GW-Impacts

# REPUBLICAN RIVER COMPACT ADMINISTRATION
## GROUND WATER MODEL
June 30, 2003

## EXECUTIVE SUMMARY

In accordance with the December 15, 2002 Final Settlement Stipulation in Kansas v. Nebraska and Colorado, No. 126 Original, the Republican River Ground Water Modeling Committee developed a comprehensive ground water model to represent the ground water flow system in the Republican River Basin. The primary purpose of the Republican River Compact Administration Ground Water Model (RRCA Model) is to determine the amount, location, and timing of streamflow depletions to the Republican River caused by well pumping and to determine streamflow accretions from recharge of water imported from the Platte River Basin into the Republican River Basin.

Representatives from the State of Colorado, State of Kansas, and State of Nebraska developed the RRCA Model, with participation from the United States Bureau of Reclamation and United States Geological Survey. The data and information used in construction and calibration of the RRCA Model were provided and shared by all three States and the United States in a collegial manner. In a similar vein, the RRCA Model was constructed and calibrated in a collaborative exercise by technical experts from all three States.

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.

## INTRODUCTION

The Republican River rises in the high plains of northeastern Colorado and western Kansas and Nebraska. The river flows in a generally eastern direction and encompasses approximately 24,900 square miles within its watershed that is illustrated below. The States of Colorado, Kansas, and Nebraska, with the consent of the United States of America, entered into the Republican River Compact in 1942 in order to equitably divide the waters of the Republican River Basin. Ground water accretions and depletions are subject to administration within the Compact for the portion of the basin that contributes flow above the streamflow gaging station on the Republican River near Hardy, Nebraska which is in the eastern part of the Republican River Basin near the Kansas-Nebraska state line.

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The Final Settlement Stipulation (FSS) in <u>Kansas v. Nebraska and Colorado</u>, No. 126 Original, which resolved that interstate dispute, provided for development of a comprehensive ground water model to represent the ground water flow system in the Republican River Basin. This document describes the content, construction, and calibration of the Republican River Compact Administration Ground Water Model (RRCA Model). Representatives from the State of Colorado, State of Kansas, and State of Nebraska developed the RRCA Model, with participation from the United States Bureau of Reclamation and United States Geological Survey (USGS).

## Purpose and Scope

The primary purpose of the RRCA Model is to determine the amount, location, and timing of streamflow depletions to the Republican River caused by well pumping and to determine streamflow accretions from recharge of water imported from the Platte River Basin into the Republican River Basin above the streamflow gaging station near Hardy, Nebraska. The RRCA Model construction and calibration represent the physical and hydrogeological characteristics of the Republican River Basin to a reasonable degree for the period 1918 to 2000. The RRCA Model simulates historical and current physical conditions; it is not an optimization or operational model and does not assess the impact of land use and conservation practices, reservoir operations, or other water supply or water administration practices.

The RRCA Model will be used to determine ground water depletions and imported water supply accretions in formulas prescribed in the RRCA Accounting Procedures. Future input data to the RRCA Model will be developed in accordance with the requirements of the Accounting Procedures.

## Document Context

This document is intended to provide a detailed description of all major facets in the RRCA Model structure, data and information, calibration, and results that were reached in its construction by the State of Colorado, State of Kansas, and State of Nebraska in consultation with the United States. Updated with annual streamflow, climatological, irrigated acreage, ground water pumping, and other information, the RRCA Model will be used to quantify said streamflow depletions caused by well pumping and imported water supply accretions for application within the formulas prescribed in the RRCA Accounting Procedures. The data and information used in construction and calibration of the RRCA Model were provided and shared by all three States and the United States in a collegial manner. In a similar vein, the RRCA Model was constructed and calibrated in a collaborative exercise by technical experts from all three States. This document reflects the RRCA Model architecture, the data sets used, and calibration agreed upon by the States as required by the FSS.

The RRCA Model, consisting of the computer code, input files, and pre-processing and post-processing programs, is provided in Appendix A on a DVD ROM. Members of the RRCA Engineering Committee are working on a RRCA Ground Water Model Users Manual that will provide details related to the use of the model in conjunction with the RRCA Accounting Procedures. The Users Manual will discuss data content and formatting, the use of pre-processing

programs, details on completing the various runs of the model, and application of the RRCA Model's outputs in the annual RRCA accounting.

## Model Findings and Summary

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 reasonably matches the trend and magnitude of ground water levels 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.

# CONCEPTUAL MODEL OF GROUND WATER FLOW SYSTEM

## Background and Physical Setting

The tributaries at the headwaters of the Republican River rise on the high plains of northeastern Colorado and western Kansas and Nebraska. The mainstem of the Republican River is formed by the junction of the North Fork of the Republican River and the Arikaree River near Haigler, Nebraska. The river flows in a generally eastern direction for approximately 445 miles before it joins the Smoky Hill River to form the Kansas River at Junction City, Kansas. The Republican River Basin encompasses approximately 24,900 square miles within its watershed that is illustrated below.

In order to include all ground water resources that affect stream flows within the Republican River Basin, the RRCA Model domain was extended beyond the Republican River watershed. The model domain boundaries extend from the Platte River in the north to the Ogallala aquifer outcrops on the southern, eastern, and western boundaries. The model domain coincides with that described in USGS Open File Report 02-175 except in the eastern portion of the Basin where it was extended eastward to the eastern edge of Kearney County, Nebraska and into Adams County, Nebraska to reflect increased water table elevations caused by imported water supplies from the Platte River. The model domain encompasses approximately 30,000 square miles. A map of the model domain, including model cell designations and boundary conditions, is provided in Appendix B.

# MATHEMATICAL REPRESENTATION OF GROUND WATER FLOW MODEL

## Model Program

The RRCA Model applies a modified version of the United States Geological Survey modular ground water model MODFLOW 2000 (Harbaugh and others, 2000) version 1.10 to numerically calculate stream depletions from ground water pumping and accretions from imported water supplies. MODFLOW is a simulation program that uses a finite-difference method to solve the ground water flow equation.

In addition to its robust numerical solver capabilities, MODFLOW also offers two significant attributes. First, it is relatively easily understood, which promotes confidence in its application by those intending to use the computer model to simulate physical and hydrological conditions. Second, it is easily enhanced to accommodate the continuing need for additional capabilities to address a variety of physical and hydrogeological conditions.

The MODFLOW program promotes simulation accuracy and computational flexibility by segmenting various hydrologic attributes such as recharge, leakage from the aquifer to the rivers, or evapotranspiration from ground water as separate or distinct packages. For application within the RRCA Model, the following enhancement modules or packages were used:

- ◆ Basic (BAS6)
- ◆ Layer Property Flow (LPF1)
- ◆ Recharge (RCH6)
- ◆ Well (WEL6)
- ◆ Stream (STR6)
- ◆ Evapotranspiration (EVT6)
- ◆ Drains (DRN6)
- ◆ Preconditioned Conjugate Gradient (PCG2)
- ◆ Hydrograph (HYMOD1)

## Model Architecture

The following items are the major components in the RRCA Model architecture:
? The model is a single layer bounded on the bottom by the impermeable Pierre Shale.
? The initial Stream Network was taken from USGS Open File Report 02-175.
? The interim aquifer base was taken from USGS Open File Report 02-175, and was adjusted to reflect elevation variances near streams and data available from Nebraska.
? Land surface elevations were obtained from the National Elevation Dataset (NED) one arc second Digital Elevation Model (DEM). The land surface elevations along stream channels were modified in order to provide strictly decreasing elevations along stream channels.
? The ground water flow system was simulated as if there were a constant transmissivity in order to preserve numerical stability.

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# Phreatophyte Area

Republican River Settlement Model Version 12p



Phreatophyte
Area (acres)
700
600
500
400
300
200
100
0

(Column)

(Row)

(feet)
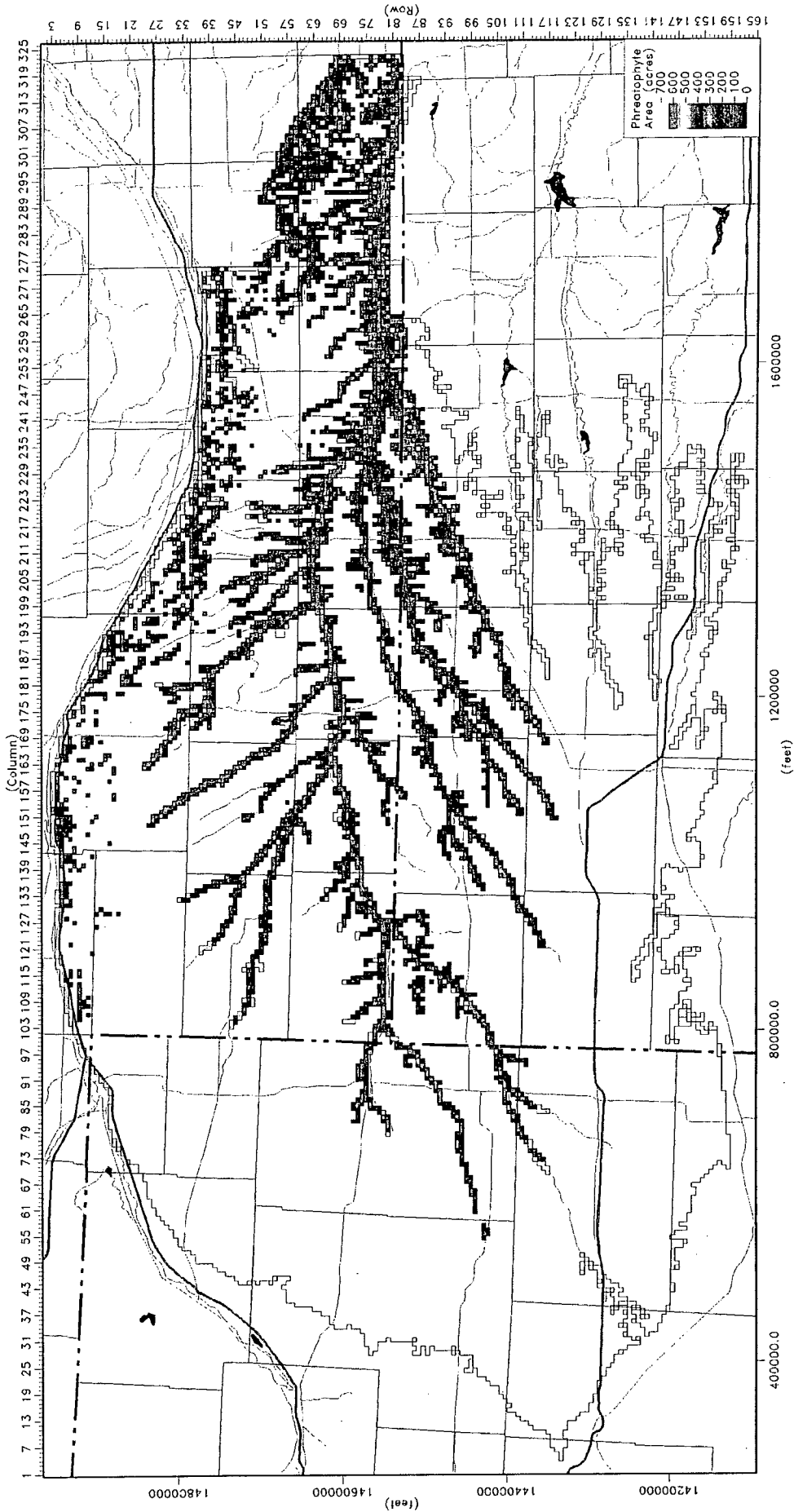
irrigated lands. The Y-axis for each curve is inches of recharge from precipitation and the X-axis depicts the total amount of precipitation each year.

Lesser calibration parameters that are used to further refine the ground water model include:

Spatial Multipliers – the Spatial Multiplier has a value of 1.0 throughout the model domain except in the mound area in Nebraska where the value is 1.5. A map of spatial multipliers with associated values is provided in Appendix Q.

Steady-State Multiplier – for the period of 1918 to 1940, the long-term average recharge is not fully indicative of all conditions in the model domain, primarily in the western area. A steady-state multiplier of 0.75 was applied to the average of the 1918-1940 recharge period throughout the Republican River Basin.

Phreatophyte potential evapotranspiration rate – the rate is indexed to the McCook and Red Cloud, Nebraska and Akron, Colorado climate stations. The annual potential evapotranspiration rates were linearly interpolated from west to east across the model domain. To improve the ability of the model to match baseflows, all phreatophyte evapotranspiration rates were adjusted by a factor of 2.0. For specific sub-basins, a second factor ranging between 0.03 and 1.12 was applied. The location of the phreatophyte areas and distribution of potential evapotranspiration are provided in Appendix R.

Saturated Thickness – Applied within the RRCA Model to improve the model performance, the saturated thickness in any given model cell was adjusted to a minimum of 10 feet. The saturated thickness is based upon average values for the period 1940-2000 and was kriged across the model domain between known data points. The distribution of saturated thickness is provided in Appendix S.

Transmissivity – The adjustments to hydraulic conductivity and saturated thickness described above were made during the calibration procedures and resulted in a distribution of transmissivity that is provided in Appendix T.

**Model Output**

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 reasonably matches the trend and magnitude of ground water levels 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 are quantified and assigned to prescribed streamflow reaches that are in accord with the RRCA Accounting Procedures.

The RRCA Model calculates the amount of ground water depletions from well pumping as the difference in streamflows using two simulation runs of the model. The "base" run is the simulation with all ground water pumping, ground water pumping recharge, and surface water recharge within the model study boundary for the period 1918 to the current accounting year "on". The "no State pumping" run is the simulation run with the same model inputs as the base run with the exception that all ground water pumping and pumping recharge for that particular State is turned "off." The amount of recharge from precipitation is recalculated by converting all ground water-only irrigated land to non-irrigated lands. The amount of depletions charged to each respective State is the difference between the "base run" and the "no State pumping run". In a similar manner, the "no NE import" run is the simulation with the same model inputs as the base run with the exception that surface water recharge from irrigation and canal leakage that is associated with Nebraska's Imported Water Supply is turned "off." The amount of recharge from precipitation is recalculated by converting all surface water-only irrigated land to non irrigated lands and the Imported Water Supply Credit is the difference in stream flows between these two model simulation runs. For commingled lands, defined as receiving irrigation water from a combination of surface and ground water supplies, there is no switch or conversion from irrigated to non-irrigated lands because it is assumed any deficit from one supply source will be replaced by the other. Therefore, while the surface or ground water return flows may be removed in a no pumping or import simulation run, the derivation of recharge from precipitation remains unchanged for commingled lands.

An output of the model is baseflows at selected stream cells. Changes in the baseflows predicted by the model between the "base" run and the "no-State-pumping" model run are considered to be the depletions to streamflows, or ground water computed beneficial consumptive use due to State ground water pumping at that location. The values for each Sub-basin include all depletions and accretions upstream of the confluence with the Main Stem. For sub-basins with reservoirs and the Main Stem, the model's output totals the depletions and accretions above and below each federal reservoir and in the reservoir reaches. The values for the Main Stem include all depletions and accretions in stream reaches not otherwise accounted for in a Sub-basin. The values for the Main Stem are computed separately for the reach above Guide Rock, and the reach below Guide Rock. For subsequent years, the RRCA Model will be extended to include new hydrologic, pumping, climate, and other annualized datasets. The data will be compiled and exchanged in accordance with the RRCA Accounting Procedures.

For illustrative purposes, impact tables that quantify the depletion of ground water well pumping and imported water supply accretions by stream reach are provided in Appendix U for the period 1981-2000.


## CONCLUSIONS

The RRCA Model fulfills the requirements of the FSS to develop a ground water model for use by the RRCA to aid in the administration of the Republican River Compact. The RRCA Model quantifies the amount, location, and timing of streamflow depletions caused by ground water well

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pumping and the accretions to streamflow from imported water across the model domain on an annual basis. The RRCA Model provides the required output information in an acceptable format to describe the amounts and timing of said ground water pumping depletions and imported water accretions that are necessary for application within the prescribed annual RRCA Accounting Procedures. The RRCA Model calibration represents the physical and hydrogeological characteristics of the Republican River Basin to a reasonable degree. The use of specific methods or computational procedures within the RRCA Model does not necessarily mean that any party represents or accepts them to be the best or only method for purposes other than that, which is applied in the RRCA Model. The RRCA Model will be used as is, with only annual updates to the appropriate data files and necessary modifications to pre-processor programs required to accommodate modified future data formats, but without recalibration, until such time as the RRCA approves any changes. The RRCA may consider revisions to the model as set forth in the FSS.

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Appendix U    RRCA Model Impacts

## Version 12p: Impact of Colorado Pumping (acre-feet)

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 1049 | 0 | 33 | 0 | 255 | 7485 | -540 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9654 | 0 | 758 | 0 | 0 | 0 | 0 | 0 | -540 | 18705 |
| 1982 | 2335 | 0 | 40 | 0 | 305 | 7822 | -883 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8566 | 0 | 760 | 0 | 0 | 0 | 0 | 0 | -882 | 18954 |
| 1983 | 1678 | 0 | 46 | 0 | 366 | 7908 | -1775 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8193 | 0 | 780 | 0 | 0 | 0 | 0 | 0 | -1775 | 17208 |
| 1984 | 1109 | 0 | 53 | 0 | 421 | 8342 | -1391 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7822 | 0 | 835 | 0 | 0 | 0 | 0 | 0 | -1391 | 17205 |
| 1985 | 516 | 0 | 61 | 0 | 471 | 8627 | -1455 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9579 | 0 | 841 | 0 | 0 | 0 | 0 | 0 | -1455 | 18656 |
| 1986 | 455 | 0 | 69 | 0 | 532 | 8757 | -1572 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7544 | 0 | 860 | 0 | 0 | 0 | 0 | 0 | -1572 | 16661 |
| 1987 | 511 | 0 | 78 | 0 | 604 | 9256 | -1699 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 9783 | 0 | 900 | 0 | 0 | 0 | 0 | 0 | -1699 | 19451 |
| 1988 | 955 | 0 | 89 | 0 | 676 | 9684 | -1978 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 7770 | 0 | 950 | 0 | 0 | 0 | 0 | 0 | -1978 | 18167 |
| 1989 | 245 | 0 | 98 | 0 | 724 | 9766 | -1957 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 8552 | 0 | 968 | 0 | 0 | 0 | 0 | 0 | -1957 | 18417 |
| 1990 | 589 | 0 | 109 | 0 | 713 | 10426 | -2114 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 9811 | 0 | 985 | 0 | 0 | 0 | 0 | 0 | -2114 | 20543 |
| 1991 | 1462 | 0 | 121 | 0 | 738 | 10837 | -1181 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 0 | 10622 | 0 | 975 | 0 | 0 | 0 | 0 | 0 | -1182 | 23598 |
| 1992 | 2233 | 0 | 134 | 0 | 745 | 11199 | -1052 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 10355 | 0 | 994 | 0 | 0 | 0 | 0 | 0 | -1053 | 24633 |
| 1993 | 2018 | 0 | 146 | 0 | 1000 | 11400 | -1067 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 0 | 9497 | 0 | 1005 | 0 | 0 | 0 | 0 | 0 | -1067 | 24025 |
| 1994 | 1149 | 0 | 157 | 0 | 901 | 11607 | -2716 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | 8999 | 0 | 1044 | 0 | 0 | 0 | 0 | 0 | -2717 | 21171 |
| 1995 | 1870 | 0 | 171 | 0 | 814 | 12011 | -2056 | -20 | 0 | 0 | 0 | 0 | 0 | 26 | 0 | 12038 | 0 | 1053 | 0 | 0 | 0 | 0 | 0 | -2058 | 25935 |
| 1996 | 1774 | 0 | 184 | 0 | 946 | 12257 | -847 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 0 | 11006 | 0 | 1054 | 0 | 0 | 0 | 0 | 0 | -867 | 26391 |
| 1997 | 1687 | 0 | 197 | 0 | 981 | 12307 | -2563 | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 0 | 9123 | 0 | 1078 | 0 | 0 | 0 | 0 | 0 | -2566 | 22847 |
| 1998 | 1239 | 0 | 207 | 0 | 717 | 12521 | -3330 | 0 | 0 | 0 | 0 | 0 | 0 | 35 | 0 | 11280 | 0 | 1121 | 0 | 0 | 0 | 0 | 0 | -3333 | 23799 |
| 1999 | 981 | 0 | 220 | 0 | 1010 | 13004 | -761 | 0 | 0 | 0 | 0 | 0 | 0 | 38 | 0 | 12429 | 0 | 1116 | 0 | 0 | 0 | 0 | 14 | -765 | 28050 |
| 2000 | 1918 | 0 | 234 | 0 | 599 | 13173 | -4253 | 0 | 0 | 0 | 0 | 0 | 0 | 42 | 0 | 9280 | 0 | 1170 | 0 | 0 | 0 | 0 | 11 | -4252 | 22178 |
| Average 1981-2000 | 1289 | 0 | 122 | 0 | 676 | 10419 | -1759 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 9595 | 0 | 962 | 0 | 0 | 0 | 0 | 0 | -1761 | 21330 |

## Version 12p: Impact of Kansas Pumping (acre-feet)

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 216 | 5205 | 0 | 0 | 0 | 0 | 298 | 214 | 0 | 230 | 0 | 4068 | 0 | 0 | -596 | 11006 | 0 | 0 | 359 | 0 | 26 | 0 | 0 | 741 | 21036 |
| 1982 | 192 | 5893 | 0 | 0 | 0 | 0 | 225 | -25 | 0 | 165 | 0 | 4542 | 0 | 0 | 2068 | 5907 | 0 | 0 | 486 | 0 | 24 | 0 | 0 | 365 | 19488 |
| 1983 | 96 | 5812 | 0 | 0 | 0 | 0 | 277 | -132 | 0 | 187 | 0 | 4086 | 0 | 0 | 2089 | 4280 | 0 | 0 | 453 | 0 | 21 | 0 | 0 | 332 | 17176 |
| 1984 | 151 | 5974 | 0 | 0 | 0 | 0 | 191 | -320 | 0 | 281 | 0 | 4055 | 0 | 0 | 2319 | 7733 | 0 | 0 | 754 | 0 | 20 | 0 | 0 | 152 | 21166 |
| 1985 | 153 | 5960 | 0 | 0 | 0 | 11 | 163 | 203 | 0 | 208 | 0 | 3525 | 0 | 0 | 2719 | 6660 | 0 | 0 | 654 | 0 | 19 | 0 | 0 | 573 | 20277 |
| 1986 | 126 | 4994 | 0 | 0 | 0 | 0 | 198 | -201 | 0 | 238 | 0 | 2195 | 0 | 0 | 905 | 6038 | 0 | 0 | 616 | 0 | 18 | 0 | 0 | 235 | 15141 |
| 1987 | 170 | 5169 | 0 | 0 | 0 | 13 | 168 | 76 | 0 | 213 | 0 | 4496 | 0 | 0 | 244 | 8101 | 0 | 0 | 551 | 0 | 17 | 0 | 0 | 458 | 19221 |
| 1988 | 154 | 4567 | 0 | 0 | 0 | 13 | 261 | -315 | 0 | 271 | 0 | 2498 | 0 | 0 | -112 | 7218 | 0 | 0 | 612 | 0 | 16 | 0 | 0 | 217 | 15187 |
| 1989 | 156 | 2321 | 0 | 0 | 0 | 15 | 185 | 190 | 0 | 213 | 0 | 751 | 0 | 0 | -803 | 6683 | 0 | 0 | 682 | 0 | 17 | 0 | 0 | 589 | 10414 |
| 1990 | 211 | 1150 | 0 | 0 | 0 | 14 | -27 | 123 | 0 | 233 | 0 | 780 | 0 | 0 | -758 | 9655 | 0 | 0 | 641 | 0 | 18 | 0 | 0 | 330 | 12046 |
| 1991 | 276 | 1223 | 0 | 0 | 0 | 21 | 163 | 20 | 0 | 252 | 0 | 2180 | 0 | 0 | -1024 | 10674 | 0 | 0 | 658 | 0 | 19 | 0 | 0 | 436 | 14468 |
| 1992 | 178 | 2904 | 0 | 0 | 0 | 12 | 426 | -50 | 0 | 50 | 0 | 4455 | 0 | 0 | -1726 | 6603 | 0 | 0 | 425 | 0 | 17 | 0 | 0 | 428 | 13302 |
| 1993 | 223 | 7614 | 0 | 0 | 0 | 0 | 236 | 124 | -14 | 18 | 0 | 14166 | 0 | 0 | 2795 | 8378 | 0 | 0 | 404 | 0 | 66 | 0 | 0 | 364 | 34024 |
| 1994 | 101 | 7570 | 0 | 0 | 0 | 0 | 236 | -221 | 0 | 188 | 0 | 6357 | 0 | 0 | 3782 | 3327 | 0 | 0 | 475 | 0 | 114 | 0 | 0 | 213 | 21949 |
| 1995 | 202 | 6882 | 0 | 0 | 0 | 12 | 19 | -369 | 0 | 218 | 0 | 3689 | 0 | 0 | 2176 | 8931 | 0 | 0 | 485 | 0 | 83 | 0 | 0 | -130 | 22336 |
| 1996 | 211 | 7005 | 0 | 0 | 0 | 16 | 326 | 328 | 0 | 218 | 0 | 5919 | 0 | 0 | 3011 | 7546 | 0 | 0 | 334 | 0 | 65 | 0 | 0 | 875 | 24988 |
| 1997 | 141 | 6815 | 0 | 0 | 0 | 14 | 232 | -395 | 0 | 178 | 0 | 4121 | 0 | 0 | 2476 | 5911 | 0 | 0 | 427 | 0 | 54 | 0 | 0 | 19 | 19984 |
| 1998 | 167 | 5618 | 0 | 0 | 0 | 12 | 39 | -386 | 0 | 168 | 0 | 2543 | 0 | 0 | 837 | 7752 | 0 | 0 | 404 | 0 | 48 | 0 | 0 | -176 | 17212 |
| 1999 | 239 | 5686 | 0 | 0 | 0 | 15 | 352 | -32 | 0 | 201 | 0 | 2479 | 0 | 0 | -198 | 8864 | 0 | 0 | 356 | 0 | 45 | 0 | 0 | 524 | 18019 |
| 2000 | 128 | 4560 | 0 | 0 | 0 | 15 | 159 | -224 | 0 | 257 | 0 | 1392 | 0 | 0 | -670 | 6320 | 0 | 0 | 407 | 0 | 42 | 0 | 0 | 196 | 12398 |
| Average 1981-2000 | 175 | 5146 | 0 | 0 | 0 | 12 | 206 | -70 | 0 | 199 | 0 | 3915 | 0 | 0 | 977 | 7379 | 0 | 0 | 509 | 0 | 37 | 0 | 0 | 337 | 18492 |

Appendix U    RRCA Model Impacts

## Version 12p: Impact of Nebraska Pumping (acre-feet)

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 261 | 5535 | 1400 | 835 | 50240 | 271 | 9755 | 40493 | 12594 | 1492 | 8786 | 0 | 4047 | 1101 | 1187 | 1004 | 840 | 0 | 0 | 1695 | 623 | 188 | 143 | 64334 | 142490 |
| 1982 | 211 | 5795 | 1476 | 830 | 51039 | 287 | 8711 | 31087 | 12456 | 1433 | 8595 | 0 | 3414 | 1282 | 2904 | 607 | 882 | 0 | 0 | 1802 | 672 | 207 | 136 | 53688 | 133825 |
| 1983 | 118 | 5301 | 1498 | 922 | 51364 | 356 | 7137 | 21529 | 13871 | 1541 | 8766 | 0 | 3131 | 1364 | 2865 | 612 | 926 | 0 | 0 | 1895 | 681 | 226 | 137 | 44077 | 124237 |
| 1984 | 181 | 5281 | 1550 | 1039 | 54366 | 390 | 9567 | 32874 | 14519 | 1380 | 9668 | 0 | 3700 | 1426 | 2909 | 673 | 994 | 0 | 0 | 2037 | 774 | 245 | 150 | 58340 | 143724 |
| 1985 | 191 | 5369 | 1647 | 1052 | 56320 | 435 | 10049 | 36237 | 14576 | 1552 | 10213 | 0 | 4168 | 1504 | 3263 | 727 | 1041 | 0 | 0 | 2200 | 713 | 266 | 157 | 62414 | 151681 |
| 1986 | 178 | 4546 | 1729 | 1073 | 57393 | 453 | 9138 | 28874 | 14815 | 1368 | 10678 | 0 | 4039 | 1590 | 2126 | 722 | 1109 | 0 | 0 | 2342 | 790 | 288 | 155 | 54195 | 143406 |
| 1987 | 190 | 4736 | 1799 | 1103 | 58503 | 516 | 9262 | 35060 | 15649 | 1398 | 11095 | 0 | 4227 | 1705 | 1461 | 730 | 1123 | 0 | 0 | 2440 | 715 | 308 | 154 | 61370 | 152176 |
| 1988 | 170 | 4097 | 1874 | 1098 | 59767 | 568 | 9340 | 30341 | 18179 | 1572 | 11387 | 0 | 4174 | 1833 | 1269 | 728 | 1171 | 0 | 0 | 2547 | 821 | 325 | 160 | 59432 | 151420 |
| 1989 | 164 | 2155 | 1940 | 1101 | 60367 | 603 | 9010 | 28409 | 17745 | 1691 | 11889 | 0 | 4153 | 1915 | 687 | 422 | 1263 | 0 | 0 | 2661 | 896 | 342 | 160 | 56855 | 147573 |
| 1990 | 204 | 1119 | 2056 | 1122 | 63991 | 692 | 10898 | 32804 | 18139 | 1603 | 12775 | 0 | 4550 | 2037 | 615 | 794 | 1336 | 0 | 0 | 2795 | 909 | 364 | 173 | 63445 | 158975 |
| 1991 | 298 | 1446 | 2221 | 1150 | 67075 | 693 | 12258 | 38384 | 20759 | 1985 | 13916 | 0 | 5185 | 2224 | 576 | 976 | 1421 | 0 | 0 | 2933 | 995 | 385 | 166 | 73386 | 175046 |
| 1992 | 210 | 3120 | 2297 | 1153 | 64303 | 689 | 10270 | 49739 | 18849 | 1723 | 13628 | 0 | 5476 | 2373 | 710 | 933 | 1307 | 0 | 0 | 3040 | 844 | 404 | 147 | 80581 | 181215 |
| 1993 | 192 | 7110 | 2286 | 1076 | 63516 | 693 | 8532 | 45586 | 16874 | 1404 | 12098 | 0 | 5083 | 2501 | 4354 | 806 | 1114 | 0 | 0 | 3081 | 642 | 409 | 131 | 72396 | 177488 |
| 1994 | 117 | 6727 | 2296 | 1044 | 67838 | 792 | 9125 | 28337 | 18763 | 1399 | 12198 | 0 | 4383 | 2563 | 4897 | 603 | 1349 | 0 | 0 | 3165 | 868 | 417 | 157 | 57624 | 167037 |
| 1995 | 233 | 6402 | 2413 | 1117 | 70355 | 848 | 10632 | 41753 | 22113 | 1905 | 13695 | 0 | 5471 | 2642 | 3552 | 889 | 1449 | 0 | 0 | 3300 | 957 | 436 | 155 | 76403 | 190318 |
| 1996 | 239 | 6270 | 2503 | 1146 | 70624 | 860 | 11074 | 52670 | 20709 | 1876 | 13687 | 0 | 5934 | 2775 | 4117 | 934 | 1363 | 0 | 0 | 3386 | 770 | 452 | 143 | 86330 | 201533 |
| 1997 | 164 | 5964 | 2568 | 1150 | 72910 | 970 | 10951 | 34408 | 22506 | 1830 | 13892 | 0 | 5313 | 2839 | 3495 | 853 | 1480 | 0 | 0 | 3464 | 963 | 464 | 162 | 69695 | 186346 |
| 1998 | 206 | 4978 | 2690 | 1196 | 73764 | 1045 | 10150 | 35058 | 21914 | 1726 | 14510 | 0 | 5338 | 2894 | 2419 | 806 | 1549 | 0 | 0 | 3606 | 949 | 483 | 180 | 68849 | 185461 |
| 1999 | 313 | 4870 | 2799 | 1171 | 75119 | 1030 | 12815 | 49574 | 21936 | 1793 | 13913 | 0 | 6346 | 3023 | 1149 | 1048 | 1345 | 0 | 0 | 3711 | 862 | 494 | 179 | 86117 | 203490 |
| 2000 | 196 | 3568 | 2912 | 1153 | 74876 | 1156 | 10260 | 30832 | 25316 | 1926 | 14585 | 0 | 5179 | 3125 | 792 | 982 | 1601 | 0 | 0 | 3848 | 989 | 505 | 220 | 68335 | 184022 |
| Average 1981-2000 | 202 | 4720 | 2098 | 1077 | 63186 | 667 | 9947 | 36203 | 18114 | 1630 | 11999 | 0 | 4666 | 2136 | 2267 | 792 | 1233 | 0 | 0 | 2797 | 822 | 360 | 158 | 65893 | 165073 |

Appendix U     RRCA Model Impacts

## Version 12p: Impact of Nebraska Imports (acre-feet)

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8539 | 49 | 0 | 6637 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8587 | 15236 |
| 1982 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6989 | 56 | 0 | 6719 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7045 | 13783 |
| 1983 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6355 | 63 | 0 | 6705 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6417 | 13140 |
| 1984 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6532 | 70 | 0 | 7122 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6600 | 13742 |
| 1985 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9461 | 80 | 0 | 7222 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9540 | 16787 |
| 1986 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5852 | 88 | 0 | 7195 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5939 | 13154 |
| 1987 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9202 | 100 | 0 | 7438 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9299 | 16759 |
| 1988 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6077 | 107 | 0 | 7604 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6181 | 13809 |
| 1989 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6178 | 114 | 0 | 7538 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6290 | 13849 |
| 1990 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7020 | 115 | 0 | 7662 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7133 | 14815 |
| 1991 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4515 | 113 | 0 | 8038 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4625 | 12688 |
| 1992 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6175 | 100 | 0 | 8371 | 0 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6272 | 14672 |
| 1993 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15487 | 191 | 0 | 8878 | 0 | 40 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15673 | 24611 |
| 1994 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7251 | 188 | 0 | 8467 | 0 | 30 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7435 | 15954 |
| 1995 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8908 | 189 | 0 | 8770 | 0 | 35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9094 | 17916 |
| 1996 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14968 | 219 | 0 | 9153 | 0 | 39 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15181 | 24395 |
| 1997 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7171 | 204 | 0 | 9020 | 0 | 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7372 | 16447 |
| 1998 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8578 | 174 | 0 | 8891 | 0 | 34 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8750 | 17694 |
| 1999 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8764 | 165 | 0 | 9482 | 0 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8925 | 18450 |
| 2000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9413 | 155 | 0 | 9058 | 0 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9564 | 18664 |
| Average 1981-2000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8172 | 127 | 0 | 7998 | 0 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8296 | 16328 |