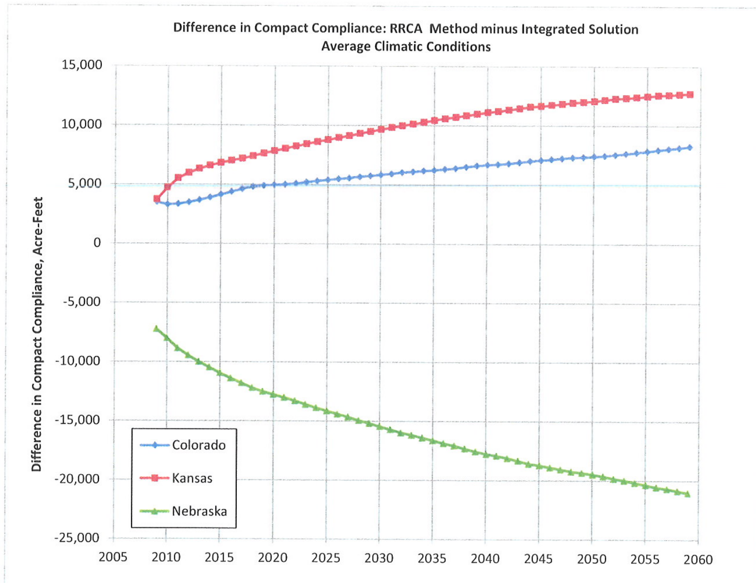

Figure 20a: Difference in Compact Compliance – Average Climatic Conditions: RRCA Method minus Integrated Solution.

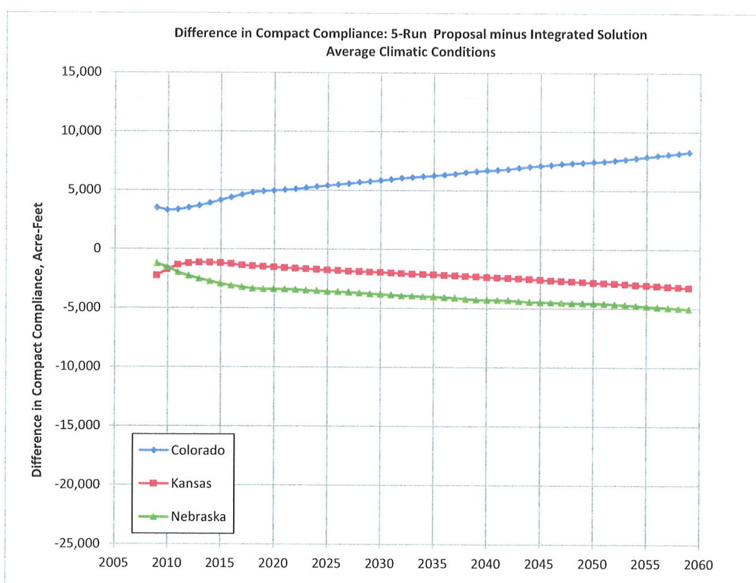

Figure207b: Difference in Compact Compliance – Average Climatic Conditions: 5-Run Proposal minus Integrated Solution.

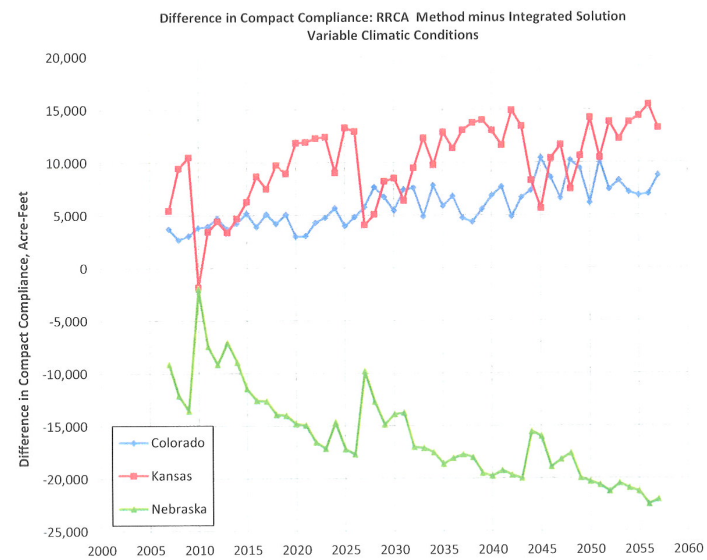

Figure 21a: Difference in Compact Compliance – Variable Climatic Conditions: RRCA Method minus Integrated Solution.

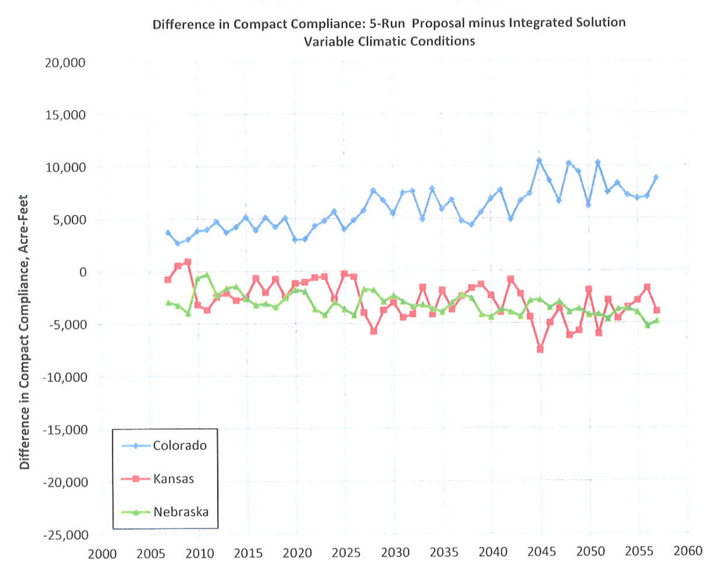

Figure 21b: Difference in Compact Compliance – Variable Climatic Conditions: **5-Run Proposal minus Integrated Solution.**

TABLES

Table 1: Compilation of Irrigation Pumping and Irrigation Return Flow from 1940 to 2010 as Reported to the RRCA by Colorado, Kansas, and Nebraska.

Year	Irrigation Pumping			Irrigation Return Flow			Fraction of Irrigation Return Flow		
	Colorado	Kansas	Nebraska	Colorado	Kansas	Nebraska	Colorado	Kansas	Nebraska
1940	1,346	3,405	37,411	404	1,022	11,223	30.0%	30.0%	30.0%
1941	1,402	2,732	30,894	421	820	9,268	30.0%	30.0%	30.0%
1942	1,900	4,099	32,301	570	1,230	9,702	30.0%	30.0%	30.0%
1943	2,819	5,409	43,642	846	1,623	13,112	30.0%	30.0%	30.0%
1944	2,901	4,541	36,628	870	1,362	11,008	30.0%	30.0%	30.1%
1945	2,302	5,150	52,091	691	1,545	16,272	30.0%	30.0%	31.2%
1946	3,616	6,287	54,937	1,085	1,886	17,215	30.0%	30.0%	31.3%
1947	5,655	5,852	44,167	1,697	1,756	13,761	30.0%	30.0%	31.2%
1948	8,355	5,494	34,217	2,507	1,648	10,786	30.0%	30.0%	31.5%
1949	10,818	5,524	41,134	3,245	1,657	12,887	30.0%	30.0%	31.3%
1950	13,987	7,644	20,814	4,196	2,293	6,665	30.0%	30.0%	32.0%
1951	13,382	4,957	16,403	4,015	1,487	5,257	30.0%	30.0%	32.0%
1952	25,658	13,136	37,180	7,697	3,941	11,734	30.0%	30.0%	31.6%
1953	26,343	14,166	46,239	7,903	4,250	14,344	30.0%	30.0%	31.0%
1954	38,708	22,522	79,373	11,612	6,757	24,396	30.0%	30.0%	30.7%
1955	53,198	36,986	92,698	15,959	11,096	28,021	30.0%	30.0%	30.2%
1956	81,808	66,607	149,712	24,542	19,982	45,452	30.0%	30.0%	30.4%
1957	63,839	58,011	167,480	19,152	17,403	51,212	30.0%	30.0%	30.6%
1958	64,301	66,158	124,591	19,290	19,848	38,756	30.0%	30.0%	31.1%
1959	97,655	85,436	275,470	29,297	25,631	84,847	30.0%	30.0%	30.8%
1960	90,282	94,722	268,480	27,085	27,606	82,263	30.0%	29.1%	30.6%
1961	87,671	79,315	222,413	25,472	22,883	67,587	29.1%	28.9%	30.4%
1962	86,757	73,950	135,464	24,392	20,799	41,059	28.1%	28.1%	30.3%
1963	142,954	123,345	314,917	38,842	33,548	94,064	27.2%	27.2%	29.9%
1964	214,073	184,225	331,942	56,005	49,665	98,372	26.2%	27.0%	29.6%
1965	155,393	140,506	277,703	39,119	36,564	81,890	25.2%	26.0%	29.5%
1966	275,095	205,817	378,582	66,726	51,962	110,059	24.3%	25.2%	29.1%
1967	362,137	231,738	443,896	83,885	57,769	128,330	23.2%	24.9%	28.9%
1968	464,363	263,347	604,914	103,235	63,225	173,241	22.2%	24.0%	28.6%
1969	531,688	303,593	584,179	112,737	70,795	165,793	21.2%	23.3%	28.4%
1970	601,750	370,066	903,174	121,851	83,594	253,722	20.2%	22.6%	28.1%
1971	630,744	424,963	881,976	127,341	93,492	244,300	20.2%	22.0%	27.7%
1972	572,578	360,368	811,664	115,603	77,507	222,780	20.2%	21.5%	27.4%
1973	609,592	454,316	888,881	123,701	94,498	241,517	20.3%	20.8%	27.2%
1974	928,838	549,301	1,220,349	187,474	110,465	328,054	20.2%	20.1%	26.9%
1975	880,638	462,786	1,264,274	177,226	89,413	336,215	20.1%	19.3%	26.6%
1976	1,006,365	777,187	1,621,818	202,940	149,289	426,919	20.2%	19.2%	26.3%
1977	919,057	520,707	1,246,573	184,955	100,154	324,442	20.1%	19.2%	26.0%
1978	1,032,721	672,554	1,689,826	207,185	128,514	436,185	20.1%	19.1%	25.8%
1979	834,075	441,661	1,182,022	167,133	84,477	301,894	20.0%	19.1%	25.5%
1980	855,547	534,424	1,549,146	172,352	103,277	391,823	20.1%	19.3%	25.3%
1981	875,096	561,600	1,111,538	175,911	107,236	278,400	20.1%	19.1%	25.0%
1982	662,140	420,593	1,036,258	133,088	81,149	257,066	20.1%	19.3%	24.8%
1983	654,017	466,787	1,204,466	131,304	90,008	297,833	20.1%	19.3%	24.7%
1984	818,038	519,377	1,491,538	163,959	100,370	362,420	20.0%	19.3%	24.3%
1985	684,041	474,299	1,368,050	137,674	91,062	328,743	20.1%	19.2%	24.0%
1986	721,067	552,279	1,390,985	145,232	105,144	331,735	20.1%	19.0%	23.8%
1987	756,271	431,503	1,301,147	151,531	85,169	307,768	20.0%	19.7%	23.7%
1988	847,765	464,451	1,639,301	162,054	91,737	383,603	19.1%	19.8%	23.4%
1989	711,202	532,617	1,514,249	136,469	107,069	349,833	19.2%	20.1%	23.1%
1990	743,432	512,588	1,718,934	136,075	98,395	392,986	18.3%	19.2%	22.9%
1991	670,431	477,883	1,908,252	123,489	88,768	431,798	18.4%	18.6%	22.6%
1992	696,201	263,613	1,123,510	127,509	46,869	251,702	18.3%	17.8%	22.4%
1993	654,381	255,110	549,078	119,628	40,179	121,570	18.3%	15.7%	22.1%
1994	827,192	392,065	1,519,332	151,617	59,726	332,647	18.3%	15.2%	21.9%
1995	680,446	366,239	1,752,046	124,131	54,428	380,042	18.2%	14.9%	21.7%
1996	594,535	364,518	1,101,024	108,090	50,396	235,820	18.2%	13.8%	21.4%
1997	721,848	414,693	1,758,118	131,998	51,085	372,074	18.3%	12.3%	21.2%
1998	744,589	382,800	1,604,741	134,098	43,380	335,454	18.0%	11.3%	20.9%
1999	643,548	333,959	1,178,570	115,724	38,007	243,417	18.0%	11.4%	20.7%
2000	901,788	495,708	2,245,099	160,118	55,777	458,496	17.8%	11.3%	20.4%
2001	876,397	451,543	1,774,258	155,370	65,559	363,542	17.7%	14.5%	20.5%
2002	906,631	569,053	2,495,095	161,160	80,733	511,836	17.8%	14.2%	20.5%
2003	890,479	520,436	2,149,726	157,780	72,387	441,155	17.7%	13.9%	20.5%
2004	730,747	518,221	1,891,480	129,883	71,050	387,084	17.8%	13.7%	20.5%
2005	724,983	425,789	1,660,810	124,574	57,620	339,850	17.2%	13.5%	20.5%
2006	761,664	464,920	1,673,444	130,791	61,700	343,381	17.2%	13.3%	20.5%
2007	650,306	446,107	1,367,300	111,738	58,658	279,886	17.2%	13.1%	20.5%
2008	660,933	432,559	1,418,878	113,613	56,153	291,758	17.2%	13.0%	20.6%
2009	522,724	324,167	1,288,940	89,798	41,839	264,932	17.2%	12.9%	20.6%
2010	669,739	394,294	1,179,792	115,027	50,884	241,954	17.2%	12.9%	20.5%

Table 2: Comparison of the Fractions of Irrigation Return Flow from 2001 to 2010 as Reported to the RRCA by Colorado, Kansas, and Nebraska.

Year	Fraction of Irrigation Return Flow			Difference of Irrigation Return Flow Fraction		Corresponding Amount of Return Flow (acre-feet)	
	Colorado	Kansas	Nebraska	Colorado minus Kansas	Nebraska minus Kansas	Colorado	Nebraska
2001	17.7%	14.5%	20.5%	3.2%	6.0%	28,127	105,941
2002	17.8%	14.2%	20.5%	3.6%	6.3%	32,534	157,850
2003	17.7%	13.9%	20.5%	3.8%	6.6%	33,923	142,151
2004	17.8%	13.7%	20.5%	4.1%	6.8%	29,694	127,755
2005	17.2%	13.5%	20.5%	3.7%	6.9%	26,466	115,101
2006	17.2%	13.3%	20.5%	3.9%	7.2%	29,711	121,298
2007	17.2%	13.1%	20.5%	4.0%	7.3%	26,230	100,103
2008	17.2%	13.0%	20.6%	4.2%	7.6%	27,812	107,564
2009	17.2%	12.9%	20.6%	4.3%	7.6%	22,333	98,575
2010	17.2%	12.9%	20.5%	4.3%	7.6%	28,597	89,702

APPENDIX

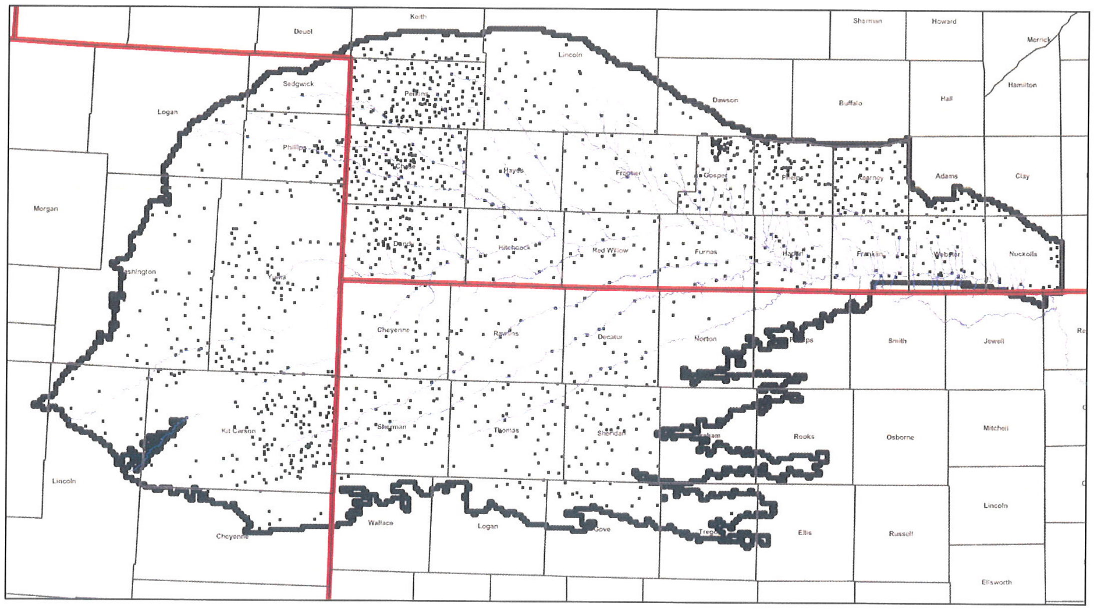

Figure A-1: Map of Well Locations.

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Appendix B

Appendix B

Detailed Description of the Integrated Solution

Sam Perkins, P.E., PhD.
Kansas Department of Agriculture, Division of Water Resources.
May 15, 2013

Table of Contents

Introduction

Appendix B presents an approximate solution for the states' impacts on computed baseflow that sum to the total impact within a tolerance that can be made as small as desired, and appropriately distributes pumping impacts among the states. We refer to this approximation as the integrated solution, which can be specified to either include or exclude imported water from the base case.

The integrated solution addresses the nonlinearity of stream depletion that occurs over the range of pumping due to stream drying; that is, as pumping increases, less streamflow is available to be depleted. The depletion response can be conceptualized as a normally decreasing function over the range of pumping from zero to the total reported pumping by the three States during any given time period. If the range of pumping is subdivided into a large number of slices, or intervals, then for each interval of total pumping we find, as the width of each interval approaches zero, the sum of the States' depletions due to varying each State's pumping separately over the range of the interval equals the total impact due to varying all of the States' pumping together. That is, as the intervals get smaller, the sum of the States' impacts becomes a better approximation for the total impact over that interval, and an exact solution for the States' impacts exists at the limit as the width of the intervals approaches zero. At that limit, the sum over the incremental impacts is represented as a continuous integration to give the exact solution.

Two techniques are used to give a good approximation for the exact solution. The mathematical basis for these techniques is described below, under Methods. One technique is to subdivide the range of pumping into intervals, and to calculate impacts over the range of each interval. A second technique is to represent the average depletion response over the range of each interval in calculating the impacts. To illustrate this technique, consider the full range of pumping as a single interval. The average depletion response for each State's impact can be applied to this interval by taking the average of two cases: first, the impact of turning the State's pumping off with all other pumping on; and second, the impact of turning the State's pumping on with all other pumping off.

Similarly, this averaging technique can be applied for any number of intervals. With ten stress intervals, each State's impact is calculated over ten-percent intervals of pumping in two "directions" and then averaged. For the interval between 90 and 100 percent of total pumping, each State's impact is calculated (a) with the State's pumping at 90 percent, holding the other States' pumping at 100 percent; and (b) with the State's pumping at 100 percent, holding the other States' pumping at 90 percent. The average depletion response over this interval is applied by taking the average of impacts according to stress decrements as in (a) and stress increments as in (b).

The integrated solution applies these techniques to approximate the exact solution as closely as desired. The solution is described in the next section and then demonstrated with an example that applies ten-percent stress intervals and average response functions to historical conditions for years 1918-2010. Results for this example show that the discrepancy with respect to the total impact is negligible.

Appendix B ends by presenting stream depletion characteristics over the full range of pumping for the total basin and for several accounting subbasins. These characteristics are a result of the integrated solution applied to the scenario of average future conditions described in the Expert Report and projected to year 2059.

Method

The mathematical basis of the integrated solution is the total differential, a concept from calculus first introduced by Gottfried Leibniz in 1684 (see Zeidler et al., 2004; Oboukhoff, 1940). The total differential states in effect that, at any point on a function, the total incremental change in the function equals the sum of impacts due to small variations in its independent variables in the limit as the magnitude of those variations approaches zero. This concept is commonly applied in uncertainty analysis (Wikipedia, 2012).

The total differential of a function can be visualized as a tangent that equals the function at a single point on the function. The tangent is a line for a function of a single independent variable, and a plane for a function of two variables; the concept generalizes to more than two variables but is difficult to visualize. With imported water supply (IWS) excluded from the base case, computed baseflow is treated as a function of a single variable to calculate the total impact of pumping, and as function of three variables to calculate the impacts of each state's pumping. Alternatively, computed baseflow can be treated as a function of four variables if IWS is included in the base case.

The total differential is approximated to calculate the total impact of pumping on computed baseflow for small but discrete variations in pumping by the three states. This is accomplished with the RRCA groundwater model with no model changes over the full range of pumping. The discretized total differential is then integrated by summing the impacts over the pumping intervals.

For computed baseflow with no IWS in the base case, the terms of the total differential, referred to as partial differentials, are represented by the product of a partial derivative and a change in the independent variable. The partial derivatives quantify how stream depletion varies over the range of pumping by each state. It is this variation that the integrated solution addresses in order to eliminate the approximation error from the calculation of the states' impacts.

The integrated solution can improve accuracy through two approaches. First, the width of stress intervals can be reduced, with corresponding increases in the number of pumping intervals and model runs. Second, the impacts calculated for each pumping interval can be approximated using either forward or central differences, as in the next section. Forward differences can be applied using either stress increments or decrements, and approximation error is roughly a linear function of stress interval. Impacts of both stress increments and decrements are calculated using a version of Willem's acct program.

Central differences greatly improve the approximation of impacts compared with forward differences, and can be expressed as the average of forward difference approximations based on stress increments and decrements. The central difference approximation is applied as a spreadsheet operation to average impacts calculated for stress increments and decrements. Using these techniques, the integrated solution is both computationally practical and accurate.

Parameterization of stress intervals

The stress fraction, f, is defined to parameterize stress intervals $h_i = fP_i$ for the ith stress, and $h = fP$ for the jointly applied stresses, so that as the combined or individual stress fraction varies between 0 and 1, the combined stress P or individual stress P_i varies from no pumping to full pumping. The number of equal discretization intervals $n = 1/f$; and for a given discretization, the kth stress fraction $f_k = k/n$ for k from 0 to n. This parameterization is used to discretize the integration of the total differential over the range of pumping as a summation of impacts over stress fractions from 0 to 1.

Model runs corresponding to a given set of stress fractions are specified using the command STRESSF, which was added to a version of the Republican River Preprocessor named rrpptestv4. Specified stress fractions can be passed to the program as command line arguments. This feature is used in batch procedures to automate the required model runs for a sequence of stress intervals.

Discretization of total differential

The total differential of computed baseflow as a function of m independent variables is approximated by

$$\Delta Q_k \approx \frac{\partial Q_k}{\partial P_1}\Delta P_1 + \frac{\partial Q_k}{\partial P_2}\Delta P_2 + \ldots + \frac{\partial Q_k}{\partial P_m}\Delta P_m, \text{ or } \Delta Q_k = \sum_{i=1}^{m} \frac{\partial Q_k}{\partial P_i}\Delta P_i\,, \qquad (1)$$

where ΔP_i represents a small but finite change in each stress. With IWS excluded from the base case, the number of independent variables m=3, and only pumping stresses are considered in Equation (1).

The subscript k indicates that each term in Equation (1) represents the impact of varying the associated stress with respect to baseflow conditions in which pumping is held at a fraction f_k of full pumping, where $f_k = k/n$. For example, if pumping is discretized into ten steps (n=10), then for k=9, the impact of variation in each state's pumping is calculated with respect to a base case that includes 90 percent of all pumping in the model.

Each partial derivative, $\partial Q_k / \partial P_i$ in Equation (1) represents the depletion response to change in a given stress, P_i, holding the other stresses constant at conditions defined for the kth stress fraction. As the increments ΔP_i approach zero, the sum of terms given by Equation (1) converges to the total differential. At this limit Equation (1) is linear, i.e. its terms are additive, and the sum of terms equals the impact of the pumping stresses combined into a single variable. With IWS included in the base case, computed baseflow is treated as a function of four independent variables corresponding to the stresses of the three states' pumping and the imported water supply. If IWS is excluded from the base case, computed baseflow is treated as a function of three independent variables, $Q(P_1, P_2, P_3)$,where P_1, P_2, P_3 correspond to Colorado, Kansas and Nebraska pumping.

Total impact and integration over range of stresses

The total impact for the kth stress interval is calculated independently for comparison with the sum of terms given by Equation (1). For this purpose, computed baseflow is treated as a function of a single variable, $Q(P)$, where P is the sum of the three states' pumping, $P = \sum P_i$. (If IWS had been included in the base case, P would include IWS as a term in the sum of four stresses.) The total depletion response to pumping is represented by the derivative dQ/dP, which is approximated by

$$\frac{\Delta Q}{\Delta P} = \frac{Q(P + \Delta P) - Q(P)}{\Delta P} \tag{2}$$

This is a forward differences approximation that is used in calculus to define the derivative in the limit as ΔP approaches zero. For each stress interval k from 1 to n, the total impact is given by

$$\Delta Q_k = \frac{dQ_k}{dP} \Delta P = Q_k(P + \Delta P) - Q_k(P) \tag{3}$$

The two terms on the right-hand side represent two model runs that differ in total pumping by ΔP, which could be either a stress increment or decrement. The total impact is integrated over the range of pumping by summing the incremental impacts,

$$\Delta Q = \sum_{k=1}^{n} \Delta Q_k \tag{4}$$

The total impact given by Equation (4) does not vary with respect to the number of discretization intervals, n, defined above. This is explained by substituting the right-hand side of Equation (3) into Equation (4), in which case all intermediate terms cancel and only the outside terms corresponding to full pumping and no pumping remain. However, calculating the total impact for each stress interval is useful for comparison with the sum of state pumping impacts given by (1). The total impact over the full range of pumping given by (4) is compared with the integration of (1) over the full range of pumping, which is described next.

Integrating the total differential

The discretized total differential given by (1) is integrated over the full range of stresses between no pumping and total pumping by summing each partial differential in (1) over *k* stress intervals from 1 to n. This integration is denoted by the approximation

$$\Delta Q \approx \sum_{k=1}^{n} \frac{\partial Q_k}{\partial P_1} \Delta P_1 + \sum_{k=1}^{n} \frac{\partial Q_k}{\partial P_2} \Delta P_2 + \ldots + \sum_{k=1}^{n} \frac{\partial Q_k}{\partial P_m} \Delta P_m \; . \qquad (5)$$

The states' pumping impacts for the *k*th stress interval in each summation on the right-hand side of Equation (5) are calculated with respect to base case conditions defined for the *k*th stress fraction. The discrepancy associated with the integrated solution is given by the difference between the sum of terms in Equation (5) and the total impact according to Equation (4).

Finite difference approximations

The approximation error in Equation (1) depends both on the discretization interval, ΔP_i, and on how the partial derivatives are approximated. The principal ways to approximate the partial derivatives are by forward and central differences; see, for example, Conte and de Boor (1980).

Forward differences

A forward difference approximation of the partial derivatives in (1) is given by

$$\frac{\partial Q}{\partial P_i} \approx \frac{Q(P_i + \Delta P_i) - Q(P_i)}{\Delta P_i} \qquad (6)$$

Then each term in (1) is given by

$$\Delta Q_{i,k} \equiv \frac{\partial Q}{\partial P_i} \Delta P_i \approx Q(P_i + \Delta P_i) - Q(P_i) \qquad (7)$$

This approximation is first-order accurate; i.e. the approximation error varies linearly with ΔP_i. Each term of Equation (1) is an incremental impact that is given by (7), and which is evaluated by calculating the differences in computed baseflow between two model runs.

Note that Equation (7) approximates the impact of a stress *increment*, as opposed to the impact of a stress *decrement*, which is expressed by

$$\Delta Q_{i,k} \equiv \frac{\partial Q}{\partial P_i} \Delta P_i \approx Q(P_i - \Delta P_i) - Q(P_i) \tag{8}$$

Central differences

A central difference approximation of the partial derivatives in (1) is given by

$$\frac{\partial Q}{\partial P_i} \approx \frac{Q(P_i + \Delta P_i) - Q(P_i - \Delta P_i)}{2\Delta P_i} \tag{9}$$

In this case, each term in (1) is approximated by

$$\frac{\partial Q}{\partial P_i} \Delta P_i \approx \frac{Q(P_i + \Delta P_i) - Q(P_i - \Delta P_i)}{2} \tag{10}$$

The central difference approximation can often improve an approximation substantially, and turns out to be very useful for our purposes.

The central difference approximation can be implemented as the average of impacts given by two forward difference approximations, where one is calculated from stress decrements and the other from stress increments. Adding and subtracting the term $Q(P_i)$ to the numerator in (6) gives

$$\frac{\partial Q}{\partial P_i} \Delta P_i \approx \frac{[Q(P_i + \Delta P_i) - Q(P_i)] + [Q(P_i) - Q(P_i - \Delta P_i)]}{2} \tag{11}$$

Equation (11) provides a convenient way to apply central differences, which is implemented as the average of impacts taken with respect to either side of a specified interval. Note that the sum over n stress intervals can be evaluated either as a sum over the averages given by (11),

$$\Delta Q_i \approx \sum_{k=1}^{n} \{[Q(P_{i,k} + \Delta P_i) - Q(P_{i,k})] + [Q(P_{i,k}) - Q(P_i - \Delta P_{i,k})]\}/2 \tag{12}$$

or as an average of sums given by

$$\Delta Q_i \approx (1/2)\left\{\sum_{k=1}^{n}[Q(P_{i,k} + \Delta P_i) - Q(P_{i,k})] + \sum_{k=1}^{n}[Q(P_{i,k}) - Q(P_i - \Delta P_{i,k})]\right\} \tag{13}$$

Equation (13) expresses the central difference approximation as an arithmetic average of two forward difference approximations that correspond to stress increments according to (7) and stress decrements according to (8).

Equation (13) is implemented as follows. First, after making the necessary model runs, the accounting program acct_base_incr, a version of Willem's acct program, is used to evaluate the forward difference approximations separately, once for stress increments and once for stress decrements. Second, the output from the accounting program is imported into Excel, where their arithmetic average is calculated to apply the central difference approximation according to Equation (13).

A version of the accounting program to calculate impacts, acct_basemon_incr, calculates impacts for each stress interval and integrates by summing impacts over the full stress range for either stress increments or decrements. An alternate version, acct_base2012, can be used to calculate and incremental impacts for each stress interval, which can be assembled in Excel to illustrate solutions in terms of incremental and cumulative impacts over the ranges of the stresses, parameterized by the stress fraction from 0 to 1, i.e. from zero to 100 percent of total pumping.

Model run naming conventions

Naming conventions for the model runs used to calculate incremental impacts were invented for testing and demonstration purposes; they deserve explanation and, eventually, improvement. Model runs were initially named to calculate impacts of stress decrements with IWS in the base case. Additional model runs were prepared and named to calculate impacts of stress increments. These naming conventions are explained as follows.

Model runs for impact accounting with IWS in the base case are named as variants of the RRCA base cases (12p.* for years 1918-2000, and 2001-2010.* for years 2001-2010). Model runs for impact accounting without IWS in the base case are named as variants of the RRCA no-mound impact cases (12p4.* for years 1918-2000, and 2001-2010d.* for years 2001-2010).

Fractions are denoted "ptf". Examples: 0.0 is pt0, 0.025 is pt025, 0.1 is pt1, 0.5 is pt5 and 0.9 is pt9; but 1 ("ON") is denoted by 1. Model runs with all stresses held at the same fraction are denoted by a suffix "ptfALL", e.g. pt0ALL, pt025ALL, pt1ALL, pt5ALL and pt9ALL. Such model runs represent either reference or combined impact cases. With IWS in the base case, file names for a model run with all stress fractions at 50 pct have the suffix 12p _pt5ALL for the 12p model (1918-2000), and 2001-2010_pt5ALL for the 12s model (2001-2010). With no IWS in the base case, corresponding suffixes are 12p4 _pt5ALL and 2001-2010d_pt5ALL.

Stress decrements:

Model runs with a stress decrement applied to one of the three or four stresses are denoted by a suffix identifying the impact stress fraction followed by the source of the stress (CO, KS, NE or MD) and then the stress decrement; the reference stress fraction is not identified explicitly. The four possible sources of the stress correspond to pumping by each of the three States (CO, KS and NE) and Imported Water Supply (IWS), also identified as the mound and abbreviated MD for identifying model runs. Examples:

pt9CO_pt1: Colorado pumping is reduced by 10 percent from 100 to 90 percent. With IWS in the base case, suffixes for the 12p model (1918-2000) are 12p for the reference case and 12p_pt9CO_pt1 for the impact case. Suffixes for the 12s model beginning in 2001 2001-2010 for the reference case and and 2001-2010_pt9CO_pt1 for the impact case. With no IWS in the base case, corresponding suffixes are 12p4 and 12p4 pt9CO pt1 for the 12p model (1918-2000), and 2001-2010d and 2001-2010d_pt9CO_pt1 for the 12s model (2001-2010).

pt8CO_pt1: Colorado pumping is reduced by 10 pct from 90 pct to 80 pct. Reference and impact suffixes with IWS in the base case are 12p_pt9ALL and 12p_pt8CO_pt1 (12p model), and 2001-2010_pt9ALL and 2001-2010_pt8CO_pt1 (12s model). Reference and impact suffixes with no IWS in the base case are 12p4_pt9ALL and 12p4_pt8CO_pt1 (12p model), and 2001-2010d_pt9ALL and 2001-2010d_pt8CO_pt1 (12s model).

pt0CO_pt1: Colorado pumping is reduced by 10 pct from 10 pct to zero.

Stress increments:

Model runs with a stress increment applied to one of the three or four stresses are denoted by a suffix that identifies the reference stress fraction followed by the impact stress fraction and then the source of the stress (CO, KS, NE or MD); the stress increment is not identified explicitly. Examples:

pt8_pt9CO: Colorado pumping is increased by 10 pct from 80 pct to 90 pct. Reference and impact suffixes with IWS in the base case are 12p_pt8ALL and 12p_pt8_pt9CO (12p model), and 2001-2010_pt8ALL and 2001-2010_pt8_pt9CO (12s model). Reference and impact suffixes with no IWS in the base case would be 12p4_pt8ALL and 12p4_pt8_pt9CO (12p model), and 2001-2010d_pt8ALL and 2001-2010d_pt8_pt9CO (12s model).

pt9_1CO: Colorado pumping is increased by 10 pct from 90 pct to 100 pct. Reference and impact suffixes with IWS in the base case are 12p_pt9ALL and 12p_pt9_1CO (12p model), and 2001-2010_pt9ALL and 2001-2010_pt9_1CO (12s model). Reference and impact suffixes with no IWS in the base case would be 12p4_pt9ALL and 12p4_pt9_1CO (12p model), and 2001-2010d_pt9ALL and 2001-2010d_pt9_1CO (12s model).

pt0_pt1CO: Colorado pumping is increased by 10 pct from zero to 10 percent.

Application to ten-percent stress intervals with central differences

We show how the integrated solution is applied for ten-percent stress intervals with IWS excluded from the base case and central difference approximation of response functions.

Impacts of ten-percent pumping decrements begin from all pumping ON to 90 percent, with impacts calculated with respect to all pumping ON; then from 90 percent to 80 percent, with impacts calculated with respect to all pumping at 90 percent; and so on. The last ten-percent reduction is from ten percent to zero pumping, with impacts calculated with respect to all pumping at 10 percent.

Similarly, impacts of ten-percent pumping increments begin from all pumping OFF to 10 percent, with impacts calculated with respect to all pumping OFF; then from 10 percent to 20 percent, with impacts calculated with respect to all pumping at 10 percent; and so on. The last ten-percent increment is from 90 percent to 100 percent pumping, with impacts calculated with respect to all pumping at 90 percent.

Two forward difference approximations of pumping impacts are given by (a) the sum over the impacts of 10-percent pumping decrements, and (b) the sum over impacts of 10-percent pumping increments. The central difference approximation is given by the average of these two sums according to Equation (13). This is equivalent to taking the average of impacts due to 10-percent pumping decrements and increments, respectively, for each interval and summing over the intervals according to Equation (12). This approach is also useful for the purpose of showing accurate plots of incremental and cumulative impacts over the range of pumping. Some of these are shown below for future average conditions.

Results

The total impact discrepancy for the integrated solution is given by the difference between the sum of terms in Equation (5) and the total impact according to Equation (4). The discrepancy for the above example is plotted in Fig. 1 for years 1950-2010. Table 1 summarizes statistics for this discrepancy for the periods 1950-2000 (mean error = –0.8 afy, standard deviation = 4.0 afy). and 2001-2010 (mean error = –2.5 afy, standard deviation = 6.1 afy).

These statistics show that, within the error tolerance summarized in Table 1, the integrated solution equals the exact solution for the states' gw CBCU. The exact solution cannot be calculated, since that would require continuous integration of the total differential (Equation (1); but we can come as close to it as we wish, limited only by computing requirements.

Table 2 summarizes the integrated solution for the states' CBCU with no IWS in the base case, averaged over years 2001-2010 for each accounting point. The solution is calculated for 10-percent pumping intervals with centered response functions, i.e. central difference approximation of the partial derivatives. Columns (left to right) correspond to the accounting subbasins, computed baseflow without IWS, total impact of gw CBCU, each state's gw CBCU, the IWS Credit according to the RRCA AP, net NE impact (gw CBCU – IWS Credit), sum of the states' gw CBCU, and discrepancy (mean error and standard deviation for 2001-2010).

The two columns on the right-hand side of Table 2 show that this integrated solution has a negligible discrepancy over this time period for all accounting points. With a discrepancy this small, the integrated solution with 10-percent intervals and centered response functions effectively equals the exact solution that would be given by a continuous integration of the total differential.

Incremental and cumulative impacts: depletion characteristics for average futures

Each term of Equation (1) is a partial derivative (i.e. response function) integrated over a stress interval. Plots of incremental impacts illustrate the nonlinear behavior of depletion response over the range of pumping. The depletion response varies among subbasins and from year to year; and normally declines with increasing stress fraction. Cumulative plots, i.e. incremental impacts accumulated from zero to full pumping, illustrate the process of integrating the incremental impacts.

Plots of incremental and cumulative impacts were produced in an Excel file for a solution for average future conditions for years 2009-2059 with IWS excluded from the base case, approximated with response-centered, 10-pct intervals. These figures give an overview how stream depletion varies with pumping, but some subbasins show more extreme nonlinearity, such as Beaver and Sappa Creeks, and the Main Stem Swanson to Harlan County Lake.

Figs. 2a-c are plots for the total basin for future year 2059. Figs. 2a and 2b are line and bar graphs, respectively; both plot impacts in ten-percent increments of incremental impacts, and are simply two ways of showing the same data. Fig. 2a shows that the increments of total impact range in descending magnitude from 44.4 KAF to 12.4 KAF. The cumulative total impact in Fig. 32 is 290.3 KAF. The plots show indiscernible discrepancy between the sum of the states' gw CBCU and the total impact, as do plots of individual subbasins (Figs. 3-8).

Projected incremental and cumulative impacts in 2059 are shown for Beaver Creek (Figs. 3a-b), Sappa Creek (Figs. 4a-b), Main Stem Swanson-Harlan County Lake (Figs. 5a-b), Main Stem Above Swanson (Figs. 6a-b), Frenchman Basin (Figs. 7a-b) and South Fork (Figs. 8a-b).

For Beaver Creek in 2059, Fig. 3a shows that no baseflow is available for depletion above 70 percent total pumping, so the cumulative impact of pumping (Fig. 3b) is constant from 70 to 100 percent pumping.

Figs. 4a and 4b show that Sappa Creek baseflow is also completely depleted above 70 percent pumping. The incremental plots for Beaver and Sappa (Figs. 3a and 4a) both show how transitions over the range in pumping in how gw CBCU is distributed between KS and NE.

Incremental impacts for the Main Stem reach from Swanson to Harlan (Fig. 5a) make a transition from large positive impacts to negative, from nearly 8 KAF in the first 10 pct of pumping, a steady decline through 60 pct pumping, then a sharper decline for 70 pct pumping and negative impacts of –3 KAF for 80 pct pumping and –2 KAF for 90 pct and 100 pct pumping. Consequently, the cumulative impacts (Fig. 5b) rise to 38 KAF at 70 pct pumping and then fall to 31 KAF at 100 pct pumping.

The Main Stem reach above Swanson (Figs. 6a-b) also shows a transition for total impact increments from positive to slightly negative above 80 pct pumping (Fig. 6a), for which the magnitude of Colorado's negative impact increments slightly exceed Nebraska's positive impact increments.

Figs. 7a-b show projected impacts in 2059 for Frenchman Creek. Colorado's incremental impacts shown in Fig. 7a decline over the range of pumping from 1625 af for the 0-10 pct pumping interval to 40 af for the 90-100 pct pumping interval. Colorado's cumulative impact shown in Fig. 7b is 7360 af at 100 pct pumping, which is 8.3 percent of the total impact of 88.4 KAF.

Figs. 8a-b show projected impacts in 2059 for South Fork Republican River, based on the scenario that Bonny is included in the model. Incremental impacts decline steadily and then sharply for the 60-70 percent interval due to the Colorado CBCU component, which declines from 1675 af for the 50-60 pct interval to 175 af for the 60-70 pct interval. Kansas and Nebraska incremental impacts are nearly constant over the full range of pumping (Fig. 8a).

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Oboukhoff, Nicholas M., 1940. The historical development of total differential as the principal part of the increment of a function of several variables. Proceedings of the Oklahoma Academy of Science for 1940, p. 121-123. http://digital.library.okstate.edu/oas/oas_pdf/v21/p121_123.pdf

Wikipedia (2012)
Experimental Uncertainty Analysis:
http://en.wikipedia.org/wiki/Experimental_uncertainty_analysis

Figures and Tables

Figures

Tables

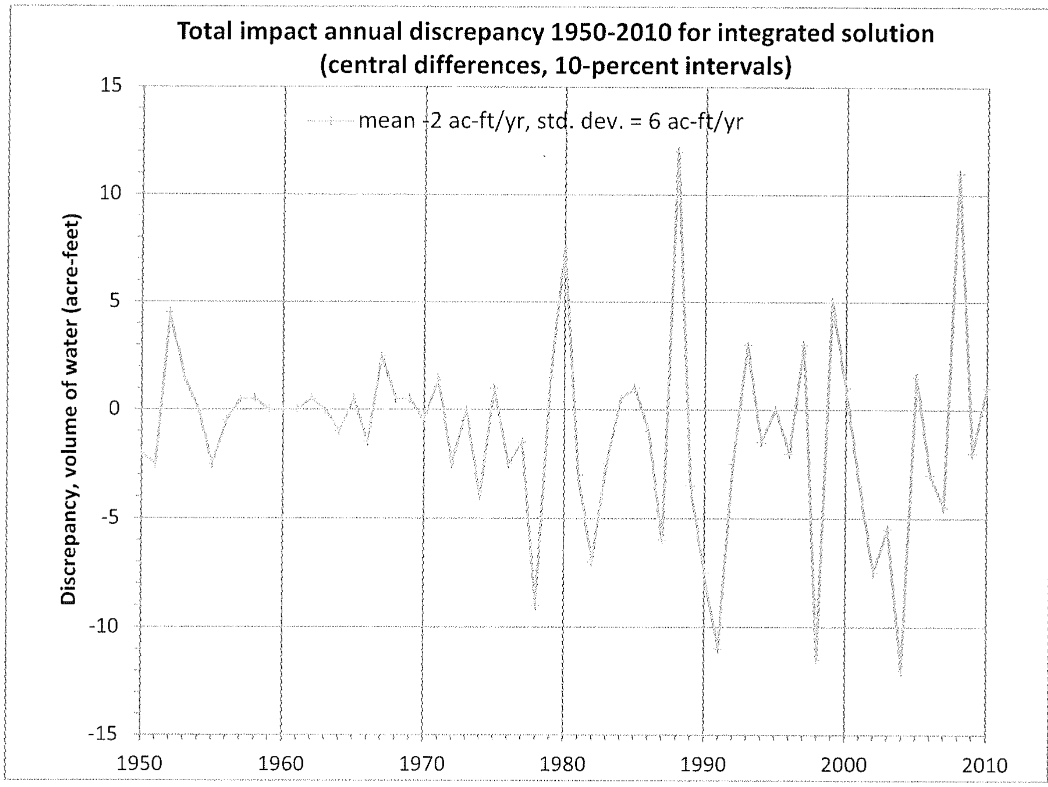

Fig. 1. Total discrepancy for cumulative impact between 0 and 100 percent stress fraction.

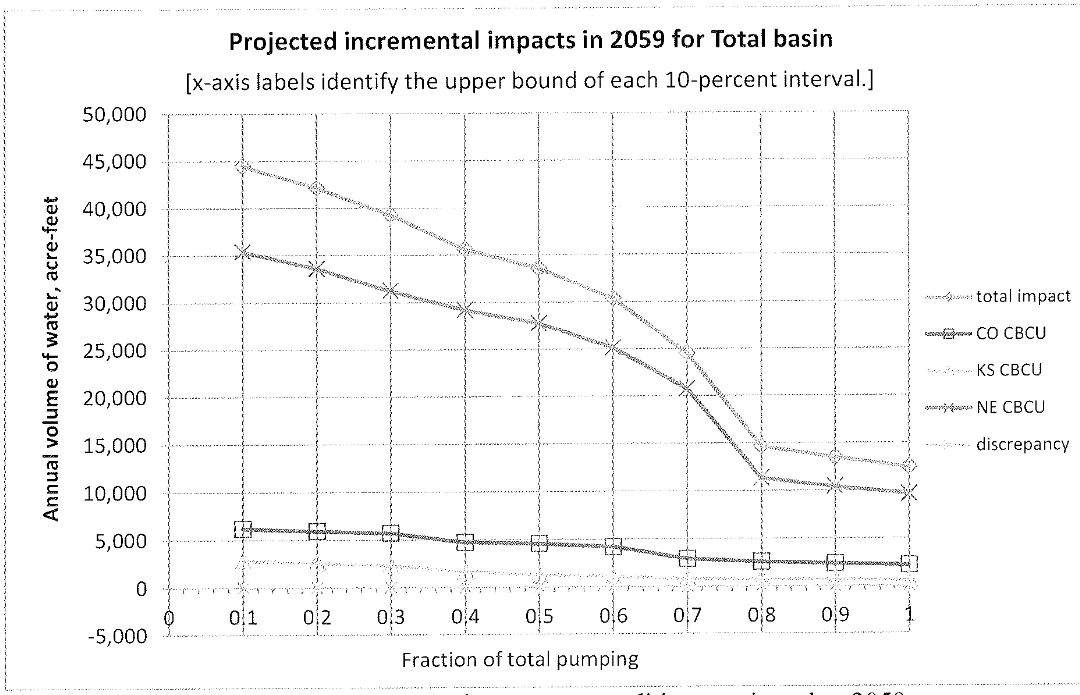

Fig. 2a. Incremental impacts, total basin for average conditions projected to 2059.

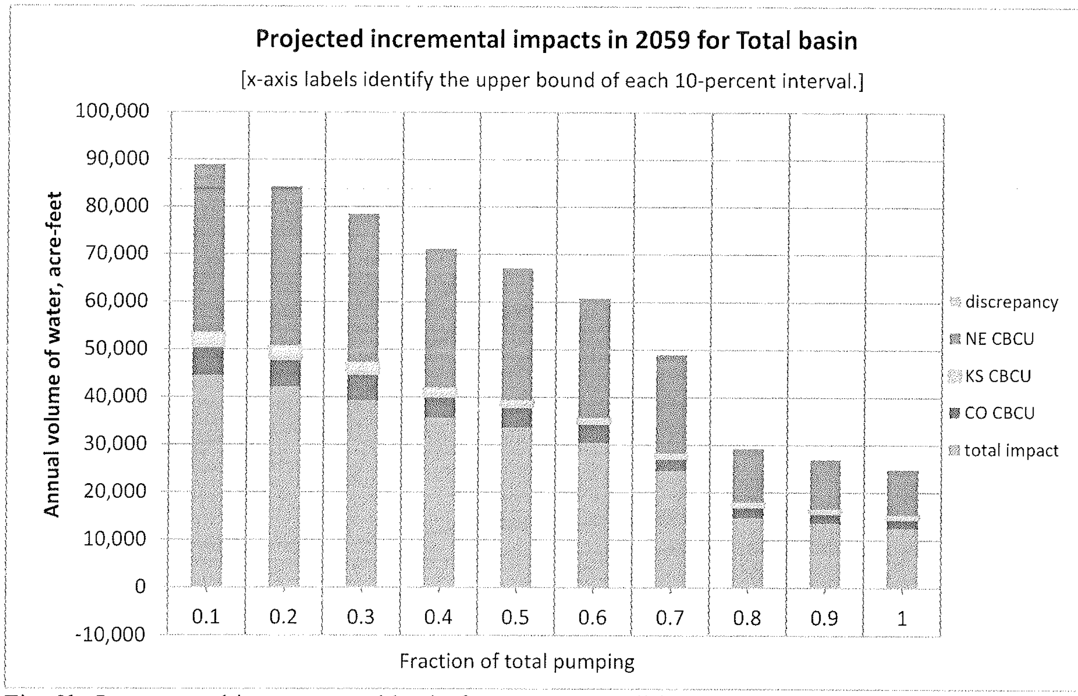

Fig. 2b. Incremental impacts, total basin for average conditions projected to 2059.

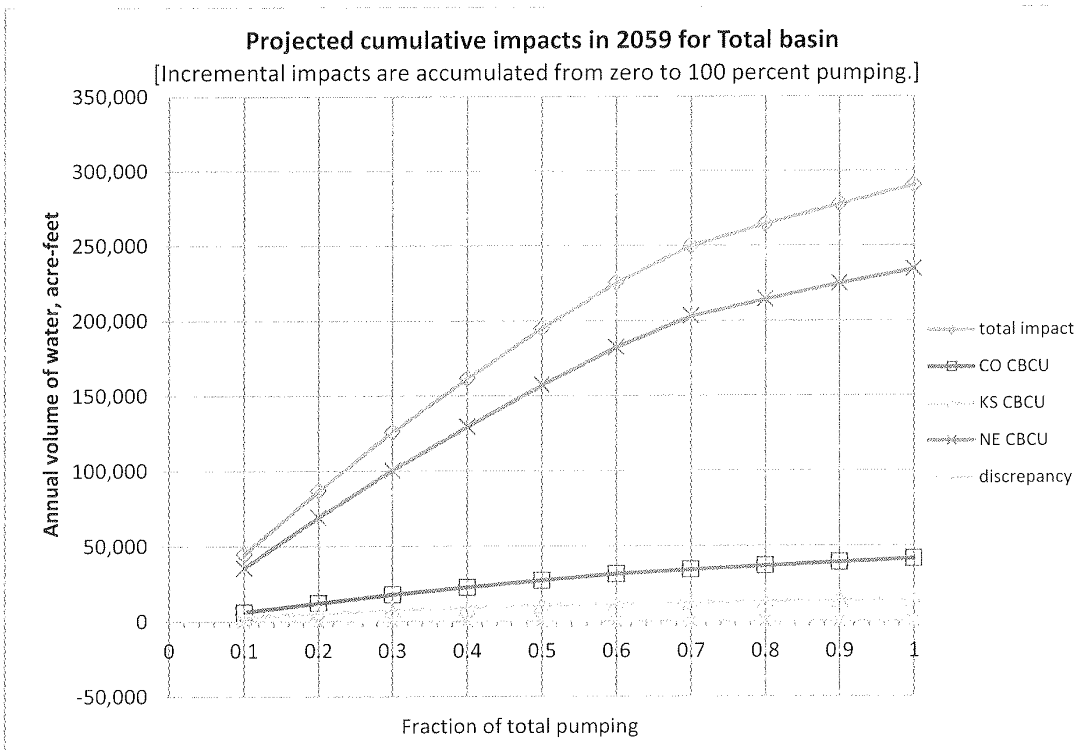

Fig. 2c. Cumulative impacts, total basin for average conditions projected to 2059.

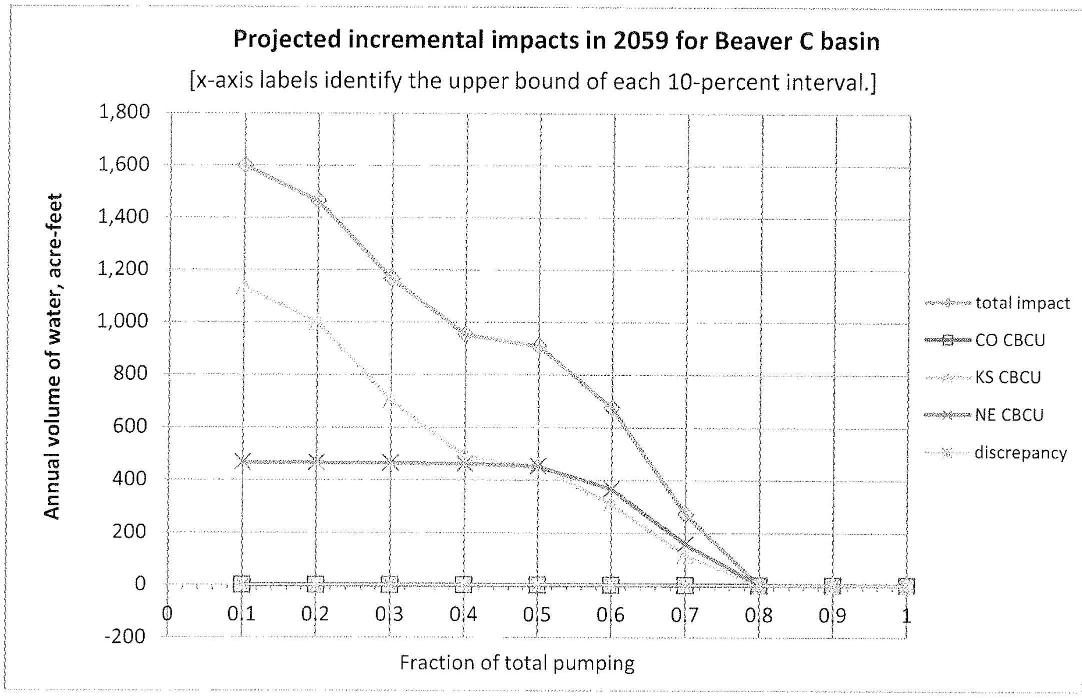

Fig. 3a. Beaver Creek: Incremental impacts projected to 2059.

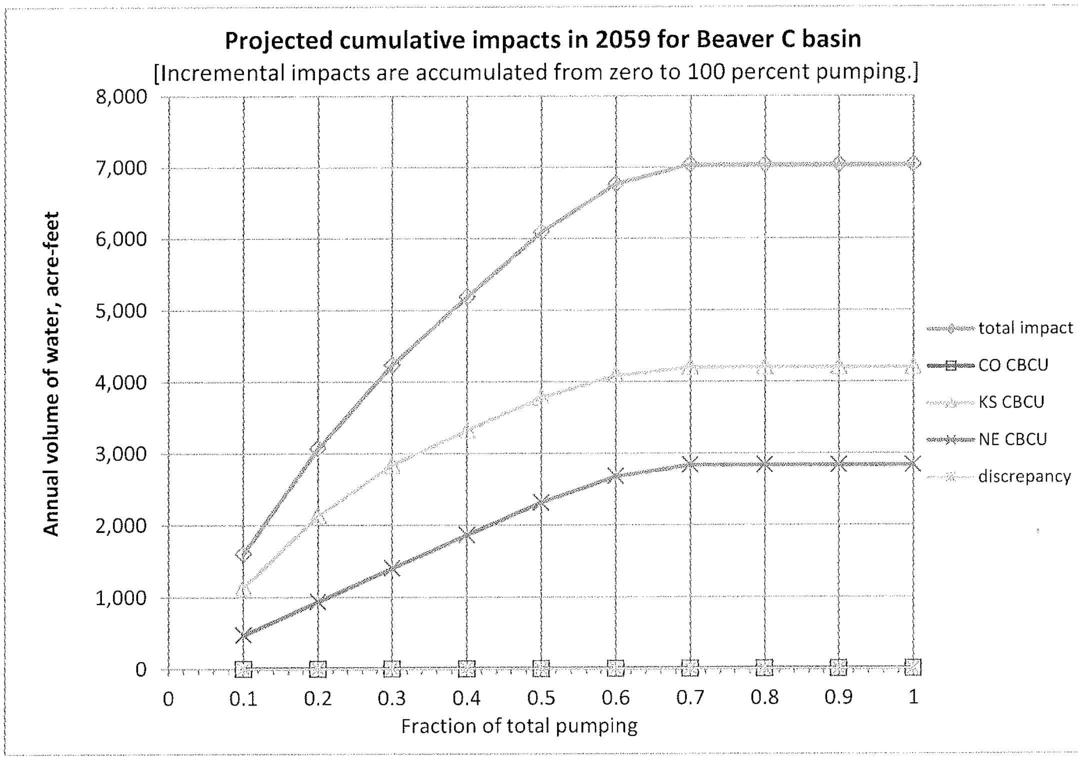

Fig. 3b. Beaver Creek: Cumulative impacts projected to 2059.

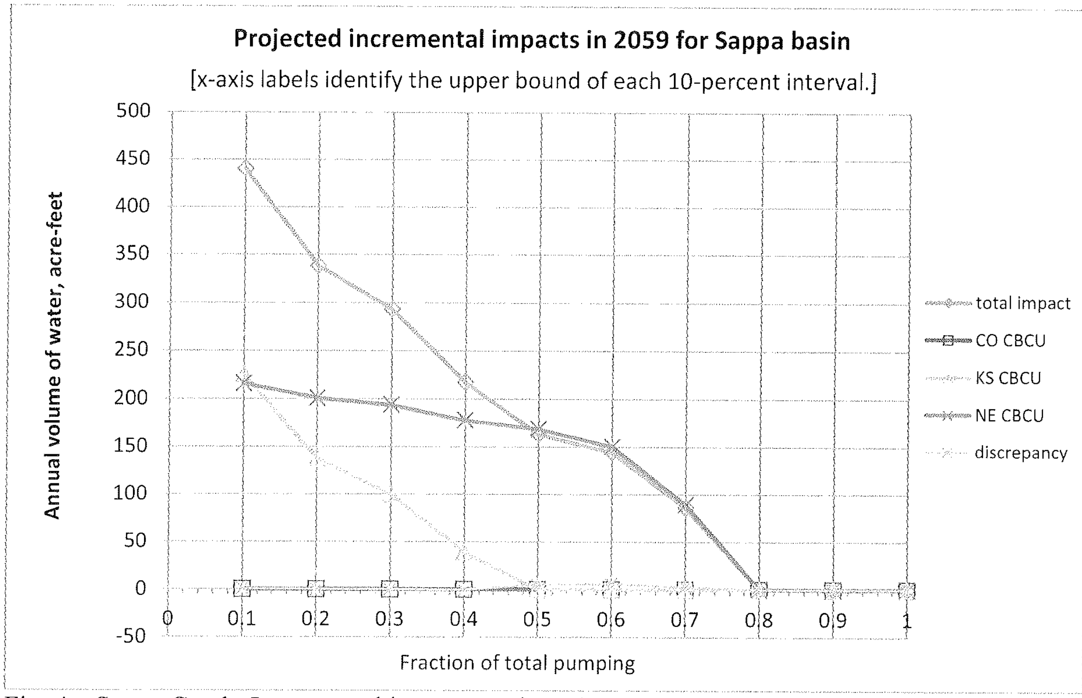

Fig. 4a. Sappa Creek: Incremental impacts projected to 2059.

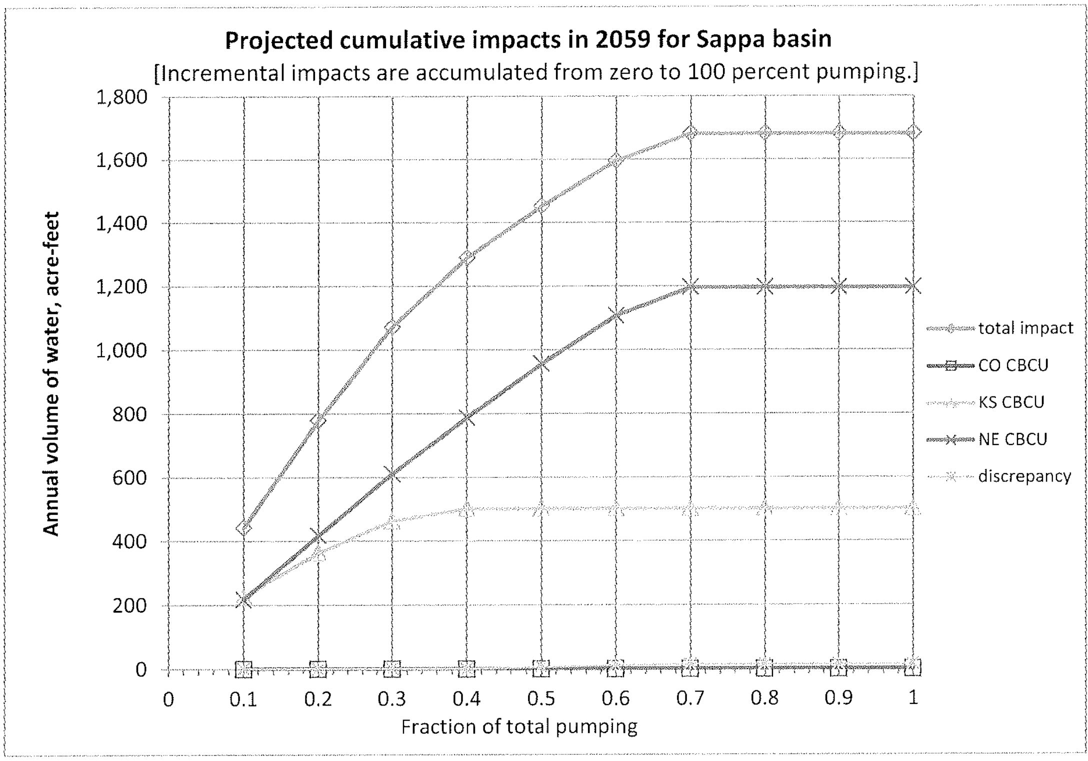

Fig. 4b. Sappa Creek: Cumulative impacts projected to 2059.

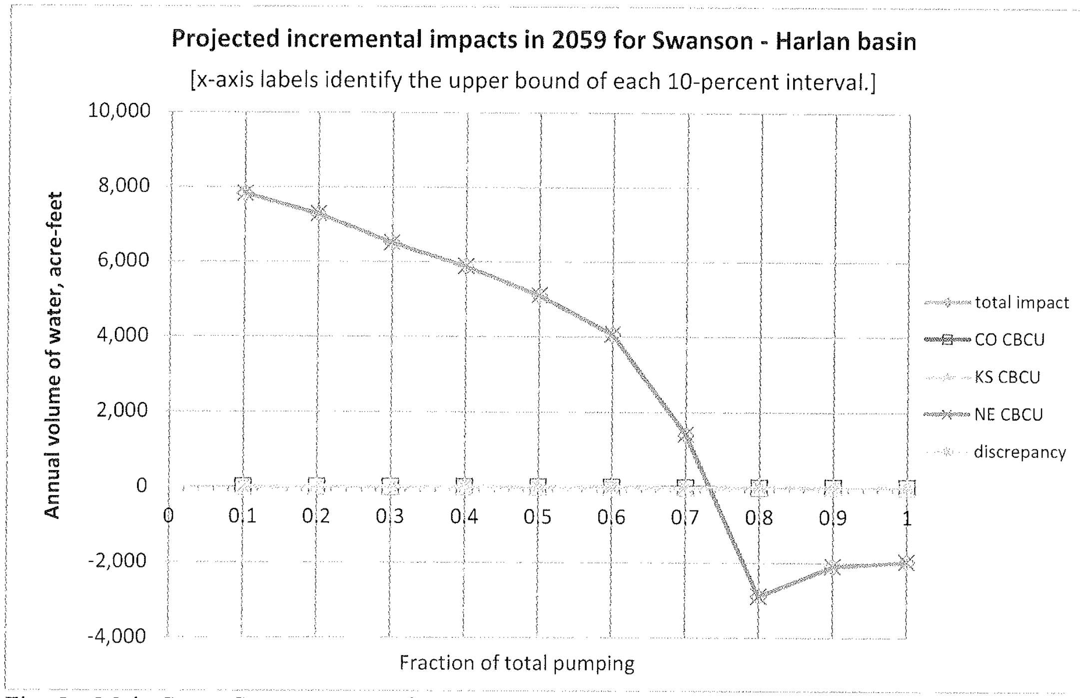

Fig. 5a. Main Stem, Swanson to Harlan County Lake: Incremental impacts projected to 2059.

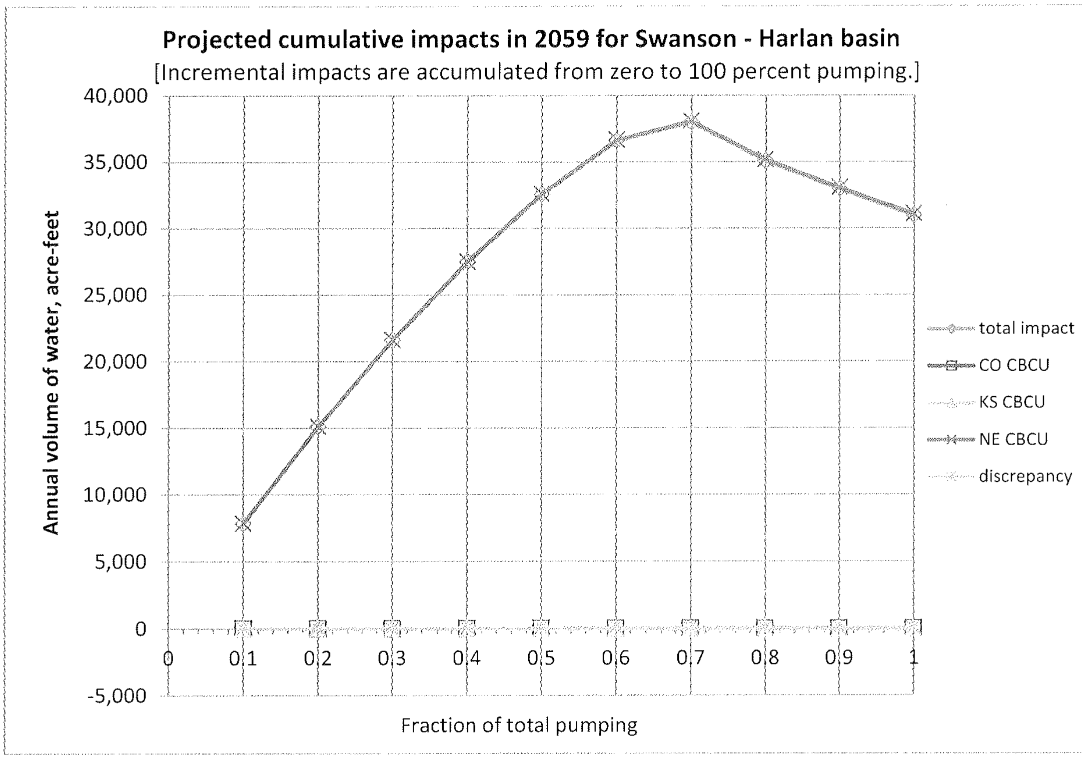

Fig. 5b. Main Stem, Swanson to Harlan County Lake: Cumulative impacts projected to 2059.

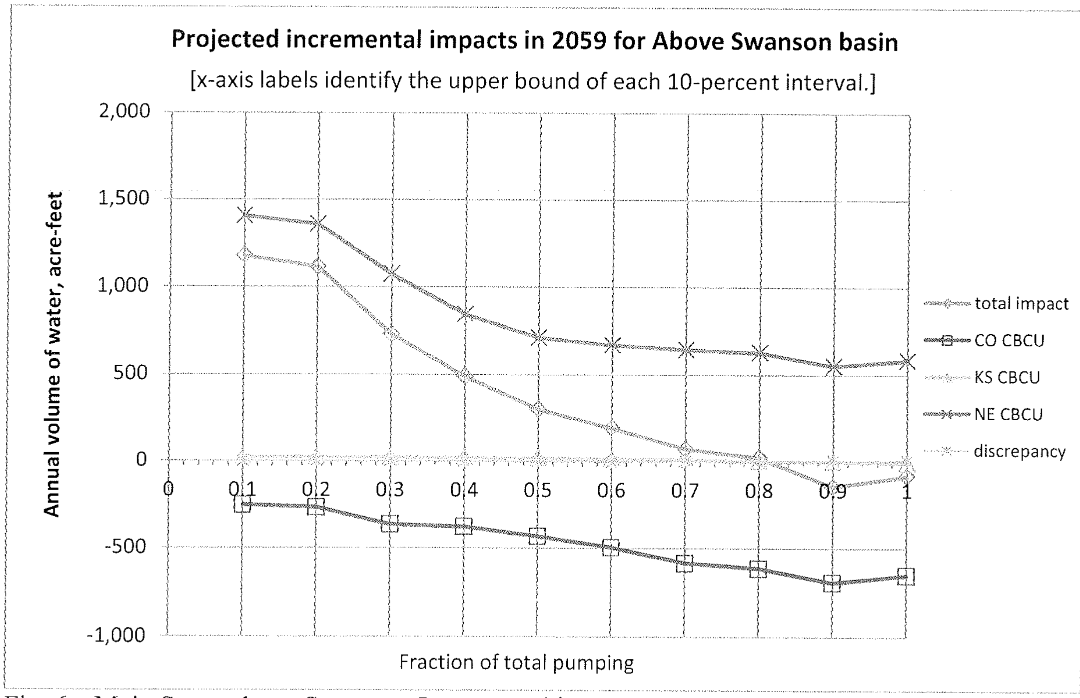

Fig. 6a. Main Stem, above Swanson: Incremental impacts projected to 2059.

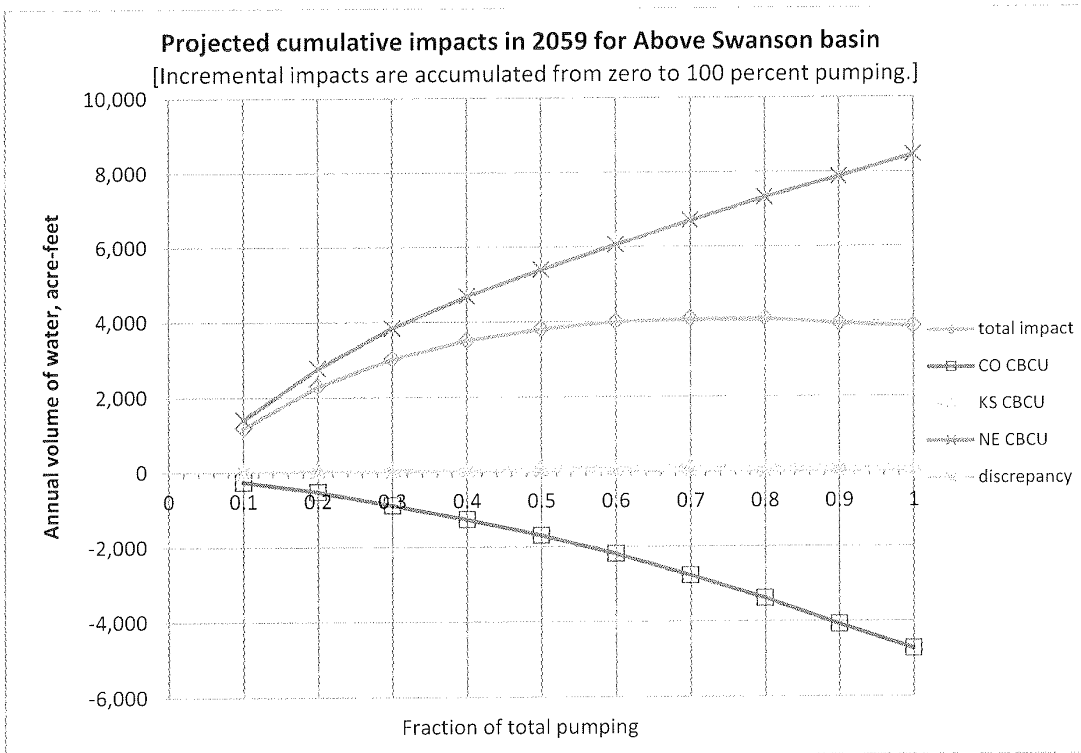

Fig. 6b. Main Stem, above Swanson: Cumulative impacts projected to 2059.

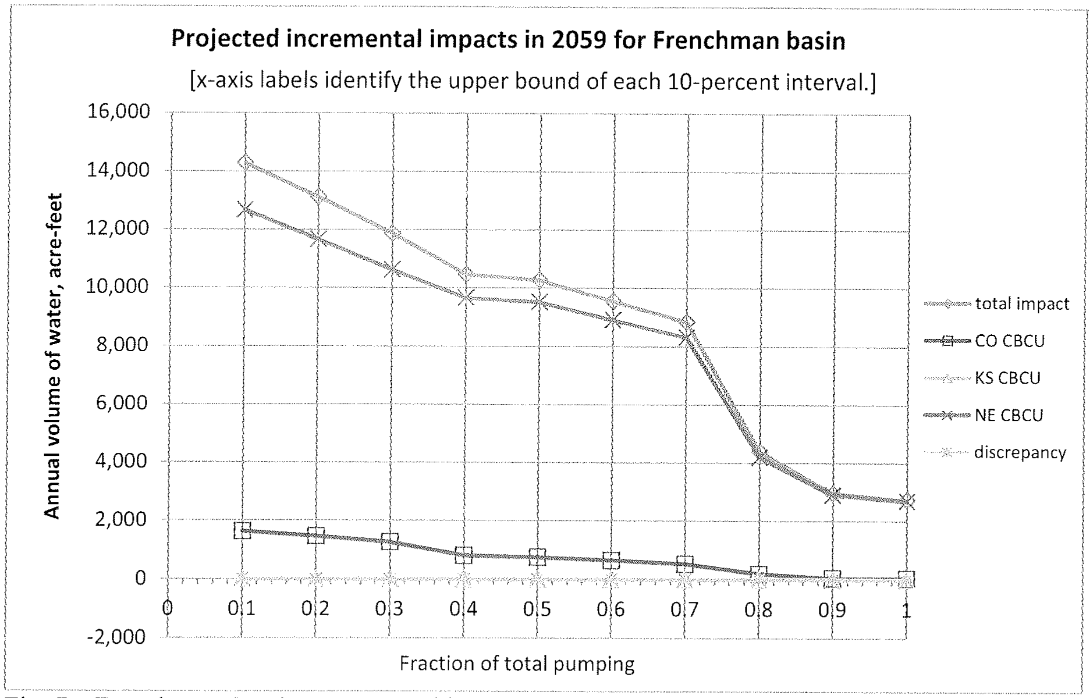

Fig. 7a. Frenchman Creek: Incremental impacts projected to 2059.

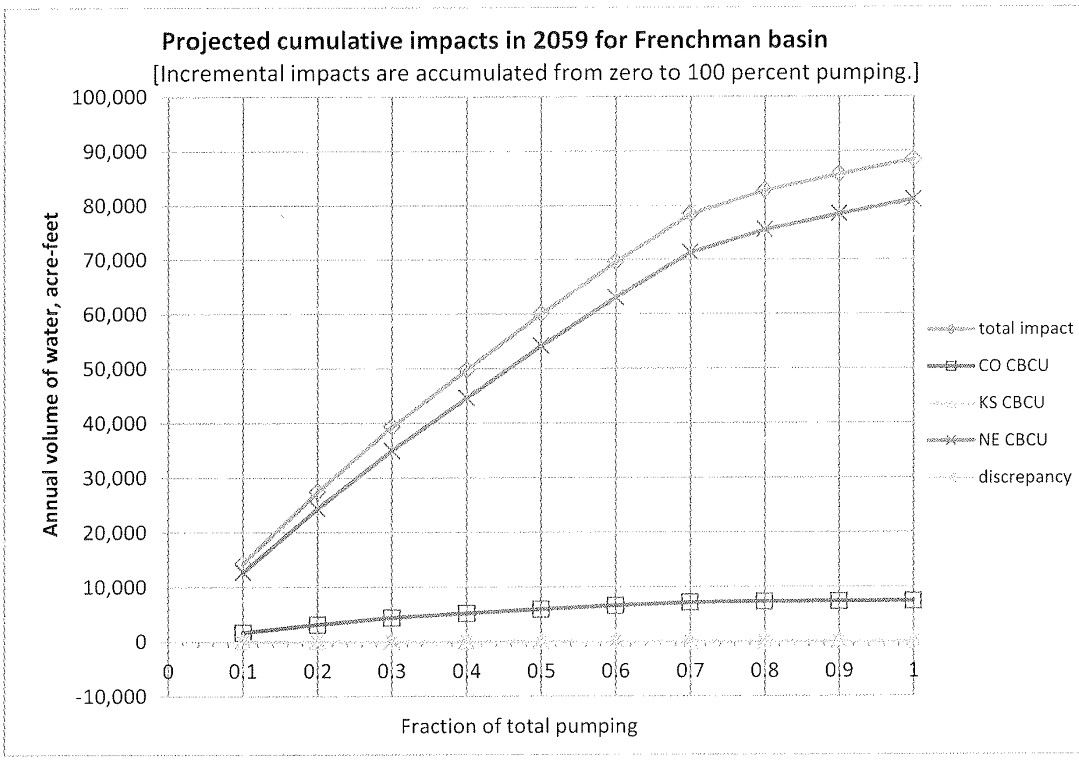

Fig. 7b. Frenchman Creek: Cumulative impacts projected to 2059.

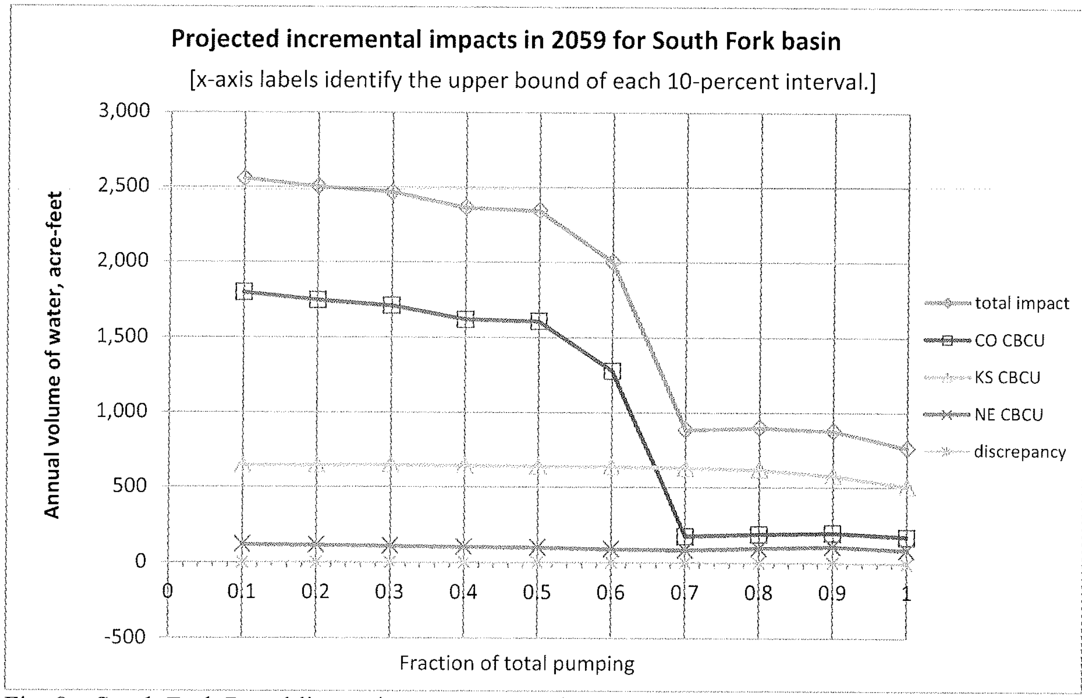

Fig. 8a. South Fork Republican River: Incremental impacts projected to 2059.

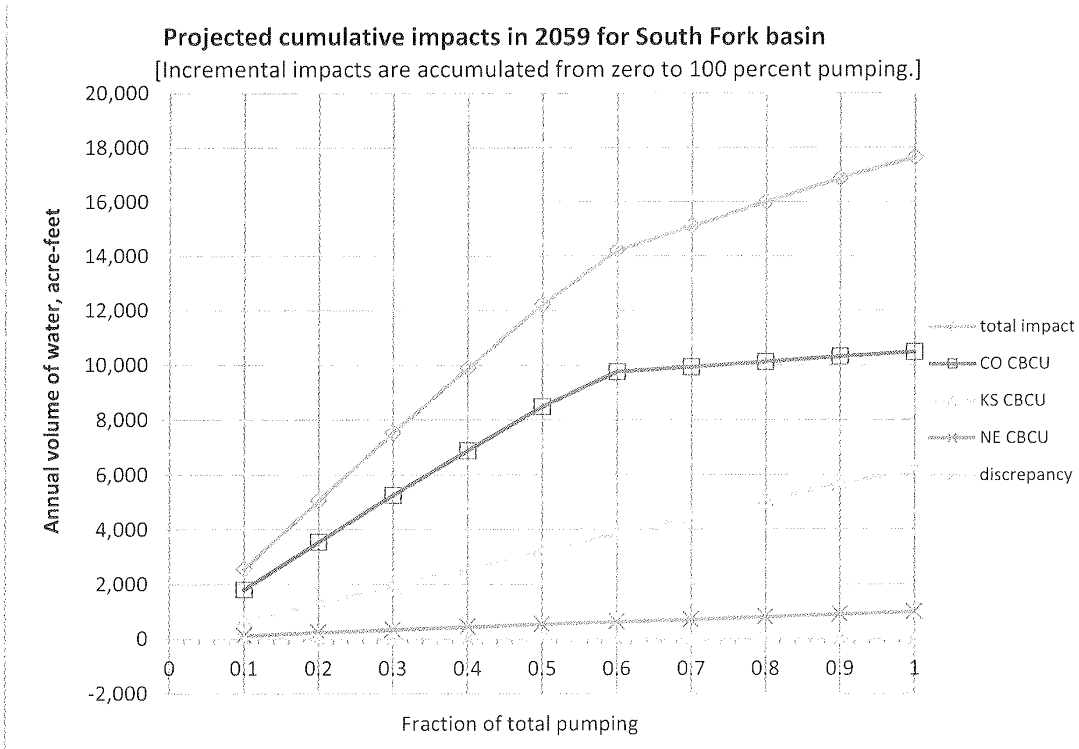

Fig. 8b. South Fork Republican River: Cumulative impacts projected to 2059.

Table 1. Summary statistics for total impact discrepancy of integrated solution (ac-ft/yr).

Period	mean	std dev	min	max
1950-2000	-0.8	4.0	-11.5	12.0
2001-2010	-2.5	6.1	-12.0	11.0

Table 2. Summary of solution average for 2001-2010 with No IWS in base case, calculated for 10-percent pumping intervals, centered response functions: computed beneficial consumptive use (CBCU), IWS Credit and discrepancy. (Solution sum_pt1avg_NoMD)

Account	computed baseflow (No IWS)	Total pumping impact	CO gw CBCU	KS gw CBCU	NE gw CBCU	IWS Credit	NE-IWS Credit	sum CO+KS+NE gw CBCU	mean error	std dev error
Arikaree	1027	1632	1249	123	260	0	260	1632	0	2
Beaver	691	9687	0	5098	4589	0	4589	9687	0	0
Buffalo	2176	3780	357	0	3423	0	3423	3780	0	0
Driftwood	1227	1324	0	0	1324	0	1324	1324	0	0
Frenchman	16481	83140	3170	0	79970	0	79970	83140	0	1
North Fork	32730	15401	14563	0	836	0	836	15399	-2	1
Above Swanson	-20422	10219	-2098	204	12112	0	12112	10219	0	5
Swanson - Harlan	-10832	29827	0	-21	29851	7118	22733	29830	3	2
Harlan - Guide Rock	37547	25465	0	0	25461	244	25217	25461	-4	4
Guide Rock - Hardy	15925	2893	0	57	2837	-1	2838	2893	0	0
Medicine	22725	20167	0	0	20167	9780	10387	20167	0	0
Prairie Dog	529	5253	0	5243	9	0	9	5251	-1	2
Red Willow	5115	6685	0	0	6685	36	6649	6685	0	0
Rock	5121	3889	71	0	3817	0	3817	3888	0	0
Sappa	237	3246	0	1196	2050	14	2035	3246	0	0
South Fork	4584	18678	11653	5786	1235	0	1235	18674	-4	8
Hugh Butler	513	1696	0	0	1696	0	1696	1696	0	0
Bonny	-1925	1269	1263	0	0	0	0	1263	-6	2
Keith Sebelius	2258	492	0	492	0	0	0	492	0	0
Enders	-3253	4468	0	0	4464	0	4464	4464	-4	1
Harlan	1574	871	0	60	811	16	796	871	0	0
Harry Strunk	-2555	347	0	0	347	0	347	347	0	0
Swanson	-1980	353	9	0	340	0	340	350	-4	3
Mainstem Total	22218	68404	-2101	243	70261	7356	62905	68404	1	4
Total	109492	250779	30241	18250	202286	17211	185075	250776	-2	6

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AVERY READY INDEX®

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KS005087

1. Master said we should ask him about backup data for mound seepage from NE?
2. NE groundwater levels mound not measured USGS, does he have access to them?
3. Has he ever seen any NE report on mound effects referred to in 2006 MM report.
4. Reference in testimony to residuals going both ways , p 743.
5. Discussion of uncertainty in the mound, p. 739 has he done any runs to examine that?
6. Perl script for compliance? Would he be willing to talk with Sam?
7.

Year	Arikaree	Beaver	Buffalo	Driftwood	Frenchman	North Fork	Above Swanson	Swanson - Harlan	Harlan - Guide Rock	Guide Rock - Hardy	Medicine	Prairie Dog	Red Willow	Rock	Sappa	South Fork	Hugh Butler	Bonny	Keith Sebelius	Enders	Harlan	Harry Strunk	Swanson	Mainstem Total	Total	col.
col.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
CO	0.785	0.2	0	0	0	0.224					0	0	0	0	0	0.444								0		4
KS	0.051	0.388	0	0.069	0	0					0	0.457	0	0	0.411	0.402								0.511		6
NE	0.168	0.406	0.33	0.164	0.536	0.246					0.091	0.076	0.192	0.4	0.411	0.014								0.489		8
Unalloc.	-0.004	0.006	0.67	0.767	0.464	0.53					0.909	0.467	0.808	0.6	0.178	0.14								0		10
T2_rec	2	10	3	7	6	1	MS	MS	MS	MS	9	12	8	4	11	5					MS		MS	15		
unalloc+ms	-0.004	0.006	0.67	0.767	0.464	0.53	1	1	1	1	0.909	0.467	0.808	0.6	0.178	0.14	0	0	0	0	1	0	1			

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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.

Initial Response to Nebraska's New Proposal for Changes to the Accounting Procedures

Expert Testimony of Steven P. Larson

S. S. Papadopulos & Associates, Inc., Bethesda, MD.

August 7, 2012

Table of Contents

Page

Introduction

On May 16, 2012, Nebraska and Colorado submitted a notice of stipulation in which Nebraska proposed and Colorado agreed to a revised proposal for changes to the accounting procedures. This revised proposal was characterized as a "subset" of the changes that Nebraska had originally proposed and Nebraska declared that it was abandoning the remainder of its original counterclaim. However, there was no definition of what constituted a "subset", especially in terms of the degree to which it departed from Nebraska's original proposal in form, content or effect.

The changes that Nebraska had originally proposed in this proceeding were the subject of a responsive expert report submitted by me and Mr. Dale Book on March 15, 2012. The original Nebraska proposal was the same proposal submitted by Nebraska in the arbitration proceeding tried by Karl Dreher in 2009. As noted by Arbitrator Dreher, the first change in the accounting procedures proposed by Nebraska was to determine the total amount of computed beneficial consumptive use of groundwater ($CBCU_G$) by running the RRCA Groundwater Model with pumping for all three States and imported water in Nebraska excluded or "all off" as it is often referred to. The result from this model run would be subtracted from a model run of historical conditions in which this pumping and imported water was all included or "all on". This difference was referred to by Nebraska as the groundwater-related portion of the virgin water supply or VWS_G (see Ex. J7, Arbitrator's Final Decision, June 30, 2009, Finding 14, page 6). The portion of this total amount of the $CBCU_G$ attributable to each State would then be determined through a series of formulae that utilized results from 16 different runs of the RRCA Groundwater Model.

The formulae in the original Nebraska proposal were based on a fundamental concept that the sum of impacts attributable to each State must equal the total amount of $CBCU_G$ determined from the difference in results between an "all off" run of the RRCA Groundwater Model and an "all on" run. This concept was referred to in an expert report submitted by Nebraska in the arbitration as "additivity" (see Ex. N1010, Ahlfeld, McDonald and Schneider Report, January 20, 2009, page 13). Furthermore, the report concluded that this amount was the best estimate of the total VWS_G and should be considered the true value of this property for purposes of compact accounting (Ex. N1010, page 9). This amount was also referred to by Kansas as the virgin water supply metric in a memorandum sent to Nebraska in 2007.

Arbitrator Dreher found that the Nebraska proposal was problematic and not appropriate in that the allocation of residuals or departures between the sum of the impacts and VWS_G as $CBCU_G$ to the different States failed to consider changes in groundwater storage. He concluded that equally dividing these residuals between two States, as proposed by Nebraska, was not appropriate (see Ex. J7, Finding 30, page 13) and recommended that RRCA consider reconvening the Technical Groundwater Modeling Committee to re-evaluate the existing procedures (see Ex. J7, Finding 36, page 15).

This report represents Kansas' initial response to Nebraska's revised proposal to change the accounting procedures. As described below, this revised proposal represents a significant change from Nebraska's original proposal that was focused on the concept of "additivity". A full and complete evaluation of the technical aspects of the revised proposal would require considerable data gathering, analysis, and testing with the RRCA Groundwater Model that could not be accomplished within the time frame available for submittal of this report.

Variations in the Nebraska Proposals Since 2007

Nebraska claims that the revised proposal originated in 2007 and that subsequent proposals were merely an extension of the original proposal. In 2007, Nebraska made presentations to Kansas and Colorado regarding perceived issues related to the accounting procedures. In June 2007, a memo was prepared by Nebraska that attempted to outline the nature of these perceived issues in technical terms and presented to Kansas and Colorado (Ex. K129, Nebraska DNR, June 2007). Although the memo did not outline a specific proposal for modifying the accounting procedures, Kansas responded to Nebraska by undertaking a technical analysis of what was claimed by Nebraska to be the "Correct Calculation of CBCU". According to the memo, this "Correct Calculation of CBCU" would be determined by running the RRCA Groundwater Model with all pumping and mound recharge removed and computing stream base flows under that condition.

In September 2007, Kansas prepared a technical response to the Nebraska memo (Ex. K127, Kansas Memorandum, September 2007). In that response, Kansas presented a metric that was referred to as the "virgin water supply metric" that was developed to test the concept of the "Correct Calculation of CBCU" that was described in Nebraska's June 2007 memo. Kansas pointed out that the alterative accounting procedures suggested by Nebraska at that time departed further from the metric than the agreed upon method described in the Final Settlement Stipulation (FSS) and the Accounting Procedures and had a negative bias. As a result, Kansas concluded that the alternative was not a better method than the agreed upon method.

Nebraska continued to pursue the general issue of problems with the accounting procedures in 2008. In January 2008, Nebraska prepared a short report describing their issues with the accounting procedures (Ex. K130, Nebraska DNR, January 2008). In that report, Nebraska presented "a list of scenarios which may be used to evaluate the impacts of importing water and pumping". The scenarios were combined in various ways to form a series of options "to calculate impacts of importation of water, groundwater pumping, or both". The report went on to describe which options would be equivalent to the agreed upon accounting procedures and which options would be a "preferred method". This so-called "preferred method" was different from Nebraska's earlier proposal and is not the same as Nebraska's revised 2012 proposal even though the method used five of the 16 model runs that were part of Nebraska's original proposal.

In March of 2008, Nebraska prepared a report to further describe their concerns and discuss Kansas' response to its January 2008 report (Ex. K131, Nebraska DNR, March 2008). In this March report, Nebraska listed ten scenarios "that might be used to calculate base-flow for estimates of impact". The report also presented a "Choice of scenarios that might be used to calculate impacts in accounting procedures" as an alternative to the agreed upon choice of scenarios. This alternative choice of scenarios was different from the "preferred method" described in the January 2008 report and is not the same as Nebraska's revised 2012 proposal. It is worth noting that this alternative choice of scenarios also used five of the 16 model runs that were part of Nebraska's original proposal. However, those five runs were not the same five runs that are included in Nebraska's revised 2012 proposal.

In August of 2008, Nebraska submitted another report describing their concerns regarding the accounting procedures (Ex. K132, Nebraska DNR et. al., August 2008). In this report, Nebraska focused on what it called the "Impact Summation Requirement". This "requirement" referred to the need for "the sum of individual impacts in a sub-basin [to] be equal to the total impact of all stresses applied simultaneously". The report went on to describe examples of violating this "requirement" in the Beaver Creek and Frenchmen Creek sub-basins and in the main stem reach from Swanson Reservoir to Harlan County Lake in specific years. After discussing these examples, a method was proposed to remedy the perceived problems that used 16 different runs of the RRCA Groundwater Model. This 16-run proposal was a precursor to the 16-run proposal that Nebraska submitted in the arbitration proceeding and the original proposed method submitted to the Special Master in this proceeding. Nebraska's revised 5-run proposal was not discussed in this report.

In January 2009, Nebraska prepared another report that was very similar in structure and content to the August 2008 report (Ex. N1010, Ahlfeld et. al., January 2009). The report continued to focus on the essence of the "Impact Summation Requirement" that was introduced in the August 2008 report. The January 2009 report suggested that a "true" value of VWS_G (virgin water supply groundwater) could be determined from running the RRCA Groundwater Model with all relevant stresses off and comparing the results to results from a model run with all relevant stresses on. A new 16-run proposal was described that modified various coefficients from the August 2008 16-run proposal so that the "true" value of VWS_G as it had been defined previously would be achieved in all the sub-basins. The report went on to describe application of the method to the Beaver Creek sub-basin. The 16-run proposal in the January 2009 report was the method submitted by Nebraska in the arbitration proceeding and is the original method proposed by Nebraska in this proceeding. The January 2009 report did not discuss Nebraska's revised 5-run proposal.

The Revised Proposal is not a Subset of the Original Proposal

The revised Nebraska proposal submitted on May 16, 2012 is significantly different from the original proposal that was evaluated as part of the arbitration. The concept of "additivity" and the notion that VWS_G computed from the difference between an "all off" model run and an "all on" model run, that was the centerpiece of the 2009 expert report to the arbitrator and touted as the true value of VWS_G, has been abandoned. The new proposal has been dubbed the "5-run proposal" as opposed to the original Nebraska proposal that was based on 16 model runs. The 5-run proposal uses a new baseline condition for evaluating the effects of pumping by each State that is not the historical condition used under the current RRCA accounting procedures described in the FSS and is different from the principal baselines used in the original 16-run proposal.

The 5-run proposal does use results from five RRCA model runs that are among the 16 results from RRCA model runs used in the original proposal. Dr. Schreüder testified in deposition that the reference to the revised proposal as being a subset of the original proposal that used 16 runs was intended to convey nothing more than the fact that the five runs in the revised proposal were also part of the original proposal.

Page 91

Q. But Paragraph 10, which is numbered as you pointed out, you say, "The solution I have identified in my report, which utilizes a five run subset of the 16 runs proposed in Dr. Schneider's report, provides an appropriate modification to the RRCA Accounting Procedures to avoid burdening any State with consumption of imported water."

Your reference to a five run subset, does that mean that five of the runs that are used in the Five-Run proposal are also runs that are used in the 16 runs proposed in Dr. Schneider's report?

A. Yes.

Q. Does it mean anything more than that?

A. On the face of it, the statement was intended to show that five runs are, indeed, a subset of the specific runs that Dr. Schneider proposed that we use. I don't know that I intended to say anything other than that.

(Ex. K137, Schreüder Deposition July 16, 2012 at page 91).

Under this definition of a subset, the current RRCA accounting procedure would also be considered a subset in that it too uses five model runs that are among the 16 model runs used in the original Nebraska proposal. Similarly, in his 2009 expert report, Dr. Schreüder enumerates several different Nebraska proposals the first of which is a 5-run proposal (Ex. K136, Schreüder Report, 2009, page 19). According to Dr. Schreüder, this 5-run proposal was presented to the RRCA in March of 2008. Since this 5-run proposal uses five model runs that are among the 16 model runs used in the original proposal, it too would fit the definition of a subset. However, this 5-run proposal does not use the same five runs as Nebraska's revised proposal and is not the proposal that Dr. Schreüder now endorses.

In fact, Dr. Schreüder, in his February 16, 2009 report, does not even recognize the revised 5-run proposal as a formal proposal (Ex. K136, Schreüder Report, 2009). In that report, Dr. Schreüder describes three Nebraska proposals. The first formal presentation described by Dr. Schreüder is in the March 2008 report that is described above. The "preferred method" in that report, as described by Dr. Schreüder, is a proposal to use five runs of the model that are not the same five runs in the revised 5-run Nebraska proposal. The other two Nebraska proposals cited by Dr. Schreüder reference the 16-run proposals of August 2008 and January 2009 described above. None of these Nebraska proposals cited by Dr. Schreüder are Nebraska's revised 5-run proposal.

Dr. Schneider also describes the revised proposal as a subset on the basis that the five runs are among the 16 runs used in the original proposal.

Page 47

A. I don't know how else to answer -- my previous answer.
Q. It could be just a yes or no. Are you recommending all of the changes in Appendix E at this time?
A. No. It's a subset of this.
Q. So the answer is, "No." What do you mean by a subset?
A. I mean that it uses a subset of the runs that the 16-Run proposal uses and a subset of the differences in those runs.

(Ex. K134, Schneider Deposition, July 17, 2012, page 47).

Later in the deposition, Dr. Schneider implies that the reference to a subset has some geographic connotation.

Q. The section entitled "The Problem," is that still applicable?
A. That's what I'm looking at now. Well, the first part is just a general description. And then the second part would be -- would remain applicable to a subset of the geographic scope of the compacts, namely the Swanson-Harlan reach off the main stem, which is extensively covered in the report.
So the subset that we're pursuing now applies primarily to that reach.

(Ex. K134, Schneider Deposition, July 17, 2012, page 48).

However, this reference appears to relate to one subarea or sub-basin rather than a subset of model runs.

The fact that the revised proposal uses five runs that are among the 16 runs used in the original proposal does not mean that the results of the two proposals are somehow equivalent or even necessarily similar. All of the different proposals that have been discussed by Nebraska or proposed to the RRCA give different results; some are more different than others. As Dr. Schreüder concluded in his 2012 expert report in describing what is now Nebraska's 5-run revised proposal:

This is not to suggest that the current approved protocol is necessarily in error, only that models and model results may be manipulated in any number of ways to reach a different result depending upon the goal of those who operate the model.

(Ex. C01, Schreüder Report, March, 2012, page 10).

The revised 5-run proposal is conceptually very different from the original 16-run proposal and gives results that are significantly different from the original proposal. As such, it should not be characterized as a subset of the original proposal.

The 5-run Revised Proposal Fails to Achieve Additivity

As noted by both Dr. Schreüder and Arbitrator Dreher, the 16-run original Nebraska proposal was focused on the concept of additivity. Dr. Schreüder states in his March 2012 expert report:

> **2. The perceived problem**
>
> Nebraska contends that the approved RRCA Accounting Procedures are flawed because the impacts computed for individual States do not equal the impacts for the three States combined, for each sub-basin, and for each year.

(Ex. C01, Schreüder Report, March, 2012, page 4).

> Nebraska's proposal has at its core the goal of matching the sum of state impacts to the total directly computed impacts Θ-CKMN. In order to achieve this goal, correctly computing the total Nebraska

Ex. C01, Schreüder Report, March, 2012, page 9).

Arbitrator Dreher also concluded that the concept of additivity was the focus of Nebraska's original proposal. Mr. Dreher concluded:

> 14. The first change proposed by Nebraska in the Accounting Procedures pertaining to $CBCU_G$ and IWS would modify the determination VWS in Finding 12 to:
>
> $VWS = VWS_S + VWS_G$
>
> where
>
> $VWS_G = (\theta - CKMN)$.
>
> In these relationships, again using the notation of Nebraska.[4] VWS_S is the surface-water-related portion of VWS. VWS_G is the groundwater-related portion of VWS. θ is the annual base flow in a Sub-basin or the Main Stem determined from running the RRCA Groundwater Model with all groundwater pumping, groundwater pumping recharge, and surface water recharge within the model study boundary for the period 1940 to a particular accounting year "off." and CKMN. is the base flow in a Sub-basin or the Main Stem determined from running the RRCA Groundwater Model with all Colorado groundwater pumping and recharge (C).
>
> 6

Kansas groundwater pumping and recharge (K), all surface water recharge from Imported Water Supply (M), and all Nebraska groundwater pumping and recharge (N) within the model study boundary for the period 1940 to a particular accounting year "on."

15. The reason stated by Nebraska for the proposed change in determining VWS is: "This independently-computed value of VWS_G is the best estimate of the impact of all groundwater-related human activity on streamflow and should be viewed as the true value of this property."[12]

16. While the independently-computed value of VWS_G $(\theta - CKMN)$ may be the best estimate of base flow discharged from the groundwater system to surface water sources "undepleted by the activities of man" over the period 1940 to a particular accounting year, it is an estimated value derived from running the RRCA groundwater model and should not be viewed as the "true value" as suggested by Nebraska. Although the RRCA Groundwater Model has presumably been properly designed and calibrated and can provide reliable estimates of base flow, the RRCA groundwater model is still an idealization of a complex hydrogeologic system and the results derived from running the model are not necessarily the true values.

17. The second and third changes proposed by Nebraska in the Accounting Procedures pertaining to $CBCU_G$ and IWS would modify the determination of $CBCU_C$, $CBCU_K$, and $CBCU_N$ specified in § III.D.1. of the Accounting Procedures as described in Finding 9 and the determination of IWS specified in § III.A.3. of the Accounting Procedures described in Finding 10 such that:

$$CBCU_C + CBCU_K + CBCU_N - IWS = (\theta - CKMN) = VWS_G$$

under all conditions.

(Ex. J7, Arbitrator's Final Decision, 2009, Findings 14 through 17, pages 6 and 7).

Nebraska's proposals since 2008 have focused on the concept of additivity. This concept is the same as Nebraska's "Impact Summation Requirement" that was discussed in the August 2008 report. Modifications to Nebraska's 16-run proposal presented in the August 2008 report were made in Nebraska's January 2009 report so that the concept of additivity could be fully achieved in all sub-basins. Nebraska's revised 5-run proposal, however, does not achieve additivity in all sub-basins.

The consequences of Nebraska abandoning the original 16-run proposal eliminates the potential negative impacts to Colorado and increases the potential negative impacts to Kansas. Under Nebraska's revised 5-run proposal, potential negative impacts to Colorado associated with the original 16-run are eliminated. These potential negative impacts are largely associated with the Frenchmen Creek sub-basin and the main stem reach of the river above Swanson Reservoir. Under the original 16-run proposal, Colorado would effectively share residual impacts with Nebraska for the Frenchmen Creek sub-basin and in the main stem reach above Swanson

Reservoir. Under Nebraska's revised 5-run proposal, these residual impacts are no longer considered and Colorado would not be negatively impacted.

Kansas, on the other hand, would be negatively impacted. In Nebraska's original 16-run proposal, some of the negative impacts to Kansas would have been offset by increases to the computed water supply that would have resulted from achieving the additivity inherent in the original 16-run proposal. For example, by including allocation of residual impacts in the Frenchmen Creek sub-basin in the original 16-run proposal, the computed water supply for that sub-basin would increase. Some of the increase in the computed water supply in the Frenchmen Creek sub-basin would be allocated to the main stem and shared between Kansas and Nebraska. Under the revised 5-run proposal, there would be no residual impacts in the Frenchmen Creek sub-basin to allocate and there would be no increase in the computed water supply allocated to the main stem that Kansas would share with Nebraska. Consequently, under the revised 5-run proposal, Kansas would be required to bear the negative impacts of the original 16-run proposal without receiving the offsets that would have been provided by adhering to the notion of additivity in all sub-basins.

Estimates of the increase in negative impact to Kansas were not provided in the report prepared by Dr. Schreüder summarizing the quantitative effect of the five run proposal (Ex. C10, Schreüder Report, June, 2012). In this report, Dr. Schreüder does compare the impacts to each State under the current RRCA accounting method with impacts associated with the Nebraska's revised 5-run proposal. Tables are provided that summarize pumping impacts, changes in water supply allocation, and changes in overall compact balance for years beginning in 2003. The summarized changes are between the current RRCA accounting method and Nebraska's 5-run proposal. These tabulations basically show that, under Nebraska's revised 5-run proposal, Kansas would be negatively impacted, Nebraska would benefit by an amount equal to Kansas' negative impact and Colorado would not be impacted.

For example, for the year 2003, the tables show that Kansas' compact balance would be reduced by over 9,000 acre feet from what it is under the current RRCA accounting method. Nebraska, on the other hand, would see their compact balance improved by over 9,000 acre feet. Colorado's compact balance would be unchanged. Tables for subsequent years show differing amounts of impact but the distribution of impacts between the States remains unchanged.

The Schreüder report of June 2012, however, does not compare the impacts to each State that would have occurred under Nebraska's original 16-run proposal. Such a comparison would show that the negative impact to Kansas' compact balance under Nebraska's original 16-run proposal was less severe than it would be under the revised 5-run proposal. For Colorado's compact balance, it would show that negative impacts would occur, primarily in the Frenchmen Creek sub-basin and in the main stem reach above Swanson Reservoir. In this main stem reach, Colorado has generally received a credit that would partially offset its overall consumptive use. Under Nebraska's original 16-run proposal, Colorado would not have received a portion of this credit.

Under Nebraska's original 16-run proposal for the Frenchmen Creek sub-basin, Nebraska and Colorado would share responsibility for residual impacts in this sub-basin. In other words, Nebraska and Colorado would be charged additional $CBCU_G$ in this sub-basin beyond what they would be charged under the current RRCA accounting method. Colorado has argued that it would be unfair to charge them with these additional impacts because Colorado pumping could not cause these impacts unless there were no pumping in Nebraska (Ex. K136, Schreüder Report, 2009, pages 1 and 3). While there may be some merit to Colorado's argument, it does not answer the question of who should be responsible for the additional $CBCU_G$.

Under Nebraska's revised 5-run proposal, the additional $CBCU_G$ in the Frenchmen Creek sub-basin and the potential reduction in Colorado's credit in the main stem reach above Swanson are ignored. This means that, under the revised proposal, neither Colorado nor Nebraska would have to take responsibility for additional $CBCU_G$ in the Frenchmen Creek sub-basin and that Colorado would not have some of its credit in the main stem reach above Swanson reduced. Kansas, on the other hand, would be negatively impacted because it would not receive the additional allocation of computed water supply that would be derived from the additional $CBCU_G$ in the Frenchmen Creek sub-basin.

As discussed previously, Dr. Schreüder's June 12, 2012 report did not include a quantification of how impacts would differ between Nebraska's original 16-run proposal and their revised 5-run proposal. Some of the backup materials from Dr. Schreüder's March 2012 expert report provide quantification under a future scenario for years 2009 to 2059. This quantification was discussed with Dr. Schreüder during his deposition of July 16, 2012 (Ex. K137, Schreüder Deposition, July 16, 2012, pages 100 to 107). The quantification showed that Colorado's compact balance would be worse off by an average of 5,564 acre feet per year for the years 2009 to 2059 under the original 16-run proposal. Under the revised 5-run proposal, Colorado's compact balance would be unchanged.

Dr. Schreüder's quantification also showed that the average impact to Kansas' compact balance for the years 2009 to 2059 would change from "negative 9,415" acre feet per year under Nebraska's original 16-run proposal to "negative 12,936" acre feet per year under the revised 5-run proposal (Ex. K137, Schreüder Deposition, July 16, 2012, page 104). Thus, this quantification showed that Kansas' compact balance would be worse off under Nebraska's revised 5-run proposal than under the original 16-run proposal by an average of about 3,500 acre feet per year. The explanation for this difference is that by ignoring responsibility for increased $CBCU_G$ in the Frenchmen Creek sub-basin, Kansas would no longer receive their share of an increase in computed water supply along the main stem of the river that would result from the inclusion of this $CBCU_G$ in the accounting procedures. Ignoring this increased $CBCU_G$ would also relieve Colorado and/or Nebraska from having to count additional consumptive use against their compact allocations.

The 5-Run Revised Proposal Uses a Baseline Run that is not Calibrated and is Subject to Considerable Uncertainty

The accounting procedures in the FSS specify that $CBCU_G$ is to be computed using the RRCA Groundwater Model as the difference between a "base" run and a "no State pumping" run (Ex. J1, Republican River Compact Administration, FSS, Appendix C, 2002, page C20). The "base" run is defined as a model run with all pumping, groundwater pumping recharge, and surface water recharge "on". This "base" run represents the historical condition in the basin.

Impacts on stream flows from pumping and imported water recharge are all determined as departures from this historical condition.

The RRCA groundwater model documentation of June 30, 2003 that was agreed upon by the modeling committee states the following as the concluding paragraph of the executive summary (Ex. J5, Final Report of the Special Master with Certificate of Adoption of Groundwater Model, 2003, pages 6 and 7):

> *The RRCA Model is fully operational and calibrated to represent the physical and hydrogeological characteristics of the Republican River Basin to a reasonable degree. The RRCA Model matches the trend and magnitude of ground water level changes and stream baseflow targets distributed throughout the Republican River Basin, without significant bias in any region or hydrologic characteristic. The RRCA Model is calibrated to a sufficient degree that depletions from ground water pumping and accretions from imported water from the Platte River System to the Republican River may be quantified and assigned to prescribed streamflow reaches in accord with the RRCA Accounting Procedures.*

The RRCA Groundwater Model was calibrated to historical conditions that were known at the time the model was developed. Data on groundwater levels, changes in groundwater levels, stream base flows and changes in stream base flows were used in the calibration process that was conducted by Republican River Groundwater Modeling Committee. This process culminated in the RRCA Groundwater Model that was calibrated to a sufficient degree that impacts from groundwater pumping and imported water recharge could be quantified and used in the accounting procedures. The calibration process represented a significant effort on the part of representatives for each State to produce a computational tool that did not contain significant bias in any region or hydrologic characteristic and would represent the physical and hydrogeological characteristics of the basin to a reasonable degree. The final model was the result of a give and take among the three States and included compromises to resolve technical issues that were confronted during the process of model development and calibration.

The 5-run revised proposal that Nebraska now supports seeks to change the "base" run or baseline condition that is used as the point of departure for determining the impacts of each State's pumping on stream flows. The baseline under the revised proposal would no longer be the historical condition, to which the model was calibrated, but instead would be a condition in which the recharge from imported water is assumed to have never occurred.

Dr. Schrueder was also concerned about using model results under conditions to which the model was not calibrated. In his February, 2009 report to the arbitrator, he concluded:

> The uncertainty in the model results is least under conditions to which the model was calibrated. Under these conditions, the model has been shown to reproduce reasonably accurate representations of historical baseflow and water levels. One therefore has confidence that the model will be able to accurately predict changes from that condition. However, the further removed the model predictions are from the conditions to which it was calibrated, the more uncertain the model predictions. The more nonlinear the model is, the faster the uncertain grows.

(Ex. K136, Schreüder Report, February, 2009, page 10).

In his deposition given on March 2, 2009, Dr. Schreuder further described his concern regarding the use of model runs that were not calibrated.

Q I'm having difficulty seeing the distinction that you are making in the historical calibration between the way the model is presently run and that suggested by Ahlfeld.

A Is that a question?

Q It is. It isn't. It was intended to be, but it isn't.

Can you explain further the distinction between how the model calculations presently occur and that proposed by Ahlfeld and why, then -- a two-part question -- why, then, the Ahlfeld would not result in greater accuracy?

A The currently approved procedure is a pertubation from a known condition. The Ahlfeld report requires a pertubation from an unknown condition.

(Ex. K135, Schreüder Deposition, March 2, 2009, pages 34 and 35)

In this exchange, Dr. Schreüder expresses a reason why the Ahlfeld proposal would be less accurate than the currently approved procedure. He notes that the Ahlfeld proposal includes perturbations from what he calls an "unknown condition" whereas the currently approved procedure is a perturbation from a known condition. The unknown condition is a reference to conditions other than the historical calibrated condition where various measurements were available to establish that condition as a "known condition". The new baseline condition in the 5-run revised Nebraska proposal would also be an unknown condition in the context described by Dr. Schreüder.

The recharge from imported water is a significant hydrologic factor in the RRCA Groundwater Model and removing it from the model input will have significant effects on model results. The amount of this recharge is on the order of 600,000 acre feet per year. By contrast, the average groundwater recharge from precipitation in the Kansas portion of the RRCA Groundwater Model, including increased recharge on irrigated land, is only about 250,000 acre feet per year. The recharge from imported water has increased groundwater levels along an area roughly parallel to the Platte River that extends from the western side of Lincoln County to beyond the eastern side of Phelps County, a distance of over 100 miles. This area is generally referred to as the mound area.

Most of the recharge from imported water in the mound area flows north toward the Platte River. However, some of the increase in groundwater levels caused by this recharge propagates southward and causes some increase in groundwater discharge to streams that are tributary to the Republican River. The accounting procedures as specified under the FSS provide for a credit to Nebraska that recognizes the degree to which this recharge has and is impacting the historical stream flow within the Republican River Basin. The amount of these impacts to stream flow is relatively small as compared to the amount of recharge from imported water that is estimated to occur within the mound area. Generally, this impact to stream flow is less than five percent of the recharge from imported water within the mound area.

Recharge from imported water within the mound area is a quantity that is estimated by Nebraska each year. Although the details of the procedures used to derive these estimates are not completely known because of the time constraints placed on Kansas in this proceeding, the procedure is generally one in which the recharge is computed as the residual of a water budget (Ex. J1, FSS, Appendix C, page C114; Ex. J5, Groundwater Model Report, page 23). The water budget domain encompasses a series of canals that convey water from the Platte River and that roughly parallel the river, delivering the water to fields along the canal system. Losses from these canals that occur along the conveyance route constitute the recharge from imported water.

In developing the water budgets for the canal systems, Nebraska attempts to account for inputs and outputs of water along the system and then assumes that the difference between these inputs and outputs must be the loss from the canal or the recharge from imported water. This estimation process is one in which the result is the difference between two relatively large numbers (total inputs and total outputs) that produces a relatively smaller number. In such a process, the uncertainty in the result is the sum of the uncertainty in the larger numbers that are subtracted from one another to produce the result. Consequently, the estimates of recharge from imported water derived in this fashion will likely have a greater degree of uncertainty than estimates of other water quantities in the RRCA Groundwater Model such as pumping.

The water budget method also provides a potential for overestimating the recharge. In applying the water budget, the differences between inputs and outputs could indicate that a canal gained water rather than lost water. Since the likelihood that canals in this part of Nebraska would gain water along the conveyance route is remote, calculations that yield this result (gain in flow) are ignored. However, in the overall estimation procedure, ignoring these results will produce an overestimation bias in terms of the differences between inputs and outputs.

In 2006, McDonald-Morrissey conducted a review of the RRCA Groundwater Model for the period from 2001 to 2004 for the Nebraska Department of Natural Resources (Ex. K128, McDonald-Morrissey, April, 2006). Both Mr. McDonald and Mr. Morrissey participated on the Technical Groundwater Modeling Committee on behalf of Nebraska. The purpose of this study was to evaluate the consistency of the RRCA Groundwater Model with groundwater level and stream flow data that were collected after 2000 and that were not available at the time the model was calibrated.

In general, the McDonald-Morrissey study found that the RRCA Groundwater Model continued to match conditions that were observed after January 1, 2001. However, they specifically noted that there were some potential problems related to the area of the mound recharge. They stated:

> The model is imprecise because it does not represent all features of the flow system but only those which are deemed to be significant and because input specifications are estimates. In one area of the RRCA model, the "mound" area or an area in portions of Kearney, Phelps, Harlan, and Franklin counties, model-calculated water levels appear to be consistently too high. A further study of the mound area and the stream depletions/accretions relating to this area is being initiated. This study will attempt to establish the reason for lack of precision in the mound area and evaluate the impact of these high water levels on stream depletions/accretion calculations.

(Ex. K128, McDonald-Morrissey, April 2006, page 7)

The occurrence of water levels that are consistently too high in the mound area could be a symptom of overestimated recharge from imported water. In any case, the report recommended that a study be conducted to evaluate the impact of these high water levels on calculations of depletions and accretions. The report indicates that such a study was being initiated.

Although we do not know whether such a study was actually conducted and completed, the overestimation of water levels in the mound area referenced in this report is also a significant consideration in evaluating the 5-run revised Nebraska proposal. Since the revised proposal would use a baseline condition that does not include recharge from imported water, the difference between what the RRCA Groundwater Model would calculate with this recharge versus without it becomes very important. In addition, the reliability and uncertainty in the estimates of recharge from imported water also become increasingly important. A full evaluation of this issue requires the assembly and analysis of considerable data on groundwater levels and stream flows and thorough review of the recharge estimation process used by Nebraska. Such an evaluation is well beyond the scope of what can be accomplished in the time available before August 7, 2012.

The Characterization of the Total Effect on Nebraska of not Implementing the Revised Proposal is Unrealistic

Nebraska had alleged that failure to adjust the accounting procedures to their original proposal could deprive them of some 800,000 acre feet of water over the next 50 years (Ex. N1002, Schneider Report, November, 2011, page ES-1). Dr. Schreüder has similarly estimated that the failure to adopt the 5-run revised proposal would charge Nebraska's compact account some 660,000 acre feet of water over the period from 2003 to 2059 (Ex. C10, Schreüder Report, June, 2012). Both of these estimates are derived from runs of the RRCA Groundwater Model using a projection of future conditions in which pumping and recharge conditions were assumed to be constant over the next 50 years.

These pumping and recharge conditions were developed by Kansas to illustrate how stream flow depletions and Nebraska's $CBCU_G$ could grow over time if no significant actions were taken to mitigate the growth (Statement of Kansas Chief Engineer David W. Barfield in Kansas' Motion for Leave to File Petition, Petition, and Brief in Support, May, 2010, pages C10 and C11, Figure 7). In this illustration, Kansas assumed that groundwater pumping in Nebraska would continue in the future at rates consistent with average groundwater pumping per acre that occurred over the period from 2003 to 2008 and other model inputs representing future conditions were generally based on average conditions that occurred over the period from 1959 to 2008. Under these conditions, stream flow depletions were projected to grow to over 250,000 acre feet per year by 2059. However, the conclusion from this analysis was that continued pumping at these rates "will extend and exacerbate the tendency to violate the Decree during dry periods" (Barfield Statement, 2010, page C11). In other words, continuing to pump at these rates and under these conditions would not be sustainable in terms of maintaining compliance with the Compact and the FSS.

Calculations of how Nebraska might be impacted under conditions that should not be allowed to occur are not informative. It is very unlikely that Nebraska's stream flow depletions due to pumping could grow to the amounts assumed in the projections used by both Schneider and Schreüder in their quantification of impacts to Nebraska without causing additional violations of the Compact and the FSS. In fact, even Nebraska has recognized that it would need to limit its annual total consumptive use to 200,000 acre feet or less in order to maintain compliance if several dry years recur within the next 10 years (Ex. K138, Dunnigan Letter to NRD Managers, Dec. 29, 2011). The notion that stream flow depletions could be allowed to grow to over 250,000 without incurring violations of the compact is unlikely. Consequently, calculations of how Nebraska might be impacted under such conditions do not provide useful information.

Language of FSS Section IV.F

The language in the FSS at Section IV.F regarding beneficial consumptive use of imported water specifies that any imported water supply credit will be calculated in accordance with the accounting procedures and by using the RRCA Groundwater Model. The development of the RRCA Groundwater Model and its use in determining depletions to stream flows resulting from pumping or the determination of an imported water supply credit were the result of a give and take process among the States. For example, the final report on the development of the groundwater model describes the method used to determine recharge from precipitation and the increase in recharge from precipitation on irrigated land as opposed to non-irrigated land (Ex. J5, Final Report of the Special Master with Certificate of Adoption of RRCA Groundwater Model, page 20). The report notes that this increase in recharge was the subject of extensive discussion and the results represented a compromise agreement. The amount of this increased recharge on irrigated land represents a direct offset to the amount of pumping for irrigation water supply and, in effect, mitigates some of the impact to stream flow associated with groundwater pumping.

Another similar factor that was an important component of the modeling process was the relative amount of irrigation return flow associated with groundwater pumping. Nebraska uses a factor of 20 percent (or 80 percent efficiency) to compute how much of the groundwater pumping returns to the groundwater as irrigation return flow. As described in the report on the groundwater model, Nebraska increased its efficiency from 70 percent in 1960 to 80 percent in 2000 to reflect information about the changes in irrigation systems over time (Ex. J5, Final Report of the Special Master with Certificate of Adoption of RRCA Groundwater Model, page 22).

Appendix J to the FSS discussed the various procedures used by the States to compute irrigation return flow associated with groundwater pumping (Ex. J1, Final Settlement Stipulation, 2002, Appendix J1, pages 11 and 12). This Appendix also noted that the RRCA Groundwater Modeling Committee would develop a common set of procedures for estimating this return flow. As of 2012, a common set of procedures has not been developed despite many requests from Kansas for investigations into the amounts of irrigation return flows assumed by Nebraska. Nebraska has continued to assume an 80 percent efficiency to compute irrigation return flow associated with groundwater pumping since 2000 and no actions have been taken to update this assumption. As with increased precipitation recharge, the amount of irrigation return flow associated with groundwater pumping mitigates some of the impact to stream flow associated with the pumping.

The amount of impact associated with these recharge issues is potentially significant and is of the same order of magnitude of the potential impacts on imported water described by Dr. Schreüder. For example, over time, the increase in GWCBCU between assuming an 80 percent efficiency and a 90 percent efficiency would amount to 10,000 to 15,000 acre feet per year. Impacts of this magnitude are of the same order as the potential impacts described by Dr. Schreüder. Furthermore, the potential value associated with these issues to the individual States is substantial. For example, in a 2003 letter from the director of the Nebraska DNR, Roger Patterson, to officials of the University of Nebraska, the work of one of the members of the Groundwater Modeling Committee on behalf of Nebraska in obtaining concessions from Kansas was highlighted (Ex. K133, Patterson Letter, October, 2003). The letter noted that Dr. Derrel Martin was instrumental in convincing Kansas to "accept a level of irrigation recharge enhancement that will provide water for Nebraska irrigators that is worth $15 million to $20 million annually to the State".

Considerations of effects such as those described above were an integral part of the give and take that led to the agreement described in the FSS and the accounting procedures. Under some circumstances, impacts may be overstated and, under other circumstances, impacts may be understated. A balance of how these overstatements or understatements might play out would have been among the factors that allowed the States to come to agreement as to how the accounting procedures would be structured and how the RRCA Groundwater Model would be used. In short, the accounting procedures and the use of the RRCA Groundwater Model as described in the FSS include compromises and concessions that allowed for a final agreement to be reached among the States.

Conclusions

In summary, the following initial conclusions have been reached regarding Nebraska's revised 5-run proposal for changes in the use of the RRCA Groundwater Model and the accounting procedures.

- Nebraska's revised 5-run proposal represents a significant change from the original 16-run proposal and from the current RRCA method in both concept and quantification.
- Nebraska's revised 5-run proposal uses a baseline condition that cannot be compared to real data because it represents an unknown condition that did not occur historically.
- Nebraska's revised 5-run proposal uses a baseline condition that cannot be calibrated to measured data and is subject to considerable uncertainty that must be evaluated in order to determine its impact on model calculations.
- References to Nebraska's revised 5-run proposal as a subset of the original 16-run proposal are nothing more than a reference to the use of five model runs that are among those used in the original 16-run proposal.
- Under this characterization of a subset, the current RRCA method would be a subset as would be other proposals that Nebraska has put forward since 2007.
- The various proposals put forward by Nebraska, including those that use five runs of the model, give different results depending on which model runs are used in a particular scenario.
- The FSS and the accounting procedures spell out how credit for recharge from imported water in Nebraska is to be determined using the RRCA Groundwater Model.
- The agreed upon RRCA Groundwater Model and accounting procedures included concessions and compromises among the States on various technical issues that ultimately affect impacts calculated with the model.

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State of Nebraska Department of Natural Resources. 2003. Letter from Roger K. Patterson to John C. Owens and Prem S. Paul, October 6.

Pursuant to 28 U.S.C. Sec. 1746, I declare under penalty of perjury that the foregoing is true and correct.

Executed on August 7, 2012

Steven P. Larson

No. 126, Original

IN THE
SUPREME COURT OF THE UNITED STATES

STATE OF KANSAS,
Plaintiff,

v.

STATE OF NEBRASKA
and
STATE OF COLORADO,
Defendants.

NOTICE OF DEPOSITION OF STEVEN P. LARSON AND SUPOENA DUCES TECUM

TO: **Steven P. Larson, P.E.**
S.S. Papadopulos & Associates
7944 Wisconsin Avenue
Bethesda, Maryland 20814

COMES NOW the State of Colorado, pursuant to Case Management Plan No. 2 ("CMP-2") and Case Management Order No. 9 (as amended by the Special Master during the May 23, 2013 telephone conference) you are hereby **ORDERED** to appear at the time, date, and place set forth below to testify at a deposition to be taken in this civil action and recorded by a certified court reporter by stenographic means.

Time: 10:30 a.m. to 1:00 p.m.
Date: June 11, 2013
Location: Hilton Kansas City Airport,
Salon F
8801 NW 112th Street
Kansas City, Missouri, 64153

The State of Colorado requests that you bring to this deposition:

1. All documents reviewed by you or anyone that assisted you in connection with preparing Kansas' Expert Report on Nebraska's 5-Run Proposal and the Appendices attached thereto (collectively, the "Expert Report");
2. Any and all documents that you relied upon in preparing the Expert Report;
3. ~~All drafts of the Expert Report;~~
4. All notes made by you or anyone that assisted you during the preparation of the Expert Report;
5. All correspondence between you and any other individual, including, but not limited to counsel for the State of Kansas related to the Expert Report;
6. All documents provided to you by counsel for the State of Kansas or any other representative of the State of Kansas in connection with the preparation of the Expert Report; and
7. All documents contained within your files related in any way to the preparation of the Expert Report, including but not limited to supplemental materials, information, data, model runs, studies, reports, electronic and other communications, maps, GIS information and data, or any other tangible thing.

The Case Management Plan for this action is attached hereto as Exhibit A. Rules 45(c) and (d) of the Federal Rules of Civil Procedure are attached hereto as Exhibit B, in accordance with Rule 45(a)(1)(A)(iv). This Subpoena is issued under Fed. R. Civ. P. 45(a)(3)(B) by Scott Steinbrecher, Counsel of Record for the State of Colorado, Colorado Department of Law, 1300 Broadway, Seventh Floor, Denver, Colorado, 80203.

Respectfully submitted this 30th day of May, 2013.

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/s/
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No. 126, Original

In The
Supreme Court of the United States

♦

STATE OF KANSAS,

Plaintiff,

v.

STATE OF NEBRASKA

and

STATE OF COLORADO,

Defendants.

♦

STATE OF NEBRASKA'S PROPOSAL FOR FURTHER PROCEEDINGS ON RESOLUTION OF ACCOUNTING PROCEDURES DISPUTE

♦

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January 22, 2013

Nebraska responds, pursuant to ¶ 7 of Case Management Order No. 8, to the Special Master's direction to propose a schedule for further proceedings "necessary to finally resolve the change in Accounting Procedures for years subsequent to 2006 so that the consumption of Imported Water Supply is not treated as the consumption of Virgin Water Supply in material amounts." Nebraska previously shared this proposal with the other parties. Kansas rejected it, and Colorado is substantially in agreement.

The following schedule is intended to provide a full and fair opportunity for the Parties to address all material issues, but ensure completion of these proceedings expeditiously.

February 1, 2013:	Nebraska resubmits its 5-Run Proposal (limited to previously filed technical material).
March 15, 2013:	Kansas files an expert report concerning the 5-Run Proposal.
April 8, 2013:	Nebraska and Colorado file responsive expert reports.
Week of April 22, 2013:	Parties appear in Portland Maine for a one day hearing.

Nebraska respectfully requests the Special Master enter an Order adopting the proposed schedule and directing the Parties to proceed forthwith.

Respectfully submitted this 22nd day of January, 2013.

STATE OF NEBRASKA,

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No. 126, Original

In The

Supreme Court of the United States

♦

STATE OF KANSAS,

Plaintiff,

v.

STATE OF NEBRASKA

and

STATE OF COLORADO,

Defendants.

♦

CERTIFICATE OF SERVICE

I, Justin D. Lavene, counsel for the State of Nebraska in the above-captioned matter, hereby certify that on January 22, 2013, one copy of the attached STATE OF NEBRASKA'S PROPOSAL FOR FURTHER PROCEEDINGS ON ACCOUNTING PROCEDURES DISPUTE was e-mailed and/or mailed and/or placed on a CD and filed with all parties as indicated in Appendix A of Case Management Plan No. 2 dated October 17, 2011.

I further certify that on the same date, this Certificate of Service was distributed to the parties listed below as specified in Appendix A of the Case Management Plan:

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No. 126, Original

IN THE
SUPREME COURT OF THE UNITED STATES

STATE OF KANSAS,

Plaintiff,

v.

STATE OF NEBRASKA and
STATE OF COLORADO,

Defendants.

COLORADO'S PROPOSAL FOR SCHEDULING FURTHER PROCEEDINGS

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January 22, 2013

No. 126, Original

In the

SUPREME COURT OF THE UNITED STATES

STATE OF KANSAS,

Plaintiff

v.

STATE OF NEBRASKA and
STATE OF COLORADO,

Defendants

OFFICE OF THE SPECIAL MASTER

CASE MANAGEMENT ORDER NO. 9

January 25, 2013

{W3519901.2}

6. **Limitations on Further Proceedings.**

Any submissions or discovery allowed under this Order will be strictly limited to the issues identified above, upon pain of being stricken or disallowed.

7. **The Timing of My Report to the Court.**

I expect that, shortly after the disposition of the foregoing proceedings, I will issue a single report recommending the final disposition of this action in its entirety.

Dated: January 25, 2013

William J. Kayatta, Jr.
Special Master

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2

NON-BINDING ARBITRATION
Pursuant to Arbitration Agreement of October 23, 2008

IN ACCORDANCE WITH:
FINAL SETTLEMENT STIPULATION

Kansas v. Nebraska and Colorado
No. 126, Original, U.S. Supreme Court
Decree of May 19, 2003, 538 U.S. 720

ARBITRATOR'S FINAL DECISION

June 30, 2009
(Corrected July 13, 2009)

No. 126 Orig.
Ex. J7

JT003175

6,445 acre-feet.[33] These values are equivalent to adding one-half of the residual (one-half of 5,395 acre-feet) to $CBCU_K$ (323 acre-feet) and one-half of the residual to $CBCU_N$ (727 acre-feet), when $CBCU_K$ and $CBCU_N$ are calculated using the methodology prescribed in the existing Accounting Procedures as described in Finding 9.[34] The residual of 5,395 acre-feet is essentially the amount of groundwater consumptive use beyond the sum of 323 acre-feet and 727 acre-feet from streamflow depletion that must come from other groundwater sources, primarily groundwater storage, and is equally divided between Kansas and Nebraska using Nebraska's proposed methodology.[35]

30. Equally dividing what are primarily additional withdrawals from groundwater storage between Kansas and Nebraska, when streamflow is depleted and there is no longer a hydraulic connection with the groundwater system, to determine $CBCU_K$ and $CBCU_N$ without regard to the decrease in groundwater storage caused by groundwater use in each state is not appropriate. Similarly, equally dividing what are primarily additional withdrawals from groundwater storage between Colorado and Nebraska in the case of Frenchman Creek, when streamflow is depleted and there is no longer a hydraulic connection with the groundwater system, to determine $CBCU_C$ and $CBCU_N$ without regard to the decrease in groundwater storage caused by groundwater use in each state is problematic given that "the majority of the Frenchman Basin is in Nebraska and Nebraska pumping can be expected to have the largest influence."[36]

31. Using the examples of Beaver Creek and Frenchman Creek, equally dividing what are primarily additional withdrawals from groundwater storage between two states when streamflow is depleted and there is no longer a hydraulic connection with the groundwater system to determine CBCU, without regard to the decrease in groundwater storage caused by groundwater use in each state, is also inconsistent with there being "very little propagation of head change across statelines."[37]

32. When the groundwater being consumptively used involves all three states, or when there is significant IWS, the residual described in Finding 27 is divided in "a more complicated way"[38] but the residual must still be related to changes in groundwater storage.

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[33] Nebraska Exhibit 30, Expert Report of Dr. David P. Ahlfeld, Michael G. McDonald, and James C. Schneider, *Estimating Computed Beneficial Consumptive Use for Groundwater and Imported Water Supply under the Republican River Compact*, January 20, 2009, p. 50.

[34] Transcript of Arbitration Proceedings, March 17, 2009, Volume VII at 1148:19-1149:4 (Ahlfeld).

[35] Transcript of Arbitration Proceedings, March 19, 2009, Volume IX at 1466:9-1470:8 (Ahlfeld).

[36] Nebraska Exhibit 30, Expert Report of Dr. David P. Ahlfeld, Michael G. McDonald, and James C. Schneider, *Estimating Computed Beneficial Consumptive Use for Groundwater and Imported Water Supply under the Republican River Compact*, January 20, 2009, p. 30.

[37] Transcript of Arbitration Proceedings, March 17, 2009, Volume VII at 1173:8-9 (Ahlfeld).

[38] *Id.*at 1149:7 (Ahlfeld).

Nebraska's expert report on this issue, and neither timely raised this assertion during the hearing conducted as part of this arbitration.

3. Nebraska's proposed procedure for determining VWS, whereby what Nebraska terms VWS_G, determined as (θ – CKMN), is more consistent with the definition of VWS established in the Compact and adopted in the Accounting Procedures than is summing $CBCU_C$, $CBCU_K$, and $CBCU_N$, less IWS, each calculated in accordance with the existing Accounting Procedures, to compute VWS_G.

4. While Nebraska's proposal for determining what it terms VWS_G is consistent with the definition of VWS established in the Compact and adopted in the Accounting Procedures, Nebraska's proposed changes to calculate $CBCU_C$, $CBCU_K$, $CBCU_N$, and IWS, are problematic and adoption of Nebraska's proposed changes by the RRCA is not appropriate.

5. Although Nebraska's proposed changes to calculate $CBCU_C$, $CBCU_K$, $CBCU_N$, and IWS, should not be adopted by the RRCA, the RRCA should consider reconvening the Technical Groundwater Modeling Committee to thoroughly re-evaluate the nonlinear response of the RRCA Groundwater Model when simulated stream drying occurs, re-evaluate the existing procedures for determining CBCU and IWS, and document its conclusions and any recommendations in a report to the RRCA.

Accounting Procedures – Haigler Canal

6. During the period of years from 1995 through 2006, the annual amounts of water measured at the Haigler Canal Spillback gage exceeded the actual annual amounts of water measured at the Arikaree Gage in 2002, 2003, 2004, and 2005, indicating that a significant portion of the water measured at the Haigler Canal Spillback gage during these years does not remain in the Arikaree River as measurable surface water at the Arikaree Gage.

7. While some of the water measured at the Haigler Canal Spillback gage undoubtedly reaches the Arikaree Gage under certain conditions, there is insufficient information to justify changing the Accounting Procedures to reduce the diversions from the North Fork Republican River into the Haigler Canal by the amount of water measured at the Haigler Canal Spillback gage, as proposed by Nebraska.

8. Consequently, the changes to the Accounting Procedures proposed by Nebraska involving VWS calculations for the North Fork of the Republican River in Colorado and the Arikaree River are not justified.

9. During the period of years from 1995 through 2006, the annual amounts of water returning to the Arikaree River from irrigation using water from the Haigler Canal, as estimated in accordance with the change to the Accounting Procedures proposed by Nebraska to apportion 49 percent of the return flows to the Arikaree River at the Arikaree Gage, exceeded the actual annual amounts of water measured at the Arikaree Gage in 2001, 2002, 2003, and 2004.

allocations determined in accordance with the Accounting Procedures using the averaging provisions for normal administration and Water-Short Year Administration as set forth in the FSS.

50. Should Nebraska fail to comply with an injunction, sanctions may be appropriate in addition to the award of additional damages to Kansas. While such sanctions may be significant, those sanctions should be based on the specific circumstances of Nebraska's failure to comply, and hence it is not appropriate to recommend the pre-establishment of such sanctions in advance, as requested by Kansas.

51. Consistent with the express provisions of the FSS, which do not provide that money can be exchanged for water in determining the 5-year averages of allocation less CBCU reduced by the IWS credit for normal administration periods or the 2-year averages for Water-Short Year Administration, and as a sanction for violating the FSS by exceeding its allocations during Water-Short Year Administration in 2005 and 2006, Nebraska should not receive credit in subsequent 5-year averages for damages that may be paid to Kansas for those violations.

52. With the injunctive relief enjoining Nebraska from exceeding its allocations in the future and sanctions for failure to comply, the cost to Nebraska for noncompliance should incentivize Nebraska to take whatever steps are necessary to ensure that it does stay within its allocations under the Compact pursuant to the FSS during all conditions including prolonged dry-year conditions.

53. In *Texas v. New Mexico*, the Court appointed a river master with the specific and limited duty "to make the required periodic calculations" in applying the approved apportionment formula.[274] Since the specific duties and authorities that a river master appointed by the Court could or should undertake in the Republican River Basin have not been specifically identified, appointment of a river master is not warranted at this time.

[274] *Texas v. New* Mexico, No.65, Original, 482 U.S. 124, 107 S.Ct. 2279, at 134.

3

Colorado's Report in Response to Nebraska Expert Report in Support of Counterclaim and Crossclaim: Nebraska's Proposed Changes to the RRCA Accounting Procedures

Willem A. Schreüder, Ph.D

March 15, 2012

Table 2c: Average 1981- 2006 (acre-feet/year)

Basin	$CBCU_C$			$CBCU_K$			$CBCU_N$			IWS			NE Residual			Basin Residual		
	RRCA	Jan09	NEnet	RRCA	Jan09	NEnet	RRCA	Jan09	NEnet	RRCA	Jan09	NEnet	RRCA	Jan09	NEnet	RRCA	Jan09	NEnet
Arikaree	981	1005	981	313	341	313	231	246	230	0	0	0	0	15	0	-65	0	-66
Beaver	0	0	0	4442	5258	4442	4051	4866	4050	0	0	0	0	816	0	-1630	0	-1631
Buffalo	160	222	160	0	0	0	2368	2430	2368	0	0	0	0	63	0	-125	0	-125
Driftwood	0	0	0	0	0	0	1146	1146	1146	0	0	0	0	0	0	0	0	0
Frenchman	558	2105	555	0	0	0	66685	68221	66658	0	14	0	28	1550	0	-3062	0	-3093
North Fork	11343	11340	11342	23	24	23	770	769	769	0	0	0	0	0	0	0	0	0
Above Swanson	-1985	-1619	-1986	172	199	172	10484	10860	10483	0	0	0	0	377	0	-770	0	-771
Swanson - Harlan	0	11	0	47	93	257	35617	32209	28686	7038	10538	7038	6931	23	0	6962	0	-179
Harlan - Guide Rock	0	0	0	0	0	0	20195	20139	20088	143	197	143	107	0	0	113	0	0
Guide Rock - Hardy	0	0	0	250	248	250	1705	1705	1708	0	0	0	0	0	0	0	0	0
Medicine	0	0	0	0	0	0	14530	14358	14187	8278	8449	8278	343	0	0	346	0	0
Prairie Dog	0	0	0	3705	3705	3705	0	0	0	0	0	0	0	0	0	0	0	0
Red Willow	0	0	0	0	0	0	4995	4988	4983	24	30	24	12	0	0	13	0	0
Rock	27	33	27	0	0	0	2454	2461	2454	0	0	0	0	0	0	-12	0	-13
Sappa	0	0	0	580	1107	566	1883	2417	1883	0	0	0	0	531	0	-1058	0	-1072
South Fork	9956	10067	9955	6982	7139	6983	864	963	863	0	0	0	0	101	0	-367	0	-368
Hugh Butler	0	0	0	0	0	0	1341	1341	1341	0	0	0	0	0	0	0	0	0
Bonny	1036	1036	1036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Keith Sebelius	0	0	0	506	506	506	0	0	0	0	0	0	0	0	0	0	0	0
Enders	0	0	0	0	0	0	3165	3166	3165	0	0	0	0	0	0	0	0	0
Harlan	0	0	0	36	32	36	825	822	826	0	0	0	0	0	0	0	0	0
Harry Strunk	0	0	0	0	0	0	223	223	224	0	0	0	0	0	0	0	0	0
Swanson	0	0	0	0	0	0	209	206	209	0	0	0	0	0	0	0	0	0
Mainstem	**-1986**	**-1632**	**-1988**	**376**	**354**	**166**	**68001**	**64914**	**60965**	**7177**	**10729**	**7177**	**7036**	**397**	**0**	**6306**	**0**	**-942**
Total	**22083**	**24179**	**22076**	**16967**	**18461**	**16744**	**173742**	**173536**	**166320**	**15491**	**19237**	**15491**	**7421**	**3470**	**0**	**361**	**0**	**-7290**

Report in Response to:

Estimating computed Beneficial Consumptive Use for Groundwater and Imported Water Supply under the Republican River Compact, Ahfed, *et al.* (January 20, 2009)

Prepared by:

Willem A. Schreüder, Ph.D.
Principia Mathmatica

February 16, 2009

Table 4c: Average 1981- 2006 (acre-feet/year)

Basin	CBCU_C				CBCU_K				CBCU_N				IWS				Basin Residual			
	RRCA	Mar08	Aug08	Jan09	RRCA	Mar08	Aug08	Jan09	RRCA	Mar08	Aug08	Jan09	RRCA	Mar08	Aug08	Jan09	RRCA	Mar08	Aug08	Jan09
Arikaree	981	1026	1005	1005	313	366	341	341	231	258	246	246	0	0	0	0	-65	59	0	0
Beaver	0	0	0	0	4442	6073	5258	5258	4051	5681	4867	4866	0	0	0	0	-1630	1628	0	0
Buffalo	160	285	222	222	0	0	0	0	2368	2493	2431	2430	0	0	0	0	-125	125	0	0
Driftwood	0	0	0	0	0	0	0	0	1146	1146	1146	1146	0	0	0	0	0	0	0	0
Frenchman	558	3651	2105	2105	0	-15	0	0	66685	69758	68221	68221	0	25	14	14	-3062	3063	0	0
North Fork	11343	11336	11340	11340	23	25	24	24	770	768	769	769	0	0	0	0	0	0	0	0
Above Swanson	-1985	-1262	-1616	-1619	172	216	202	199	10484	11227	10863	10860	0	0	0	0	-770	742	0	0
Swanson - Harlan	0	-26	0	-11	-47	-80	-108	-93	35617	28862	32194	32209	7038	13967	10555	10538	6962	-6780	-46	0
Harlan - Guide Rock	0	0	0	0	0	0	0	0	20195	20084	20139	20139	143	249	197	197	113	-110	0	0
Guide Rock - Hardy	0	0	0	0	250	247	248	248	1705	1705	1705	1705	0	0	0	0	0	0	0	0
Medicine	0	0	0	0	0	0	0	0	14530	14185	14357	14358	8278	8620	8449	8449	346	-345	0	0
Prairie Dog	0	0	0	0	3705	3706	3705	3705	0	0	0	0	0	0	0	0	0	0	0	0
Red Willow	0	0	0	0	0	0	0	0	4995	4982	4988	4988	24	36	30	30	13	-13	0	0
Rock	27	40	33	33	0	0	0	0	2454	2467	2461	2461	0	0	0	0	-12	12	0	0
Sappa	0	0	0	0	580	1639	1106	1107	1883	2955	2416	2417	0	0	0	0	-1058	1071	0	0
South Fork	9956	10156	10072	10067	6982	7275	7144	7139	864	1042	968	963	0	0	0	0	-367	307	15	0
Hugh Butler	0	0	0	0	0	0	0	0	1341	1341	1341	1341	0	0	0	0	0	0	0	0
Bonny	1036	1036	1036	1036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Keith Sebelius	0	0	0	0	506	506	506	506	0	0	0	0	0	0	0	0	0	0	0	0
Enders	0	0	0	0	0	0	0	0	3165	3167	3166	3166	0	0	0	0	0	0	0	0
Harlan	0	0	0	0	36	28	32	32	825	819	822	822	0	0	0	0	0	0	0	0
Harry Strunk	0	0	0	0	0	0	0	0	223	224	223	223	0	0	0	0	0	0	0	0
Swanson	0	0	0	0	0	0	0	0	209	203	206	206	0	0	0	0	0	0	0	0
Mainstem	**-1986**	**-1293**	**-1628**	**-1632**	**376**	**382**	**342**	**354**	**68001**	**61879**	**64901**	**64914**	**7177**	**14208**	**10747**	**10729**	**6306**	**-6147**	**-40**	**0**
Total	**22083**	**26235**	**24189**	**24179**	**16967**	**19983**	**18454**	**18461**	**173742**	**173367**	**173527**	**173536**	**15491**	**22901**	**19258**	**19237**	**361**	**-255**	**-27**	**0**

Summary of the Quantitative Effect of the Five Run Proposal

Willem A Schreüder

June 19, 2012

In response to a question posed by the Special Master, we prepared the attached tables to show the quantitative effect of Nebraska's proposal (the "Five Run Proposal"). The Five Run Proposal alters the current RRCA compact accounting in order to prevent the States from being charged for the consumption of imported water. The Five Run Proposal differs from the current RRCA approved procedure only in that surface water imports (also called the Mound) is turned off in both runs when calculating the Computed Beneficial Consumptive Use (CBCU) for each State.

This analysis shows that the current RRCA procedure will charge Nebraska's compact account for consumption of imported water by an average 11,648 acre-feet per year or about 660,000 acre-feet total over the period 2003 to 2059. Figure 1 summarizes this change in Nebraska's total compact account balance over time. The Five Run Proposal eliminates consumption of imported water from the current procedure.

Colorado's compact account balance is unchanged because Colorado has no Mainstem allocation and imported water does not materially effect Colorado's CBCU.

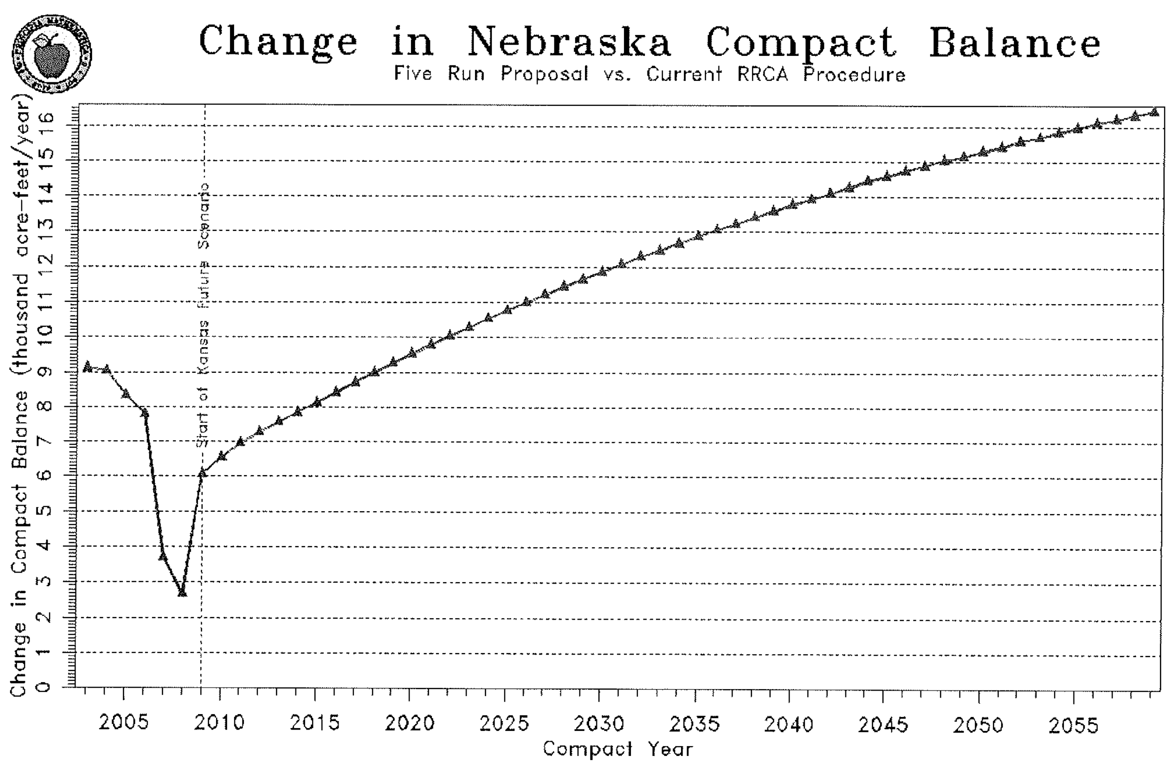

Figure 1.

The complete results of the Five Run Proposal are presented as a sequence of tables for the years 2003 to 2059, and the average for 2003 to 2059. The tables were generated from simulations performed by Nebraska and submitted with their expert report. The years 2003 to 2008 were extracted from a simulation spanning 2001 to 2010 and the years 2009 to 2059 were extracted from a simulation spanning 2009 to 2059.

In each table, the pumping impacts (also called $CBCU_G$) as calculated for each State are shown using the current RRCA method labeled ***Current*** and the Five Run Proposal labeled ***Proposed***. The change in the computed pumping impacts is labeled ***Change*** and highlighted in yellow.

The Five Run Proposal does not alter the RRCA approved method to calculate the Imported Water Supply credit for Nebraska shown in the column labeled ***Nebraska Mound Credits***. This value is shown for completeness only.

The change in the Computed Water Supply (CWS) is shown in the column highlighted in blue. This column is the sum of the changes to the CBCU. Therefore, the sum of the three yellow columns equals the blue column.

As the CWS changes, the allocation of the CWS to each State also changes. The sum of the change in allocations to the States equals the change in the CWS. However, for individual sub-basins the computation is complicated by the fact that some of the allocation may be to the Mainstem. For reaches where the allocation is entirely to the Mainstem, the change in allocation columns are labeled MS. For sub-basins such as, for example, Frenchman Creek, where 46.4% of the allocation is to the Mainstem and 54.6% is to Nebraska, the change in allocation resulting from the change in CWS is split between the sub-basin and the Mainstem.

Finally, the tables show the change in the compact account balance for each state. The change in the compact account balance reflects the change in the pumping impacts (CBCU) minus the change in allocation. All other components in the compact accounting calculations remain the same and so should not change as a result of the proposed change to the CBCU calculation. For sub-basins where the allocation is entirely to the Mainstem, the MS label is used to indicate that the change is represented entirely in the Mainstem calculation. For sub-basins like, for example, Frenchman Creek where some of the allocation to the Mainstem, the change in the compact balance reported by sub-basin should be interpreted in conjunction with the value for the Mainstem.

2003 (acre-feet/year)

Basin	Pumping Impacts									Nebraska Mound Credits	Change in CWS	Change in Allocation			Change in Compact Balance		
	Colorado			Kansas			Nebraska										
	Current	Proposed	Change	Current	Proposed	Change	Current	Proposed	Change			Colorado	Kansas	Nebraska	Colorado	Kansas	Nebraska
Arikaree	125	125	0	226	226	0	502	502	0	0	0	0	0	0	0	0	0
Beaver	0	0	0	323	323	0	727	727	0	0	0	0	0	0	0	0	0
Buffalo	268	268	0	0	0	0	3333	3333	0	0	0	0	0	0	0	0	0
Driftwood	0	0	0	0	0	0	1391	1391	0	0	0	0	0	0	0	0	0
Frenchman	36	37	1	0	0	0	81213	81164	-49	0	-48	0	0	-26	-1	0	23
North Fork	14158	14158	0	33	33	0	1255	1255	0	0	0	0	0	0	0	0	0
Above Swanson	126	126	0	-61	-60	1	17999	17999	0	0	1	MS	MS	MS	MS	MS	MS
Swanson - Harlan	0	0	0	56	0	-56	27275	10101	-17174	144	-17230	MS	MS	MS	MS	MS	MS
Harlan - Guide Rock	0	0	0	0	0	0	27708	27457	-251	182	-251	MS	MS	MS	MS	MS	MS
Guide Rock - Hardy	0	0	0	359	359	0	2258	2261	3	0	3	MS	MS	MS	MS	MS	MS
Medicine	0	0	0	0	0	0	20684	20212	-472	9429	-472	0	0	-43	0	0	429
Prairie Dog	0	0	0	1136	1136	0	0	0	0	0	0	0	0	0	0	0	0
Red Willow	0	0	0	0	0	0	6056	6018	-38	20	-38	0	0	-7	0	0	31
Rock	59	59	0	0	0	0	3420	3420	0	0	0	0	0	0	0	0	0
Sappa	0	0	0	-323	-323	0	500	496	-4	0	-4	0	-2	-2	0	-2	2
South Fork	10851	10851	0	5286	5286	0	1336	1335	-1	0	-1	0	0	0	0	0	0
Hugh Butler	0	0	0	0	0	0	1759	1759	0	0	0	0	0	0	0	0	0
Bonny	1326	1326	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Keith Sebelius	0	0	0	542	543	1	0	0	0	0	1	0	0	0	0	0	0
Enders	0	0	0	0	0	0	4437	4437	0	0	0	0	0	0	0	0	0
Harlan	0	0	0	36	37	1	884	886	2	12	3	MS	MS	MS	MS	MS	MS
Harry Strunk	0	0	0	0	0	0	455	456	1	0	1	0	0	0	0	0	0
Swanson	20	20	0	0	0	0	483	483	0	0	0	MS	MS	MS	MS	MS	MS
Mainstem	**121**	**121**	**0**	**358**	**304**	**-54**	**75240**	**57818**	**-17422**	**321**	**-17956**	**0**	**-9175**	**-8780**	**0**	**-9121**	**8640**
Total	**26966**	**26967**	**1**	**7628**	**7576**	**-52**	**203675**	**185692**	**-17983**	**9790**	**-18035**	**0**	**-9177**	**-8857**	**-1**	**-9125**	**9126**

2004 (acre-feet/year)

Basin	Pumping Impacts									Nebraska Mound Credits	Change in CWS	Change in Allocation			Change in Compact Balance		
	Colorado			Kansas			Nebraska										
	Current	Proposed	Change	Current	Proposed	Change	Current	Proposed	Change			Colorado	Kansas	Nebraska	Colorado	Kansas	Nebraska
Arikaree	161	161	0	311	311	0	427	427	0	0	0	0	0	0	0	0	0
Beaver	0	0	0	271	271	0	1183	1183	0	0	0	0	0	0	0	0	0
Buffalo	294	294	0	0	0	0	3327	3327	0	0	0	0	0	0	0	0	0
Driftwood	0	0	0	0	0	0	1479	1479	0	0	0	0	0	0	0	0	0
Frenchman	38	39	1	0	0	0	85202	85149	-53	0	-52	0	0	-28	-1	0	25
North Fork	14503	14503	0	31	31	0	1301	1301	0	0	0	0	0	0	0	0	0
Above Swanson	-1268	-1268	0	159	160	1	13823	13823	0	0	1	MS	MS	MS	MS	MS	MS
Swanson - Harlan	0	0	0	93	0	-93	33960	16976	-16984	623	-17077	MS	MS	MS	MS	MS	MS
Harlan - Guide Rock	0	0	0	0	0	0	29155	28889	-266	199	-266	MS	MS	MS	MS	MS	MS
Guide Rock - Hardy	0	0	0	178	178	0	2275	2279	4	0	4	MS	MS	MS	MS	MS	MS
Medicine	0	0	0	0	0	0	20898	20384	-514	9527	-514	0	0	-47	0	0	467
Prairie Dog	0	0	0	1327	1327	0	0	0	0	0	0	0	0	0	0	0	0
Red Willow	0	0	0	0	0	0	6448	6414	-34	25	-34	0	0	-7	0	0	27
Rock	57	57	0	0	0	0	3582	3582	0	0	0	0	0	0	0	0	0
Sappa	0	0	0	-271	-271	0	558	553	-5	0	-5	0	-2	-2	0	-2	3
South Fork	11591	11591	0	5724	5724	0	1192	1192	0	0	0	0	0	0	0	0	0
Hugh Butler	0	0	0	0	0	0	1773	1773	0	0	0	0	0	0	0	0	0
Bonny	1343	1343	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Keith Sebelius	0	0	0	496	496	0	0	0	0	0	0	0	0	0	0	0	0
Enders	0	0	0	0	0	0	4528	4528	0	0	0	0	0	0	0	0	0
Harlan	0	0	0	34	34	0	778	782	4	15	4	MS	MS	MS	MS	MS	MS
Harry Strunk	0	0	0	0	0	0	398	399	1	0	1	0	0	0	0	0	0
Swanson	18	18	0	0	0	0	487	487	0	0	0	MS	MS	MS	MS	MS	MS
Mainstem	**-1276**	**-1275**	**1**	**434**	**343**	**-91**	**79213**	**61967**	**-17246**	**817**	**-17853**	**0**	**-9123**	**-8730**	**0**	**-9031**	**8512**
Total	**26732**	**26733**	**1**	**8365**	**8276**	**-89**	**212772**	**194926**	**-17846**	**10392**	**-17938**	**0**	**-9125**	**-8813**	**-1**	**-9036**	**9033**

2059 (acre-feet/year)

Basin	Pumping Impacts									Nebraska Mound Credits	Change in CWS	Change in Allocation			Change in Compact Balance		
	Colorado			Kansas			Nebraska										
	Current	Proposed	Change	Current	Proposed	Change	Current	Proposed	Change			Colorado	Kansas	Nebraska	Colorado	Kansas	Nebraska
Arikaree	306	306	0	181	181	0	68	68	0	0	0	0	0	0	0	0	0
Beaver	0	0	0	2362	2360	-2	1474	1473	-1	0	-3	0	-1	-1	0	0	0
Buffalo	591	591	0	0	0	0	4021	4021	0	0	0	0	0	0	0	0	0
Driftwood	0	0	0	0	0	0	1213	1213	0	0	0	0	0	0	0	0	0
Frenchman	325	325	0	0	0	0	74982	74673	-309	0	-309	0	0	-166	0	0	143
North Fork	24553	24553	0	25	25	0	3447	3447	0	0	0	0	0	0	0	0	0
Above Swanson	-5922	-5922	0	-153	-153	0	6131	6131	0	0	0	MS	MS	MS	MS	MS	MS
Swanson - Harlan	-13	-13	0	-317	-1631	-1314	57960	30169	-27791	163	-29105	MS	MS	MS	MS	MS	MS
Harlan - Guide Rock	0	0	0	0	10	10	45188	43994	-1194	1201	-1184	MS	MS	MS	MS	MS	MS
Guide Rock - Hardy	0	0	0	130	130	0	3749	3760	11	-25	11	MS	MS	MS	MS	MS	MS
Medicine	0	0	0	0	0	0	30452	25754	-4698	7835	-4698	0	0	-428	0	0	4270
Prairie Dog	0	0	0	2497	2497	0	0	0	0	0	0	0	0	0	0	0	0
Red Willow	0	0	0	0	0	0	8747	8613	-134	34	-134	0	0	-26	0	0	108
Rock	141	141	0	0	0	0	6175	6175	0	0	0	0	0	0	0	0	0
Sappa	0	0	0	-265	-329	-64	1143	1136	-7	0	-71	0	-29	-29	0	35	-22
South Fork	10359	10359	0	6002	6002	0	931	931	0	0	0	0	0	0	0	0	0
Hugh Butler	0	0	0	0	0	0	3368	3368	0	0	0	0	0	0	0	0	0
Bonny	1892	1892	0	67	67	0	0	0	0	0	0	0	0	0	0	0	0
Keith Sebelius	0	0	0	920	920	0	0	0	0	0	0	0	0	0	0	0	0
Enders	112	112	0	0	0	0	6436	6436	0	0	0	0	0	0	0	0	0
Harlan	0	0	0	27	28	1	1189	1216	27	127	28	MS	MS	MS	MS	MS	MS
Harry Strunk	0	0	0	0	0	0	300	301	1	11	1	0	0	0	0	0	0
Swanson	30	30	0	0	0	0	390	390	0	0	0	MS	MS	MS	MS	MS	MS
Mainstem	**-5935**	**-5935**	**0**	**-331**	**-1645**	**-1314**	**113028**	**84054**	**-28974**	**1339**	**-34784**	**0**	**-17775**	**-17009**	**0**	**-16472**	**11938**
Total	**32374**	**32374**	**0**	**11490**	**10113**	**-1377**	**257363**	**223270**	**-34093**	**9359**	**-35464**	**0**	**-17805**	**-17658**	**0**	**-16428**	**16435**

Average 2003- 2059 (acre-feet/year)

Basin	Pumping Impacts									Nebraska Mound Credits	Change in CWS	Change in Allocation			Change in Compact Balance		
	Colorado			Kansas			Nebraska										
	Current	Proposed	Change	Current	Proposed	Change	Current	Proposed	Change			Colorado	Kansas	Nebraska	Colorado	Kansas	Nebraska
Arikaree	422	422	0	194	194	0	89	89	0	0	0	0	0	0	0	0	0
Beaver	0	0	0	3179	3179	0	2284	2284	0	0	0	0	0	0	0	0	0
Buffalo	428	428	0	0	0	0	3619	3619	0	0	0	0	0	0	0	0	0
Driftwood	0	0	0	0	0	0	1220	1220	0	0	0	0	0	0	0	0	0
Frenchman	350	351	0	0	0	0	75786	75616	-170	0	-170	0	0	-91	0	0	79
North Fork	19220	19220	0	24	24	0	2287	2287	0	0	0	0	0	0	0	0	0
Above Swanson	-4065	-4065	0	4	4	0	7412	7412	0	0	0	MS	MS	MS	MS	MS	MS
Swanson - Harlan	-3	-3	0	-147	-1439	-1292	50175	29250	-20925	2375	-22217	MS	MS	MS	MS	MS	MS
Harlan - Guide Rock	0	0	0	0	2	1	36234	35601	-633	745	-632	MS	MS	MS	MS	MS	MS
Guide Rock - Hardy	0	0	0	136	136	0	3284	3290	6	-13	6	MS	MS	MS	MS	MS	MS
Medicine	0	0	0	0	0	0	25387	22757	-2630	8817	-2630	0	0	-239	0	0	2391
Prairie Dog	0	0	0	2955	2955	0	3	3	0	0	0	0	0	0	0	0	0
Red Willow	0	0	0	0	0	0	7750	7668	-82	35	-82	0	0	-16	0	0	66
Rock	137	137	0	0	0	0	5216	5216	0	0	0	0	0	0	0	0	0
Sappa	0	0	0	-83	-137	-54	1269	1264	-5	0	-59	0	-24	-24	0	30	-19
South Fork	10756	10756	0	5692	5692	0	928	928	0	0	0	0	0	0	0	0	0
Hugh Butler	0	0	0	0	0	0	2536	2536	0	0	0	0	0	0	0	0	0
Bonny	1531	1531	0	30	30	0	0	0	0	0	0	0	0	0	0	0	0
Keith Sebelius	0	0	0	735	735	0	0	0	0	0	0	0	0	0	0	0	0
Enders	41	41	0	0	0	0	5413	5413	0	0	0	0	0	0	0	0	0
Harlan	0	0	0	42	44	1	930	941	11	62	13	MS	MS	MS	MS	MS	MS
Harry Strunk	0	0	0	0	0	0	293	294	0	1	0	0	0	0	0	0	0
Swanson	21	21	0	0	0	0	352	352	0	0	0	MS	MS	MS	MS	MS	MS
Mainstem	**-4072**	**-4072**	**0**	**1**	**-1290**	**-1292**	**97105**	**75553**	**-21552**	**3105**	**-25376**	**0**	**-12967**	**-12409**	**0**	**-11678**	**9132**
Total	**28835**	**28835**	**0**	**12775**	**11430**	**-1344**	**232467**	**208039**	**-24428**	**12035**	**-25771**	**0**	**-12991**	**-12779**	**0**	**-11647**	**11648**

Average 2003- 2059 (acre-feet/year)																	
Basin	**Pumping Impacts**									**Nebraska Mound Credits**	**Change in CWS**	**Change in Allocation**			**Change in Compact Balance**		
	Colorado			**Kansas**			**Nebraska**										
	Current	**Proposed**	**Change**	**Current**	**Proposed**	**Change**	**Current**	**Proposed**	**Change**			**Colorado**	**Kansas**	**Nebraska**	**Colorado**	**Kansas**	**Nebraska**
Arikaree	422	422	0	194	194	0	89	89	0	0	0	0	0	0	0	0	0
Beaver	0	0	0	3179	3179	0	2284	2284	0	0	0	0	0	0	0	0	0
Buffalo	428	428	0	0	0	0	3619	3619	0	0	0	0	0	0	0	0	0
Driftwood	0	0	0	0	0	0	1220	1220	0	0	0	0	0	0	0	0	0
Frenchman	350	351	0	0	0	0	75786	75616	-170	0	-170	0	0	-91	0	0	79
North Fork	19220	19220	0	24	24	0	2287	2287	0	0	0	0	0	0	0	0	0
Above Swanson	-4065	-4065	0	4	4	0	7412	7412	0	0	0	MS	MS	MS	MS	MS	MS
Swanson - Harlan	-3	-3	0	-147	-1439	-1292	50175	29250	-20925	2375	-22217	MS	MS	MS	MS	MS	MS
Harlan - Guide Rock	0	0	0	0	2	1	36234	35601	-633	745	-632	MS	MS	MS	MS	MS	MS
Guide Rock - Hardy	0	0	0	136	136	0	3284	3290	6	-13	6	MS	MS	MS	MS	MS	MS
Medicine	0	0	0	0	0	0	25387	22757	-2630	8817	-2630	0	0	-239	0	0	2391
Prairie Dog	0	0	0	2955	2955	0	3	3	0	0	0	0	0	0	0	0	0
Red Willow	0	0	0	0	0	0	7750	7668	-82	35	-82	0	0	-16	0	0	66
Rock	137	137	0	0	0	0	5216	5216	0	0	0	0	0	0	0	0	0
Sappa	0	0	0	-83	-137	-54	1269	1264	-5	0	-59	0	-24	-24	0	30	-19
South Fork	10756	10756	0	5692	5692	0	928	928	0	0	0	0	0	0	0	0	0
Hugh Butler	0	0	0	0	0	0	2536	2536	0	0	0	0	0	0	0	0	0
Bonny	1531	1531	0	30	30	0	0	0	0	0	0	0	0	0	0	0	0
Keith Sebelius	0	0	0	735	735	0	0	0	0	0	0	0	0	0	0	0	0
Enders	41	41	0	0	0	0	5413	5413	0	0	0	0	0	0	0	0	0
Harlan	0	0	0	42	44	1	930	941	11	62	13	MS	MS	MS	MS	MS	MS
Harry Strunk	0	0	0	0	0	0	293	294	0	1	0	0	0	0	0	0	0
Swanson	21	21	0	0	0	0	352	352	0	0	0	MS	MS	MS	MS	MS	MS
Mainstem	**-4072**	**-4072**	**0**	**1**	**-1290**	**-1292**	**97105**	**75553**	**-21552**	**3105**	**-25376**	**0**	**-12967**	**-12409**	**0**	**-11678**	**9132**
Total	**28835**	**28835**	**0**	**12775**	**11430**	**-1344**	**232467**	**208039**	**-24428**	**12035**	**-25771**	**0**	**-12991**	**-12779**	**0**	**-11647**	**11648**

calculation to make that comparison. And, therefore, your direct question being that would the uncertainty in that calculation change, it would not.

The change that the 5-run procedure applies as opposed to the current procedure is to look at the CBCU calculation and compare the CBCU calculation with imported water on versus imported water off. And this is directly related to the extent that the system is nonlinear. Had the system been perfectly linear, it wouldn't have mattered because we remove it or we add it in both runs. So the uncertainty that is introduced by uncertainties in the mound calculation is a second or a third order effect that is derived from the nonlinearities in the model.

Q. But my question wasn't whether the uncertainty itself in that figure changes. It's whether the impact of that uncertainty would change in any material respect, because you're using it slightly differently now.

A. **I don't think so.**

Q. And could you explain to me why not?

A. **Well, we're not talking about a whole lot of**

water. Much of the water in this area -- and I think Mr. Larson estimated about 600,000 acre-feet -- runs directly back to the South Platte. So we're only interested in the amount of water that actually goes south into the basin. And what we are specifically after is to what extent does that change the state of the system such that when we do the CBCU calculation, does it actually change? How that mostly manifests itself is in the situation of stream drying.

So as I was explaining in my direct testimony, if you imagine that there is, let's say, 100 cfs of flow in the stream and turning on the wells completely depletes all of that, that is essentially the CBCU calculation. And once the stream is dry, you can't deplete it by any more than it already is there. So when you have imported water in the stream, so there's, let's say, another 5 or 10 percent of imported water, that CBCU calculation then gives you an additional depletion that is included in the CBCU even though that's imported water. And I would hope that the Court would agree with me that the FSS says that that is a special case that we shouldn't include.

So the volume of water that we're talking about is not the 600,000 or so that is actually recharge at the northern end, but is primarily what finally shows up near the stream system. And that's a relative small number.

Q. If that small number is a small residual of the 600,000, is it the case that a relative small percentage change in the 600,000 could double or eliminate that residual?

A. **I don't think so. I think it would be much more of a proportionality. Again, it won't be directly proportional; but if you're off in the 600,000 by, let's say, 10 percent, it may change the amount of the stream by probably off that same order of magnitude.**

Q. As I understand your testimony about the 16-run proposal, certain residuals would have been -- that would result from running that proposal would have been assigned to Colorado or in part to Colorado?

A. **Yes, your Honor.**

Q. And those particular residuals would be residuals, if I understand you correctly, that would only -- the amount of those residuals would depend upon the extent of pumping in Nebraska?

A. **In the case of Colorado, primarily per Nebraska, yes.**

Q. And under the 5-run proposal, those residuals are not assigned to Colorado; is that correct?

A. **They are not assigned at all.**

Q. What happens to them if they're not assigned?

A. **We just ignore them. The approach that we took was to make sure that the procedure we used for calculating the allocation on the virgin water supply calculations are the same as that we assign the burden to each state in terms of their consumption. So the advantage of that procedure is that if you were to evaluate what a state could achieve by curtailing all of their wells, we would have a consistent procedure in calculating the allocation as well as an assignment burden. The problem that I primarily had with the 16-run proposal and using the no pumping simulation as the baseline was that it would assign a burden to a state to achieve certain results that it couldn't on its own, that it needed cooperation from another state. And that's a real problematic issue.**

Q. To the extent the model -- suppose you have the hypothetically perfect model here that actually

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not only simulates, but replicates reality in its results, and you have got these residuals that the model shows. Does that then mean that when you assign -- when you determine the total amount to be allocated and you determine the shares, that you have got this remainder that exists in reality but you're not dealing with in assigning under the model?

A. **No, your Honor. These residuals exist in reality because while we use the model to evaluate them, the result from the nonlinear system -- or the nonlinear behavior of the real system, they're not an artificial result of the model itself. And so it's simply the problem that we have of trying to shoehorn a nonlinear groundwater system into a linear Compact that we had originally.**

Q. If they exist in reality and they're not being assigned, does that mean that the total estimated virgin water supply is either off in a positive or negative direction from reality by the amount of that residual?

A. **Yes.**

Q. In which direction?

A. **It goes both ways. Sometimes we overestimate; sometimes we underestimate.**

Q. And if it's underestimated, then would that mean the model is producing for Kansas a total allocation that is slightly less than what the real world allocation would be if those residuals were dealt with?

A. **In the case that the model -- that -- in the way that you frame it that if it was less, yes.**

Q. Now, how often -- does that have a bias in one direction or the other as to whether the deviation is going to be positive or negative?

A. **If -- for the evaluation that we made for -- that I quote in my report, I think I show that in -- for the period 19 -- well, let me look and show you the result.**

The number minus 136 sticks in my mind. I'm just trying to locate it for you real fast. Sorry.

It was a small negative number. So -- which means that the virgin water supply was underestimated for the period.

Q. By how much?

A. **I think it was 136 acre-feet in -- using the currently approved procedure it was 136 acre-feet over the period 1981 to 2006, I believe was the number. It's in my report. I'm just trying to**

locate it for you.

Q. I can get it out of the report.

That's all right, Dr. Schreüder. I have your report.

I have no more questions for Dr. Schreüder. If anyone has questions that they would like to ask as a follow-up to my inquiry, we'll -- what we'll do is we'll take a break and you can do that. If no one does, then we'll excuse Dr. Schreüder now. So is anyone going to want to ask questions of Dr. Schreüder based on my questions?

MR. DRAPER: Yes, your Honor. We would. And we would appreciate a break, a somewhat longer break, if possible.

SPECIAL MASTER KAYATTA: Nebraska?

MR. WILMOTH: No, your Honor.

SPECIAL MASTER KAYATTA: Colorado?

MS. BERNHARDT: We may ask some questions, but taking a break is fine.

SPECIAL MASTER KAYATTA: Well, in light of the number of questions that I asked, why don't we -- we will take a 20-minute break to give you more time to follow up on my questions.

So that will mean that we will reconvene at quarter to 11:00.

(Time noted: 10:25 a.m.)

(Recess called)

(Time noted: 10:45 a.m.)

SPECIAL MASTER KAYATTA: Mr. Draper?

MR. DRAPER: Thank you, your Honor.

RECROSS-EXAMINATION

BY MR. DRAPER:

Q. Doctor?

A. **Mr. Draper?**

Q. You mentioned that along with you and Mr. Slattery, Mr. Larson was on the modeling committee that developed the RRCA Accounting Procedures and the Model?

A. **Yes.**

Q. And isn't it true that also Mr. Book and Mr. Barfield from Kansas were part of that committee?

A. **That's correct.**

Q. And that the Nebraska members of that committee were Mike McDonald and Dan Morrisson?

A. **I don't think I noted the names; but those are the two individuals from Nebraska that were, I would say, the lead modelers.**

No. 126, Original

In The
Supreme Court of the United States

DEPOSITION OF WILLIAM A. SCHRE?DER, PH.D

STATE OF KANSAS,

Plaintiff,

v.

STATE OF NEBRASKA

and

STATE OF COLORADO,

Defendants.

Monday, July 16, 2012

8:15 a.m.

PURSUANT TO NOTICE and the Federal Rules of Civil Procedure, the above-entitled deposition was taken on behalf of Plaintiff, at the Office of the Attorney General, 1525 Sherman Street, 7th Floor, Denver, Colorado, before Katherine Richmond, Certified Court Reporter and Notary Public within Colorado.

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APPENDIX A

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♀ 3

I N D E X

APPENDIX A

show with respect to the averages for the period 2009 to 2059 with respect to the total compliance balance?

A. I believe the total number that Colorado would be -- Colorado's compact balance would be worse off from the point of view of Colorado to the tune of 5,864 acre-feet per year on average for the period 2009 to 2059.

Q. Under which proposal?

A. Under the 16-Run proposal -- looking at the total column, which is what you asked me, I believe.

Q. Yes. Did the difference there have any relevance to your switching from opposition to the new proposal to finding the fixed proposal appropriate?

♀ 102

A. Can you ask that question again? There was a word in there that bothered me, and I forgot by the time you got to the end.

(Question read back by reporter.)

A. My position has been consistently from the time that the 16-Run proposal was first floated that it was inappropriate because it would burden the states with potential impacts that didn't actually occur.

So, for example, in this particular instance, the bulk of that comes from the Frenchman Basin where the average is over that period 4,917 acre-feet.

Those impacts that would be assessed to Colorado would be the result of impacts that would have occurred -- or largely would have been the results of impacts that would have occurred had Nebraska never pumped.

So I have consistently in all of my reports indicated that I find the 16-Run proposal inappropriate for that reason.

So that obviously factored into my opinion in

APPENDIX A

part. However, I was also opposed to the 16-Run proposal for the reason that as far as the consumption of imported water is concerned, the 16-Run proposal didn't solve that problem but, in fact, exacerbated it.

So throughout this process over the last several years I have consistently opposed the 16-Run solution,

which is called "New" here, and suggested that the Five-Run proposal, which is called the "Fixed" here, is a more appropriate solution because it specifically addressed the issue of imported water.

Q. Your table here also shows over 1,000 acre-feet on average of detriment to Colorado in the reach above Swanson; is that right?

A. That's what the table shows, yes.

Q. Do you know why that would occur?

A. Because in a similar vein to some of these other basins, these would burden Colorado with impacts that would occur in that reach had Nebraska and Kansas not pumped.

So the way I would phrase it is that Colorado doesn't get charged for the actual depletions, but gets charged -- or any of the states potentially get charged for potential depletions that may never have occurred due to actions in other states.

Q. Turning to the third page of the exhibit, you have a table entitled "Change in Kansas Compliance (acre-feet/year)."

Looking at the next page showing the totals for the same period, what does that show with respect to impacts upon Kansas of the New versus the Fixed?

A. In this instance, the New indicates -- you're

asking about the total again, right?

Q. Yes.

A. The totals under New indicates negative 9,415 acre-feet, and the Fixed indicates a negative 12,936 acre-feet.

Q. And what do those numbers mean with respect to the impact on Kansas?

A. I think the answer is probably more nuanced than the one that I could give you in one sentence, but I think it basically reflects the fact that Kansas has been benefiting by having an increased allocation due to imported water being included in the CBCU assigned to Nebraska -- attributed to Nebraska.

Q. But this is a comparison of New and Fixed.

A. That's correct. And as you'll recall, my answer two or three questions ago was that the problem with the 16-Run solution is that it didn't solve the imported water problem. It actually exacerbated it.

And so what this reflects is, at least in part, the result of correctly dealing with imported water.

Q. Is it also true that in moving from the 16-Run proposal to the Five-Run proposal that the impacts on Kansas increased from 9,400 acre-feet to approximately 12,900, on average?

A. Quantitatively that's what this analysis shows,

yes.

Q. So moving from the original counterclaim to the Five-Run proposal increased the impact being proposed on Kansas; is that right?

APPENDIX A

Q. (By Mr. Draper) Doctor, before the break we were talking about how phreatophytes are represented in the model. Would a study of consumption by phreatophytes possibly allow a more accurate representation of phreatophytes in the model?

A. I'm not sure what you mean by "a study of phreatophytes."

Q. Well, the degree of consumption through phreatophytes, in other words, ET, if that could be accomplished, could the accuracy of the model be improved in that regard?

A. I'm not sure there is a black and white answer to that particular question. As a general rule in science, better information is always an advantage. But in a

complex model all of the inputs in the model really ought to be considered in concert.

So it's difficult to give a clear "yes" or "no" to that particular issue in a purely -- in an isolated way, the way you framed the question.

Q. Looking a little further back in Mr. Slattery's report, which is Deposition Exhibit 8, on Pages 5 and 6 he describes the present procedure to use the RRCA groundwater model, and he concludes at the end of that section with the statement that says, "The groundwater committee was fully aware of the non-linear behavior at the aquifer system, and the model was developed in 2002-2003 and agreed that the above described procedure to determine the computed beneficial consumptive use of groundwater of each State was the most reasonable and fair approach to estimate the depletions to streamflows due to

APPENDIX A

each State's groundwater pumping."

Do you agree with that statement?

A. In the context of his prior discussions of the 16-Run proposal, which I think is the primary thrust of his discussion where the States would be charged for potential depletions in addition to the actual depletions, I think that is an accurate statement, yes.

Q. Let me turn your attention, if I may, to your March report, Exhibit 3. In Section 2.5 which starts on

114

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Page 11 and runs over onto Page 12, you discuss model calibration and uncertainty.

Do you see that?

A. I do.

Q. And on Page 12 in the second to the last paragraph in the section, you start the paragraph by saying, "The uncertainty in the model's results is least under conditions to which the a model was calibrated" -- I think there's an extra "a" in there, right?

A. Yes.

Q. -- "to which the model was calibrated."

And you say other similar things. But just to pick out the second to the last sentencethen, you say, "However, the further removed model predictions are from the conditions to which the model was calibrated, the more uncertain the model predictions."

That was a criticism that you were leveling at the 16-Run proposal; isn't that right?

A. Primarily, yes -- although I think the statement is probably generally true.

Q. And the Five-Run proposal suffers from the same problem, doesn't it?

APPENDIX A

A. Not nearly as much. The key being that in all of these simulations what we do is to deviate from the baseline condition only as much as is needed. And if you

♀ 115

turn off the mounding ports, it does make a change to the model, but it's not nearly as large as would occur in the 16-Run solution.

Q. And how did you determine that?

A. Well, for example, look at Figure 9b.

Q. Is that on Bates Page 429?

A. Correct. So the -- I forget what term is used now. I think it's called the No Nebraska Mound Simulation. Basically it switches off the mound in terms of making the new run that is used for comparison as shown in Figure 9c.

And as you can see, the difference between the amount of flow in the Harlan to Swanson reach, which is most affected by imported water, is actually relatively small compared to, for example, the change that would occur when you turn off the pumping in Nebraska, Colorado, or Kansas.

So while generically we would like to stay as close to the baseline conditions as possible, in practice the run without imported water is still relatively close to that.

Q. How do you determine how far you can diverge from the historical condition to which you calibrated before it becomes too uncertain? Obviously you've taken the opposite positions here. One is it's okay, the other

♀ 116

isn't. What's the difference quantitatively?

APPENDIX A

A. I don't know that it's a bindery decision, that it's truly black and white. The way I would phrase it is, the objection is to -- for example, switching off all of the pumping in the basin, as well the mound, and then switching on, for example, just the pumping in Kansas, I don't believe that that is nearly as reliable as the prediction has if you, for example, start from a baseline condition, which is all of the historical pumping and the mound imports on, and just turning off, for example, pumping in Kansas.
So the principle followed by the Five-Run solution is to stay as close to the baseline as practically possible.
Q. But you do agree that it's a disadvantage to move away from the historical condition?
A. As a purely abstract hypothetical, yes.
Q. And that it actually is a disadvantage in this case with respect to the certainty of the modeling results.
A. I'm not sure that the second statement that you just made is entirely something I can agree with.
The difference between the simulation with imported water and without imported water is very small compared to the difference between, for example, pumping

♀ 117

in Nebraska and no pumping in Nebraska.
Q. But still, if you're moving away from the historical condition, that is a disadvantage if you're trying to get the most accurate prediction, isn't it?
A. Did you want to rephrase it, or you want me to answer the last one?
Q. Answer the last one if you would, please.

APPENDIX A

A. What I'm struggling with is "that it's a disadvantage." You have to run the model under conditions that it wasn't calibrated to. Otherwise, you can't make an impact difference. So it's unavoidable.

I believe that the Five-Run solution deviates from the baseline condition only to the extent absolutely required by the FSS.

Q. But in terms of model accuracy, you agree, don't you, that the further away you move from the historical condition to which you calibrated the model, the more the accuracy of the predictions from the model suffers?

A. As an abstract hypothetical, I would agree to that, yes.

Q. And that abstract hypothetical, as you call it, is a principle of modeling that applies in this case, doesn't it?

A. I'm struggling how to answer that. In order to do these impact runs, we have to do simulations to which

♀ 118

the model wasn't calibrated. Otherwise, we couldn't calculate these impacts.

So I'm struggling with how to answer your question that it's something that the model is less accurate. It's the best estimate that we have by making these simulations to which the model wasn't calibrated, and the difference against the solution we have to compare it against in order to calculate those impacts. CBCU is really what you want to call it.

Q. But you're the one who is imposing this artificial condition that did not exist in reality as the base run, isn't it? You take something that occurred

APPENDIX A

historically -- you take it out of the base run and you use that to calculate impacts.

A. Yes. That's how we calculate the CBCU or the impacts is, we remove a stress from the model, and then we see how the model predictions change as a result.

Q. What you just described is between the historical condition and divergence from that, and I would agree with that. But you're starting with an artificial condition, which is an historical aspect is removed from the model, and you're not starting from historical conditions.

A. I think to clean up the record, we probably should define what we're talking about. In the Five-Run solution when we need to calculate the CBCU, we first move

the imported water, because that's what the FSS requires.

So that condition is not the condition the model was calibrated to, but that's what the FSS requires us to do. First that we evaluate the CBCU in the absence of imported water, and then as the second step we turn off the pumping in each state -- or at least that's what the Five-Run proposal does -- to calculate the CBCU in the absence of imported water.

Q. How much water is involved with the imported water supply?

A. I don't have a good answer to that. The numbers that we see in terms of how much of that actually makes it to the Republican River, we're talking about a few thousand acre-feet.

Q. 2 or 3,000 acre-feet?

A. I don't recall the exact number. I would have to look at the tables to refresh my memory, but it's a few thousand acre-feet.

APPENDIX A

A. I can't give you a quantification of what exactly that is, no.

Q. Are you assuming for your position on the Five-Run proposal that that information, the data and estimates that are associated with the mound recharge numbers, are equally accurate to the historical values of base flow and water levels to which the model is calibrated?

A. I'm having a hard time with that question. I think the way I would answer it is that the estimates of imported water supply and groundwater CBCU in the current RRCA procedure and the Five-Run solution is about the same.

And so to the extent that those estimates are acceptable for the accounting procedures that we currently have in Appendix C, I don't believe that the numbers that we would get out of the Five-Run solution would be significantly more or less reliable in terms of the pure quantification.

Of course, where they would differ is whether we charge Nebraska with the consumption of imported water or not.

Q. Are you saying that the accuracy of the numbers we have with respect to mound recharge are -- that the degree of accuracy with respect to those numbers is the same as the accuracy that we have with respect to base flows and water levels?

A. It's very hard to make a comparison between, you know, such disparate quantities. I think the way I would answer it is that in terms of estimating all of those

APPENDIX A

quantities as required by the accounting that we do for any year, they have certainly been acceptable for those purposes so far.

And if the Five-Run proposal was to be adopted, I don't believe that the overall accuracy of the numbers would be significantly greater or less.

Q. But wouldn't a switch to the Five-Run proposal from the current accounting procedures make the determinations based on the model less accurate to the degree to which there are inaccuracies in the mound recharge numbers?

A. It all depends on your definition of "accurate." If, for example, you care about following the FSS and not charging states for imported water, I would certainly argue that the Five-Run proposal would be significantly more accurate in that sense.

In terms of the calculations of CBCU, I don't believe that the Five-Run procedure is comparable to the kinds of calculations that we would have been required to do under the 16-Run procedure where we would start from a virgin condition where all of the states would be off and we would be looking at the potential impacts that would

♀ 123

have occurred had only one state started operating, which was the criticism that I leveled in the sections that you were calling from.

Q. And the present RRCA accounting procedures don't have that problem, do they?

A. They do have a problem in the sense that if we turn off pumping to evaluate the impacts, we are running the model under a condition to which the model was not

APPENDIX A

calibrated, and we are asserting that that particular simulation is sufficiently reliable that we can take the difference with the historical condition to which it was calibrated and use those for the calculation of CBCU.

It's something that we would have liked to have avoided, but it is inevitable or unavoidable if you want to make those kind of impact calculations.

MR. DRAPER: Let's take a few minutes break.

(Recess taken 5:31 p.m. to 5:42 p.m.)

Q. (By Mr. Draper) Doctor, looking at your 2009 expert report, Exhibit 2 to the deposition, Page 10, at the bottom of Page 10 there is a paragraph. The last paragraph starts with this language, "The States agreed to the current method after careful deliberation and considering numerous facts such as those enumerated above. Nebraska presents their proposal as an improvement based on a single criteria. Colorado disagrees with this

position."

That is true with the Five-Run proposal, it's a change being proposed on the basis of that single criteria, is it not?

A. Yes. But that criteria has an important distinction in the case of the criterion as discussed here. This was to result in no basin residual. This is a requirement that I can't find in the FSS or the Five-Run proposal.

The specific criterion or specific problem that we're trying to address on imported water, the emphasis is totally ambiguous as to the position of imported water.

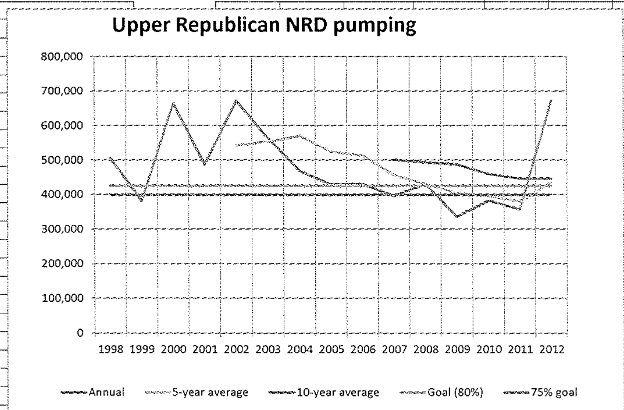
While the enumeration of the number of criteria may be the same, I think the urgency is very, very

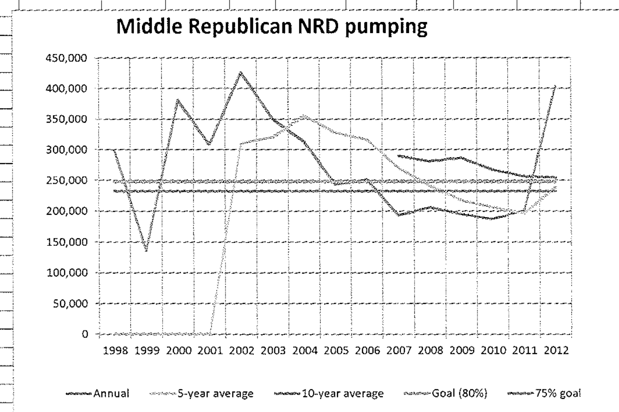
APPENDIX A

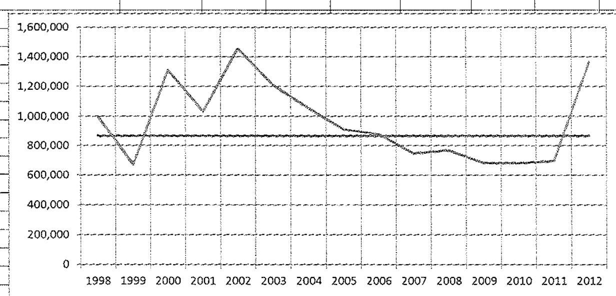
Republican River NRD pumping

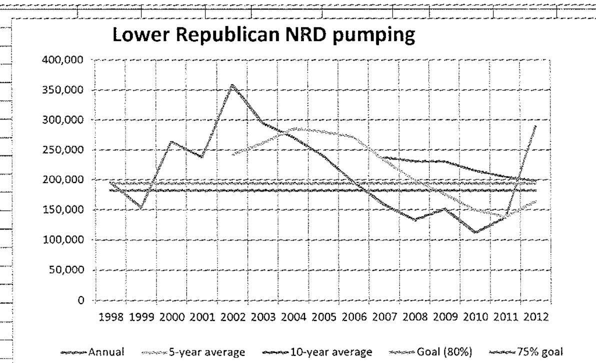
	Upper			Middle			Lower			Total		Goals							
Long-term	80% of base	add'l 5% reduction		80% of base	add'l 5% reduction		80% of base	add'l 5% reduction				UR	UR	MR	MR	LR	LR	Sum	Sum
	425,000	398,438		247,580	232,106		194,000	181,875				80%	less 5%	80%	less 5%	80%	less 5%	80%	less 5%
Year	Annual	5-year average	10-year average	Annual	5-year average	10-year average	Annual	5-year average	10-year average		5-year average								
1998	504,859			297,808			194,882			997,549		425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
1999	381,302			135,841			153,768			670,911		425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2000	665,286			380,525			264,353			1,310,164		425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2001	486,740			307,879			237,558			1,032,177		425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2002	671,639	541,965		426,026	309,616		358,833	241,879		1,456,498	1,093,460	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2003	563,466	553,687		350,125	320,079		294,908	261,884		1,208,499	1,135,650	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2004	468,435	571,113		312,953	355,502		271,677	285,466		1,053,065	1,212,081	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2005	428,114	523,679		242,494	327,895		239,464	280,488		910,072	1,132,062	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2006	430,258	512,382		251,329	316,585		195,103	271,997		876,690	1,100,965	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2007	395,197	457,094	499,530	192,968	269,974	289,795	158,599	231,950	236,915	746,764	959,018	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2008	429,697	430,340	492,013	205,891	241,127	280,603	132,834	199,535	230,710	768,422	871,003	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2009	335,762	403,806	487,459	194,653	217,467	286,484	151,044	175,409	230,437	681,459	796,681	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2010	381,554	394,494	459,086	186,674	206,303	267,099	111,697	149,855	215,172	679,925	750,652	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2011	356,655	379,773	446,078	201,184	196,274	256,430	137,041	138,243	205,120	694,880	714,290	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419
2012	672,499	435,233	446,164	403,306	238,342	254,158	288,836	164,290	198,120	1,364,641	837,865	425,000	398,438	247,580	232,106	194,000	181,875	866,580	812,419

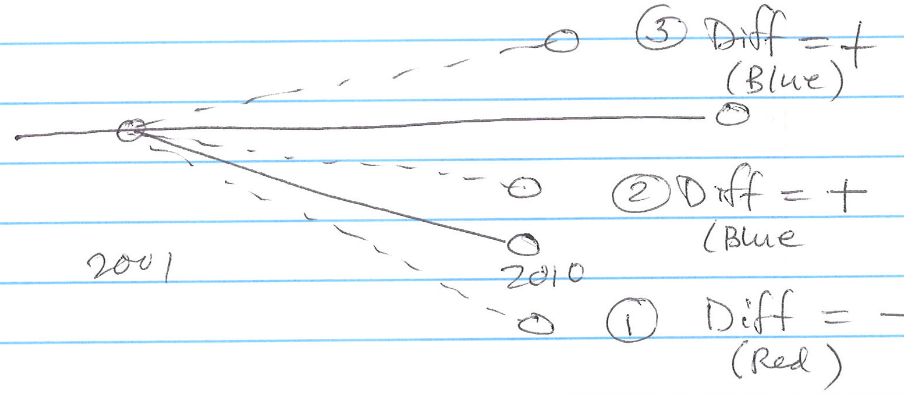
updated 5/20/2013 based on April 2013 data exchange

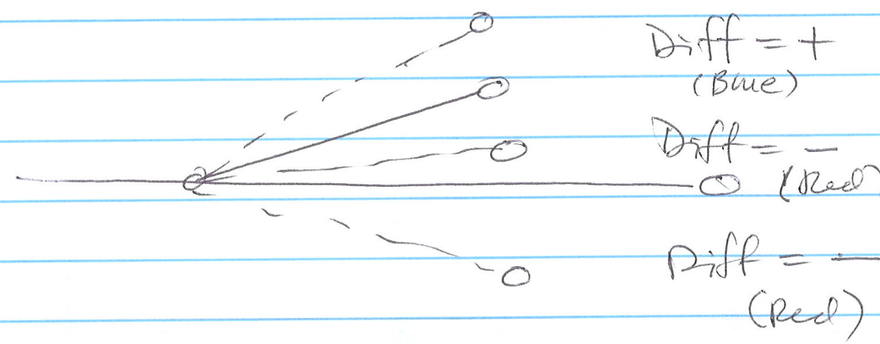









2001
2010
③ Diff = +
(Blue)
② Diff = +
(Blue
① Diff = −
(Red)


Diff = +
(Blue)
Diff = −
(Red)
Diff = −
(Red)

Average RRCA CWS minus IS										
206	1981-2006									
Average 5-run CWS minus IS										
-7395	1981-2006									

81-06 Avg	206	(530)	1,195	(457)	208	1,568	2,930	(4,496)	2
	RRCA	Allocation difference from IS				Compliance difference from IS			
	CWS	CO	KS	NE	Total	CO	KS	NE	Total
1981	(1,837)	151	(608)	(1,383)	(1,839)	658	313	(973)	(2)
1982	1,094	(123)	892	325	1,094	963	671	(1,633)	0
1983	1,501	71	1,162	271	1,504	1,100	1,224	(2,321)	3
1984	935	(196)	942	183	929	1,180	1,211	(2,397)	(6)
1985	(730)	(123)	104	(711)	(731)	1,279	(113)	(1,166)	(1)
1986	922	(289)	1,103	99	913	842	2,459	(3,310)	(9)
1987	(2,759)	(303)	(761)	(1,700)	(2,765)	1,262	669	(1,937)	(6)
1988	(228)	(379)	640	(485)	(225)	1,253	2,516	(3,765)	3
1989	(2,383)	(1,170)	(142)	(1,062)	(2,375)	755	2,580	(3,327)	8
1990	(3,849)	(1,305)	(706)	(1,838)	(3,849)	674	2,724	(3,399)	(1)
1991	(214)	(1,070)	1,199	(343)	(214)	310	4,538	(4,848)	0
1992	(1,631)	(774)	377	(1,224)	(1,621)	442	4,445	(4,877)	10
1993	(2,313)	377	(601)	(2,087)	(2,311)	1,588	(1,711)	125	2
1994	5,165	113	3,317	1,730	5,159	2,198	1,963	(4,166)	(5)
1995	1,506	(99)	1,612	(3)	1,511	2,201	1,701	(3,898)	5
1996	(1,167)	(30)	297	(1,434)	(1,166)	1,568	(519)	(1,048)	1
1997	3,745	(87)	2,875	952	3,740	2,308	2,888	(5,201)	(5)
1998	(1,408)	(509)	489	(1,388)	(1,408)	2,654	2,367	(5,022)	(1)
1999	931	(451)	1,660	(270)	939	1,476	3,643	(5,111)	8
2000	(3,410)	(497)	(286)	(2,624)	(3,408)	2,723	2,357	(5,078)	2
2001	(5,991)	(1,515)	(1,392)	(3,077)	(5,983)	2,955	2,452	(5,399)	7
2002	(977)	(919)	1,188	(1,245)	(976)	3,262	3,540	(6,802)	0
2003	7,085	(1,757)	5,760	3,081	7,084	(68)	9,377	(9,310)	(1)
2004	5,755	(1,419)	5,092	2,093	5,766	1,658	8,454	(10,102)	11
2005	3,012	(839)	3,597	262	3,020	2,536	8,195	(10,722)	9
2006	2,609	(630)	3,254	(3)	2,621	2,986	8,246	(11,220)	12

81-06 Avg	(7,395)	(530)	(2,666)	(4,199)	(7,394)	1,567	(714)	(851)	1
	5-run	Allocation difference from IS				Compliance difference from IS			
	CWS	CO	KS	NE	Total	CO	KS	NE	Total
1981	(2,723)	151	(1,053)	(1,824)	(2,726)	658	(10)	(651)	(3)
1982	(1,797)	(122)	(574)	(1,100)	(1,797)	964	(701)	(262)	0
1983	(2,451)	71	(842)	(1,679)	(2,450)	1,100	(630)	(470)	0
1984	(3,436)	(196)	(1,279)	(1,965)	(3,440)	1,180	(726)	(459)	(5)
1985	(2,153)	(123)	(612)	(1,419)	(2,154)	1,279	(1,067)	(213)	(1)
1986	(5,065)	(289)	(1,941)	(2,846)	(5,076)	842	(252)	(601)	(11)
1987	(5,462)	(303)	(2,125)	(3,038)	(5,467)	1,262	(790)	(477)	(5)
1988	(6,893)	(380)	(2,750)	(3,761)	(6,892)	1,252	(446)	(804)	1
1989	(8,555)	(1,171)	(3,276)	(4,102)	(8,549)	755	(783)	34	6
1990	(9,952)	(1,305)	(3,799)	(4,849)	(9,953)	674	(320)	(356)	(2)
1991	(9,206)	(1,070)	(3,375)	(4,763)	(9,208)	310	98	(410)	(2)
1992	(10,171)	(774)	(3,970)	(5,418)	(10,162)	442	1,087	(1,521)	9
1993	(646)	378	262	(1,284)	(644)	1,587	(1,505)	(80)	2
1994	(2,694)	113	(678)	(2,134)	(2,700)	2,197	(1,767)	(436)	(6)
1995	(5,360)	(99)	(1,876)	(3,381)	(5,355)	2,200	(1,292)	(904)	5
1996	(1,517)	(32)	131	(1,617)	(1,517)	1,544	(1,234)	(310)	(0)
1997	(5,993)	(87)	(2,080)	(3,832)	(5,999)	2,307	(1,318)	(995)	(6)
1998	(9,599)	(509)	(3,670)	(5,423)	(9,601)	2,649	(1,429)	(1,224)	(3)
1999	(8,125)	(451)	(2,950)	(4,714)	(8,114)	1,478	87	(1,555)	11
2000	(10,488)	(497)	(3,870)	(6,119)	(10,486)	2,722	(1,902)	(817)	2
2001	(15,435)	(1,515)	(6,186)	(7,730)	(15,431)	2,953	(1,515)	(1,435)	3
2002	(13,417)	(919)	(5,104)	(7,394)	(13,417)	3,262	(2,330)	(932)	(1)
2003	(10,817)	(1,757)	(3,349)	(5,713)	(10,818)	(68	321	(255)	(2)
2004	(12,041)	(1,419)	(3,960)	(6,652)	(12,030)	1,659	(507)	(1,141)	11
2005	(13,519)	(839)	(4,807)	(7,863)	(13,509)	2,536	(83)	(2,443)	10
2006	(14,767)	(630)	(5,573)	(8,554)	(14,757)	2,985	442	(3,418)	10

Fig. 3. Total Basin: Difference in CWS - Historical Conditions: RRCA vs IS and 5-Run vs IS*

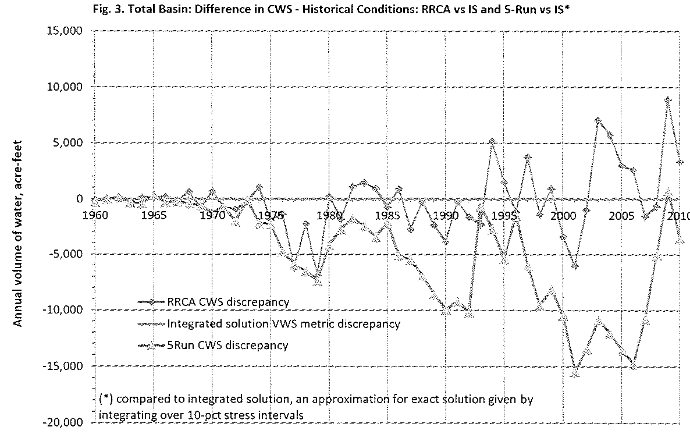


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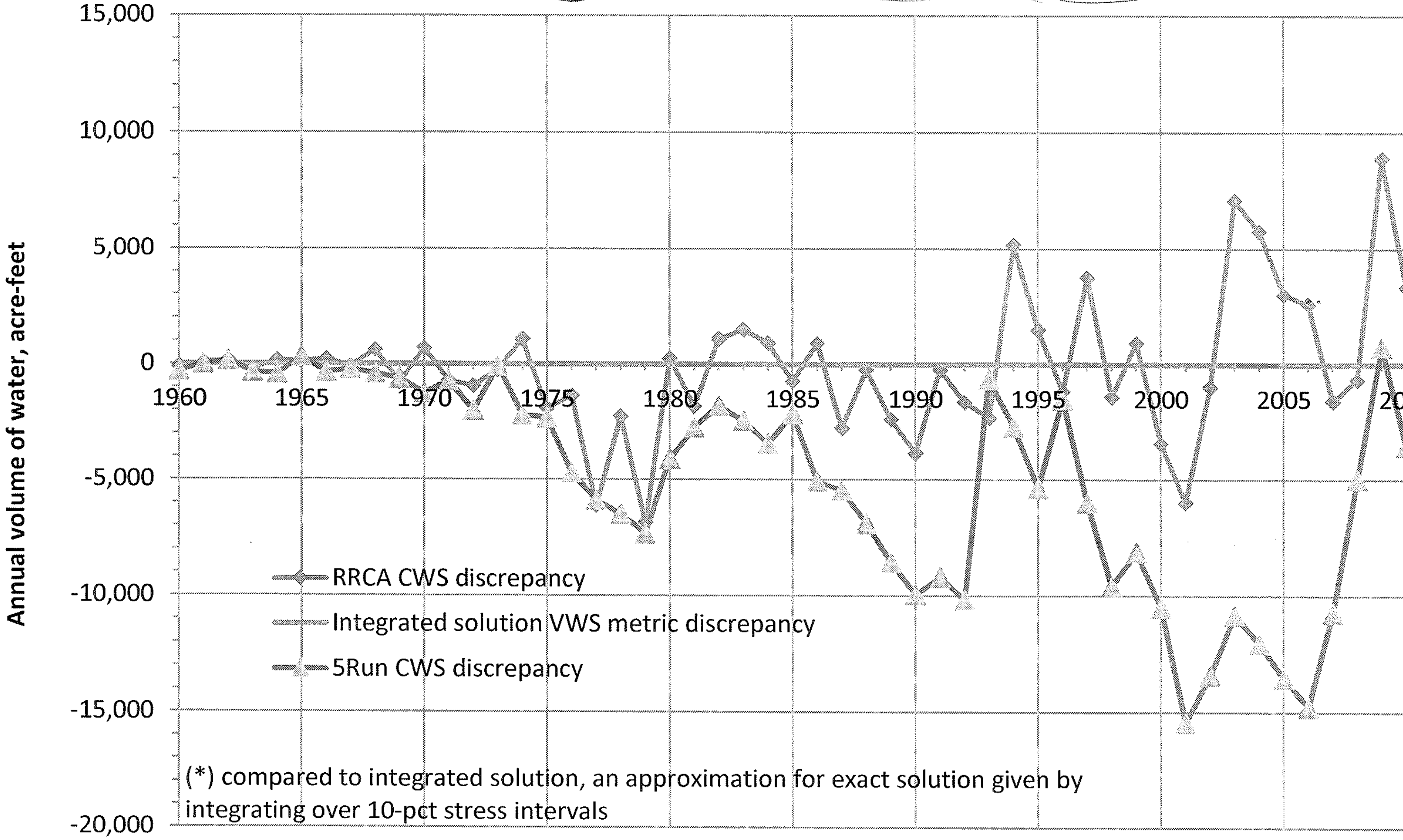
Fig. 3. Total Basin: Difference in CWS - Historical Conditions: RRCA vs IS and 5-Run vs IS*



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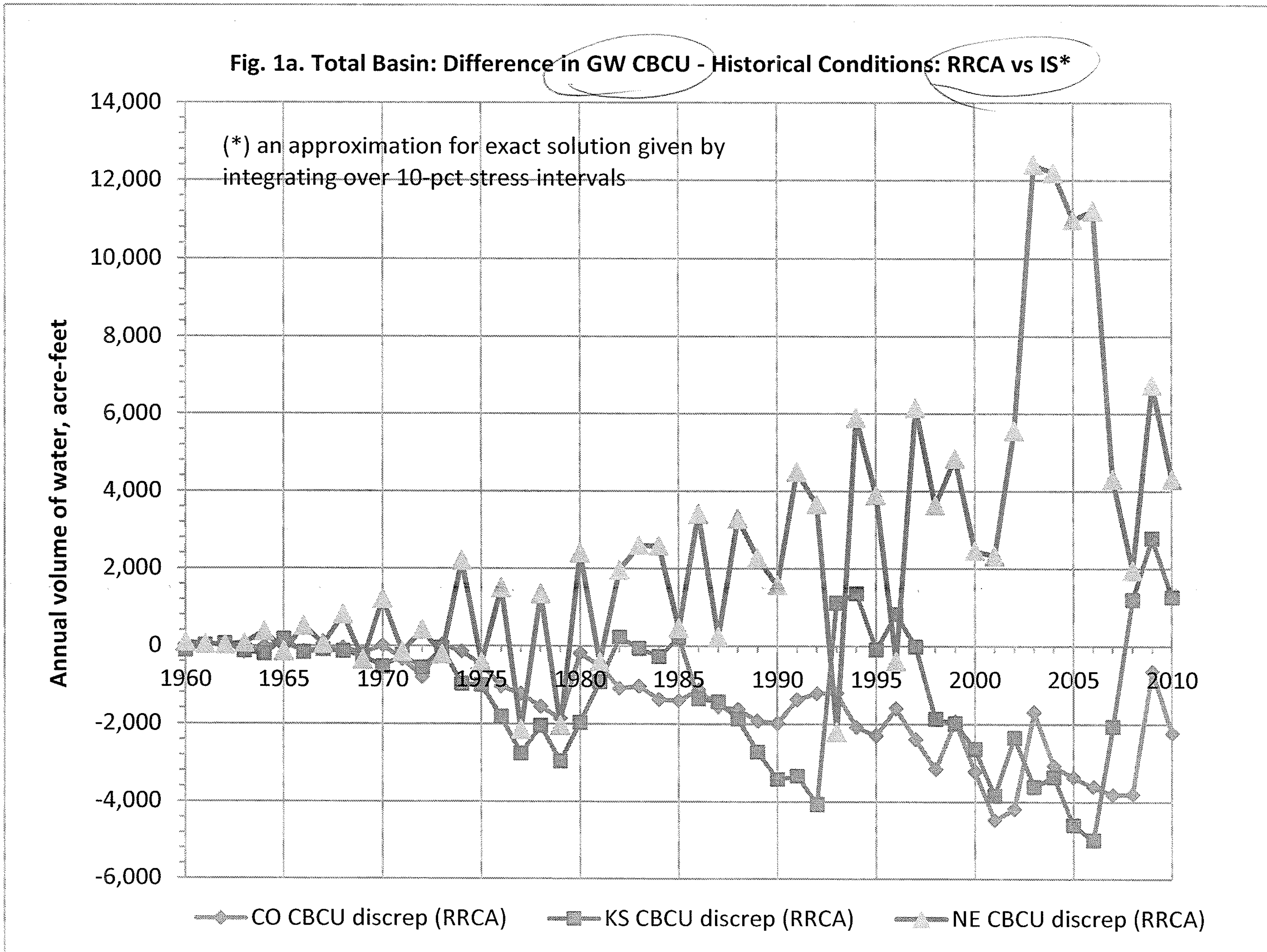

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Fig. 1b. Total Basin: Difference in GW CBCU - Historical Conditions: 5-Run vs IS*

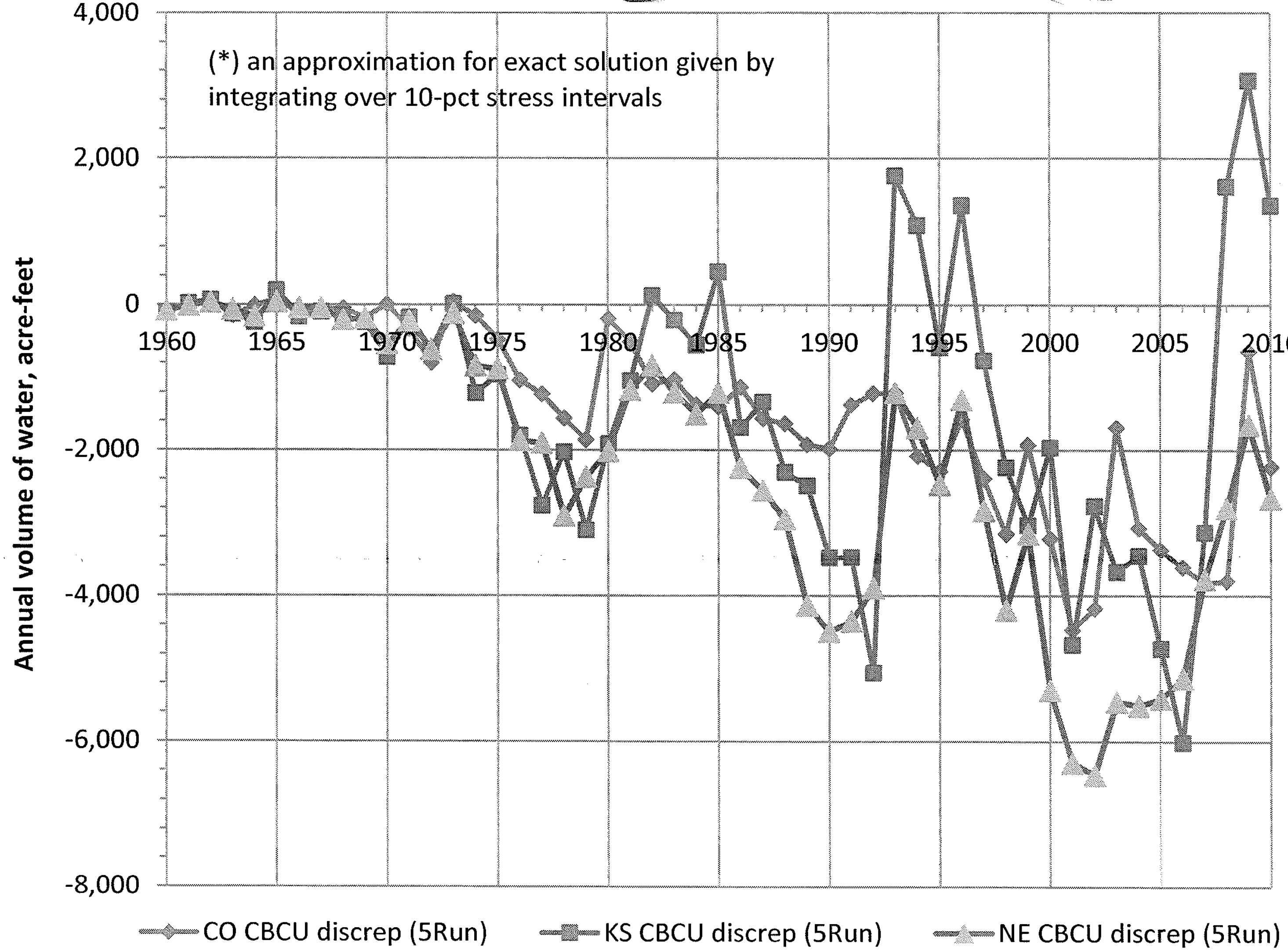

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Fig. 5a. Total Basin: Difference in Allocation - Historical Conditions: RRCA vs IS*

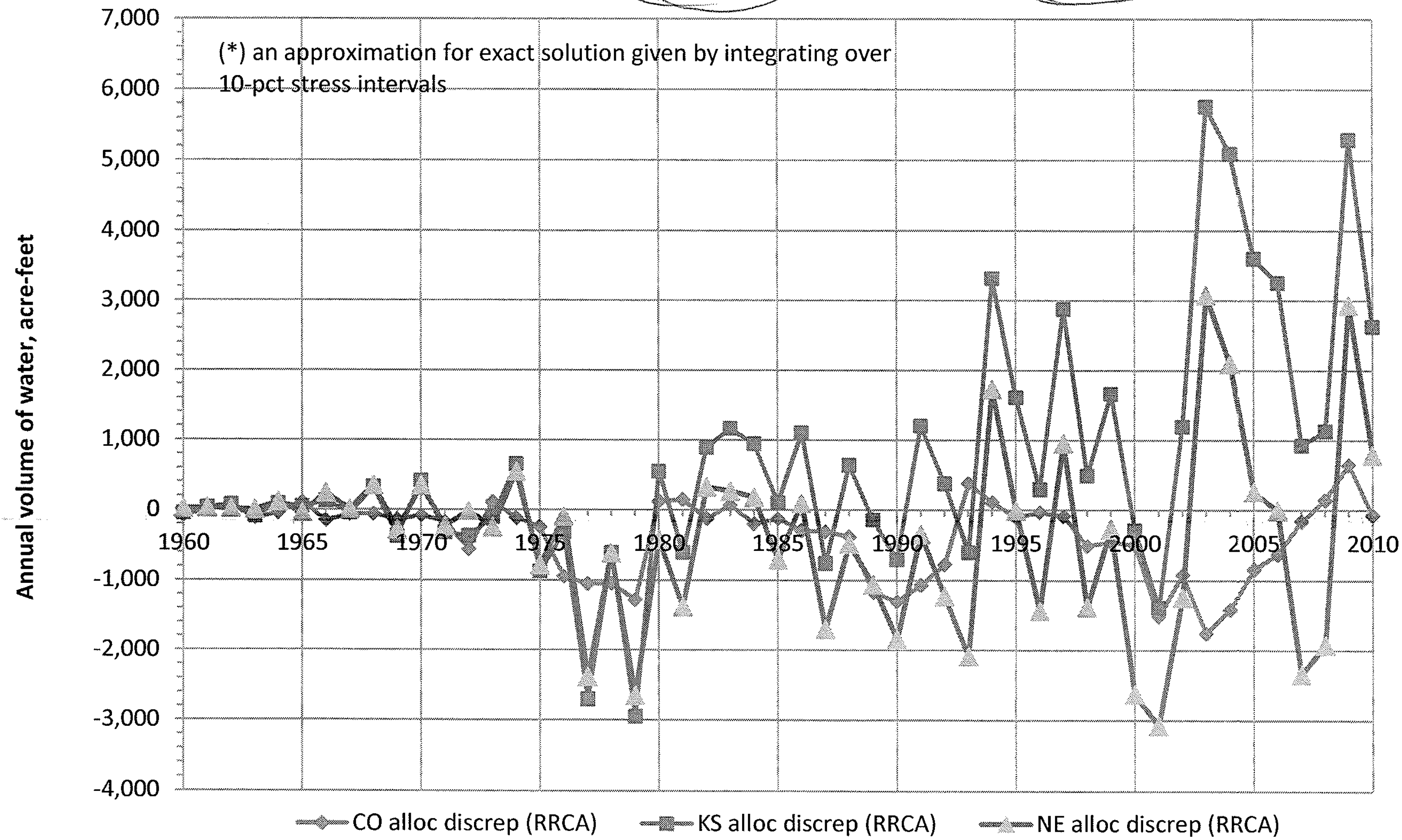

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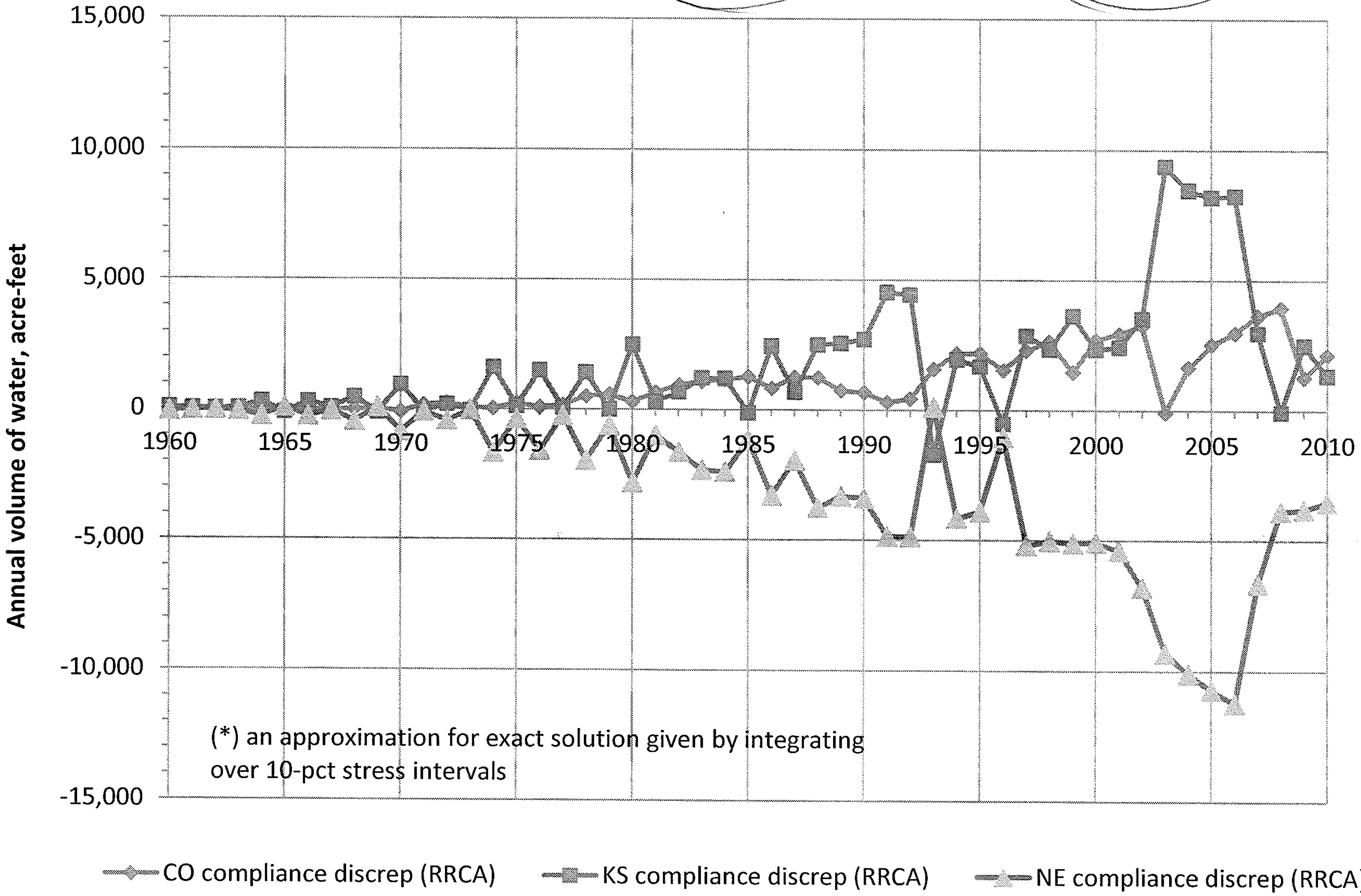
Fig. 7a. Total Basin: Difference in Compact Compliance - Historical Conditions: RRCA vs IS*



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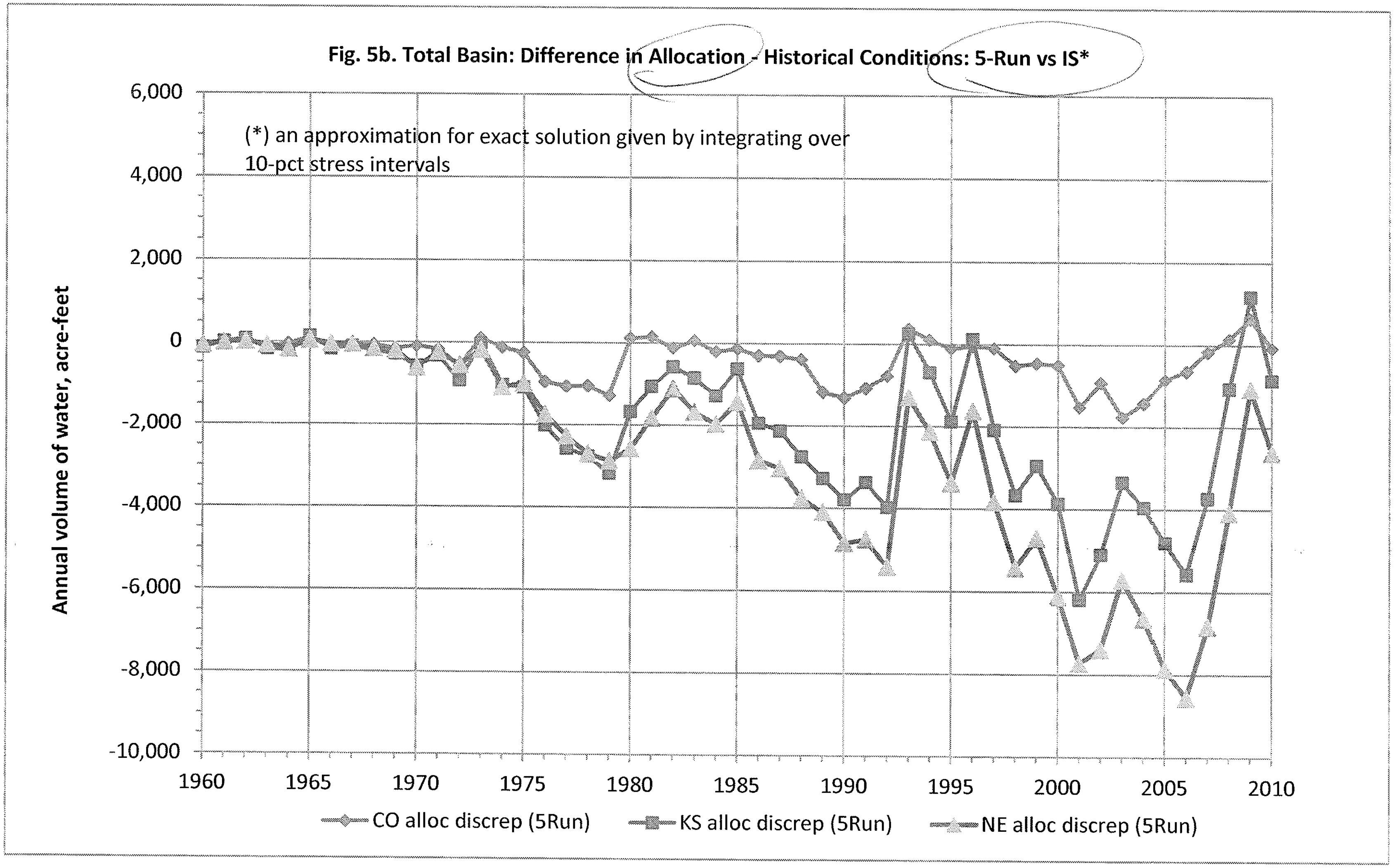

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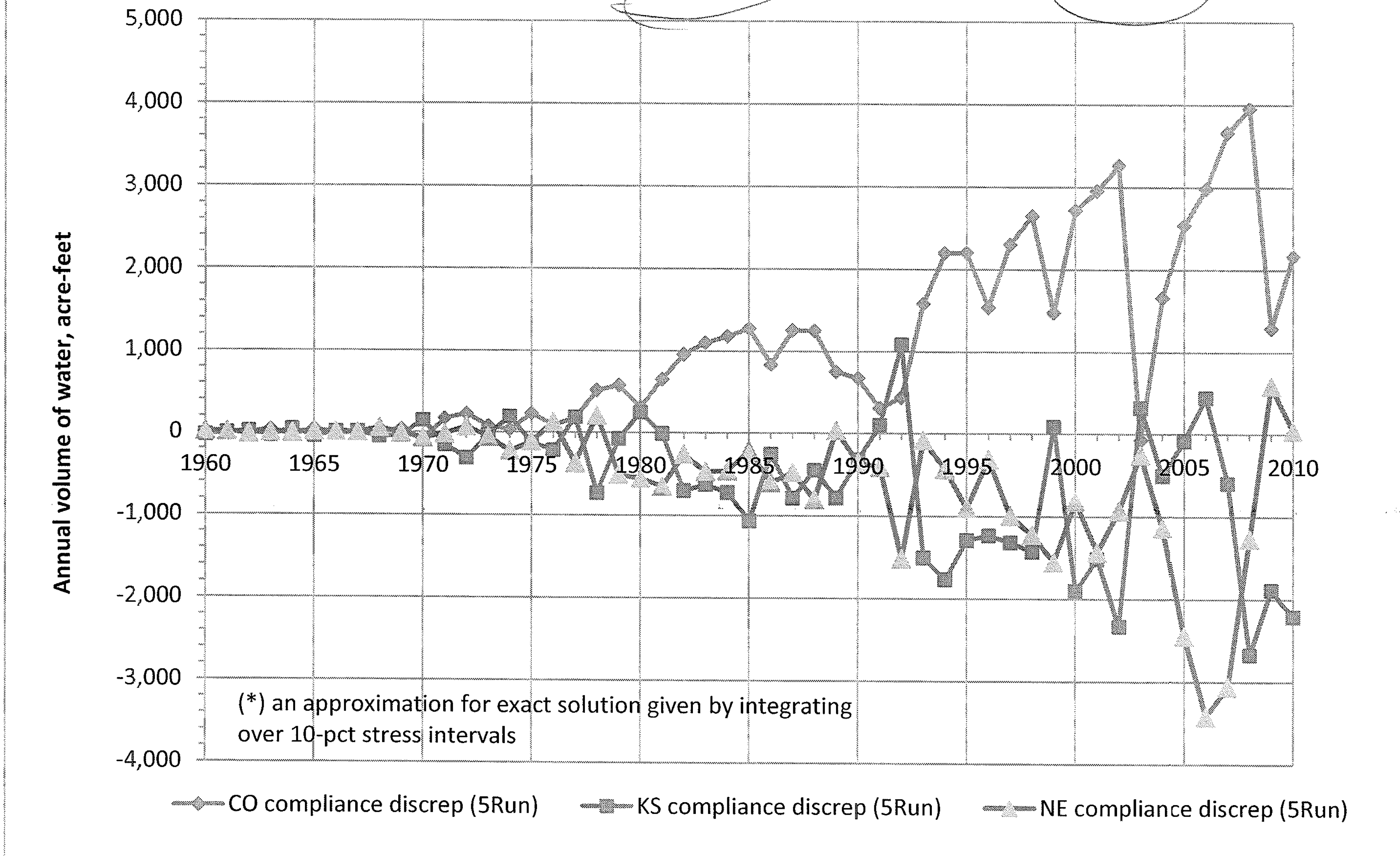
Fig. 7b. Total Basin: Difference in Compact Compliance - Historical Conditions: 5-Run vs IS*



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Review of Model Calibration Data Beyond 2001

Kansas compiled available groundwater level data from two sources, the U. S. Geological Survey (USGS) and from the State of Nebraska. Data from the USGS were downloaded from its online database. The data were compiled and wells with more than 20 measurements were selected:

- Colorado: 683 wells, 28652 measurements, 9/1/1947 – 12/29/2010
- Kansas: 517 wells, 33897 measurements, 7/6/1942 – 12/29/2010
- Nebraska: 2014 wells, 192628 measurements, 10/1/30 – 12/29/2010

Wells with available data in both 2001 and 2010:

- Colorado: 548
- Kansas: 299
- Nebraska: 882

In response to discovery requests from Kansas, Nebraska directed Kansas to the website maintained by the University of Nebraska where groundwater-related information collected by the State and other sources are stored. Data were downloaded and compiled:

- 5599 wells
- 216444 measurements, 10/1/1930 – 11/2/2010
- 3543 wells not common with the dataset downloaded from the USGS online database presented above (no minimum number of measurements applied to the UofNE dataset)
- 23902 measurements, 10/1/1930 – 11/2/2010
- 306 wells have more than 20 measurements during that period.
- 344 wells not included in the USGS dataset with data for the period 2001-2010 and measurements in both 2001 and 2010 (not considering number of measurements during the entire historical period or the period 2001-2010)
- 7715 measurements, 3/5/2001 – 11/2/2010

Streamflow data were downloaded from the USGS online database. Streamflow rates at 67 gages within the RRCA model domain were downloaded and compiled.

4

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DRAFT

Review of RRCA Model Calculation of Imported Water Supply Credit

prepared for
Nebraska
Department of Natural Resources

by

McDonald Morrissey ASSOCIATES, Inc.

Reston, Virginia
and
Concord, New Hampshire

January 10, 2007

Table of Contents

List of Figures

List of Tables

1.0 Introduction

The Republican River Compact Administration (RRCA) ground-water model was developed to calculate accretions to flow in the Republican River from imported water and depletions to flow in the Republican River caused by pumping (Figure 1.1). This report relates to accretions to flow from imported water from the Platte River Basin.

Water from the Platte River is imported to the Republican basin by canals containing water diverted from the Platte River. Some water from the canals percolates deeply into the ground. Other water from the canals is used to irrigate crops. Some of the irrigation water percolates deeply into the ground. The combination of leakage from the canals and excess irrigation water has caused water levels to rise significantly in an area immediately south of the Platte. That area is referred to as the "mound". Some of that water migrates back to the Platte River; some migrates to the Republican River.

The accounting system used for the Republican River Compact gives Nebraska credit for water from the mound that results in flow in the Republican River as determined by the model. The amount of water from the mound is calculated with the RRCA ground-water model by simulating the ground-water flow system as it actually was --- the base model ---and then again as it would have been if the canals did not import water from the Platte --- the mound-off model. The amount of water calculated by the base model as having discharged to the Republican River less the amount of water calculated by the mound-off model that would have discharged to the Republican River if water had not been imported from the Platte. That value is the mound credit.

The mound credit as calculated by the model was generally on the order of 13,000 – 18,000 acre-feet/year (AF/Y) for the years 1980 through 2004 (Figure 1.2). For several years it was nearly 25,000 AF/Y. Between 2000 and 2004 the mound credit has decreased to about 10,000.

During that period, changes to several important hydrologic stresses related to the mound and mound credit were occurring simultaneously. The source of water to the mound, canal seepage and surface-water irrigation return flow from Platte River waters, was reduced. Pumping both in uplands and in the alluvium increased dramatically. Finally, a severe drought that occurred between 2000 and 2004 reduced precipitation recharge and possibly increased evapotranspiration demand.

The interaction and relative importance of each of these changes in stress and their impact on the groundwater system and the mound credit was the focus of this investigation.

2.0 Objective

The objective of this study is to develop an understanding of the mound and the mound credit that will permit an explanation of the dramatic reduction in mound credit that occurred between 2000 and 2004.

3.0 Approach

To accomplish the objective a two-pronged strategy was used: a Sensitivity Analysis Approach and a Flow Component Approach. The sensitivity analysis was intended to determine the stresses on the ground-water system that are responsible for the decrease in mound credit. It entailed experiments with the model to evaluate the relative importance of a variety of stresses.

The flow component approach was used to identify the specific mechanisms that caused the decrease in mound credit. It entailed studying sources and sinks of water at a variety of temporal and spatial scales. At the cell level the input specifications were examined to determine the impact of head changes on flow components. Among those specifications were: water levels, streambed conductance, streambed elevation, ground-water levels, evapotranspiration rate, extinction depth and evapotranspiration surface. Results are figures and tables showing the relation of sources and sinks in broad areas and in single cells. These results are also summarized for single months and entire years. The approach does not include evaluation of the adequacy of the specifications to the model or the processes for estimating specifications; specifications identified during the development of the model were accepted.

Both approaches concentrated on examination of factors that resulted in the very different mound credits for 1999 and 2003.

4.0 Background Issues

The RRCA model, completed July 1, 2003, was developed as a mechanism for estimating the accretions to the flow of Republican River caused by importation of water and depletions to the flow of the Republican River caused by pumping. The adequacy of the model to calculate accretions and depletions was established during development by two processes: first analyzing sources and sinks for water and hydraulic parameters, then calibrating the model to water levels and base flow observed during the calibration period 1918-2000.

Sources and sinks for water are represented by monthly estimates. The procedures for estimating the sources and sinks were agreed upon by the three states during the calibration process. Among the sources and sinks represented by the model are: recharge from precipitation, recharge from excess irrigation, leakage from canals, discharge to pumping, recharge to and discharge from rivers and discharge to evapotranspiration (NOTE: The term "discharge to evapotranspiration (ET)" in this report refers to evapotranspiration by phreatophytes.

For each year subsequent to 2000, Kansas, Colorado, and Nebraska provide data sets of pumping, canal losses, and surface-water irrigation application to the RRCA. These data are combined with information on precipitation and evapotranspiration parameters to derive an annual update. Initial ground-water levels specified for each annual simulation are set equal to the previous year's final simulated ground-water levels.

For this investigation, model results for the period 1918 to 2000 were combined with model results for the period January 1, 2001 to December 31, 2004.

Computer simulations were completed using MODFLOW-2000 version 1.11.01 with modifications for Nebraska for use in Republican River Compact negotiations. The modifications include the capability of segregating recharge into four MODFLOW Recharge packages. The packages include terms for precipitation, ground-water return flow, surface-water return flow, and canal seepage recharge. The source code was then compiled with Lahey-Fujitsu FORTRAN Professional Compiler v5.7 in double precision.

MODFLOW represents ground-water systems as if it consists of a rectilinear grid of cells. The RRCA model represents the ground-water system associated with the Republican River as a single layer with 30,000 square cells each of which is a mile on each side. MODFLOW calculates water levels so that for every cell and for every month the sum of all flows going into a cell plus water coming from storage in the cell is equal to the sum of all flows leaving the cell plus water going into storage in the cell. That equality is referred to as "mass balance". The individual flows and the water going into or out of storage are referred to as "flow components".

Following completion of MODFLOW-2000 simulations, model output was post-processed to allow analyses of trends in simulated ground-water levels and stream baseflows. Simulated surface-water baseflows and ground-water levels were stored during the simulation using the HYDMOD package of MODFLOW-2000. The HYDMOD package allows the storage of water level data and simulated stream-flows at specified locations in an unformatted file for later processing. Flow terms between model cells used in the Mass Balance Analyses were stored in the unformatted MODFLOW cell-by-cell flow file.

4.1 Concept of Mound Credit

The Mound Credit is the net increase in discharge from the ground into the Republican River channel and its tributaries (the river) that is caused by migration of water imported from the Platte River. Water imported from the Platte River seeps into the ground from canals and recharges from agricultural land that have more water applied than is consumed by crops. It is referred to as a mound because it has caused high ground-water levels in the area adjacent to the Platte River. Some of the water from the mound migrates toward the Republican River and discharges to the river channel. For water to discharge from the ground to the river it must first migrate into the ground-water system adjacent to the river. It then must discharge to the river.

Water may be expected to move from the ground to the river channel or from the river channel to the ground at every point along the river. Since it is impossible estimate such interchanges at an infinite number of points on the river it is estimated for a finite number of river reaches. Examples of such reaches may be: "Medicine Creek above Curtis", "the Main Stem of the Republican River between the mouth of Turkey Creek and the mouth of Spring Creek". The term sub-reach will be used in this report to mean a reach that is part of a larger reach. The smallest reach that will be considered in this report will be one that lies completely within the area represented by a single cell of the ground-water model. In this report such a reach will be referred to as a "cell-reach". All larger reaches consist of a string of cell-reaches.

The Mound Credit, therefore, is the sum of credits for all sub-reaches, regardless as to how the river with its tributaries is divided into sub-reaches. In this report we discuss several different divisions of the river into sub-reaches. In some places we discuss reaches that are 40 or 50 miles long e.g. Medicine Creek or the Main Stem from Cambridge to Harlan. In other places we refer to cell-reaches that are on the order of a mile long. Whether we are referring to long reaches or short reaches the Mound Credit is the sum of credits for all sub-reaches.

Theoretically the mound may have caused discharge along the entire reach of the Republican River and all of its tributaries above Hardy, but, in fact, as will be discussed later, the discharge from the ground caused by migration of water from the Platte River is essentially confined to Medicine Creek and the Main Stem of the Republican River and Tributaries between the mouth of Medicine Creek and Harlan County Lake.

The definition of the Mound Credit implies that the Mound Credit is always positive. Surprisingly, credits for sub-reaches are not necessarily positive. For example: if the existence of the mound causes more water to move from the river channel to the ground than would have moved if the mound had not existed then the credit is negative; there is a debit for that sub-reach. For a certain sub-reach that will be discussed below water levels in the ground were low but if the mound had not existed there would have been no water in the channel to move into the ground. For the same sub-reach, with the mound, water that had moved from the ground to the river channel upstream was available to move from the channel to the ground. There was a debit for that sub-reach.

When summing credits, therefore, debits are represented as negative credits. Credits are summed for two reasons: to combine credits for months into an annual credit and to combine credits from sub-reaches to represent a longer reach. In this report sums of credits, especially where some credits may be debits, may be referred to as "net credits".

In other words the Mound Credit is equal to the amount of water attributable to the mound that is in the river channel at the Compact Accounting Point above Harlan County Lake. There is no way to measure that amount of water at the Compact Accounting point that is attributal to the mound. It is, therefore, estimated by summing all gains and losses from the ground caused by the mound. Although it might have been expected that the mound would never cause losses that is not the case. If there is a downward gradient from the river channel to the ground and there is water in the river channel there will be a loss. The estimates of gains and losses are made by the RRCA ground-water model. The sum of all of the gains is expected to be greater than the sum of all losses.

4.2 Calculation of Mound Credit in the RRCA Model

The mound credit is specifically calculated using two simulations of the RRCA ground-water model. First, a "base" run simulation is completed where all standard model stresses, ground-water pumping, ground-water and surface-water irrigation return flow, canal leakage, precipitation recharge are represented. As part of this simulation, the resulting discharges to and recharge from streams are calculated and summed over specified reaches. The downstream ends of the reaches are referred to "accounting points" (Figure 4.1) Then a second simulation the "mound-off" simulation is completed in which the same stresses are specified except for those representing recharge affected by water imported from the Platte

River. The exceptions include leakage from canals at the mound and excess surface-water irrigation return flow at the mound. Again resulting discharges to and recharge from streams are calculated and summed over specified reaches.

The mound credit for each reach is the difference between net discharge for the base run and net discharge for the mound-off run. The mound credit for the basin is the sum of the mound credits for all reaches.

4.3 Description of Mass Balance Concept and Analysis Tools

MODFLOW is based on the concept that all water must come from somewhere and must go to somewhere --- water can be neither created nor destroyed. Mass is conserved for every cell in the model and for every collection of cells. For every cell and for every set of cells all of the sources and sinks for water (flow components) can be identified and added to establish that sources and sinks for water are balanced. In this report the "flow component" and "mass balance term" are used interchangeably. For this study sources and sinks were reviewed collectively for all cells in the model, for all cells containing the Republican River and its tributaries, for all cells containing certain reaches of the river and tributaries, and for some individual cells.

For this report those cells containing the Republican River or tributaries will be referred to as "alluvial cells". Study of the mass terms for sets of alluvial cells identified reaches that receive water because water was diverted from the Platte

River. Study of the set of all model cells in Nebraska permitted analysis of effects of regional changes on mound credits. Study of individual cells permitted analysis of the precise reason for changes in mound credit as a function of water levels, ET surface, ET extinction depth, river elevation and other local factors.

4.4 Description of MODFLOW Stream Package

The Stream or Streamflow-Routing Package for MODFLOW was developed by the US Geological Survey to simulate interaction between surface-water and ground-water (Prudic, 1989). It is an accounting program that keeps track of flows in one or more streams which interact with groundwater

Streams are represented by reaches that are entirely within an area corresponding to a single model cell. Several such reaches may be represented within a model cell to account for meanders and confluences. Each reach includes specifications of model layer, model row, model column, stage or routing parameters to calculate stage, streambed conductance, and elevation of the streambed bottom and top. A group of reaches connected in downstream order is referred to as a segment.

Stream gains are calculated for each reach on the basis of the difference between head in the aquifer and stream stage and the conductance of the stream bed. Stream losses are calculated similarly except that loss is limited to the amount of water in the channel. The stream stage can be specified or calculated based on the Manning formula under the assumption of a rectangular stream channel.

The Republican River model includes specifications for about 260 segments and 2900 reaches. The initial stream network was taken from the USGS Open File Report 02-175. Streambed conductances, thickness, and area were adopted by the RRCA from the USGS Open File Report 02-175 document verbatim. Streambed elevations were adjusted to reflect more accurate elevation data as it became available. The stream network developed for the Republican River ground-water model is illustrated in three diagrams (Figures 4.2 to 4.4). These figures identify the connectivity of stream segments in the model. In addition, the figures identify key reaches, e.g., those reaches that occur at gaging stations or RRCA accounting points. These key reaches are identified by stream package segment and reach.

5.0 Analysis

Water from the Platte River recharges the ground either as seepage from irrigation canals or as excess surface-water irrigation. It forms a mound readily distinguished on a water table map (Figure 5.1). The crest of the mound forms a ground-water divide between the Platte River and the Republican River. Most of the water in the mound flows to the north back to the Platte River. Some flows east to the Little Blue River. Some flows to the south toward the Republican River. That water from the mound that increases discharge to the Republican River because of the mound constitutes the mound credit. As a result of the distribution of canal seepage and surface-water application and the geometry of streams in the Republican River basin, mound credit is not evenly distributed within the basin.

Development of the RRCA ground-water model included studying sources and sinks for water and properties of subsurface materials that control movement of water from sources to sinks. The expectation therefore was that the model would act like the actual ground-water system. In this analysis the process was reversed. The model is being studied to reveal how the ground-water system works. Sensitivity experiments were conducted to establish the relative significance of the changes in stresses with respect to the change in mound credit. Flow components were analyzed to determine the precise mechanisms that affect the mound credit.

A review of the mound credits by stream reach indicated that these analyses could be focused on reaches where major changes in mound credit were occurring. As shown in Figure 1.2, Nebraska-Area mound credit dropped significantly since 2000, from about 20,000 AF to 10,000 AF. For accounting purposes, mound credit is provided both Nebraska wide and within certain sub-basin reaches. Mound credit within these sub-reaches varies dramatically (Figure 5.2). Mound credit for most sub-basin accounting reaches is below 25 AF per year. Only two reaches, Medicine Creek, and the Republican River from Swanson Reservoir to Harlan County Lake, have a significant contribution to the Nebraska-Area Mound credit. Mound credit on Medicine Creek has been steadily increasing and undiminished in recent years. Mound credit within the Swanson Reservoir to Harlan County Lake reach has dropped significantly. Furthermore, if the Swanson Reservoir to Harlan County Lake reach is broken into two segments, Swanson Reservoir to Cambridge and Cambridge to Harlan County Lake, the contribution to mound credit from the Swanson Reservoir to Cambridge reach is near zero. Therefore, the major change in the Nebraska-Area mound credit must be attributed to conditions between Cambridge and Harlan County Lake (Figure 5.3).

5.1 Sensitivity Analysis

A series of experiments were conducted to evaluate the sensitivity of select model specifications on the mound credit generated between Cambridge and Harlan County Lake. Experiments were conducted with respect to three areas: 1) --- the Cambridge to Harlan County Lake alluvium (CH_Alluvium) defined as all areas represented by model cells containing a reach of the main stem or a tributary between Cambridge and Harlan County Lake, 2) ---the Nebraska model area (Nebraska_Area) defined as all of that area within Nebraska represented by the model and 3) --- the uplands (Uplands) defined as the Nebraska_Area outside of the CH_Alluvium (Figure 5.4).

Specifications selected for experimentation were those representing external stresses on the ground-water system. The specifications that were tested included precipitation recharge, pumping, and canal seepage. Note that adjustments made to pumping were also made to corresponding ground-water return flow rates.

5.1.1 Methods of Analysis

The sensitivity of the Cambridge to Harlan County Lake Mound Credit was evaluated against precipitation recharge, discharge to pumping wells, combinations of pumping and precipitation recharge, and canal seepage. In each of the sensitivity runs, certain model specifications were held constant over time. For the majority of these runs, model specifications for 1999 were assigned to the period 2001 through 2004. This year was chosen because it represented a recent year where the Mound Credit was still high. The specifications in 1999 are characterized by low to average pumping, average precipitation recharge, and average Nebraska canal seepage. Subsequent years included periods of high pumping and low precipitation recharge, and a declining Nebraska canal seepage. By selectively replacing specifications for the period 2001 to 2004 with those of 1999, comparisons could be made between what the Mound Credit would have been if average conditions had persisted as opposed to actual conditions. A summary of the sensitivity simulations is provided in Table 5.1.

Specifications were tested for the CH_Alluvium, the Nebraska_Area, and/or the Uplands. Although the primary focus of the sensitivity simulations was the response of the Mound Credit to changes in model specifications, a secondary focus was an understanding of why changes in Mound Credit occurred.

Results of each sensitivity experiments are provided in Figures 5.5 through 5.15. On each of these figures, two panels are provided. The panel on the left summarizes mass balance terms for the CH_Alluvium. The panel on the right summarizes mass balance terms for the Nebraska_Area. Mound Credit generated between Cambridge and Harlan County Lake is provided in both panels. Changes to annual mound credit and key model specifications for 1999 to 2004 are provided in Table 5.2.

5.1.2 Selection of Parameters to Vary

For each of the experiments, flow components were calculated for both CH_Alluvium and the Nebraska_Area. Specifications for sensitivity experiments were selected by analysis of the base run (Figure 5.5).

- Pumping in both the CH_Alluvium and the Nebraska_Area has increased dramatically in recent years. Between 1980 and 2000 pumping within the CH_Alluvium averaged 20,000 AF/YR. In the Nebraska_Area pumping averaged 1,400,000 AF/YR. In 2003 pumping within the CH_Alluvium was greater than 30,000 AF and within the Nebraska_Area it was greater than 2,000,000 AF. In 1999 pumping was 13,500 AF in the CH_Alluvium and 1,100,000 AF in Nebraska_Area.

- Precipitation recharge varied greatly from year to year since 1940. In 2002 it was at a 30 year low. Precipitation recharge in 1999 was about equal to the long term average.

- Canal seepage from Platte River sources within the Republican River Basin started in 1940 remained above 500,000 acre-ft until 2001. By 2004, canal seepage from the Platte River sources has dropped to close to 400,000 acre-ft. In the CH_Alluvium canal seepage has remained relatively steady at about 5,000 acre-ft.

- Surface-water return flows are small relative to other flow components. In both the Nebraska_Area and the CH_Alluvium they have been relatively steady decreasing slightly over the last ten years simulated.

- In the Nebraska_Area evapotranspiration (ET) had been relatively steady from 1940 until about 1997. Since then it has decreased by about 20%. ET is a major sink for water. In the CH_Alluvium ET has been fairly consistently decreasing since 1940. In recent years it has been about 30% lower than it was in 1940. In the CH_Alluvium ET is the largest sink for water. ET is a function of atmospheric conditions and ground-water levels in the aquifer. Atmospheric conditions are specified to the model as maximum evapotranspiration rate. That value shows annual variations but no discernible trend. Thus it was not deemed important for experimentation. Trends in ET in both the CH_Alluvium and Nebraska_Area must, therefore, be a function of water levels in the ground.

- A key component of flow in the CH_Alluvium is net ground water-inflow. Net ground-water flow integrates all of the sources and sinks of water outside of the CH_Alluvium. It is all of the water moving from the Uplands to the CH_Alluvium including water from the mound that justifies the mound credit. Net ground-Water inflows to the CH_Alluvium increased from about 40,000 to about 60,000 acre-ft from 1940 and 1970. It has been relatively steady since then with a drop of about 10% in the last few years.

- In the Nebraska _Area net stream leakage is always a sink for ground water. Within the CH_Alluvium stream leakage had been a source for water in the 1940's but became a sink for water in the 1950's and has remained so ever since. Stream leakage is a function of water levels in the ground-water system and, therefore, not a subject for sensitivity experiments.

- Mound credit in the CH_Alluvium had wide annual swings trending consistently upward from 1960 until 1985. Then it leveled off at about 9,000 AF/YR except for big jumps during wet years in the 1990's. Since 2000 it has been reduced to a few hundred acre-feet.

Based on these observations a series of sensitivity experiments were conducted for pumping, precipitation recharge and Platte canal seepage all of which are independent of conditions in the ground.

5.1.3 Results of Sensitivity Experiments

Qualitative results of the sensitivity experiments were derived from visual examination of Figures 5.5 through 5.15. Quantitative results were derived from examination of Table 5.2. The following list of results is based on Table 5.2. The name of the experiment on which results are based is given in parentheses.

Mound credit for the CH_Alluvium was 8,763 AF for 1999 and 145 AF for 2003 (Base Run). If pumping rates within the CH_Alluvium had remained steady and at 1999 rates from 2001 through 2004, the 2003 Mound Credit between Cambridge and Harlan County Lake would have been 4,098 AF (Alluvial Pumping). If precipitation recharge in the CH_Alluvium in 1999 had remained steady and at 1999 rates from 2001 through 2004 then the 2003 Mound Credit would have been 840 AF (Alluvial Precipitation). If both precipitation recharge and pumping in the CH_Alluvium had been at the 1999 rates then mound credit would have been 6,651 AF (Alluvial Precipitation/Pumping).

If precipitation recharge had been steady at 1999 rates from 2001 to 2004 in the Uplands rather than in the CH_Alluvium the mound credit between Cambridge and Harlan County Lake would have been only 172 AF (Upland Precipitation). If pumping had been steady in the Uplands the mound credit would have been only 547 AF (Upland Pumping). Mound credit is very sensitive to recent precipitation recharge and recent pumping in the CH_Alluvium but not to recent precipitation and recent pumping in the Uplands.

If precipitation recharge in the entire Nebraska_Area had been at 1999 rates from 2001 through 2004 the 2003 Mound Credit between Cambridge and Harlan County Lake would have been 959 AF (Nebraska Precipitation). If pumping in the entire Nebraska_Area had been held at 1999 rates from 2001 through 2004 the 2003 Mound Credit would have been 5,174 AF (Nebraska Pumping). If both had been held steady Mound Credit would have been 11,323 AF (Nebraska Precipitation/Pumping). Clearly the Mound Credit is a non-linear function of changes in specifications.

Canal seepage the Nebraska-Area has declined over the last four or five years. Canal seepage in the CH_Alluvium has declined very little. Canal On first inspection, the change in Nebraska_Area seepage would appear to coincide with a change in Mound Credit. Two experiments one with 1999 Nebraska-Area canal seepage and one with 1988 Nebraska-Area canal seepage suggest that short term changes in canal seepage such as the recent decline would take a long time to impact Mound Credit. If canal seepage had been at 1999 rates from 2001 through 2004 the mound credit between Cambridge and Harlan County Lake for 2003 would have been 201 AF (Nebraska Canals (1999). Even if the relatively high

1988 canal seepage rates had been held steady from 1988 through 2004 the 2003 mound credit would have been only 242 AF (Nebraska Canals (1988)).

The results of the sensitivity analysis indicate the following:

1) The increase in pumping in the CH_Alluvium that occurred between 1999 and 2003 is probably responsible for most of the reduction in the mound credit.

2) The reduction in precipitation recharge is partly responsible for the reduction in the mound credit.

3) Pumping outside of the CH_Alluvium had very limited responsibility for reduction of the mound credit

4) Reduction in water imported from the Platte has had very limited impact on the mound credit and probably will for years into the future.

5.2 Flow Component Analysis

Flow component analysis entailed: 1) studying the relation among flow components for base conditions and mound-off conditions and for 1999 and 2003 and 2) studying the input specifications that explained the changes in relationships. It was conducted at several scales of space: Nebraska wide, the Republican River and its tributaries from Cambridge to Harlan County Lake, subreaches from Cambridge to Harlan County Lake and finally a single target cell. It was also conducted for annual and monthly time periods.

5.2.1 Nebraska_Area Analysis

For Nebraska the major source of water to the ground has been precipitation recharge (Figure 5.16). It has generally ranged from about 250,000 AF/YR to about 2,000,000 AF/YR and has averaged about 1,000,000 AF/YR since 1940. Canal seepage has ranged from about 500,000 – 700,000 AF/YR. Surface water irrigation return flow has been relatively small and steady --- about 100,000 AF/YR. NOTE: return flow is that part of applied irrigation water that infiltrates into the ground rather than meeting the ET demand of a crop. In the RRCA model ground water return flow is accounted for by reducing specified pumping rates. Surface water return flow is represented explicitly.

Major consistent sinks for water have been discharge to constant heads (primarily the Platte River) --- about 500,000 AF/YR until about 2000 when it decreased to about 400,000 AF/YR and evapotranspiration --- a relatively steady 400,000 AF/YR until about 2000 when it started to decrease. Since 1970 pumping has become a major sink for water averaging 1,000,000 AF/YR since 1970 and 1,500,000 AF/YR since 2000. The Republican River and its tributaries have been an important destination for water but relatively minor in quantity as compared to ET. It had been receiving about 150,000 AF/YR for many years which has decreased to about 100,000 AF/YR.

Between 1940 and 1970 sources exceded sinks by about 600,000 AF/YR which was retained in stoarge in the aquifer. Between 1970 and 2000 sinks exceded sources by about 200,000 AF/YR which caused a corresponding loss of water in the aquifer. Since 2000 outflow exceded inflow by 1,000,000 AF/YR which caused a further reduction of water in the aquifer of 1,000,000 AF/YR.

Examination of the Nebraska-area flow components shows that the reduction in mound credit since 2000 coincided with increased pumping, reduced precipitation recharge and reduced canal seepage.

5.2.2 Analysis of Alluvium on the Main Stem from Cambridge to Harlan County Lake

Figure 5.17 shows components of flow for the CH_Alluvium on the main stem between Cambridge and Harlan County Lake. In this usage "alluvium" means all of that area represented by model cells that contain a reach of the main stem of the Republican River or a reach of its tributaries. The "alluvium" contains all of the cells for which mound credit must be calculated. It is also the zone through which ground-water, from the mound, must pass to migrate to the Republican River.

Figure 5.17 shows the ground-water flow components for the alluvium on the Republican River between Cambridge and Harlan County Lake. The major source for water to the alluvium has been ground-water from the uplands. It has increased from about 42,000 AF/YR in 1940 before the importation of water from the Platte to about 55,000 - 60,000 AF/YR by about 1970 with a decrease to about 52,000 AF/YR in 2004. The increase in ground-water in this reach into the alluvium accounts for the mound credit.

The other consistent major source for water to the alluvium has been recharge from precipitation. It has generally ranged from close to zero to 25,000 AF/YR and averaged about 10,000 – 15,000 AF/YR. The river had been a net source for about 10,000 AF/YR in the 1940's, became a net sink for about 10,000 AF/YR through the 1990's and has netted out to zero since 2000. Seepage from canals within the CH_Alluvium has been a relatively steady source of about 5,000 AF/YR since the 1950's.

Evapotranspiration has been the major sink for water. It has generally decreased from about 65,000 AF/YR in the 1940's to about 55,000 AF/YR in the 1990's. It has decreased to about 45,000 AF/YR since 2000. Pumping has generally increased as a sink for water from about 4,000 AF/YR in the 1960's to about 20,000 AF/YR in the 1990's to between 25,000 and 30,000 AF/YR since 2000. Accumulation of water in storage has been a minor sink for water until 2000 when it became a source for water.

In summary, sources for water since 1980 have been primarily ground-water and precipitation recharge. Sinks for water have been ET, pumping and the river.

The sources for water, over the long term, are relatively steady and independent of conditions in the ground. Of the sinks for water, pumping is unique in that it is independent of conditions in the ground whereas discharge to ET and the river is dependent on conditions in the ground. Therefore, with a relatively fixed amount of water going into the CH_Alluvium as pumping increases ET and discharge to rivers have to decrease.

5.2.3. Analysis of Subdivision of the Main Stem from Cambridge to Harlan County Lake

To narrow the range of analysis even further the Main Stem between Cambridge and Harlan County Lake was subdivided into sub-reaches for further analysis. Figure 5.18 shows the sub-reaches described in this section. For each sub-reach flow components were analyzed to establish where mound credits were most significant.

Upper Turkey Creek --- sub-reach 7 --- accounted for about 2/3 of the credits for the entire Cambridge to Harlan County Lake reach. Upper Spring Creek accounted for 1/5 of the credits between Cambridge and Harlan County Lake. Upper Muddy Creek accounted for most of the balance. Most of the mound debits were accounted for by three reaches on the Main Stem between the confluence of Turkey Creek and Harlan County Lake --- sub-reaches 18, 19 and 20.

Figure 5.19 shows the mound credit generated in the Upper Turkey Creek sub-reach for each year between 1945 and 2004. The credit increased steadily to about 9,000 acre-feet in 2000 then decreased about 10% after 2000. In contrast Figure 5.20 shows mound credit for the sub-reach between the mouth of Turkey Creek and the mouth of Spring Creek (Zone 18). It shows a negative mound credit --- a mound debit --- for most years. The annual variation in mound debit for the CH_Alluvium, which contains Zone 18, shows substantial annual variation (Figure 5.5). The variation in mound credit shown in Figure 5.5 is not caused by variation in water from the mound but rather use of water on the main stem.

In 2003 the mound credit developed in Upper Turkey Creek (zone 7) (Figure 5.19) was about 8,000 AF nearly as large as the 9,000 AF in 1999. In zone 18, however, the mound debit was 5,000 AF in 2003 (Figure 5.20) whereas it was only about 1,700 AF in 1999. The mound credit generated in Upper Turkey Creek in 2003 was reduced by more than half on the main stem in zone 18.

5.2.4 Analysis of Flow Components in a Single Target Cell

A single cell in model row 68, column 229 was selected as a target cell for further study because it is within zone between the mouth of Turkey Creek and the mouth of Spring Creek (zone 18) where most of the loss of mound credit occurs in 2003.

The target cell had a mound debit in 1999 of 23 AF. In 2003 the same cell had a debit of 1,035 AF approximately 20% of the mound debit generated in zone 18. Monthly flow components for the target cell are given in detail in Table 5.3.

Table 5.4 shows flow components and mound debits for the target cell for 1999 and 2003.

The mound debit is shown in the shaded cells of the table. They represent the reduction in flow to the stream in the target cell if the mound had not been in existence. In 1999 recharge from the stream to the ground was 934 AF. If there had not been a mound in 1999 then recharge to the ground would have been 911 AF. Therefore if there had not been a mound the discharge from the stream would have been 23 AF less than it actually was --- i.e. the mound debit was 23 AF.

In 2003, recharge from the stream to the ground was 1,035 AF. If there had not been a mound in 2003 then recharge to the ground would have been 0 AF. Therefore if there had not been a mound the discharge from the stream would have been 1,035 AF less than it actually was --- the mound debit was 1,035 AF.

The reason the target cell mound debit for 2003 was so much larger than the debit for 1999 is that had there not been a mound in 2003 there would have been no water in the river at the target cell to recharge the aquifer whereas had there not been a mound in 1999 there still would have been plenty of water in the river at the target cell. Notice there is no mention of pumping, precipitation recharge or ET in that reason.

With respect to recharge from the river to the ground at the target cell in 2003 head in the ground at the target cell is irrelevant. So is the head gradient between the river and the ground. So is pumping at the target cell in 2003, ET at the target cell in 2003 and precipitation recharge at the target cell in 2003.

In 2003, as represented by the base case, there was base flow in the river that was available to meet the ET demand. If there had been no mound there would not have been base flow in the river at the target cell to meet the ET demand. To understand why there had been mound water in the river at the target cell in 1999 but not in 2003 is explained with reference to the following accounting of mound water in the river itself.

5.3. Accounting for Water in the River Channel from Cambridge to Harlan County Lake

As described above the relationship between the rivers and the ground-water system is represented by the Stream package of MODFLOW. The Stream package represents reaches that are entirely contained within a single cell. The reaches are collected into segments to represent the relation among reaches. A specific reach is identified by its segment and reach numbers.

Figure 5.21 shows the main stem network with segment and reach numbers. The target cell discussed above is segment 224 reach 9. It is on the main stem between the mouth of Turkey Creek and the mouth of Spring Creek. Recall that reach has several meanings. In MODFLOW parlance that portion of a stream or river lying entirely within a ground-water model cell is referred to as a reach. In the field a reach is a length of river or stream with all tributaries not explicitly omitted.

Figure 5.22 shows the ground-water model cells corresponding to each reach. Notice that there may be several Stream Package reaches in the same cell. For example: the reach on Deer Creek just above the mouth and the main stem reach just above the mouth of Deer Creek and the main stem reach just below the mouth of Deer Creek are all in cell row 62, column 208. The target cell in row 68, column 229 corresponds to only one Stream Package reach segment 224 reach 9.

Figures 5.23, 5.24, 5.25 and 5.26 show gains and losses for each reach for Base and Mound-Off runs for 1999 and 2003, respectively. Gains, discharges from the ground to the river, shown as negative losses are shaded tan. Losses are shaded green. The base run shows that the target cell lost 934 AF in 1999.

Mound credit for a reach is gain for the base run minus gain for the mound-off run. Figures 5.27 and 5.28 show mound credit for each reach in the stream network for 1999 and 2003, respectively. Credits are shown as tan; debits as green. The uppermost reach of Turkey Creek shows a credit of 1,542 AF for 1999. At the target cell there was a debit of 23 AF.

Figures 5.29 through 5.32 show stream base flow for each reach for 1999 and 2003 and for the Base run and the mound-off run. The stream flow is based on the gains shown in figures 5.23 to 5.26. For example, Figure 5.31 shows that for the target cell base flow in 2003 was 5,312 AF. Figure 5.32 shows that for the same cell that if there had not been a mound base flow would have been 0.

Figure 5.33 and 5.34 show the accumulation of mound credits and debits from headwaters to the accounting point at Harlan County Lake. For example in Figure 5.33 the reach mound credits accumulate during 1999 in the Upper reaches of Turkey Creek then lose a small amount down to the mouth. A credit of 1,201 AF is picked up at the main stem to bring the total mound credit at the mouth of Turkey Creek to 9,544 AF. Debits reduce the credit along the main stem then get a credit from Spring Creek bringing it back up to 10,938 AF. From Spring Creek down to Harlan County Lake debits are somewhat greater than credits so that at Harlan County Lake the final mound credit at the accounting point for the main stem amounts to 9,013 AF.

Figure 5.34 shows accumulation of mound credits and debits for 2003. Somewhat less credit is generated on Turkey Creek but there are no credits at the mouth from upstream on the main stem. Downstream from the mouth of Turkey Creek debits overwhelm the credit at the mouth so that just upstream from Spring Creek the mound credit is only 1,067 AF. Spring Creek adds more credits but they too are lost upstream from Harlan County Lake where the final credit is only166 AF.

The accumulation of debits along the main stem in 2003 corresponds to the reaches where there is no base flow calculated between Turkey Creek and Spring Creek in (Figure 5.32). Without the mound there would not have been water to meet the ET demand.

Because, in 2003, there would have been no flow in the stream if there had not been a mound there could be no infiltration of water to the ground to meet the ET demand.

There would have been no water in the stream at the target cell in 2003 if there had not been a mound because water was removed from the stream upstream.

5.4 Summary of Results of Flow Component Analysis

Analysis of flow components at various temporal and spatial scales has revealed the details of why the mound credit in 2003 was so much smaller than the mound credit in 1999. The analysis entailed study of the mass balance in both the ground-water system and the river channel.

The conclusion of the analysis is that the primary reason the mound credit, in 2003, was much lower than it was in 1999 was that, on the Main Stem of the

Republican River , a large mound debit in 2003 took the place of a small mound debit in 1999. The large mound debit in 2003 was generated because the infiltration of water from the river that took place in 2003 would not have occurred had there not been a mound. That is in contrast to conditions in 1999. In 1999 infiltration from the river with water attributable to the mound was only slightly greater than it would have been had there been no mound.

The conclusion of the analysis is that the primary reason the mound credit, in 2003, was much lower than it was in 1999 was that, on the Main Stem of the Republican River, a large mound debit in 2003 took the place of a small mound debit in 1999. The large mound debit in 2003 was generated because the infiltration of water from the river that took place in 2003 would not have occurred had there not been a mound. That is in contrast to conditions in 1999. In 1999 infiltration from the river of water attributable to the mound was only slightly greater than it would have been had there been no mound.

6.0 Summary and Conclusions of Combined Analyses

In 1999 the total mound credit was 18,450 AF (Table 6.1); about 9,482 AF of which was accounted for at the mouth of Medicine Creek while most of the balance was accounted for at Harlan County Lake. In 2003 the total mound credit was about 9,782 AF nearly all of which was accounted for at the mouth of Medicine Creek and 144 AF of which was accounted for at Harlan County Lake. It was the mound credit to the Main Stem between Cambridge and Harlan County Lake that explains the drop in credit between 1999 and 2003.

Flow component analysis showed that the mound credit for the Cambridge-Harlan County Lake reach accumulated primarily in the Upper Reaches of Turkey Creek was offset by mound debits on the main stem downstream from Turkey Creek. The debits on the main stem were generated because base flow that had been in the stream channel in 2003 would not have been there if there had been no mound. At the target cell there had been enough base flow in the stream channel in 2003 so that 1050 AF could go into the ground to partially satisfy ET demand. If there had not been a mound that base flow would not have been in the stream channel at the target cell. There would have been no base flow in the stream because of the increase in pumping.

The sensitivity analysis showed that the increase in pumping between 1999 and 2003 was responsible for about 7,000 AF of the decrease in the mound credit in 2004. About 4,000 AF of that decrease was caused by pumping from the alluvium between Cambridge and Harlan County Lake. Reduced recharge from precipitation was responsible for about 1,000 AF of the mound credit.

Although there was pumping in the target cell; that would not have been the cause of the dry river channel. It was the pumping upstream from the target cell. Pumping from the target cell could only affect the stream flow down stream from the target cell. Furthermore, storage of water in the ground attenuates the impacts caused by pumping --- pumping within the alluvium during one year may affect mound credits a year or two in the future.

7.0 Recommendations

This study dealt only with changes in stresses specified to the model that might have explained the reduction in the mound credit between 1999 and 2003. Model experiments might be used to evaluate the impact of assumed properties on the mound credit. Those properties would include stream bed conductance, stream bed elevation, ET surface and extinction depth. The approach used in this study could also be used to study depletions caused by pumping throughout the basin.

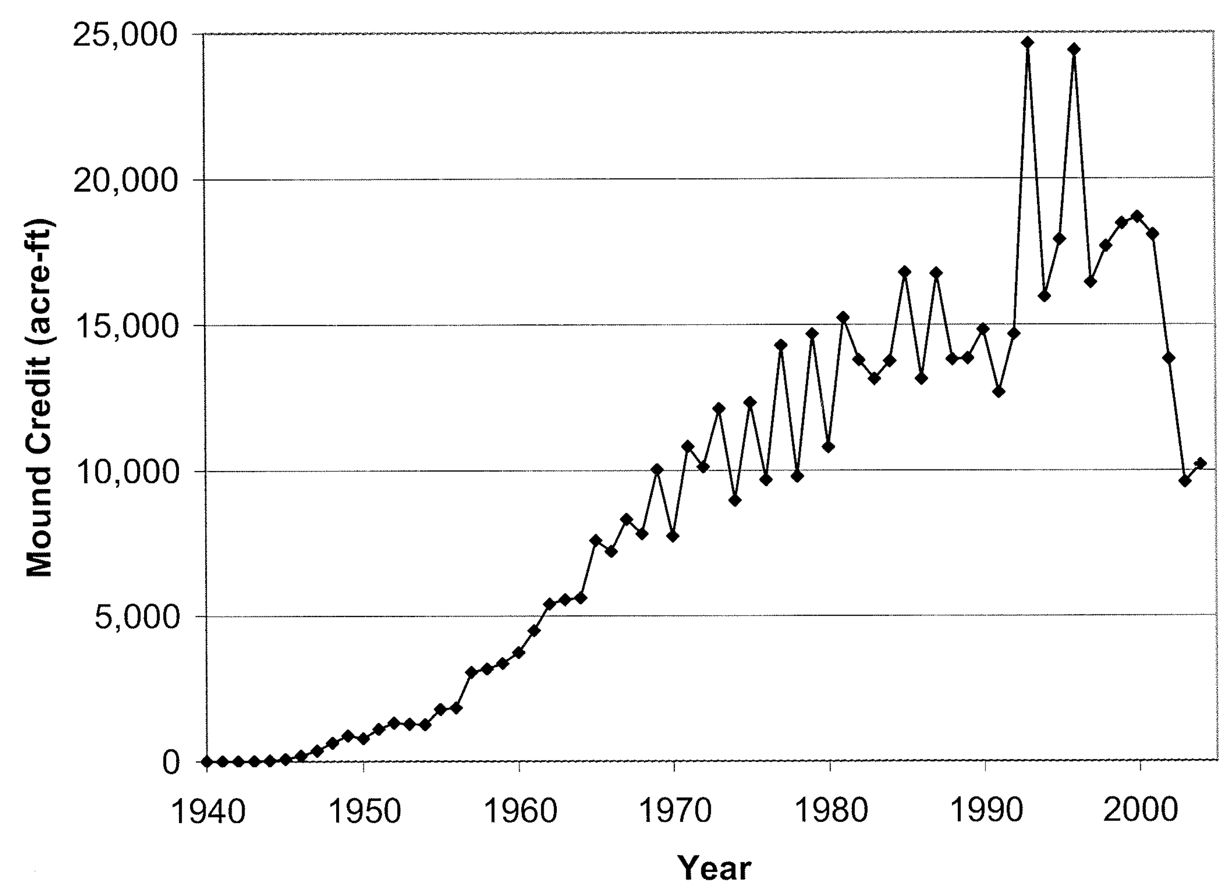

Figure 1.2. Graph showing total mound credit as calculated by the RRCA ground-water model from 1940 to 2004.

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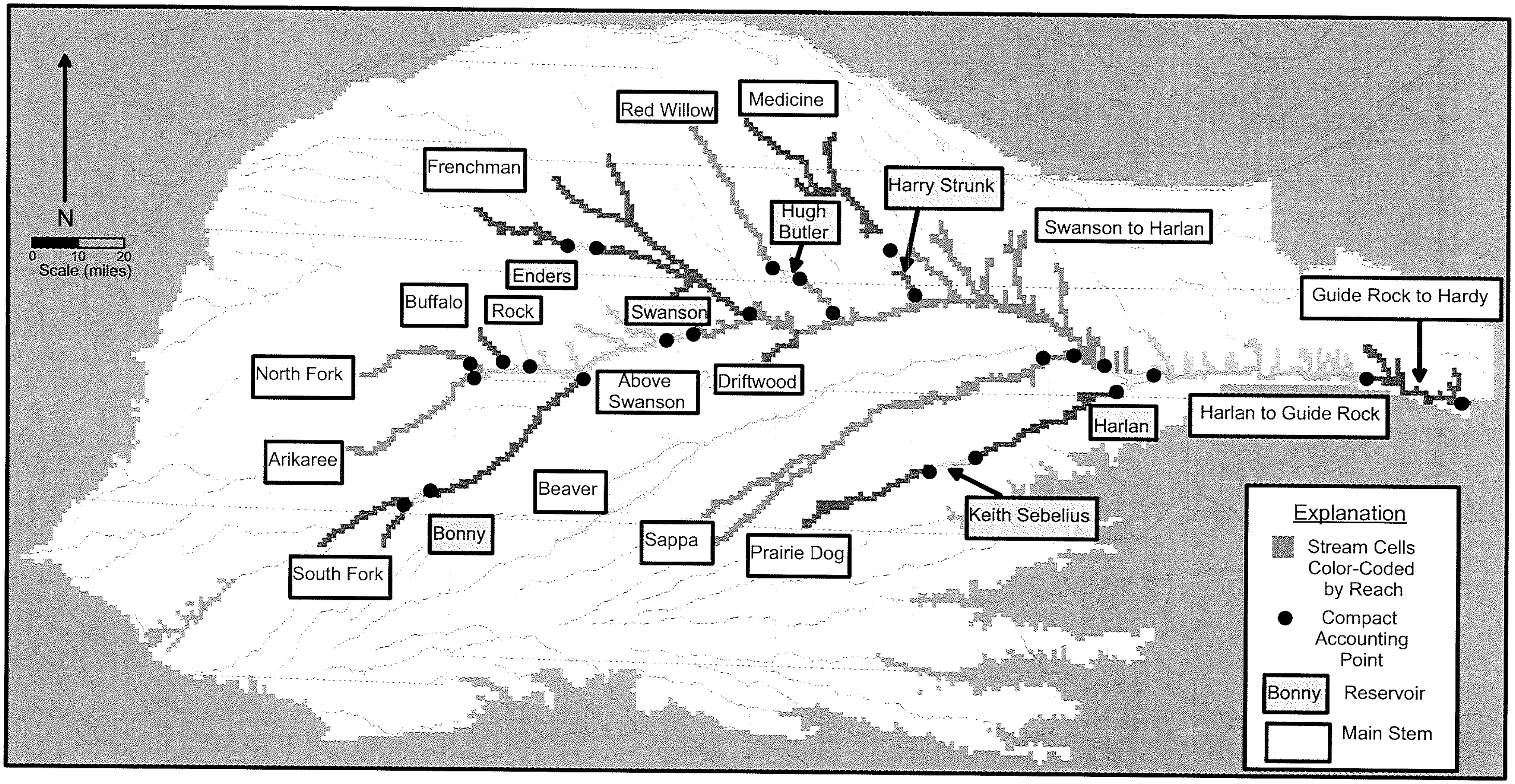

Exhibit A
Page 44 of 92

Figure 4.1. Map showing RRCA ground-water model reaches and accounting points.

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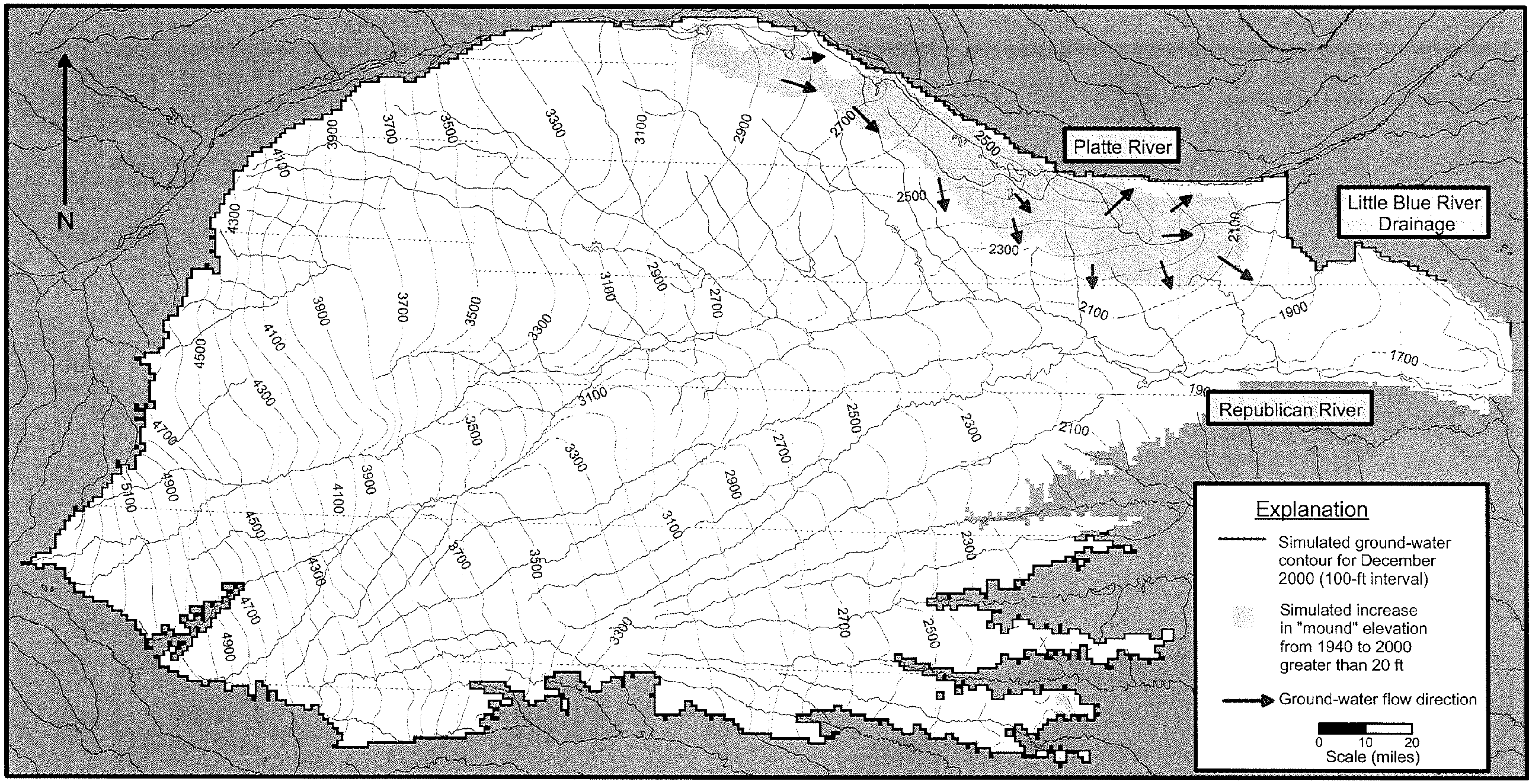

Exhibit A
Page 48 of 92

Figure 5.1. Map showing simulated 2000 ground-water levels and flow directions.

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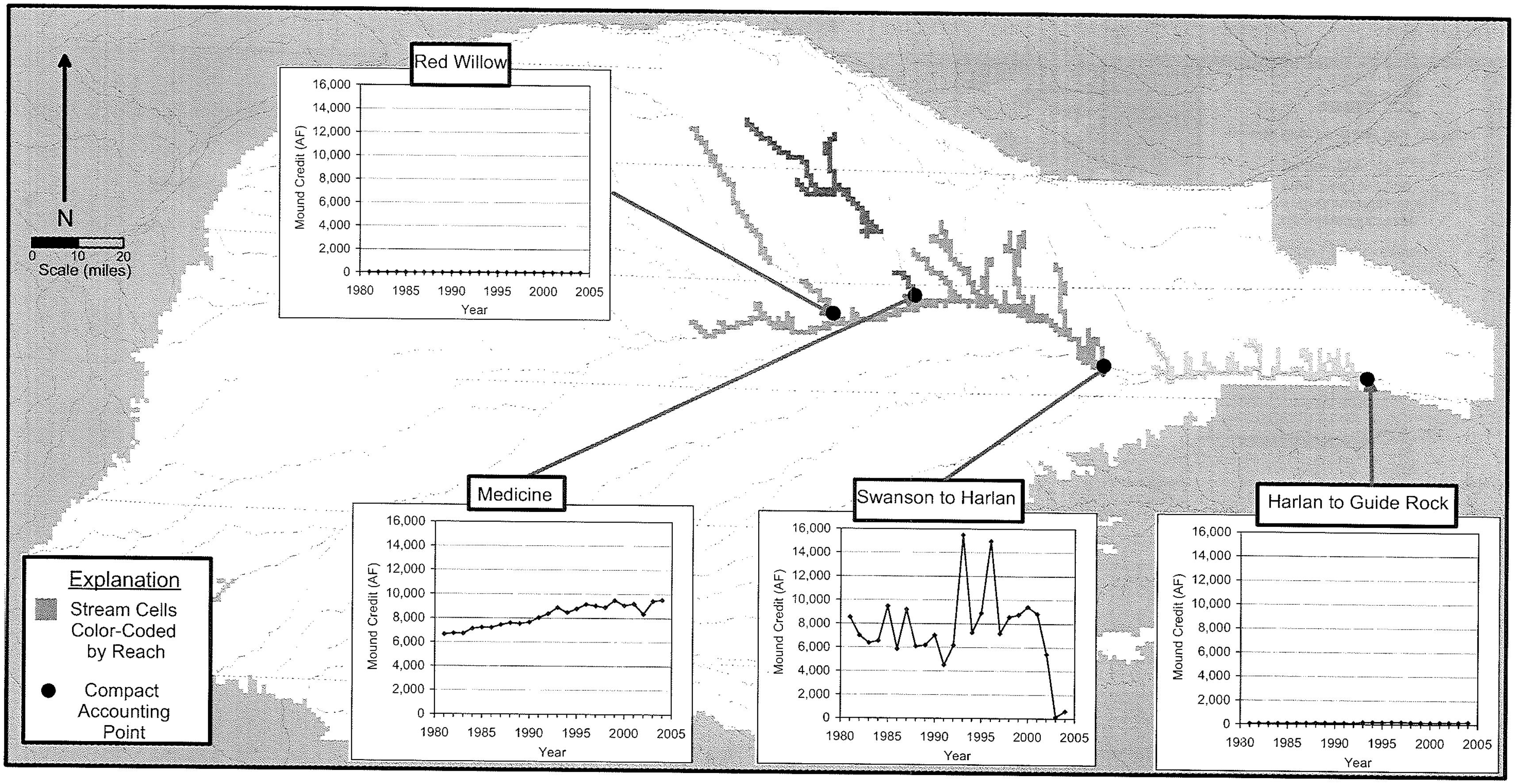

Data from RRCA Compact Website.

Figure 5.2. Mound Credit from 1981 to 2004 in Republican River Compact accounting reaches with a mound credit consistently greater than 25 AF per year.

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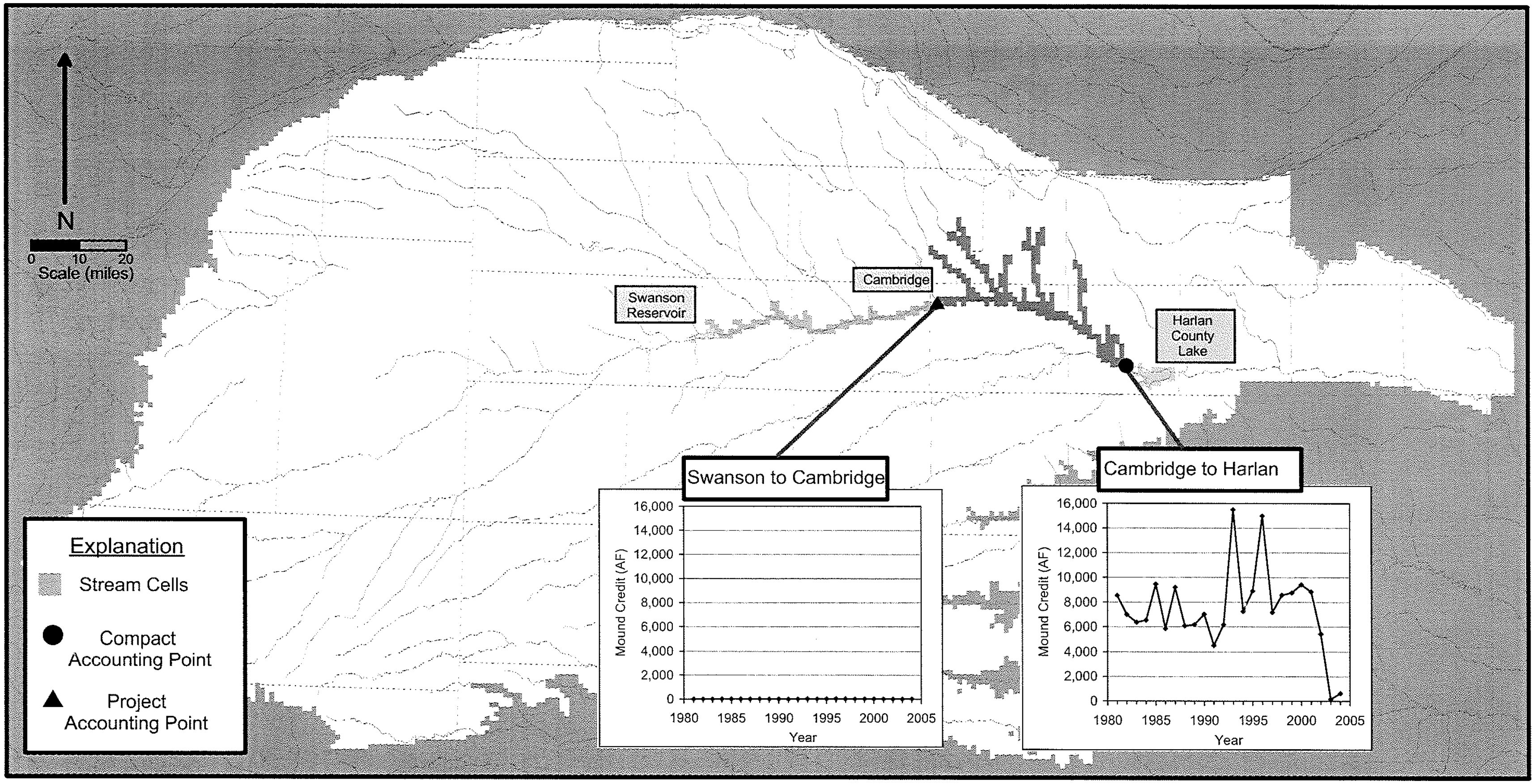

Figure 5.3. Map showing distribution of Mound Credit between Swanson Reservoir and Harlan County Lake from 1981 to 2004.

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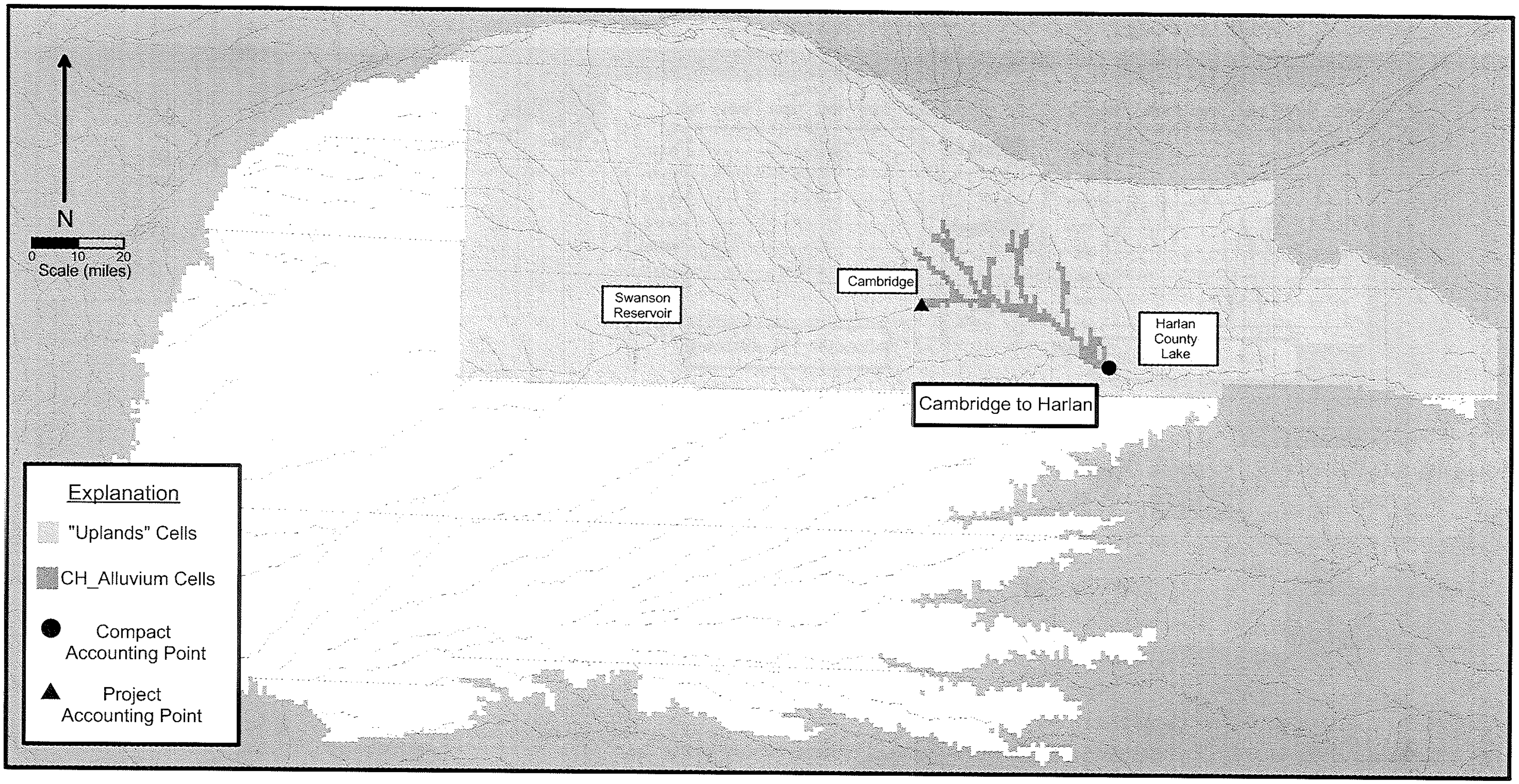

Figure 5.4. Map showing location of CH_Alluvium and "Uplands" zones.

McDonald Morrissey Associates, Inc.

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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 The Honorable William J. Kayatta, Jr.
Special Master

♦

DECLARATION OF STEVEN P. LARSON
March 2, 2013

♦

COMES NOW Steven P. Larson, pursuant to 28 U.S.C. § 1746, and, having personal knowledge of the matters contained herein, states as follows:

1. I am over 18 years of age. My qualifications have been previously submitted in a in this case.

2. I am writing in support for Kansas' Second Request for Approval of Discovery. Much of the information that Kansas seeks in its Second Set of Interrogatories and Requests for Production Pursuant to CMO No. 9 relates to uncertainties regarding the amount of seepage of Platte River water and computed water levels in the mound area.

3. The 5-run proposal uses the same procedure for calculating pumping impacts as the currently approved procedure except it makes those calculations without the mound seepage rather than with the historical condition with the mound seepage included.

4. The historical condition was the basis for calibrating the groundwater model, the condition without the mound seepage was not. The 5-run proposal represents a fundamental change in how pumping impacts would be calculated as compared to what was agreed to in the FSS.

5. In 2006 McDonald-Morrissey Associates, Inc. conducted a study entitled "*Review of RRCA Model for the Period 2001 to 2004*" (McDonald-Morrissey Report) for the State of Nebraska. The McDonald-Morrissey Report recognized a potential problem with the model calibration in the area of the mound and the potential impact of that problem on the calculation of depletions and accretions. Specifically, the McDonald-Morrissey Report stated as follows:

> The model is imprecise because it does not represent all features of the flow system but only those which are deemed to be significant and because input specifications are estimates. In one area of the RRCA model, the "mound" area or an area in portions of Kearney, Phelps, Harlan, and Franklin counties, model-calculated water levels appear to be consistently too high. A further study of the mound area and the stream depletions/accretions relating to this area is being initiated. This study will attempt to establish the reason for lack of precision in the mound area and evaluate the impact of these high water levels on stream depletions/accretion calculations.

McDonald-Morrissey Report at pg. 7.

6. Kansas shares the concern expressed in the McDonald-Morrissey Report. As I explained in my *Initial Response to Nebraska's New Proposal for Changes to the Accounting Procedures* (Aug. 7, 2012), since the 5-run proposal would use a baseline condition that does not include recharge from imported water, the difference between what the RRCA Groundwater Model would calculate with this recharge versus without becomes very important. In addition, the reliability and uncertainty in the estimates of recharge from imported water also become

increasingly important. A fair evaluation of the issue requires an analysis of the data on groundwater levels and stream flows and a review of the recharge estimation process used by Nebraska. The information Kansas is requesting in its Second Set of Interrogatories and Requests for Production Pursuant to CMO No. 9 is the type of information Kansas needs to evaluate the nature of the problem and its impact on the calculation of depletions due to pumping under the 5-run proposal.

7. The 16-run proposal was based on achieving the "virgin water supply metric" or, in other words, being sure that the sum of the impacts would equal the total impact determined from an "All on" versus and "All off" condition in the model. The fundamental concern with the 16-run proposal is how to distribute the total impacts defined by the "virgin water supply metric" among the individual states.

8. As can be seen from the "*Response to Expert Report of James C. Schneider, Ph.D., on Nebraska's Proposed Changes to the RRCA Accounting Procedures*" (Larson & Book, March 15, 2012), in responding to the 16-run proposal, Kansas was focused on the "virgin water supply metric," and did not consider the mound issues to be critical. That changed in the Spring of 2012 when Nebraska and Colorado informed the Special Master and Kansas that they had agreed to abandon the 16-run proposal and advocate for the 5-run proposal.

9. In contrast to the 16-run proposal, the 5-run proposal is not premised on meeting the "virgin water supply metric" and differs from the 16-run proposal in determining the amount of pumping impact that will be assigned to each state. Although the degree that the sum of the impacts would depart from the "virgin water supply metric" is still an issue for the 5-run proposal, an additional fundamental concern with the 5-run proposal is whether the modeled condition without the mound seepage included can serve as a reliable baseline for determining

pumping impacts. The information that Kansas is seeking in its Second Set of Interrogatories and Requests for Production Pursuant to CMO No. 9 will assist Kansas in assessing this issue.

10. In sum, the uncertainty in the mound data became a focus of this case for Kansas only after Nebraska and Colorado changed to the 5-run proposal. While we do not know what the data and information requested by Kansas will show, it may be important for Kansas to assess the 5-run proposal and to determine if other alternative accounting methods are more desirable.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on March 2, 2013.

Steven P. Larson

No. 126, Original

In the

SUPREME COURT OF THE UNITED STATES

STATE OF KANSAS,

Plaintiff

v.

STATE OF NEBRASKA and
STATE OF COLORADO,

Defendants

OFFICE OF THE SPECIAL MASTER

ORDER ON KANSAS' REQUEST FOR APPROVAL OF DISCOVERY

February 18, 2013

ORDER ON KANSAS' REQUEST FOR APPROVAL OF DISCOVERY

On February 5, 2013, Kansas filed a Request for Approval of Discovery, with the requested discovery attached thereto as Exhibit A. Kansas additionally filed, on February 7, 2013, a Supplemental Filing re Request for Approval of Discovery. In response to Kansas' filings, Nebraska submitted a Request for Hearing and Leave to File Written Objections on February 7, 2013, and Colorado subsequently also filed a Request for Conference and Leave to File Brief on February 8, 2013. In light of the requests for briefing and conference by Nebraska and Colorado, and in accord with Case Management Order (CMO) No. 9, ¶ 3.1, I directed the parties to file any further succinct written comments by Wednesday, February 13, 2013, and I scheduled a conference of counsel for February 14, 2013. All parties filed additional briefing on Kansas' Request for Approval of Discovery by the deadline, and the conference was held as scheduled.

After review of the submissions by all parties in connection with Kansas' Request for Approval of Discovery, and in light of the further discussion with counsel during the February 14, 2013 telephone conference, I conclude as follows:

Kansas' discovery requests are unnecessarily broad. It appears that Kansas has not yet reviewed all the data it already has that is encompassed within the scope of its requests. Kansas also seeks discovery on technical matters that could be amply addressed without formal discovery. In this regard, it appears that Kansas has declined an invitation from Colorado to have Mr. Larson speak directly with Dr. Schreüder. Kansas' reluctance to avail itself of efficient informal discovery is directly at odds with its assertion that the parties should pursue nonbinding dispute resolution on these issues through the RRCA.

Colorado's filing also reveals that Kansas already questioned Dr. Schreüder prior to last August's hearing precisely on the issues identified in CMO No. 9, ¶ 1.2. The record also shows that Kansas then chose not to explore those issues in examining Dr. Schreüder at the hearing itself. The testimony by Dr. Schreüder elicited by Kansas last summer, to which my attention has now been directed for the first time, would support a finding that the impact of any alleged uncertainties in Mound recharge data would have been no less material under the 16-run solution than under the 5-run solution. Such a finding would undercut Kansas's basic argument that it had no reason to explore this issue prior to Nebraska's announcement in this action that it sought the 5-run solution as a remedy. Kansas nevertheless offers, at this point, no contrary evidence in seeking extensive discovery on this issue, notwithstanding my order that discovery must be "essential" and the party seeking discovery must show why the discovery "could not have been sought in June, 2012 (or before)." CMO No. 9, ¶ 3.1.

Kansas's argument that it could not have sought discovery on this issue during much of 2012 because the formal deadline for discovery had expired would be of some force only if one were to conclude that the relevance of the information became clear only when Nebraska changed its requested relief, and that Kansas also justifiably concluded either 1) that I would not allow the discovery notwithstanding my statements that I was willing to take the actions necessary to mitigate any prejudice to Kansas caused by allowing the change, or 2) that it was certain that none of the information could be produced and reviewed within three months. The granting of post-deadline discovery requests last spring, the testimony of Dr. Schreüder appended to Colorado's filing, and the current ambitious discovery requests made under an expedited schedule run counter to any such conclusions.

Finally, the form of the discovery requests, especially the requests for production of documents, generally lacks the specificity that I would require at this stage. After the substantial proceedings to date, and if it avails itself of the opportunity to have Mr. Larson talk directly with Dr. Schreüder, Kansas should have a greater understanding of the specific documents and data, if any, it needs to address the limited issues set forth in CMO No. 9.

For all of these reasons, Kansas' request is DENIED in part and GRANTED in part, as set forth below:

1. Interrogatories and Requests for Production

Nebraska is not required to respond to Kansas' Interrogatory Nos. 1 and 2. Nebraska is directed to respond to Interrogatory Nos. 3 and 6. Nebraska is further directed either to file supplemental objections to Interrogatory Nos. 4 and 5 explaining with particularity why those interrogatories are unduly burdensome, or to respond to Kansas' Interrogatory Nos. 4 and 5.

Kansas' requests for production are denied, but Kansas has leave to re-file properly limited requests for production. Any further requests for production must be targeted at specific documents or data that Kansas knows to be material. Further, the requests must be supported by a showing, first, that Kansas does not have access to the documents or data requested and cannot obtain access absent formal discovery; second, that Kansas's request is demonstrably essential to a fair resolution of the issues described in CMO No. 9, ¶ 1; and, third, that Kansas could not have sought the discovery in June, 2012 (or before).

2. Deposition of Willem A. Schreüder, Ph.D.

Kansas' request to depose Dr. Schreüder is denied.

SO ORDERED.

Dated: February 18, 2013

/s/ William J. Kayatta, Jr.
William J. Kayatta, Jr.
Special Master

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