First Annual Report for the Republican River Basin-Wide Plan

Data and Progress Updates, 2014–2018

Submitted at the First Annual Meeting

February 20, 2020

Jointly prepared by

Upper Republican Natural Resources District

Middle Republican Natural Resources District

Lower Republican Natural Resources District

Tri-Basin Natural Resources District

&

Nebraska Department of Natural Resources

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Introduction

The *Republican River Basin-Wide Plan* (basin-wide plan) was developed by the Nebraska Department of Natural Resources (NeDNR) and the Upper Republican, Middle Republican, Lower Republican, and Tri-Basin Natural Resources Districts (NRDs), in consultation and collaboration with a Stakeholder Advisory Committee. The time frame to implement the basin-wide plan is approximately 25 years, spanning from the effective date of the basin-wide plan (March 1, 2019) to April 17, 2044, which is 30 years after the operative date of LB 1098 (2014), as specified in *Neb. Rev. Stat.* § 46-755.

Action Item 3.2.2 of the basin-wide plan specifies that NeDNR and the NRDs will annually exchange reports containing data and information about water supplies and uses in the Republican River Basin, management activities, and progress toward the goals and objectives of the basin-wide plan. This report contains the data and information exchanged by NeDNR and the NRDs at the first annual meeting.

In future years, the annual report for the basin-wide plan will contain data and plan progress updates from a single, previous calendar year. For example, the second annual report will contain data and information about plan implementation progress for the 2019 calendar year. This first annual report is different, because it covers 2014–2018 (i.e., the first five years since the passage of LB 1098 (2014)), rather than only a single year.

Progress toward Goals, Objectives, and Action Items

Management Activities

Under *Neb. Rev. Stat.* § 46-755 (4), the basin-wide plan was required to include a timeline of up to 30 years after April 17, 2014, to meet the plan's goals and objectives. For the first five of those 30 years, 2014–2018, NeDNR and the NRDs worked together to develop and finalize the basin-wide plan, including the plan's goals, objectives, and action items. Plan development progress and accomplishments from 2014–2018 can be briefly summarized as follows:

- Planning preparation, April 2014–March 2015
    - Stakeholder Advisory Committee recruitment and compilation
    - Consultant selection
    - NeDNR and NRD coordination
- Plan development, January 2015–June 2018
    - 22 NeDNR/NRD Coordination meetings
    - 15 Stakeholder Advisory Committee meetings
- Plan finalization, June 2018–December 2018
    - Stakeholder Advisory Committee final votes
    - Public hearings and evaluation of testimony
    - Agreement by NeDNR and NRDs on final plan

The basin-wide plan took effect on March 1, 2019. Progress toward the goals, objectives, and action items for the 2014–2018 period consisted of developing, finalizing, and reaching agreement on them. Reporting on progress toward implementing the basin-wide plan's goals, objectives, and action items will begin in the second annual report. The second annual report will focus on 2019, the first year of plan implementation.

Assessment of Measurable Hydrologic Objectives (MHOs)

Under *Neb. Rev. Stat.* § 46-755 (4)(b), this basin-wide plan is required to include measurable hydrologic objectives (MHOs) to ensure that reasonable progress is being made toward achieving the goals and objectives of the plan. From 2014–2018, NeDNR and the NRDs worked together to develop and finalize the basin-wide plan, including the plan's MHOs.

There are five MHOs, which will each be evaluated either annually or every five years, as specified in the basin-wide plan. The MHOs and their assessment schedules are summarized in Table 1. Because the basin-wide plan took effect in 2019, there is no plan implementation progress to assess for the 2014–2018 period. Assessment of the MHOs will begin in the second annual report, which will focus on 2019, the first year of plan implementation.

Table 1. Measurable Hydrologic Objectives (MHOs) agreed to during plan development and adoption. During plan implementation, each MHO will be evaluated either annually or every 5 years, as specified in the basin-wide plan.

Measurable Hydrologic Objective (MHO)	Evaluation Frequency
MHO A: Maintain each NRD's net groundwater depletions to streamflow within its portion of Nebraska's allowable groundwater depletions to streamflow	Annually
MHO B: Limit groundwater depletions to streamflow to a relatively constant level over the long-term both across the basin as a whole and within each NRD	Every 5 years
MHO C: Ensure there is always enough groundwater for all groundwater uses within the timeframe of this plan, either by stabilizing groundwater levels or managing declining groundwater levels	Every 5 years
MHO D: Continue existing and initiate new actions that reduce the need for special regulations in the Rapid Response Area for Compact compliance	Annually
MHO E: Continue existing and initiate new actions that reduce the need for administration of surface water use for Compact compliance	Annually

For three of the MHOs (MHOs A, D, and E), the basin-wide plan included descriptions of how those MHOs will be assessed. The remaining two MHOs (MHOs B and C) are more technically complex. For those two MHOs, the basin-wide plan specifies that NeDNR and the NRDs would develop written procedures detailing analyses for those MHOs before the first annual meeting. The assessment procedures for MHO B are included in this report as Appendix A (page 45), and the assessment procedures for MHO C are included in this report as Appendix B (page 55). As agreed to in the basin-wide plan, these two procedural documents will also be appended to the plan as supplementary technical memorandums.

Water Supplies and Uses in the Basin

In accordance with the requirements of *Neb. Rev. Stat.* §§ 46-755 (5)(a) and 46-755 (5)(b), the basin-wide plan contains a monitoring plan, which includes a process to gather and evaluate data, information, and methodologies to increase understanding of the surface water and hydrologically connected groundwater system with the basin and to test the validity of the conclusions, information, and assumptions upon which the plan is based.

One component of the monitoring plan is a list of data on water supplies and uses in the Republican River Basin that will be reported annually by NeDNR and the NRDs (Table 3.1 of the basin-wide plan). As stated in the basin-wide plan's Monitoring section, it will take time for NeDNR and the NRDs to prepare each category of data for distribution; some of the listed data are readily available within existing data sets, while others will take significantly longer for methodology development. As a result, NeDNR and the NRDs will gradually increase the number of data items that will be reported on each year as they are able. In addition, as also noted in the plan, the list of data reported is subject to change as data needs and resources change over time.

This first annual report contains data for the years 2014–2018. The following data are included in this annual report:

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Upper Republican Natural Resources District

Current Allocations

Upper Republican NRD's allocations and related rules for the 2018–2022 allocation period are summarized in Table 2. In this context, an allocation is a regulatory measure that stipulates the amount of water available to be used for irrigation. Upper Republican NRD's allocations were the same for the 2013-2017 allocation period.

Table 2. Summary of current allocation for groundwater irrigation use in the Upper Republican NRD, 2018–2022 allocation period.

Total Allocation	65 Inches/Acre/5 Years
Annual or Base Allocation	Allocation is over 5 Years, not annual
Maximum Annual Use	65 Inches/Acre
Carry over amount that can be used in the following allocation period	7.5 Inches/Acre (Max)
Hard Cap	None
Pooling allowed?	Yes
How are the allocations affected by surface water use?	Allocations are not affected by surface water use. Irrigators may use their full groundwater allocation, regardless of any surface water use.
Special allocations for designated groundwater management areas? Or subbasins?	None
Rapid Response Area Allocations?	Not unless augmentation projects are insufficient to meet Compact obligations and Rapid Response Area allocations are needed. Allocations would depend upon projected Compact shortfalls.
Penalty for exceeding allocation	For every inch of excess use, 2 inches of allocation lost for next allocation period.
Penalty for exceeding carry over	2 inches carry-over deducted for every inch of carry-over used above 7.5 inches

Annual Groundwater Use for Irrigation

Annual groundwater use for irrigation in Upper Republican NRD, for 2014–2018, is summarized in Table 3. This summary includes:

- The total number of certified acres within the district. For the purposes of this report, certified acres are acres certified by the NRD to be allowed to be irrigated with groundwater.
- The total number of effective acres within the district. For the purposes of this report, effective acres are acres where groundwater irrigation was possible (i.e., certified acres minus acres enrolled in a conservation program prohibiting irrigation)
- The total volume of groundwater pumped for irrigation within the district.
- The average depth of water applied for irrigation on effective acres within the district.

Table 3. Annual groundwater use for irrigation in Upper Republican NRD, 2014–2018. The difference between certified and effective acres is described in the body of the report.

Year	Certified Acres	Effective Acres	Volume Pumped (acre-feet)	Average Depth (inches/effective acre)
2014	442,612	430,200	370,392	10.3
2015	442,372	429,980	434,374	12.1
2016	442,781	430,389	388,715	10.8
2017	442,243	430,131	440,644	12.3
2018	441,987	430,154	349,833	9.8

Conservation/Retirement Programs

Retired acres are acres enrolled in a program that prohibits the use of water for irrigation, either temporarily or permanently. Table 4 summarizes the number of acres within Upper Republican NRD that were enrolled in retirement programs, 2014–2018.

Table 4. Acres within the Upper Republican NRD that are retired from irrigation, either permanently or temporarily. During 2014–2018, retirement programs in effect in this NRD included the Cooperative Reserve Enhancement Program (CREP) and the Agricultural Water Enhancement Program (AWEP).

Year	Acres Enrolled in CREP	Acres Enrolled in Other Retirement Programs
2014	10,870	1,546 (AWEP)
2015	10,846	1,546 (AWEP)
2016	10,846	1,546 (AWEP)
2017	10,566	1,546 (AWEP)
2018	10,287	1,546 (AWEP)

Groundwater Levels and Observation Well Locations

The locations of wells used to monitor groundwater levels for all NRDs in the District are shown in Figure 1. Groundwater level data are provided to NeDNR by this NRD as part of the analysis of MHO C for the basin-wide plan. A summary of the data will be provided in the report of the next five-year technical analysis for the plan. Groundwater level data are available from the NRD upon request.

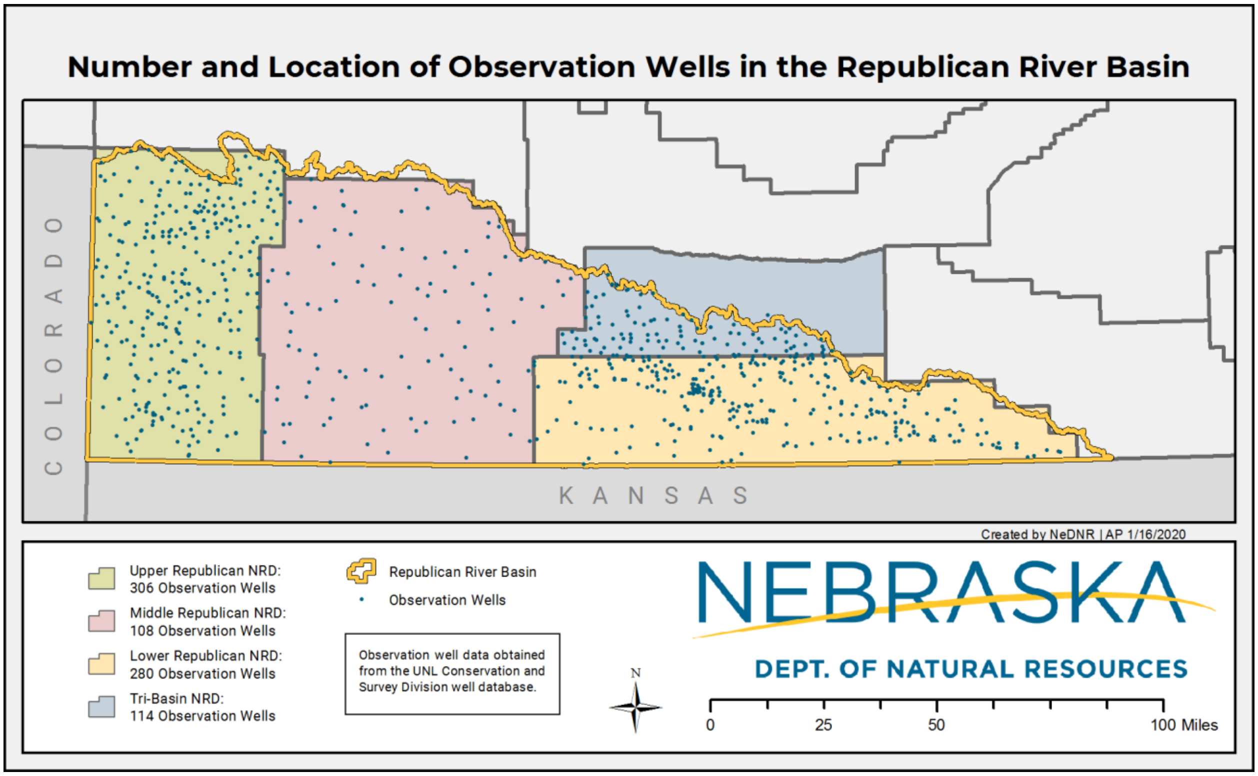

Figure 1. Location and number of groundwater observation wells within the Republican River Basin, by NRD, according to the UNL Conservation and Survey Division well database.

Curtailment of Groundwater Pumping for Compact Compliance

Under the Integrated Management Plan jointly developed by the Upper Republican NRD and NeDNR, curtailment of groundwater pumping in an area called the “Rapid Response Area” may be required by the NRD if necessary for compliance with Nebraska’s obligations under the Republican River Compact (Compact). During 2014–2018, Upper Republican NRD did not curtail groundwater pumping in the Rapid Response Area for Compact compliance at any time.

Middle Republican Natural Resources District

Current Allocations

Middle Republican NRD's allocations and related rules for the 2018–2022 allocation period are summarized in Table 5. In this context, an allocation is a regulatory measure that stipulates the amount of water available to be used for irrigation. Middle Republican NRD's allocations were the same for the 2013-2017 allocation period.

Table 5. Summary of current allocations for groundwater irrigation use in the Middle Republican NRD, 2018–2022 allocation period.

Total Allocation	60 Inches/Acre/5 Years
Annual or Base Allocation	12 Inches/Acre/Year
Maximum Annual Use	60 Inches/Acre (15 Inches/Acre in a Compact Call Year)
Carry over amount that can be used in the following allocation period	12 Inches/Acre (Max)
Hard Cap	15 Inches/Acre/Year
Pooling allowed?	Yes
How are the allocations affected by surface water use?	Allocations are not affected by surface water use. Irrigators may use their full groundwater allocation, regardless of any surface water use.
Special allocations for designated groundwater management areas? Or subbasins?	None
Rapid Response Area Allocations?	None
Penalty for exceeding allocation	See explanation below*
Penalty for exceeding carry over	See explanation below*

***Middle Republican NRD Penalty for exceeding allocation:**

If an operator has <u>exceeded</u> his or her allocation, the allocation for the next allocation period shall be reduced by the number of acre inches, by which said allocation was exceeded in the prior period. A penalty of 1 inch for every inch over the first 3 inches and 2 inches for every inch over 3 inches of overuse will be applied.

<u>Overuse</u> of the adjusted base allocation during a Compact Call Year shall result in a penalty of 2 inches for every inch over the first 3 inches and 3 inches for every inch over 3 inches of overuse will be applied. This penalty will result in a correction to the remaining allocation following the compact call year. This penalty shall be in addition to the penalties imposed by 5-4.16 if the compact call year is the last year of an allocation period.

Annual Groundwater Use for Irrigation

Annual groundwater use for irrigation in Middle Republican NRD, for 2014–2018, is summarized in Table 6. This summary includes:

- The total number of certified acres within the district. For the purposes of this report, certified acres are acres certified by the NRD to be allowed to be irrigated with groundwater.
- The total number of effective acres within the district. For the purposes of this report, effective acres are acres where groundwater irrigation was possible (i.e., certified acres minus acres enrolled in a conservation program prohibiting irrigation)
- The total volume of groundwater pumped for irrigation within the district.
- The average depth of water applied for irrigation on effective acres within the district.

Table 6. Annual groundwater use for irrigation in Middle Republican NRD, 2014–2018. The difference between certified and effective acres is described in the body of the report.

Year	Certified Acres	Effective Acres	Volume Pumped (acre-feet)	Average Depth (inches/effective acre)
2014	308,556.98	280,966.20	211,904.46	9.07
2015	297,136.02	282,613.86	229,514.28	9.75
2016	296,882.04	282,404.66	241,096.90	10.25
2017	296,801.43	281,904.14	254,656.21	10.84
2018	297,010.28	282,138.84	164,965.96	7.02

Conservation/Retirement Programs

Retired acres are acres enrolled in a program that prohibits the use of water for irrigation, either temporarily or permanently. Table 7 summarizes the number of acres within Middle Republican NRD that were enrolled in retirement programs, 2014–2018.

Table 7. Acres within the Middle Republican NRD that are retired from irrigation, either permanently or temporarily. During 2014–2018, retirement programs in effect in this NRD included the Cooperative Reserve Enhancement Program (CREP) and the Agricultural Water Enhancement Program (AWEP).

Year	Acres Enrolled in CREP	Acres Enrolled in Other Retirement Programs
2014	16,917	2,423
2015	16,739	3,949
2016	16,629	3,427
2017	15,550	5,903
2018	15,661	6,521

Groundwater Levels and Observation Well Locations

The locations of wells used to monitor groundwater levels for all NRDs in the District are shown in Figure 1 (page 11). Groundwater level data are provided to NeDNR by this NRD as part of the analysis of MHO C for the basin-wide plan. A summary of the data will be provided in the report of the next five-year technical analysis for the plan. Groundwater level data are available from the NRD upon request.

Curtailment of Groundwater Pumping for Compact Compliance

Under the Integrated Management Plan jointly developed by the Middle Republican NRD and NeDNR, curtailment of groundwater pumping in an area called the “Rapid Response Area” may be required by the NRD if necessary for compliance with Nebraska’s obligations under the Republican River Compact (Compact). During 2014–2018, Middle Republican NRD did not curtail groundwater pumping in the Rapid Response Area for Compact compliance at any time.

Lower Republican Natural Resources District

Current Allocations

Lower Republican NRD's allocations and related rules for the 2018–2022 allocation period are summarized in Table 8. In this context, an allocation is a regulatory measure that stipulates the amount of water available to be used for irrigation. Lower Republican NRD's allocations were the same for the 2013-2017 allocation period.

Table 8. Summary of current allocations for groundwater irrigation use in the Lower Republican NRD, 2018–2022 allocation period.

Total Allocation	45 Inches/Acre/5 Years
Annual or Base Allocation	9 Inches/Acre/Year
Maximum Annual Use	45 Inches/Acre (13 Inches/Acre in a Compact Call Year)
Carry over amount that can be used in the following allocation period	9 Inches/Acre (Max)
Hard Cap	13 Inches/Acre/Year (in a Compact Call Year)
Pooling allowed?	Yes
How are the allocations affected by surface water use?	Allocations are not affected by surface water use. Irrigators may use their full groundwater allocation, regardless of any surface water use.
Special allocations for designated groundwater management areas? Or subbasins?	None
Rapid Response Area Allocations?	See explanation below**
Penalty for exceeding allocation	See penalty explanation below***
Penalty for exceeding carry over	See penalty explanation below***

***Lower Republican NRD Rapid Response Area Allocations:**

During Non-Compact Call years, the Rapid Response Area has the same Allocation as the rest of the District. During a Compact Call Year, the Allocation shall be set at the maximum allowable that would not cause the District's depletions to streamflow to exceed the District's allowable Ground Water depletions after taking into consideration other actions and controls that the District would implement. As set forth in the IMP, DNR will perform all calculations relating to the District's forecasted allowable Ground Water depletions, forecasted depletions, and potential yield from implementing actions and controls.

*****Lower Republican NRD Rule 3-2 Penalties:**

3-2.1. Unless otherwise provided, imposition of penalties shall be at the discretion of the Board and may include, but are not limited to:

(a) A reduction (in whole or in part) of a Person's Allocation of Ground Water;
(b) A reduction (in whole or in part) of a Person's Certified Irrigated Acres; and
(c) Decommissioning of Water Wells.

3-2.2. Where penalties are enumerated in the Rules and Regulations, the Board may impose additional penalties, up to and including a permanent forfeiture of Certified Irrigated Acres, and/or a permanent forfeiture of all future Allocations, under the following circumstances: (1) previous violations of any Rule or Regulation, (2) multiple violations of these Rules and Regulations, (3) engaging in willful and wanton misconduct, or (4) certification by the record owner to the District of the non-irrigation status of certain Certified Irrigated Acres in order to opt-out of an Occupation Tax levied by the District, which status is later found to be false in whole or in part.

3-2.3. Any Person who violates a cease and desist order issued by the District pursuant to *Neb. Rev. Stat.* § 46- 707(h) may be subject to a civil penalty assessed pursuant to *Neb. Rev. Stat.* § 46-745.

Annual Groundwater Use for Irrigation

Annual groundwater use for irrigation in Lower Republican NRD, for 2014–2018, is summarized in Table 9. This summary includes:

- The total number of certified acres within the district. For the purposes of this report, certified acres are acres certified by the NRD to be allowed to be irrigated with groundwater.
- The total number of effective acres within the district. For the purposes of this report, effective acres are acres where groundwater irrigation was possible (i.e., certified acres minus acres enrolled in a conservation program prohibiting irrigation)
- The total volume of groundwater pumped for irrigation within the district.
- The average depth of water applied for irrigation on effective acres within the district.

Table 9. Annual groundwater use for irrigation in Lower Republican NRD, 2014–2018. The difference between certified and effective acres is described in the body of the report.

Year	Certified Acres	Effective Acres	Volume Pumped (acre-feet)	Average Depth (inches/effective acre)
2014	320,562.69	306,505.58	144,201.12	5.65
2015	320,318.79	310,441.06	188,869.29	7.30
2016	320,362.37	310,740.50	206.894.17	7.99
2017	320,208.13	310,613.67	167,629.89	6.48
2018	320,092.49	310,156.61	125,725.60	4.86

Conservation/Retirement Programs

Retired acres are acres enrolled in a program that prohibits the use of water for irrigation, either temporarily or permanently. Table 10 summarizes the number of acres within Lower Republican NRD that were enrolled in retirement programs, 2014–2018.

Table 10. Acres within the Lower Republican NRD that are retired from irrigation, either permanently or temporarily. During 2014–2018, retirement programs in effect in this NRD included the Cooperative Reserve Enhancement Program (CREP) and the Agricultural Water Enhancement Program (AWEP).

Year	Acres Enrolled in CREP	Acres Enrolled in Other Retirement Programs
2014	7749	6,308
2015	7,754	2,124
2016	7,509	2,122
2017	7,551	2,044
2018	7,928	2,008

Groundwater Levels and Observation Well Locations

The locations of wells used to monitor groundwater levels for all NRDs in the District are shown in Figure 1 (page 11). Groundwater level data are provided to NeDNR by this NRD as part of the analysis of MHO C for the basin-wide plan. A summary of the data will be provided in the report of the next five-year technical analysis for the plan. Groundwater level data are available from the NRD upon request.

Curtailment of Groundwater Pumping for Compact Compliance

Under the Integrated Management Plan jointly developed by the Lower Republican NRD and NeDNR, curtailment of groundwater pumping in an area called the “Rapid Response Area” may be required by the NRD if necessary for compliance with Nebraska’s obligations under the Republican River Compact (Compact). During 2014–2018, Lower Republican NRD did not curtail groundwater pumping in the Rapid Response Area for Compact compliance at any time.

Tri-Basin Natural Resources District

Current Allocations

Tri-Basin NRD's allocations and related rules for the 2018–2020 allocation period are summarized in Table 11. In this context, an allocation is a regulatory measure that stipulates the amount of water available to be used for irrigation. Tri-Basin NRD's allocations were the same for the 2012-2014 and 2015-2017 allocation periods.

Table 11. Summary of current allocations for groundwater irrigation use in the Tri-Basin NRD, 2018–2020 allocation period.

Total Allocation	27 Inches/Acre/3 Years
Annual or Base Allocation	9 Inches/Acre/Year
Maximum Annual Use	27 Inches/Acre
Carry over amount that can be used in the following allocation period	9 Inches/Acre (Max)
Hard Cap	None
Pooling allowed?	Yes
How are the allocations affected by surface water use?	Allocations are not affected by surface water use. Irrigators may use their full groundwater allocation, regardless of any surface water use.
Special allocations for designated groundwater management areas? Or subbasins?	Allocation only required in Phase 3 groundwater quantity management areas. Current Phase 3 area is Township 5 North, Range 22 West (Union Twp.) in Gosper County.
Rapid Response Area Allocations?	None
Penalty for exceeding allocation	1.5 times the overuse amount
Penalty for exceeding carry over	1.5 times the overuse amount

Annual Groundwater Use for Irrigation

Annual groundwater use for irrigation in Tri-Basin NRD, for 2014–2018, is summarized in Table 12. This summary includes:

- The total number of certified acres within the district. For the purposes of this report, certified acres are acres certified by the NRD to be allowed to be irrigated with groundwater.
- The total number of effective acres within the district. For the purposes of this report, effective acres are acres where groundwater irrigation was possible (i.e., certified acres minus acres enrolled in a conservation program prohibiting irrigation)
- The total volume of groundwater pumped for irrigation within the district.
- The average depth of water applied for irrigation on effective acres within the district.

Table 12. Annual groundwater use for irrigation in the Republican River Basin portion of Tri-Basin NRD, 2014–2018. The difference between certified and effective acres is described in the body of the report.

Year	Certified Acres	Effective Acres	Volume Pumped (acre-feet)	Average Depth (inches/effective acre)
2014	189647.14	187870.54	97774	6.25
2015	189969.1	188192.50	137221	8.75
2016	189982.99	188206.39	162157	10.34
2017	189882.31	188228.31	117370	7.48
2018	190260.62	188606.62	81306	5.17

Conservation/Retirement Programs

Retired acres are acres enrolled in a program that prohibits the use of water for irrigation, either temporarily or permanently. Table 13 summarizes the number of acres within the Republican River Basin portion of Tri-Basin NRD that were enrolled in retirement programs, 2014–2018.

Table 13. Acres within the Republican River Basin portion of Tri-Basin NRD that are retired from irrigation, either permanently or temporarily. During 2014–2018, retirement programs in effect in this NRD included the Cooperative Reserve Enhancement Program (CREP).

Year	Acres Enrolled in CREP	Acres Enrolled in Other Retirement Programs
2014	1,602	None
2015	1,602	None
2016	1,570	None
2017	1,752	None
2018	1,831	None

Groundwater Levels and Observation Well Locations

The locations of wells used to monitor groundwater levels for all NRDs in the District are shown in Figure 1 (page 11). Groundwater level data are provided to NeDNR by this NRD as part of the analysis of MHO C for the basin-wide plan. A summary of the data will be provided in the report of the next five-year technical analysis for the plan. Groundwater level data are available from the NRD upon request.

Nebraska Department of Natural Resources

The Republican River Basin is located at the intersection of Nebraska, Colorado, and Kansas (Table 14 and Figure 2). The Republican River Compact (Compact), administered by the Republican River Compact Administration (RRCA) is an interstate agreement that allocates consumption of the waters of the Republican River Basin among the three states. Unless otherwise indicated, the data reported in the NeDNR section of this report are either from the RRCA's approved accounting data or the data Nebraska provided to Colorado and Kansas as part of the RRCA's annual data exchange, or else they were calculated from those data using the RRCA groundwater model.

Table 14. Area of Nebraska, Kansas, and Colorado within the Republican River Basin (USGS Hydrologic Unit Code: 102500).

State	Republican River Basin Area (mi^2)
Colorado	7,816
Kansas	7,551
Nebraska	9,546

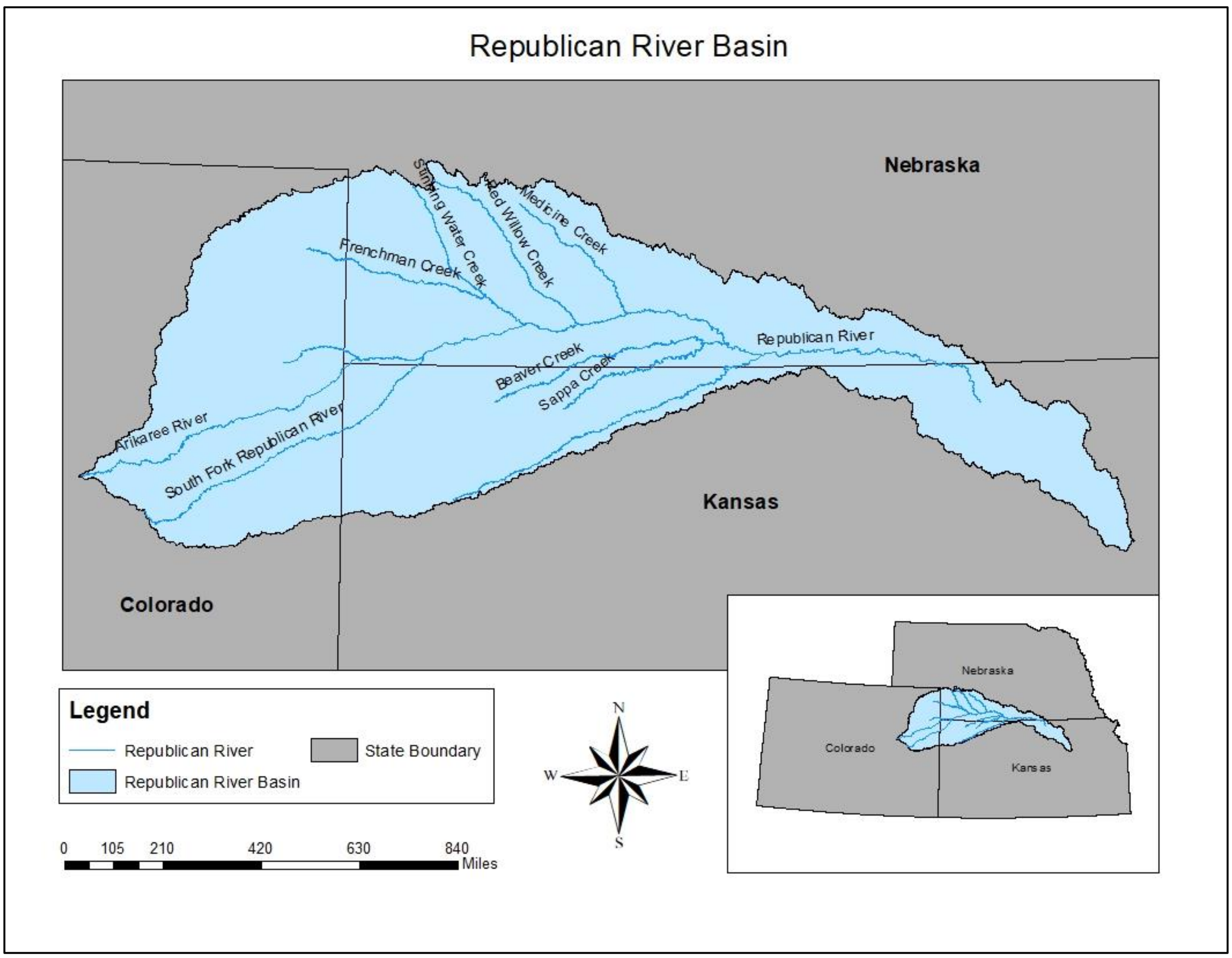

Figure 2. Extent of Republican River Basin within Nebraska, Kansas, and Colorado (USGS Hydrologic Unit Code: 102500).

Precipitation

From 2014–2018, annual precipitation measured at National Weather Service cooperative stations across the Republican River Basin in Nebraska, as used in RRCA analyses, ranged from 15.04 inches (in 2017) to 36.43 inches (in 2015) per year for a single station. Figure 3 displays the 2014–2018 annual distribution of precipitation across the Nebraska stations. Figure 4 displays the 2018 precipitation at each of the cooperative stations used by the RRCA. Additional stations outside of Nebraska and the basin are used by the RRCA to fill in precipitation across the whole RRCA model area which extends beyond the basin boundary.

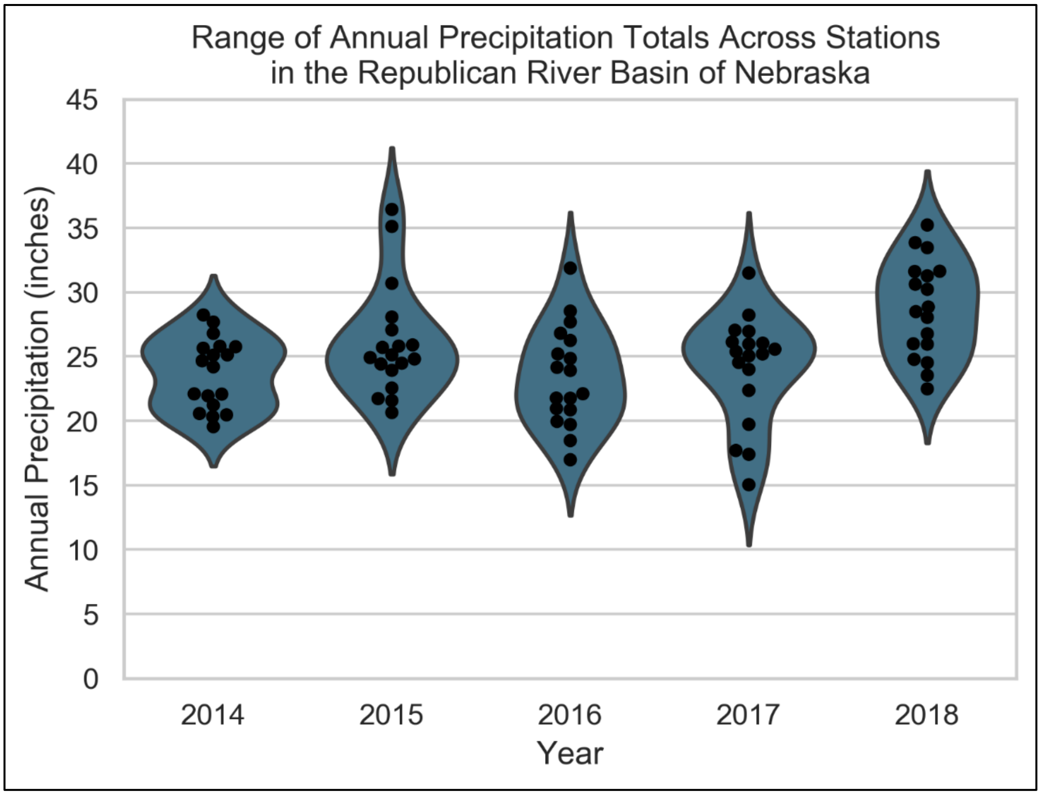

Figure 3. Annual distribution of precipitation measured at National Weather Service cooperative stations across the Republican River Basin in Nebraska, as used in Republican River Compact Administration analyses. The points for each year represent the entire range of precipitation across the stations; the width of the shape represents a smoothed frequency of the stations' annual precipitation

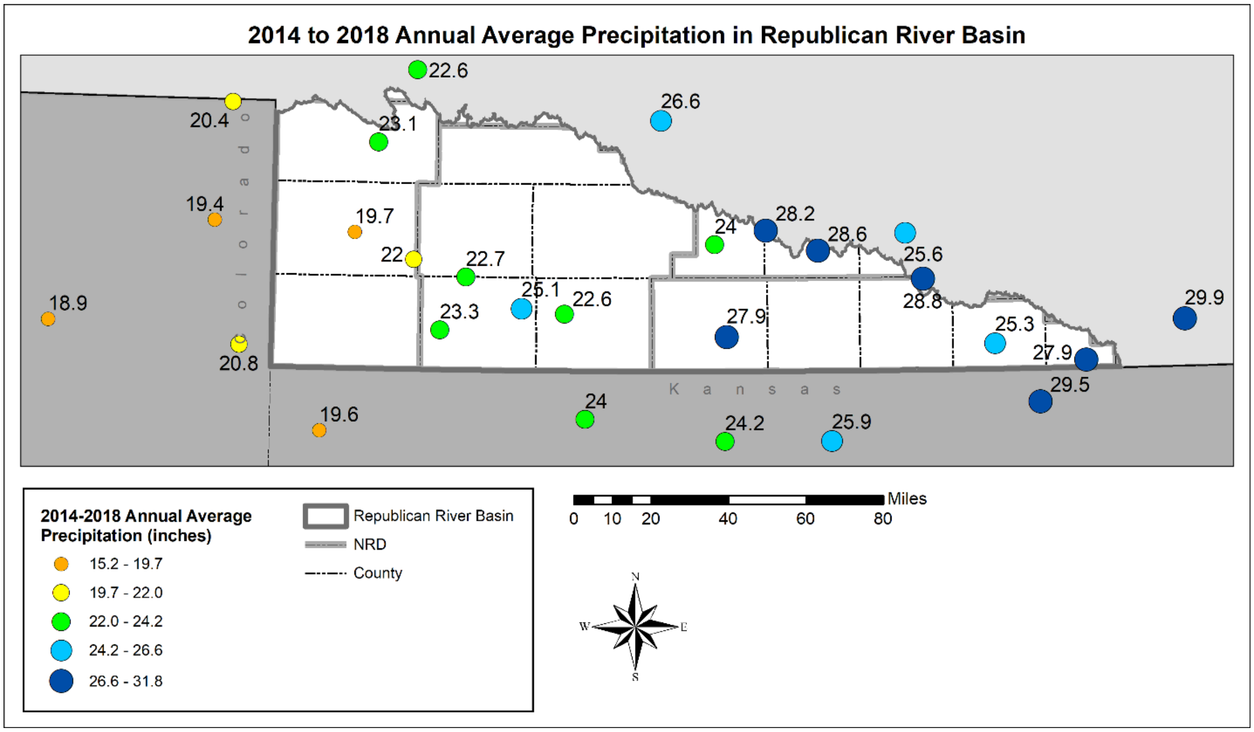

Figure 4. 2014–2018 annual average precipitation in inches from National Weather Service cooperative stations, as used in RRCA groundwater model processing.

Streamflow

Under the Republican River Compact, allocations within each Republican River subbasin include the streamflow at the downstream end of the subbasin. Subbasin streamflow is measured for the Compact by 13 USGS gages and one NeDNR gage (Figure 5 and Tables 15 and 16). The most downstream streamgages in Nebraska are on the Main Stem of the Republican River at Guide Rock and Hardy. Tables 15 and 16 present the total amount of water in acre-feet and average discharge in cubic feet per second (cfs), respectively, measured past each of the streamgages from 2014–2018. For more details and to obtain continuous stream and reservoir, partial year, canal, canal return flow, and miscellaneous spot measurement data from over 250 gaging sites visit the NeDNR website: https://nednr.nebraska.gov/RealTime/.

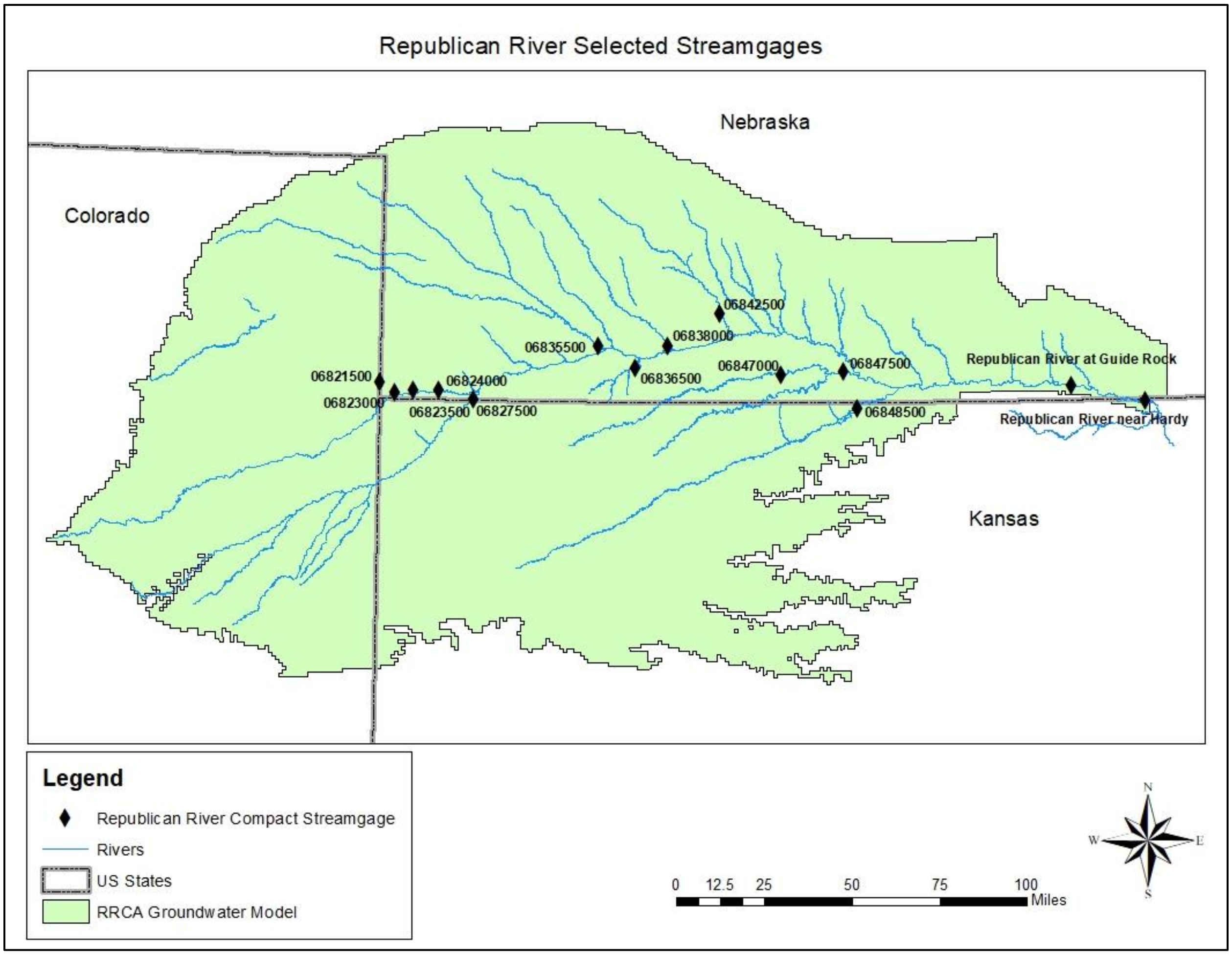

Figure 5. Location of subbasin streamgages within the Republican River Basin

Table 15. Annual streamflow volumes in acre-feet from Republican River subbasin streamgages used in the Republican River Compact accounting.

	Annual Streamflow (acre-feet)				
Streamgage	**2014**	**2015**	**2016**	**2017**	**2018**
USGS 06823000 - North Fork of the Republican River at Colorado-Nebraska State Line	26,707	27,895	28,091	26,046	32,580
USGS 06821500 - Arikaree River at Haigler	0	142	397	646	821
USGS 06823500 - Buffalo Creek near Haigler	1,463	1,623	1,536	1,282	1,858
USGS 06824000 - Rock Creek at Parks	23,088	5,644	4,613	8,686	4,095
USGS 06827500 - South Fork Republican River near Benkelman	0	4,819	3,898	2,385	1,970
USGS 06835500 - Frenchman Creek at Culbertson	31,021	19,213	18,852	27,490	25,906
USGS 06836500 - Driftwood Creek near McCook	1,232	2,454	3,280	2,392	3,911
USGS 06838000 - Red Willow Creek near Red Willow	7,643	3,460	3,936	4,346	3,932
NeDNR 06842500 - Medicine Creek below Harry Strunk Lake	40,561	56,850	57,014	41,207	25,135
USGS 06847000 - Beaver Creek near Beaver City	412	652	809	1,082	1,023
USGS 06847500 - Sappa Creek near Stamford	1,687	3,679	5,376	8,238	12,574
USGS 06848500 - Prairie Dog Creek near Woodruff, Kansas	1,363	1,445	2,839	2,181	4,205
USGS 06853020 - Republican River at Guide Rock	35,041	29,772	47,639	94,437	63,585
USGS 06853500 - Republican River near Hardy	50,362	104,931	80,515	127,121	110,861

Table 16. Annual average streamflow rates in cfs from Republican River subbasin streamgages used in the Republican River Compact accounting.

	Annual Streamflow (cfs)				
Streamgage	**2014**	**2015**	**2016**	**2017**	**2018**
USGS 06823000 - North Fork of the Republican River at Colorado-Nebraska State Line	37	39	39	36	45
USGS 06821500 - Arikaree River at Haigler	0	0	1	1	1
USGS 06823500 - Buffalo Creek near Haigler	2	2	2	2	3
USGS 06824000 - Rock Creek at Parks	32	8	6	12	6
USGS 06827500 - South Fork Republican River near Benkelman	0	7	5	3	3
USGS 06835500 - Frenchman Creek at Culbertson	43	27	26	38	36
USGS 06836500 - Driftwood Creek near McCook	2	3	5	3	5
USGS 06838000 - Red Willow Creek near Red Willow	11	5	5	6	5
NeDNR 06842500 - Medicine Creek below Harry Strunk Lake	56	79	79	57	35
USGS 06847000 - Beaver Creek near Beaver City	1	1	1	1	1
USGS 06847500 - Sappa Creek near Stamford	2	5	7	11	17
USGS 06848500 - Prairie Dog Creek near Woodruff, Kansas	2	2	4	3	6
USGS 06853020 - Republican River at Guide Rock	48	41	66	130	88
USGS 06853500 - Republican River near Hardy	70	145	111	176	153

Irrigated Acres

For the Republican River Compact Administration Groundwater Model, Nebraska currently reports irrigated acres as one of the following:

1. Groundwater-only irrigated acres.
2. Surface water-only irrigated acres or surface water and groundwater (commingled) irrigated acres.

Acres irrigated with groundwater are reported with metered pumping annually by the Natural Resources Districts to the Department, or are estimated for the portions of the RRCA model area that are in NRDs without metered pumping. Acres irrigated with surface water and commingled are flagged annually based on use from a master database developed from water right information. Annual irrigated acres within the RRCA model from 2014–2018 have been divided into the two reporting methods and groundwater acres have been delineated by the NRD that the model cells primarily overlay (Figure 6). Nebraska annual total surface water and commingled and total groundwater irrigated acres are also presented in Table 17.

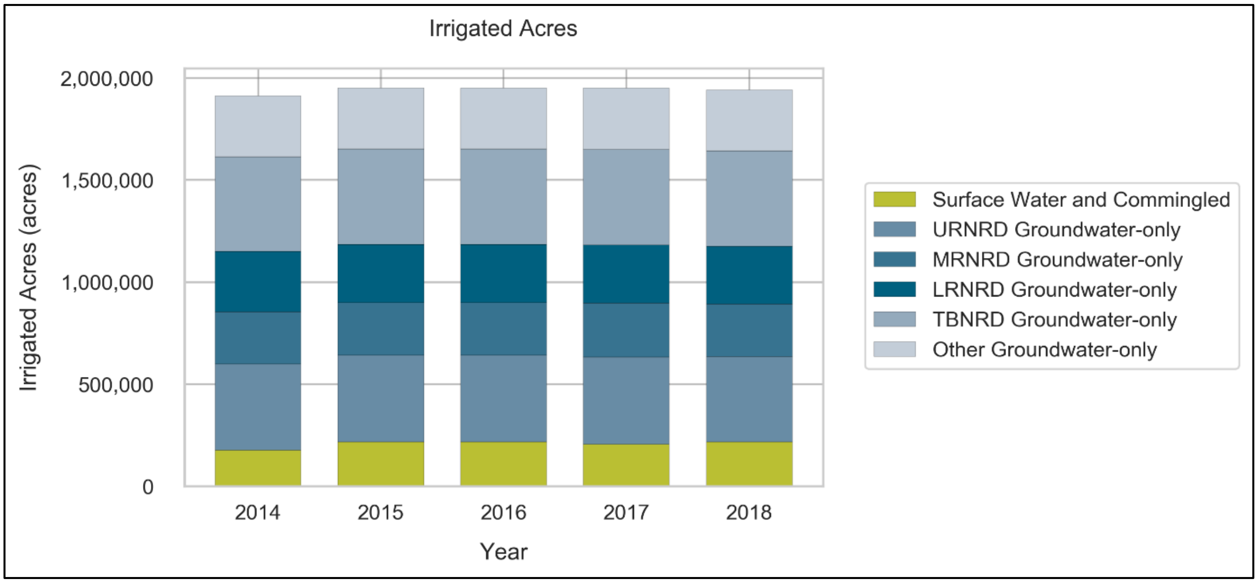

Figure 6. Annual acres irrigated by surface water and commingled (surface water and groundwater irrigated) or acres irrigated by only groundwater, delineated by the NRD that the model cells primarily overlay in the Nebraska portion of the RRCA groundwater model. Because all of Tri-Basin NRD (TBNRD) is included in the RRCA groundwater model area, the groundwater-irrigated acres shown here for Tri-Basin NRD include acres that are located in the Platte, Little Blue, and Republican River Basins.

Table 17. Annual division of acres irrigated by surface water and commingled (surface water and groundwater irrigated) or acres irrigated by only groundwater in the Nebraska portion of the RRCA groundwater model. Because all of Tri-Basin NRD is included in the RRCA groundwater model area, the groundwater-irrigated acres shown here for Tri-Basin NRD include acres that are located in the Platte, Little Blue, and Republican River Basins.

Area and Irrigation Type	2014	2015	2016	2017	2018
Nebraska Model Area – Surface Water and Commingled	175,233	215,389	215,869	205,121	215,874
Upper Republican NRD – Groundwater-only	423,772	426,887	426,887	427,746	419,912
Middle Republican NRD – Groundwater-only	255,374	256,586	256,554	264,815	256,027
Lower Republican NRD – Groundwater-only	295,198	284,538	284,284	285,131	283,447
Tri-Basin NRD – Groundwater-only	464,398	468,200	468,200	468,208	468,176
Other – Groundwater-only	298,948	299,346	299,346	299,350	299,345

Allocation and Computed Beneficial Consumptive Use (CBCU)

Under the Republican River Compact, the total water supply and how much of the total supply each state is entitled to beneficially use is referred to as “Allocation.” The allocations are calculated from the water supply of the basin if it had been undepleted by the activities of man. Each state is allotted a fixed percentage of the undepleted water supply in each of the Republican River subbasins to obtain the states’ allocations. The calculated uses of the water supplies are referred to as “Computed Beneficial Consumptive Use” or “CBCU”. The CBCU in the Republican River Basin includes direct surface water uses, such as reservoir evaporation and consumption of diverted water, and withdrawal or interception of streamflow by groundwater pumping (groundwater depletions to streamflow). Groundwater pumping can have a lagged effect on streamflow. The RRCA groundwater model considers the effects of pumping since early well development in the 1940s, therefore, the groundwater consumptive use of streamflow in each year is impacted by pumping in that year and all previous years. Table 18 presents total CBCU in Colorado, total CBCU in Kansas, and the breakdown of total CBCU as surface water or groundwater CBCU from Nebraska. Nebraska groundwater CBCU are presented for the effects of pumping from each basin NRD separately (Upper Republican, Middle Republican, Lower Republican, and Tri-Basin NRDs) and all other NRDs within the model area collectively (Other NRD) in Table 18. Each NRD’s groundwater CBCU is equivalent to the net depletions to streamflow due to groundwater pumping within that NRD.

Table 18. Annual total Computed Beneficial Consumptive Use (CBCU) by Kansas and Colorado and annual Nebraska total surface water CBCU and division of groundwater CBCU (i.e., net depletions to streamflow) by each NRD. The sum of Nebraska CBCU presented in this table may vary slightly from the statewide CBCU in Nebraska's Compact compliance tables due to rounding.

	CBCU (acre-feet)				
	2014	2015	2016	2017	2018
Colorado	32,100	33,780	33,930	31,810	35,130
Kansas	60,060	50,890	51,320	62,040	51,450
Nebraska Surface Water	20,603	45,820	51,038	47,924	43,733
Lower Republican NRD Groundwater	44,218	49,336	51,221	49,298	51,418
Middle Republican NRD Groundwater	50,429	54,705	56,353	52,594	66,622
Upper Republican NRD Groundwater	79,170	79,883	83,551	78,367	87,235
Tri-Basin NRD Groundwater	9,819	11,979	12,032	11,976	14,779
Other NRD Groundwater	1,778	1,822	1,929	1,987	2,284

Reservoir Storage and Evaporation

Federal Reservoir Storage

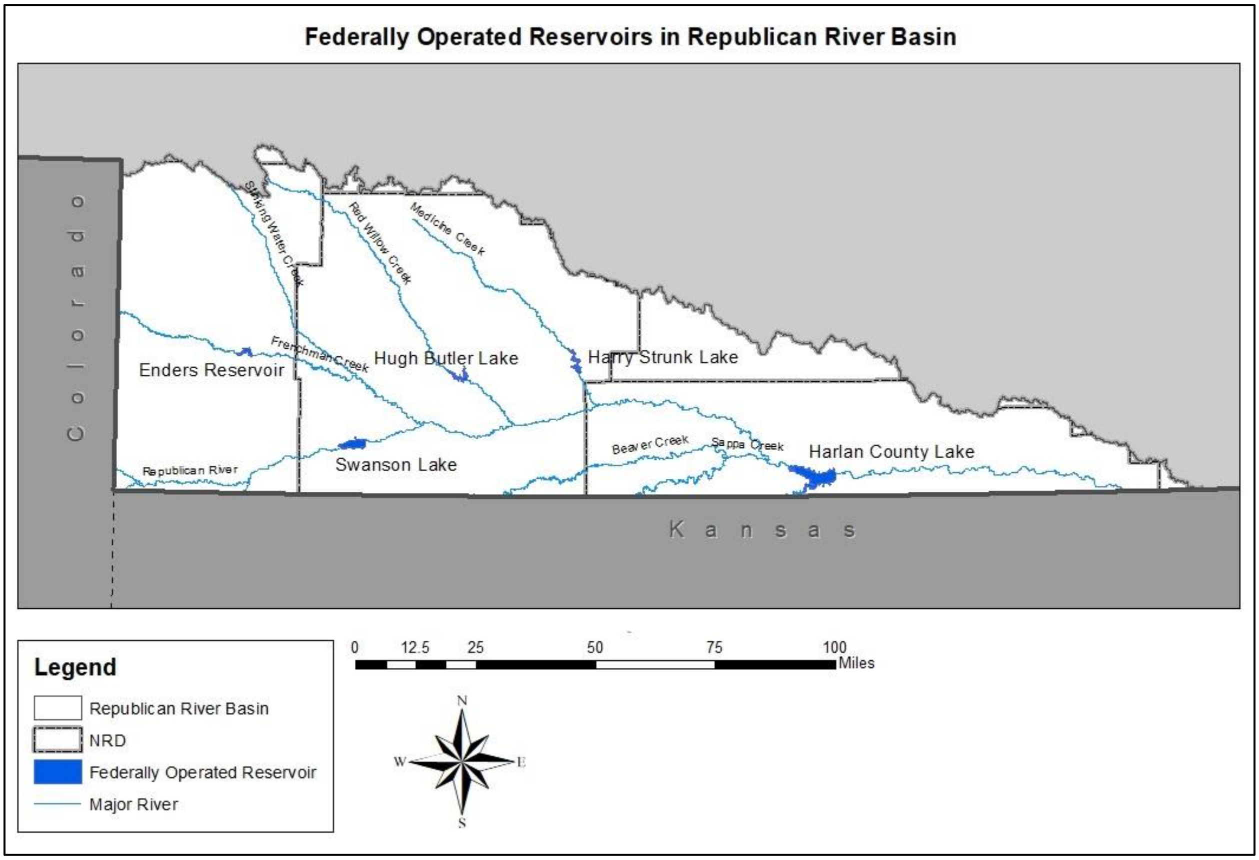

Figure 7. Location of federal reservoirs located in Nebraska portion of the Republican River Basin.

There are five federally operated reservoirs within the Republican River Basin in Nebraska: Enders Reservoir on Frenchman Creek, Hugh Butler Reservoir on Red Willow Creek, Harry Strunk Reservoir on Medicine Creek, and Swanson Lake and Harlan County Lake on the Republican River (Figure 7). Annual end of year storage volumes from 2014–2018 for each Republican River Basin reservoir in Nebraska are shown in Figure 8. Storage data were obtained from the United State Bureau of Reclamation (USBR), which are available on the USBR's automated data system HydroMet at https://www.usbr.gov/gp/hydromet/.

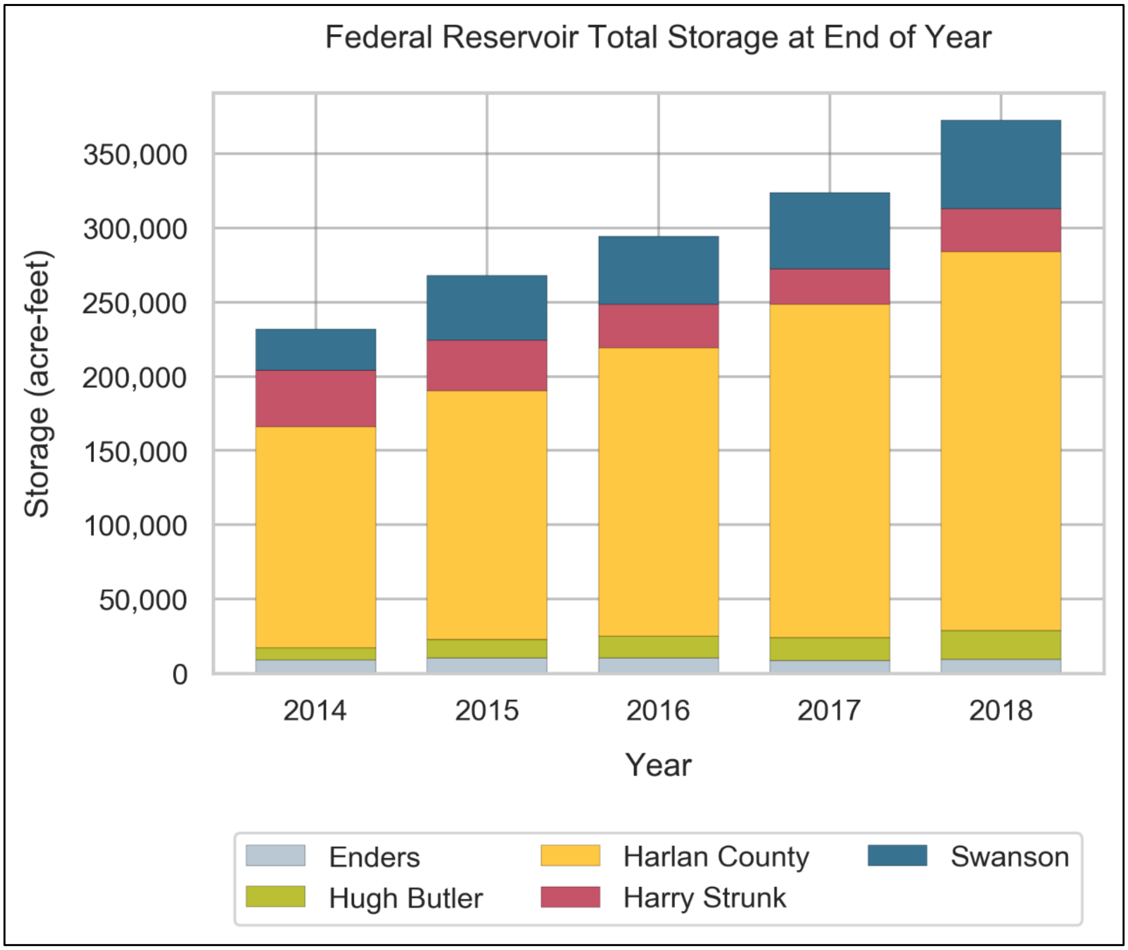

Figure 8. End-of-year reservoir contents for the federally operated reservoirs within the Republican River Basin in Nebraska: Enders Reservoir on Frenchman Creek, Hugh Butler Reservoir on Red Willow Creek, Harry Strunk Reservoir on Medicine Creek, and Swanson Lake and Harlan County Lake on the Republican River.

Reservoir Evaporation

From 2014–2018, net evaporation from the five federal reservoirs in Nebraska averaged 20,701 acre-feet and 1,533 acre-feet annually from non-federal reservoirs. Federal and non-federal reservoir evaporation are beneficial consumptive uses of surface water. For the RRCA, federal and non-federal reservoir CBCU are calculated as net evaporation, which is evaporation from the reservoir minus precipitation directly intercepted by the reservoir. Figure 9 displays the net evaporation from 2014–2018, broken down into evaporation that occurs from non-federal reservoirs and federal reservoirs located in the Republican River Basin in Nebraska.

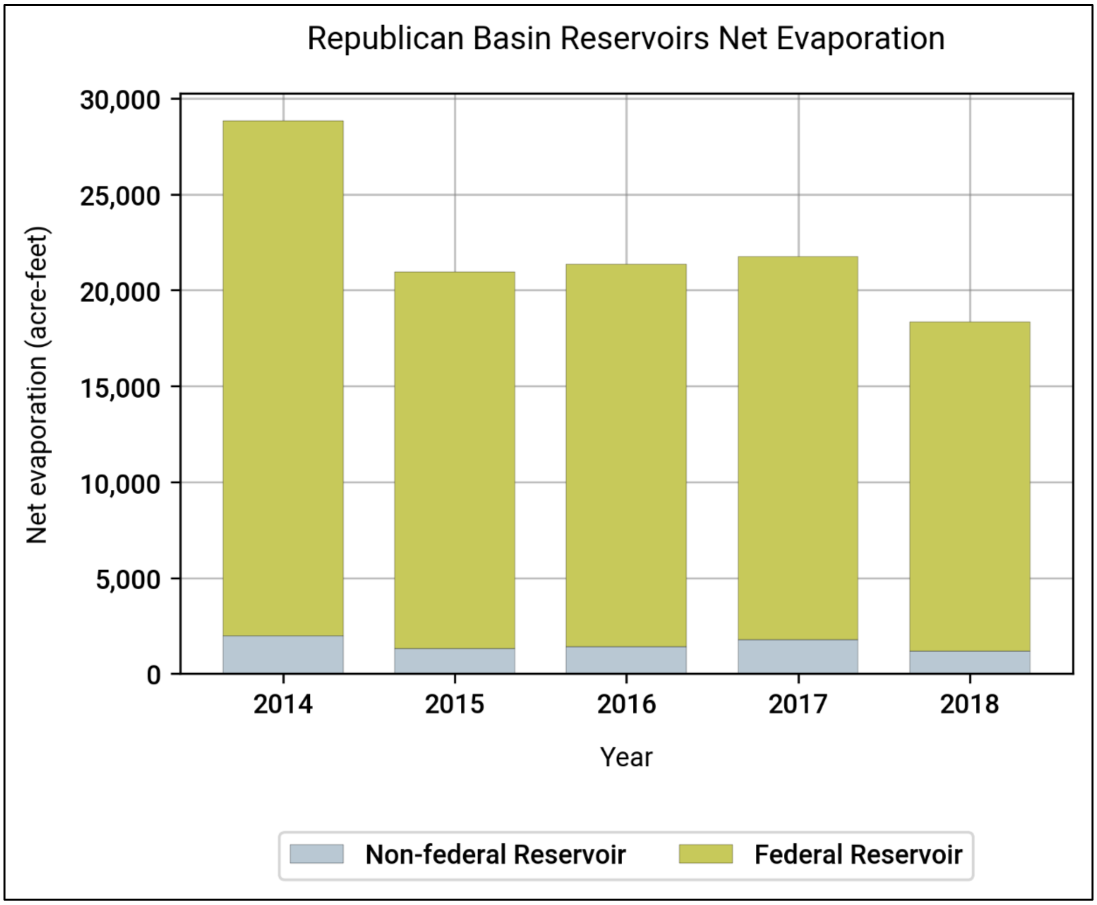

Figure 9. Total volumes of annual net evaporation (evaporation minus direct precipitation) from non-federal reservoirs and the five federal reservoirs in the Nebraska portion of the Republican River Basin.

Surface Water Municipal and Industrial CBCU

During the reporting year, there were no permitted municipal nor industrial uses of surface water in the Republican River Basin. For more information on surface water permitting, visit NeDNR's Surface Water Permitting and Data website at: https://dnr.nebraska.gov/surface-water.

Surface Water Administration for Compact Compliance

Under the Integrated Management Plans jointly developed by NeDNR and the Upper Republican, Middle Republican, and Lower Republican NRDs, NeDNR may administer and regulate surface water if necessary to ensure compliance with Nebraska's obligations under the Compact during Compact Call Years. Compact Call Years are years in which NeDNR's analysis following the forecast procedures contained in the Integrated Management Plans for the Upper Republican, Middle Republican, and Lower Republican NRDs indicate the potential for noncompliance with the Compact if sufficient management actions are not taken. Water administration for Compact compliance due to a Compact Call occurring in 2014–2018 is summarized in Table 19. Administration for Compact compliance due to a Compact Call is considered a management action for the purposes of evaluating the basin-wide plan's MHO E.

Surface water is also administered under the Water-Short Year provisions of the Final Settlement Stipulation (FSS) for the Compact. This type of water administration is triggered automatically under the terms of the FSS: whenever the projected or actual irrigation supply available in Harlan County Lake is less than 130,000 acre-feet and water is needed for direct diversion at Guide Rock, Nebraska must close appropriations downstream of Harlan County Lake that are junior to February 26, 1948. Because this type of water administration is triggered automatically, it is not considered a management action for the purposes of evaluating the basin-wide plan's MHO E.

Table 19. Surface Water Administration in the Republican River Basin for Compliance with the Republican River Compact (Compact), 2014–2018. A Compact Call can be issued during Compact Call years if necessary to ensure compliance with Nebraska's obligations under the Compact. Compact Call Years are years in which NeDNR's analysis following the forecast procedures contained in the basin's Integrated Management Plans indicate the potential for noncompliance with the Compact if sufficient management actions are not taken.

Year	Water Administration for Compact Compliance due to Compact Call
2014	January 1, 2014: closing notice mailed to all irrigation and storage permit holders June 27, 2014: opened appropriations up to 3/29/1923 July 2, 2014: opened all appropriations upstream of Harlan County Lake; opened appropriations downstream of Harlan County Lake up to 2/26/1948 September 5, 2014: closed all appropriations in the basin to 8/23/1945
2015	January 1, 2015: closed all permits in the basin February 26, 2015: opened all IR (irrigation) and senior SO (storage use only) permits upstream of Harlan County Dam
2016	None
2017	None
2018	None

Augmentation Pumping and Net Impacts Analysis

This section contains a summary of pumping data for the augmentation projects in the basin, as well as NeDNR's analysis of the net impacts of augmentation pumping for the N-CORPE and Rock Creek Augmentation projects. NeDNR's net impacts analysis fulfills a requirement of the Integrated Management Plans jointly developed by NeDNR and the Upper Republican, Middle Republican, and Lower Republican NRDs. The IMPs state that "…all new net depletions to streamflow that result from augmentation pumping (as calculated by the RRCA ground water model) will be mitigated to ensure protection of existing surface water appropriations." All 2019 data are provisional at the time of this report.

N-CORPE Augmentation Project

Pumping

The Nebraska Cooperative Republican Platte Enhancement project (N-CORPE) is operated through an interlocal cooperative agreement formed in 2012 by Upper Republican NRD, Middle Republican NRD, Lower Republican NRD, and Twin Platte, NRD. A summary of N-CORPE pumping for 2014–2018 is provided in Table 20.

Table 20. Summary of N-CORPE augmentation project pumping, 2014–2018. The "Days Pumped for Compact Compliance" column indicates the number of days the project was pumped to augment streamflow for Compact compliance purposes. The "Total Pumped Volume" column provides the volume of water pumped in that year for all purposes, including augmentation and maintenance pumping.

Year	Days Pumped for Compact Compliance	Total Pumped Volume (acre-feet)
2014	321	42,758
2015	159	25,932
2016	185	25,503
2017	89	8,438
2018	0	97

Net Impacts Analysis

The IMPs for the Upper Republican NRD, Middle Republican NRD, and Lower Republican NRD state that "…all new net depletions to streamflow that result from augmentation pumping (as calculated by the RRCA ground water model) will be mitigated to ensure protection of existing surface water appropriations." This evaluation provides the most recent estimate of the difference in depletions from the historical operation of N-CORPE and depletions from a simulated continuation of irrigation pumping for lands retired through the implementation of each augmentation project.

Augmentation projects affect streamflow in two ways: by increasing streamflow through direct addition of pumped groundwater, and by impacts to baseflows (groundwater discharge to the stream) from pumping groundwater, with the sum of these being the net streamflow impacts. The amount of direct groundwater addition to streamflow is metered by the NRDs and reported to NeDNR. The impacts to baseflow are determined by comparing model-estimated impacts from the historical simulation that includes all of the augmentation pumping but ceases irrigation operations once the projects were initiated with a simulation where an estimation of irrigation pumping is included for lands retired through the development of each augmentation project and augmentation pumping from the beginning of the projects through 2019 is excluded (Figure 10 and Figure 11). All 2019 data are provisional.

The N-CORPE augmentation project was operational each year from its first year through 2017 to offset depletions for Compact compliance, and through 2019 for maintenance purposes. Any net depletive effects from those years of operation were offset by augmentation pumping (Figure 12 and Figure 13), so no additional offsets are needed at this time.

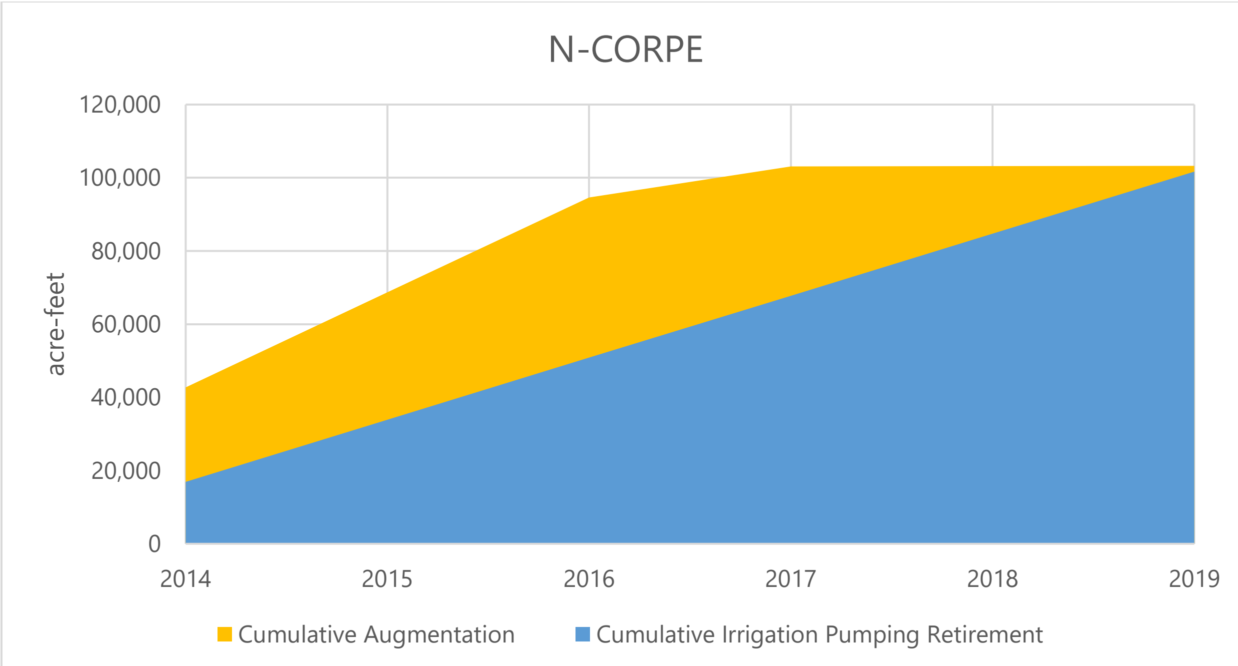

Figure 10: Cumulative water use for augmentation and estimated irrigation pumping on acres retired under the N-CORPE Augmentation Project.

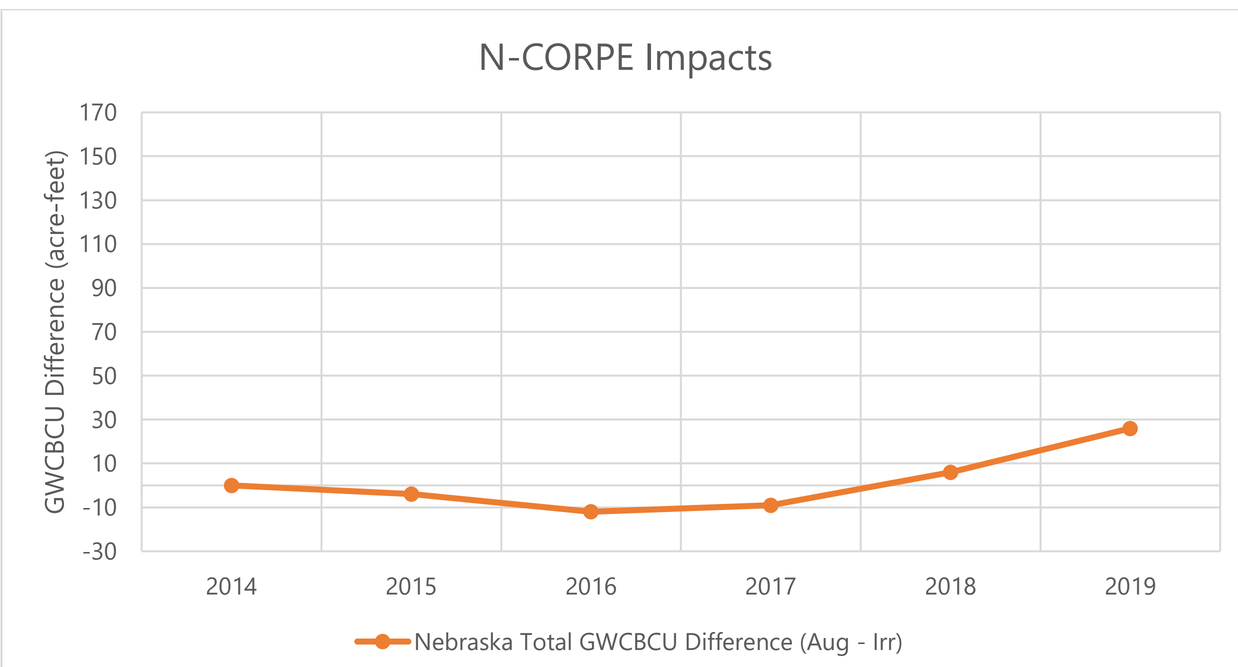

Figure 11: The difference between modeled CBCU (depletions) from N-CORPE Augmentation pumping and modeled CBCU from estimated irrigation pumping on the N-CORPE retired acres had those acres been used for irrigation.

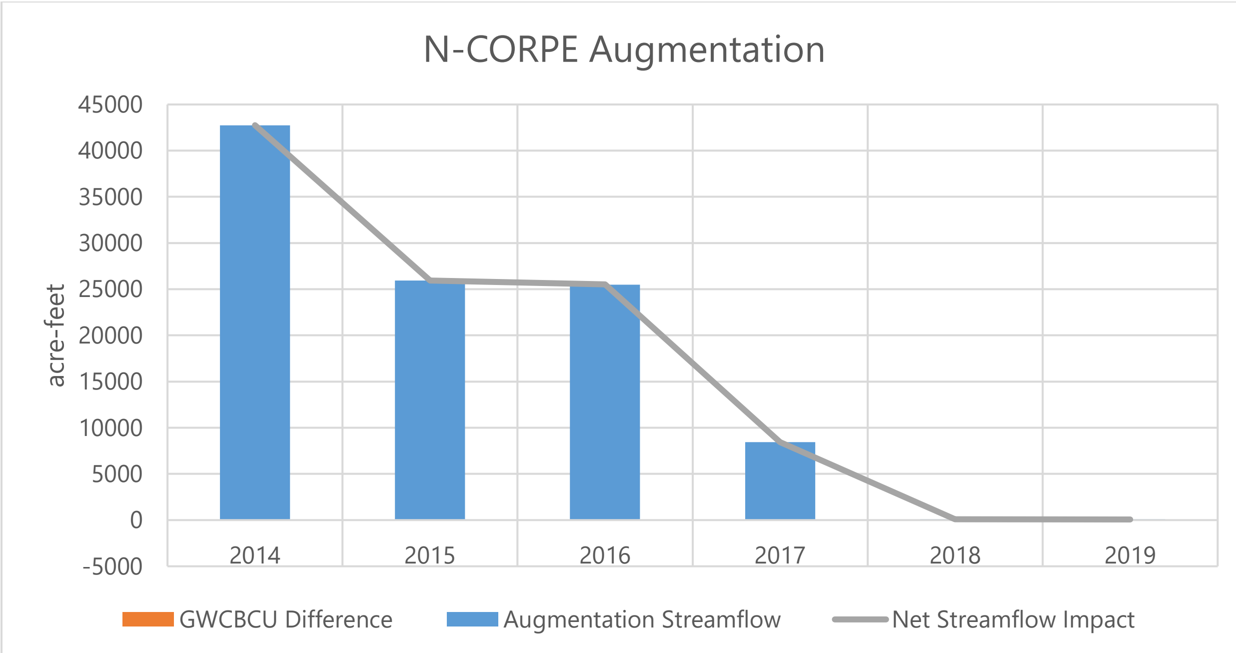

Figure 12: The net impacts to streamflow from the N-CORPE Augmentation Project.

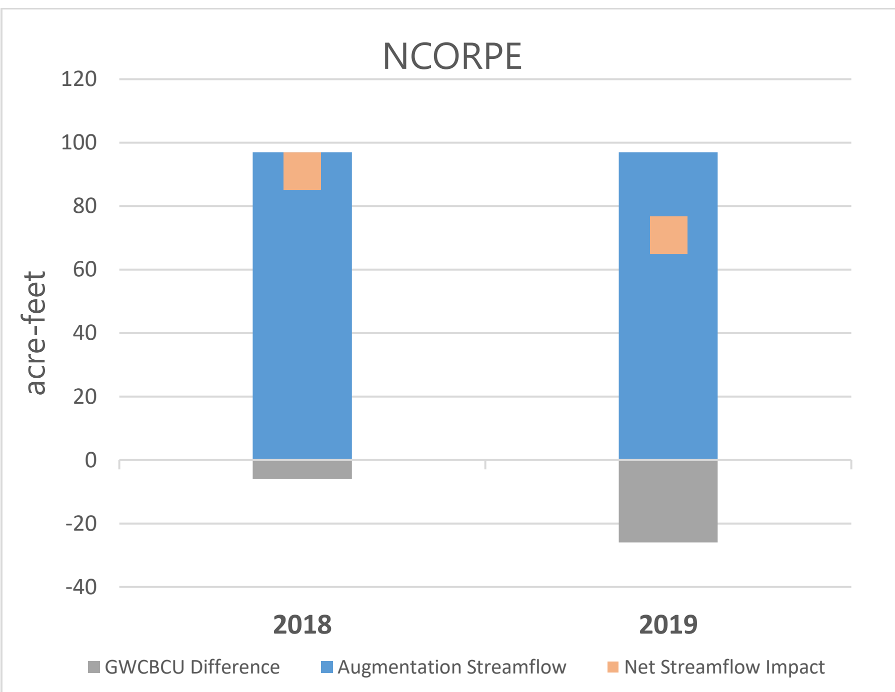

Figure 13: 2018 and 2019 net impacts to streamflow. 2019 data are provisional as of this report

Rock Creek Augmentation Project

Pumping

The Rock Creek augmentation project is operated by Upper Republican NRD. A summary of Rock Creek augmentation project pumping for 2014–2018 is provided in Table 21.

Table 21. Summary of Rock Creek augmentation project pumping, 2014–2018. The "Days Pumped for Compact Compliance" column indicates the number of days the project was pumped to augment streamflow for Compact compliance purposes. The "Total Pumped Volume" column provides the volume of water pumped in that year for all purposes, including augmentation and maintenance pumping.

Year	Days Pumped for Compact Compliance	Pumped Volume (acre-feet)
2014	350	19,297
2015	50	1,098
2016	48	499
2017	140	4,563
2018	21	47

Net Impacts Analysis

The IMP for the Upper Republican NRD states that "…all new net depletions to streamflow that result from augmentation pumping (as calculated by the RRCA ground water model) will be mitigated to ensure protection of existing surface water appropriations." This evaluation provides the most recent estimate of the difference in depletions from the historical operation of the Rock Creek augmentation project and depletions from a simulated continuation of irrigation pumping for lands retired through the implementation of each augmentation project.

Augmentation projects affect streamflow in two ways: by increasing streamflow through direct addition of pumped groundwater, and by impacts to baseflows (groundwater discharge to the stream) from pumping groundwater, with the sum of these being the net streamflow impacts. The amount of direct groundwater addition to streamflow is metered by the NRDs and reported to NeDNR. The impacts to baseflow are determined by comparing model-estimated impacts from the historical simulation that includes all of the augmentation pumping but ceases irrigation operations once the projects were initiated with a simulation where an estimation of irrigation pumping is included for lands retired through the development of each augmentation project and augmentation pumping from the beginning of the projects through 2019 is excluded (Figure 14 and Figure 15). All 2019 data are provisional.

The Rock Creek augmentation project was operational each year from its first year through 2017 to offset depletions for Compact compliance, and through 2019 for maintenance purposes. Any net depletive effects through 2017 were offset by augmentation pumping in those years (Figure 16). Augmentation pumping alone did not fully offset augmentation pumping from N-CORPE in 2018 and 2019 (Figure 17). A 2019 analysis by NeDNR concluded that maintenance pumping plus temporary retirements and permanent decertifications located either upstream of the Rock Creek confluence or in close proximity to the eastern end of the Rock Creek subbasin provides a total offset that well exceeds the new depletions from previous Rock Creek augmentation pumping, mitigating any potential effects to downstream users (Figure 18–Figure 20).

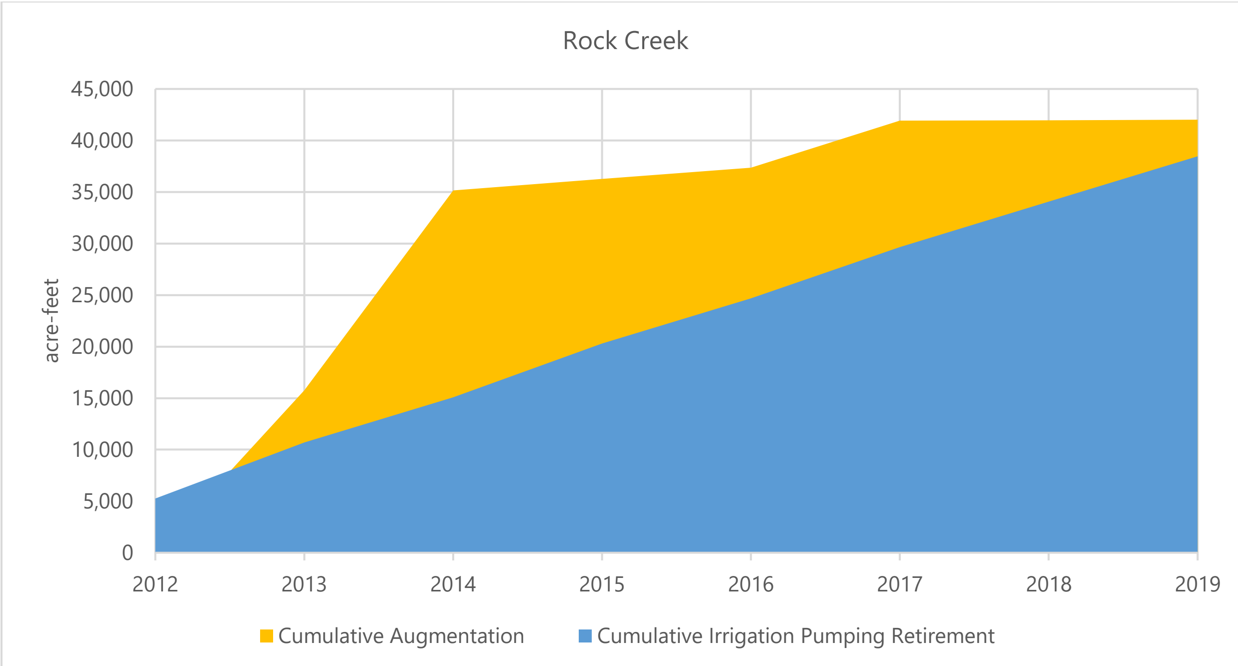

Figure 14: Cumulative water use for augmentation and estimated irrigation pumping on acres retired under the Rock Creek Augmentation Project.

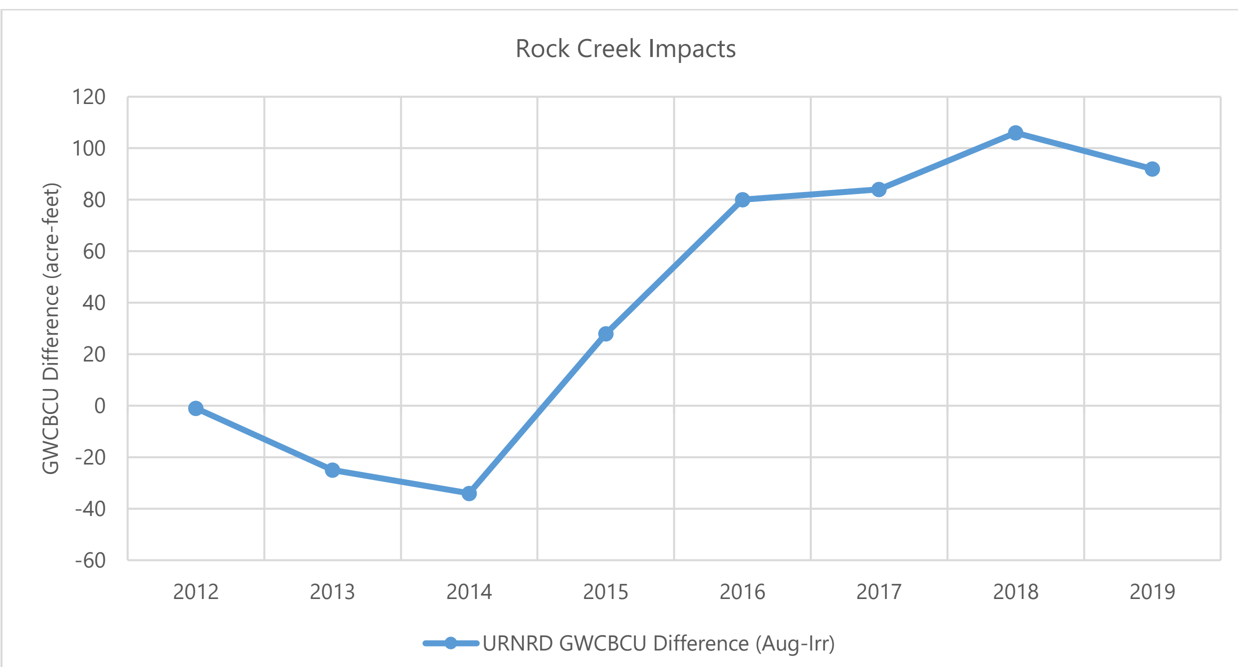

Figure 15: The difference between modeled CBCU (depletions) from Rock Creek Augmentation pumping and modeled CBCU from estimated irrigation pumping on the Rock Creek retired acres had those acres been used for irrigation.

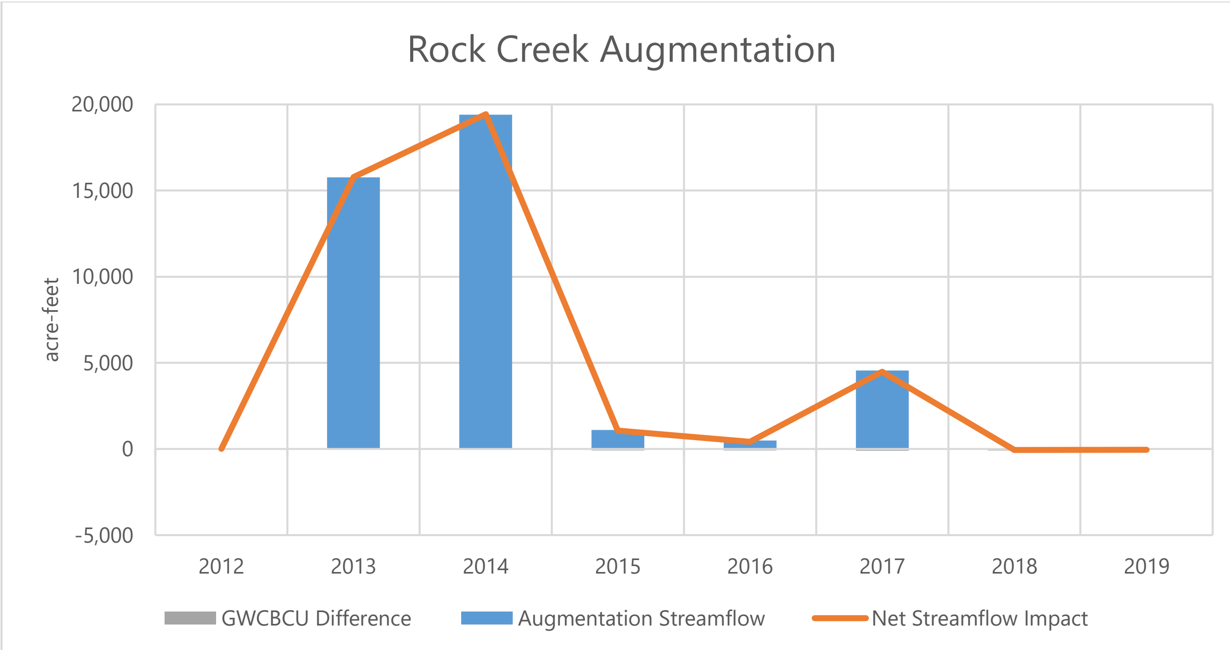

Figure 16: The net impacts to streamflow from the Rock Creek Augmentation Project.

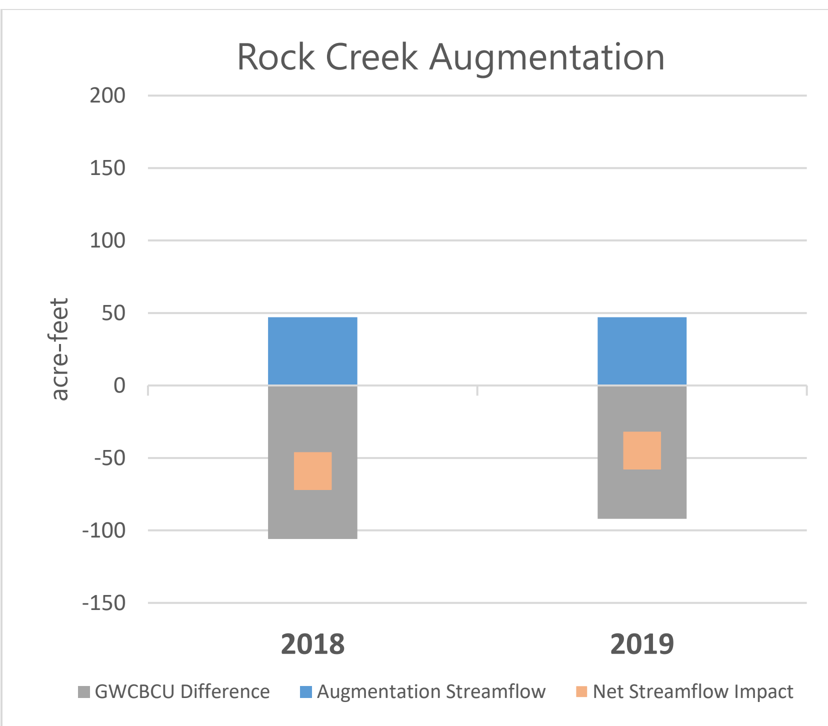

Figure 17: 2018 and 2019 net impacts to streamflow. 2019 data are provisional as of this report.

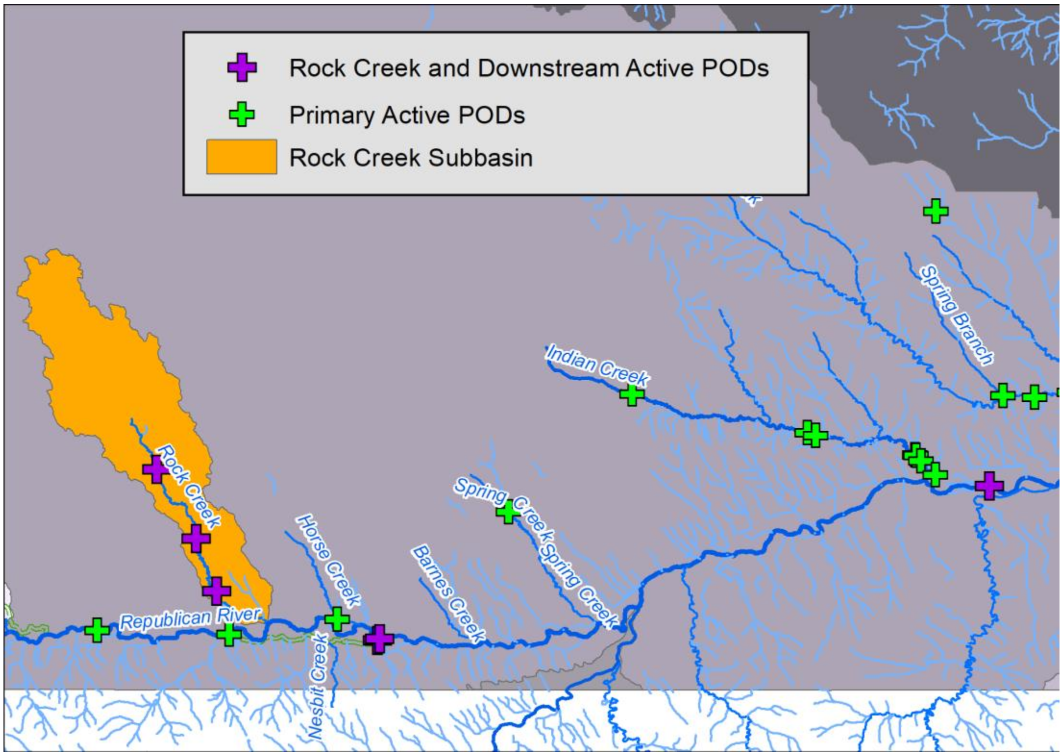

Figure 18: Surface water permitted users that were analyzed for negative impacts from the Rock Creek Augmentation Project.

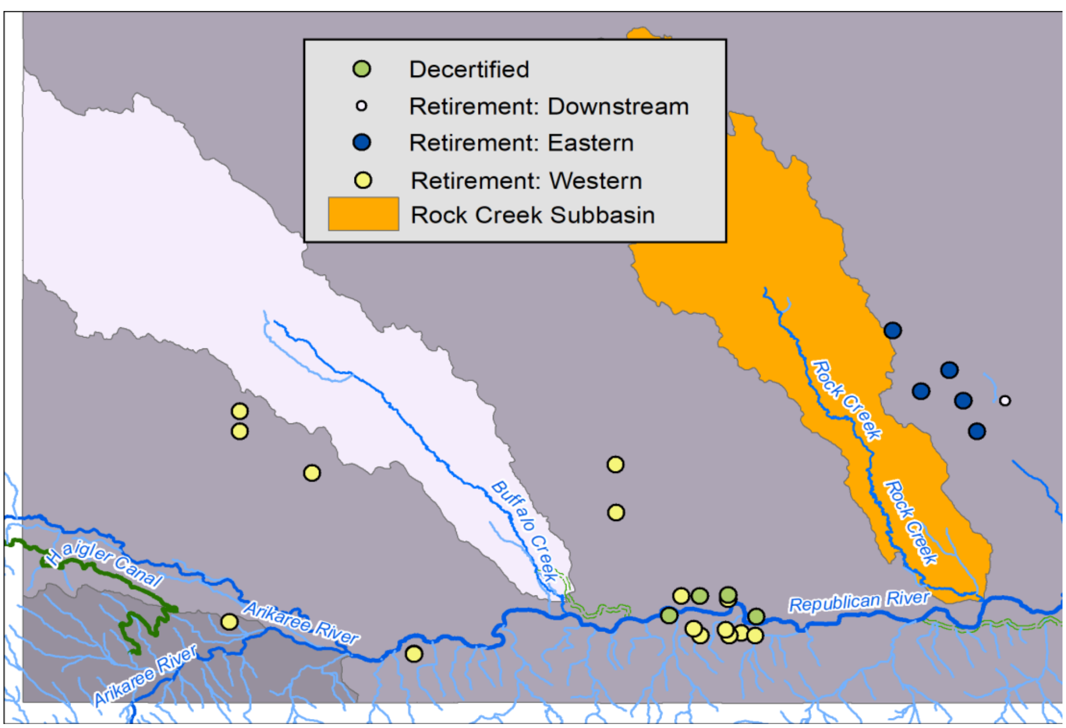

Figure 19: Subset of Upper Republican NRD retired groundwater irrigated acres that were analyzed for offsetting impacts from the Rock Creek Augmentation Project

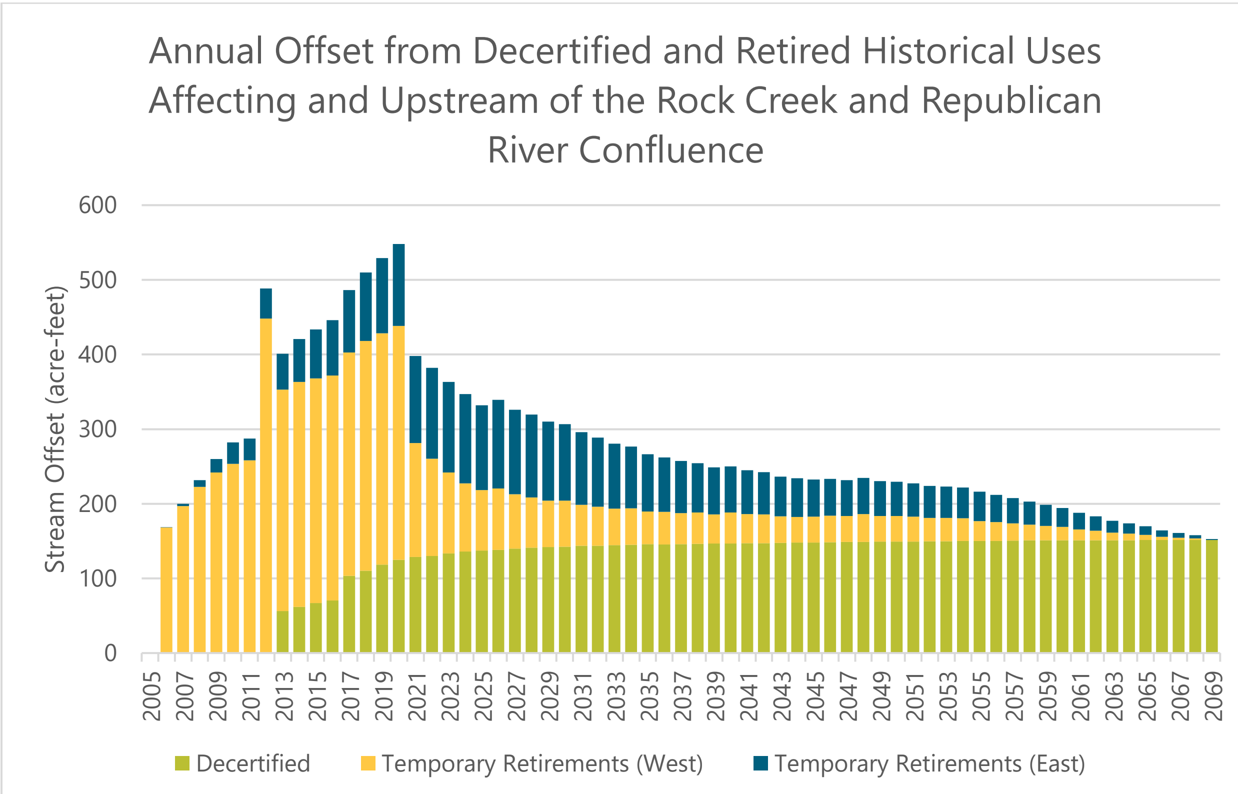

Figure 20: Estimated impacts of mitigation for the Rock Creek Augmentation Project

Turkey Creek Augmentation Well

Pumping

The Turkey Creek augmentation well is operated by Tri-Basin NRD as part of the NRD's Republican Basin Streamflow Augmentation Project. Construction was completed in 2016. From 2016–2018, this well was not operated for augmentation purposes.

Appendix A: Written Procedures for MHO B Analysis

DRAFT Supplement to the *Republican River Basin-Wide Plan*

Methodology for MHO B

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Purpose and Background

Statute requires that the *Republican River Basin-Wide Plan* include Measurable Hydrologic Objectives (MHOs) to ensure that reasonable progress is being made toward achieving the goals and objectives of the plan (*Neb. Rev. Stat.* § 46-755). Five MHOs were agreed-upon during the planning process and adopted as part of the basin-wide plan. For MHOs B and C, which are more technically complex than the basin-wide plan's other three MHOs, it was important to members of the Stakeholder Advisory Committee that more specific assessment methodology be developed by the Nebraska Department of Natural Resources (NeDNR) and Natural Resources Districts (NRDs) than was feasible during the stakeholder process. NeDNR and the NRDs committed to developing assessment procedures before the basin-wide plan's first annual meeting, to be appended to the basin-wide plan upon completion. This document describes the assessment procedures for MHO B. MHO B is shown in Figure 21, along with contextual information about where it fits within the plan's goals, objectives, and action items.

Goal 1. Maintain Nebraska's compliance with the Republican River Compact and applicable state laws

Objective 1.3. Assess progress toward meeting the goals and objectives of the Plan, and share the results of this assessment with the Public and the Nebraska Legislature

Action Item 1.3.2. Evaluate progress toward each of the Plan's measurable hydrologic objectives at the intermediate dates specified in the Plan for each one

MHO B. Limit groundwater depletions to streamflow to a relatively constant level over the long-term both across the basin as a whole and within each NRD

Figure 21. MHO B is one of the *Republican River Basin-Wide Plan*'s Measurable Hydrologic Objectives (MHOs). The MHOs are part of Action Item 1.3.2, Objective 1.3, and Goal 1.

Introduction

MHO B is to "Limit groundwater depletions to streamflow to a relatively constant level over the long-term both across the basin as a whole and within each NRD." Developing methodology for MHO B requires defining and setting parameters for what the terms in MHO B mean and how they will be evaluated.

Groundwater Depletions to Streamflow

Baseflow is the water which flows between the stream and the aquifer. When groundwater is used, less baseflow flows from the aquifer to the stream than would have flowed to the stream had groundwater not been used. **"Groundwater depletions to streamflow"** are the difference in baseflow with and without groundwater use, and they are estimated using a groundwater model. For this procedure, groundwater uses within each NRD are evaluated with the Republican River Compact Administration (RRCA) model, using a modified 32-run procedure that isolates impacts to streamflow due to pumping within each NRD. Groundwater data that have been exchanged between the NRDs and NeDNR and remaining model data that have been approved by the RRCA are to be used in this analysis, unless there is a delay in RRCA approval of data for any year. In the event of a delay in data approval by the RRCA, then the most recent provisional data are used instead.

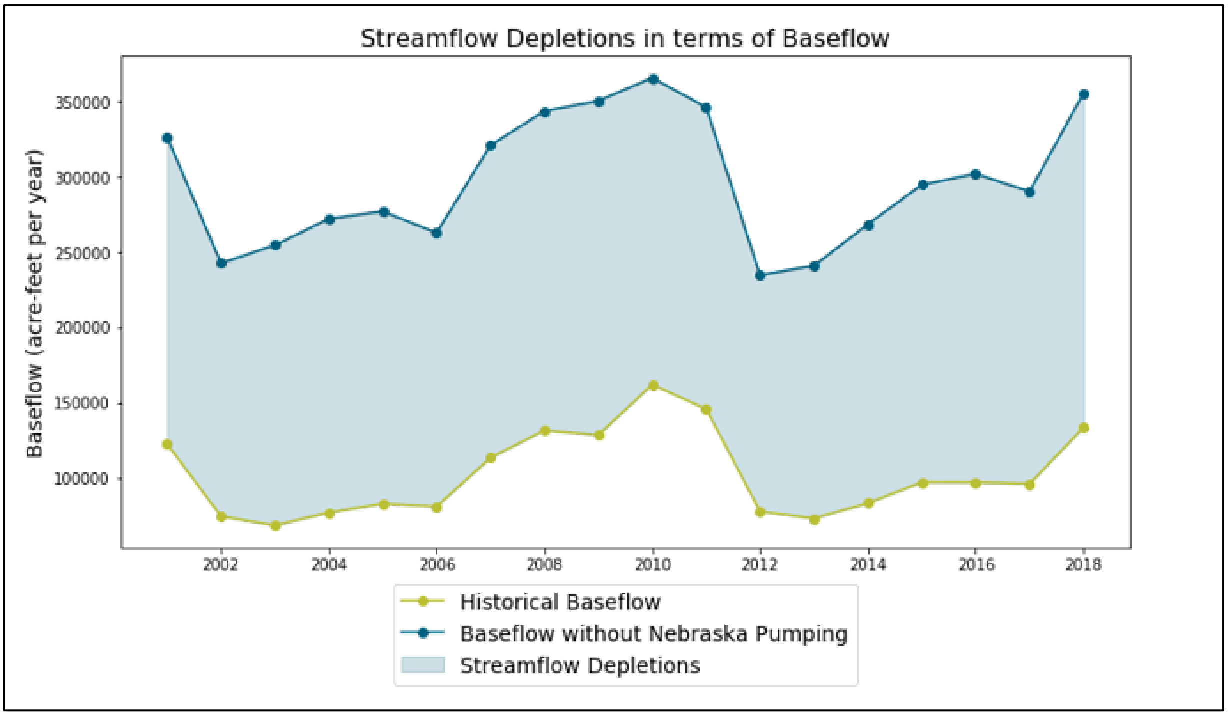

Figure 22. Illustration of groundwater depletions to baseflow. Depletions are calculated using a groundwater model as the difference between simulated baseflow with and without groundwater pumping using a groundwater model.

Relatively Constant over the Long-Term

During basin-wide plan development, the intent discussed among the parties was that MHO B was to be consistent with the requirements of the existing Integrated Management Plans (IMPs) for the Republican River Basin NRDs; therefore, the time periods selected for the analysis of **"relatively constant over the long-term"** differ among the four NRDs due to differences in the requirements of the IMPs for each NRD. For the Upper Republican, Middle Republican, and Lower Republican NRDs, the analysis of "relatively constant over the long-term" includes depletions during all years beginning with 2008. The 2008 start date for these three NRDs corresponds with the adoption of their second generation IMPs, which introduced the compliance standard requiring maintenance of groundwater depletions to streamflow at a relatively constant level over time for those NRDs. For Tri-Basin NRD, the analysis includes depletions during all years beginning with 2013. Using a 2013 start date for Tri-Basin NRD will allow the MHO B assessment to maintain consistency with the current *hydrologically balanced* test from the IMP for the Republican River Basin portion of Tri-Basin NRD. The evaluation of whether groundwater depletions to streamflow have been relatively constant over these time periods is based on a statistical trend analysis, described below.

Statistical Trend Analysis

Groundwater depletions to streamflow from each NRD[1] are assessed for being relatively constant over the long-term by the trend analysis statistics discussed in this section. These statistics are applied to each of the following:

- Unmodified groundwater depletions to streamflow
- Groundwater depletions to streamflow decorrelated for precipitation
- Groundwater depletions to streamflow decorrelated for undepleted baseflow, and
- Groundwater depletions to streamflow decorrelated for Virgin Water Supply.

The temporal trends in groundwater depletions decorrelated for precipitation, undepleted baseflow, and Virgin Water supply provide additional information over the trend in unmodified groundwater depletions but should not be used in an additive manner as the variables are not independent. The statistical test used is described in the next section. Decorrelation for precipitation, undepleted baseflow, and Virgin Water Supply is described beginning on page 49.

Mann-Kendall Trend Test

The trend test used for this analysis is the **Mann-Kendall Trend Test**[2,3] (MK test). The MK test is a non-parametric test for monotonic linear or non-linear trends. "Non-parametric" means that no assumptions need to be made about the distributions of the depletions data. "Monotonic" means that the trends detected will be consistently increasing or decreasing. "Linear or non-linear" means that the test will detect changes that are well represented by a line, curve, or step change. In addition to these features of the MK test, it has the advantage of not being dependent on the magnitude of the depletions, i.e., the presence of a trend will not be skewed by the magnitude of any extreme depletions values. A limitation of the MK test is that, as with many other statistical trend tests, statistical confidence increases with size of the dataset; however, the MK test is one of the few statistical trend tests which is recommended for use on small datasets like those being analyzed here.

The MK test is calculated by pairwise comparison of each annual depletion value to each previous annual depletion value. If the later depletion is greater than the earlier depletion, 1 is added to the MK test statistic. If the later depletion is less than the earlier depletion, 1 is subtracted from the MK test value. If the pair of depletions are the same, the MK test value does not change. After comparing all pairs, if the MK test value is a large positive number, then an

[1] For Tri-Basin NRD, groundwater depletions to streamflow are evaluated as the net of groundwater depletions to streamflow and the mound credit, for consistency with the requirements of the Tri-Basin NRD IMP.

[2] *Statistical Methods in Water Resources* by D.R. Helsel and R.M. Hirsch, chapter 12 'Trend Analysis'. Book 4 in the Hydrologic Analysis and Interpretation Series by USGS (https://pubs.usgs.gov/twri/twri4a3/twri4a3.pdf).

[3] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)

upward trend in depletions is shown. If the MK test value is a large negative number, then a downward trend in depletions is shown. If the MK test value is near 0, then no trend is shown.

The significance of the MK test value depends on the number of years in the test. If the number of years is less than or equal to 10, then the MK test value is compared directly to a table of probabilities.[4] If the number of years is greater than 10, then the variance of the MK test value is calculated as a function of the number years and the number of identical depletion values. The MK test statistic is then calculated as a function of the MK test value and the variance of the MK test value. The MK test statistic is then compared to the corresponding Z value for the desired significance.[5] For the MHO B assessment, a p-value of 0.05 is used as the threshold to determine significance. Example MK test results are shown in Figure 23.

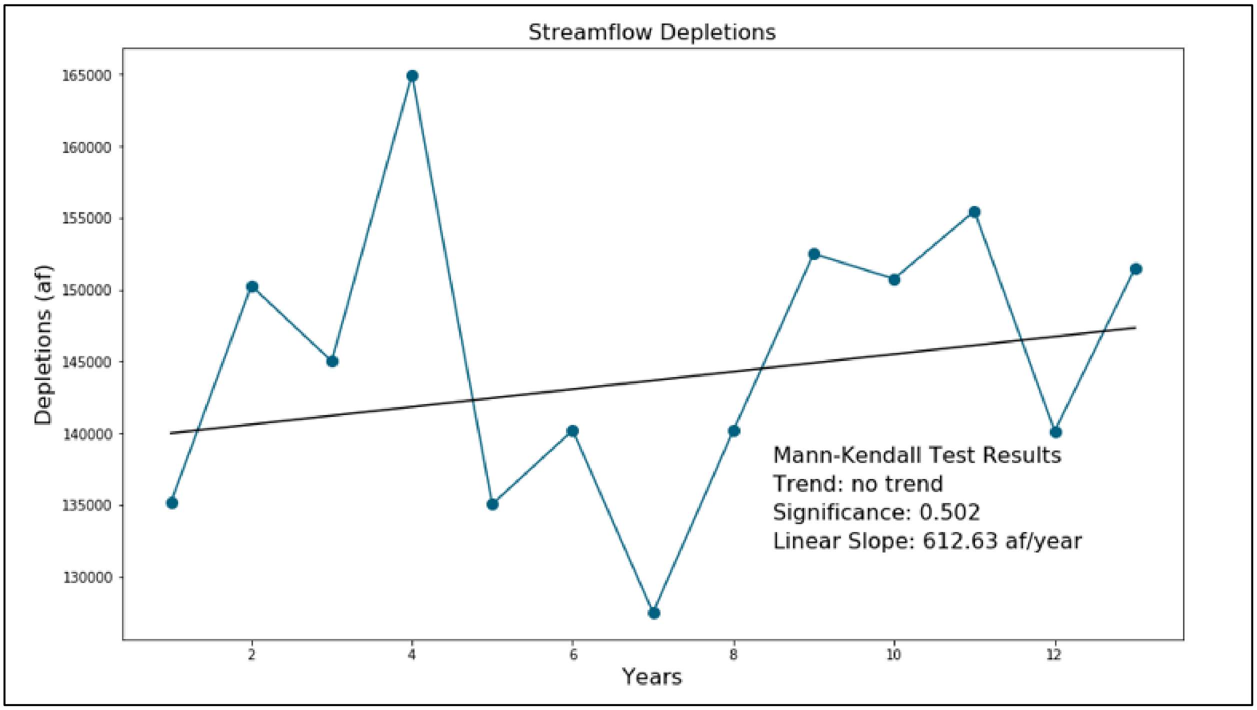

Figure 23. Example Mann-Kendall test results using made-up data.

Decorrelation

The objective of this analysis is to identify a trend in depletions attributable to groundwater pumping. Annual depletions are also affected by factors outside of the management of the NRDs, such as weather, climate, and hydrologic conditions. If only unmodified groundwater depletions are evaluated, then trends in these ambient conditions over the time period of this analysis could result in the analysis either identifying a trend in depletions that is not directly

[4] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)
[5] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)

attributable to groundwater pumping, or failing to identify an existing trend that is directly attributable to groundwater pumping or other land use factors within the control of water users.

For these reasons, we have included associations with non-pumping variables on depletions and attempted to remove the correlative effect of the variable on NRD groundwater depletions to streamflow. For this analysis, annual NRD groundwater depletions to streamflow are each linearly decorrelated for annual precipitation, annual undepleted baseflow, and Virgin Water Supply separately. An ordinary least squares linear fit of depletions to each of the variables is performed. The resulting residuals between the observed depletions and the fit are used as the decorrelated depletions for each variable.

Annual precipitation has been found to be greatly correlated to annual depletions. The correlation relationship is multilayered and interconnected; there are both direct influences, for example through precipitation recharge, and indirect, such as its influence on crop irrigation requirements or groundwater pumping. Gridded annual precipitation is collected for the RRCA groundwater model pre-processor input files. Precipitation from 34 locations is obtained from the National Climatic Data Center TD3220 Cooperative Summary of the Month dataset which is interpolated to the model grid. Model-wide total precipitation appears to be a sufficient indicator of hydrology, thus, the model-wide gridded precipitation values are totaled for this analysis (Figure 24).

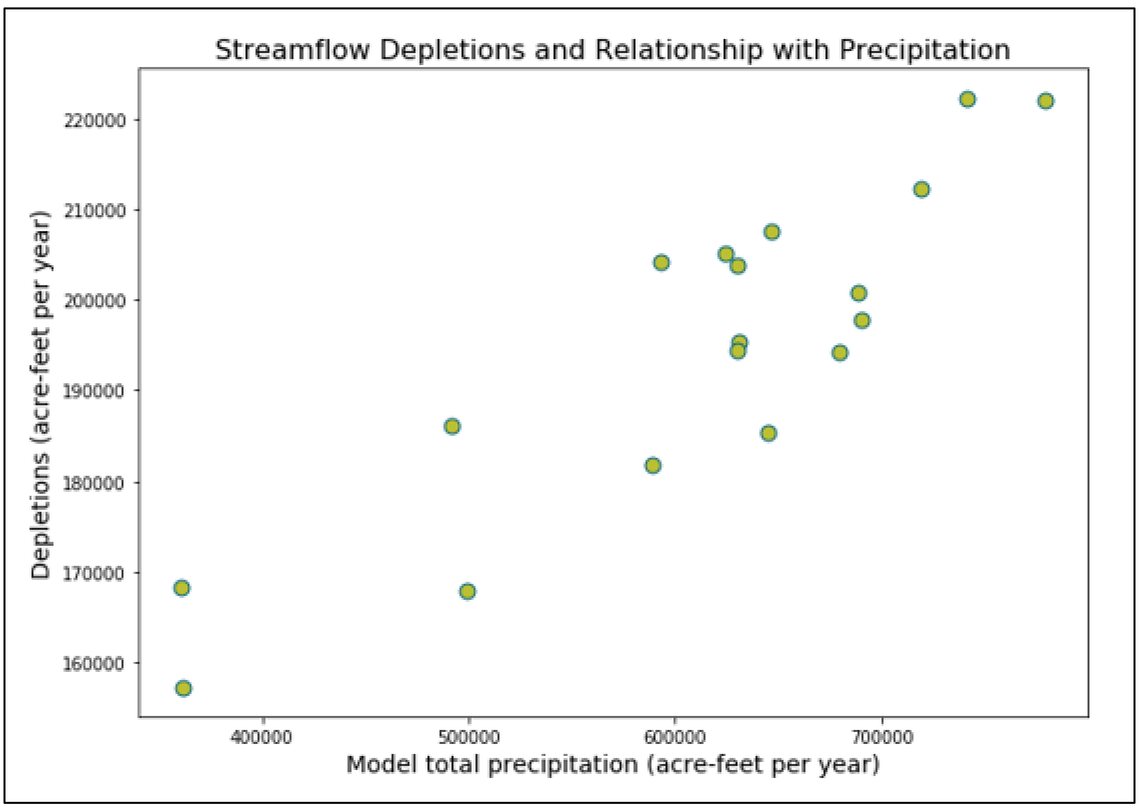

Figure 24. Relationship between Nebraska streamflow depletions and RRCA model-wide precipitation, 2008–2018.

Annual undepleted baseflow sets the annual limit of baseflow available for depletions. Conceptually it is the closest variable to the dependent variable and is mathematically most similar, incorporating nearly the same calculation assumptions and uncertainties. Annual undepleted baseflow is estimated from the RRCA groundwater model run with Nebraska pumping turned off (not included) as executed for the RRCA 5-run procedure for determining each depletions attributable to pumping from each state. The baseflows to the Republican River and major tributaries are used in both this analysis and the depletions quantifications. The use of the exchange between the major reservoirs and the aquifer is suggested to be considered for further assessment in this analysis (Figure 25).

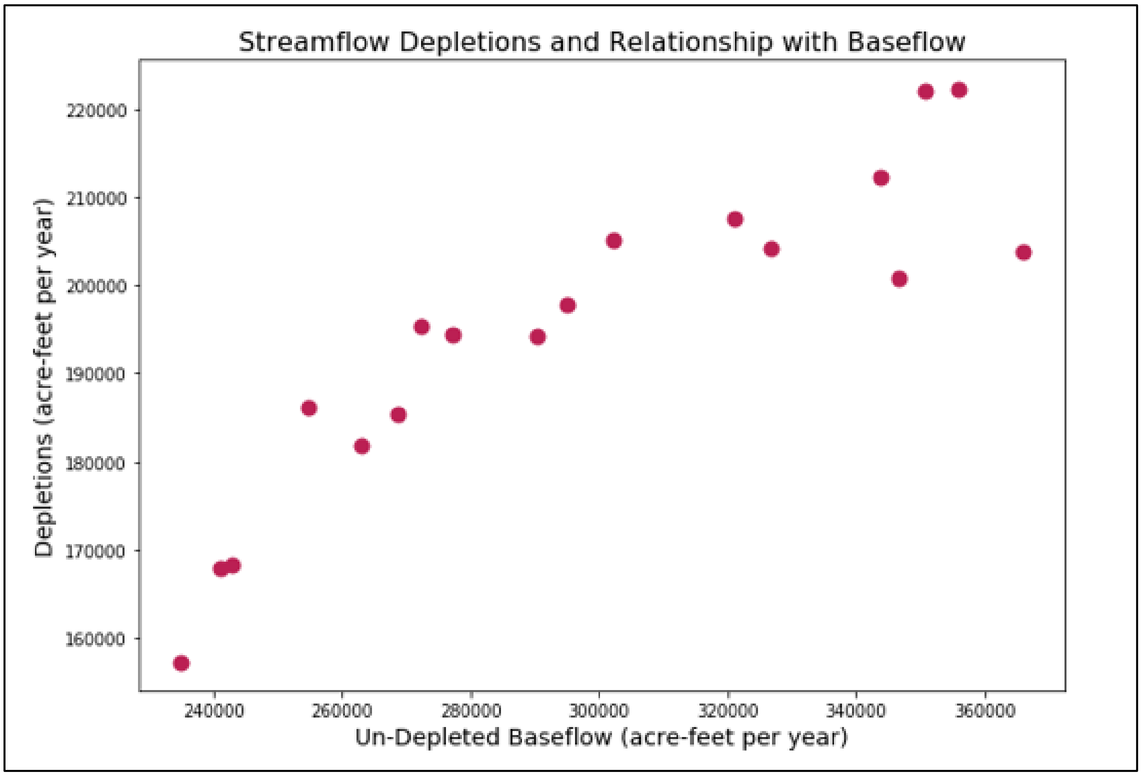

Figure 25. Relationship between Nebraska streamflow depletions and undepleted baseflow, 2008–2018.

Virgin Water Supply is defined in the FSS/Accounting Procedures as the streamflows within the Republican Basin undepleted by the activities of man, excluding water supply imported by a State from outside the basin resulting from activities of man. Virgin Water Supply is calculated in the RRCA Accounting Procedures essentially by summing annual streamflow, computed consumptive use of streamflow resulting from select activities of man, and the change in reservoir storage less the imported water. Groundwater depletions to streamflow are a component of consumptive use, therefore groundwater depletions are a portion of the Virgin Water Supply. Virgin Water Supply is a broad indicator of hydrology incorporating both baseflow and other sources of streamflow including precipitation (Figure 26).

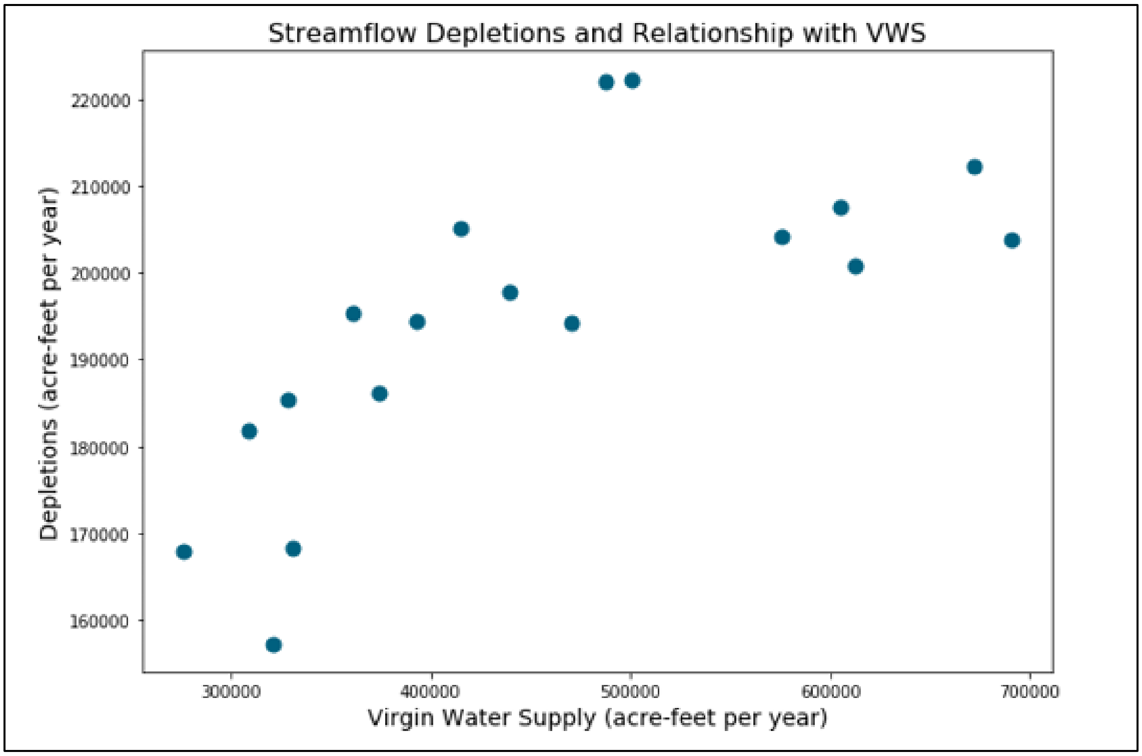

Figure 26. Relationship between Nebraska streamflow depletions and Virgin Water Supply, 2008–2018.

For this statistical trend analysis, the MK test (page 48) is applied to unmodified groundwater depletions data for the analysis period and to the same data decorrelated for each of the factors described above. Evaluation of all four MK test results will determine whether management actions are needed as a result of MHO B, as described beginning on page 53.

Future Work

We are continuing to assess the influences of weather, hydrology, and other outside factors on NRD depletions to streamflow in order to capture a trend in depletions that is only representative of factors within NRD control. Precipitation, undepleted baseflow, and Virgin Water Supply do not have the same correlation to each NRD's depletions, e.g., over the period analyzed, precipitation had a stronger correlation to upstream NRD depletions, while baseflow had a stronger correlation to downstream NRD depletions. Additionally, the influences of these variables on depletions may not be best removed through a linear fit, which requires additional assessment. We are also continuing to assess if there is a time period over which weather and outside factors could be considered relatively constant, and therefore their effects on depletions to streamflow would be relatively constant.

Assessment of Whether Management Actions Are Needed

As described in the basin-wide plan, if NeDNR and the NRDs determine that an MHO is not being achieved, they will determine what actions to take to achieve that MHO in the future. The process described below summarizes the decision framework that is followed to determine whether an NRD needs to take management actions as a result of this analysis of MHO B. The full decision framework is shown in Figure 27.

There are three phases in the decision framework for MHO B: the screening phase, the discussion phase, and management actions. Figure 27 includes details about each phase, including its purpose and timeframe, the decisions that are made during each phase, and what is reported as a result of it.

The screening phase takes place as part of each five-year technical analysis for the basin-wide plan. During the screening phase, NeDNR and the NRDs determine whether or not all four MK tests for an NRD agree either that there has or has not been a statistically significant increase in groundwater depletions to streamflow. Depending on the results of the MK tests, the screening phase could result in one of three determinations for each NRD: no further investigation or management actions are needed because MHO B is being achieved, that management actions are needed because MHO B is not being achieved, or that further consideration of the analysis results is needed due to conflicting results among the four MK tests.

The discussion takes place within approximately one year of when the five-year technical analysis results are presented. During this phase, NeDNR and the NRDs discuss the results of all four MK tests and other relevant information available and decide whether there is enough evidence to conclude that streamflow depletions have increased and that management actions are needed at this time. If management actions are needed, the discussion phase results in identification of what management actions the NRD will take in order to be able to meet MHO B in the future. If management actions are not needed at this time, NeDNR and the NRD still discuss ideas for potential management actions that could be taken if needed following the next five-year technical analysis.

If either the screening phase or the discussion phase identifies that an NRD needs to take management actions because MHO B is not being achieved, the NRD will begin the selected management action or actions no later than the annual meeting that takes place two years after presentation of the five-year technical analysis.

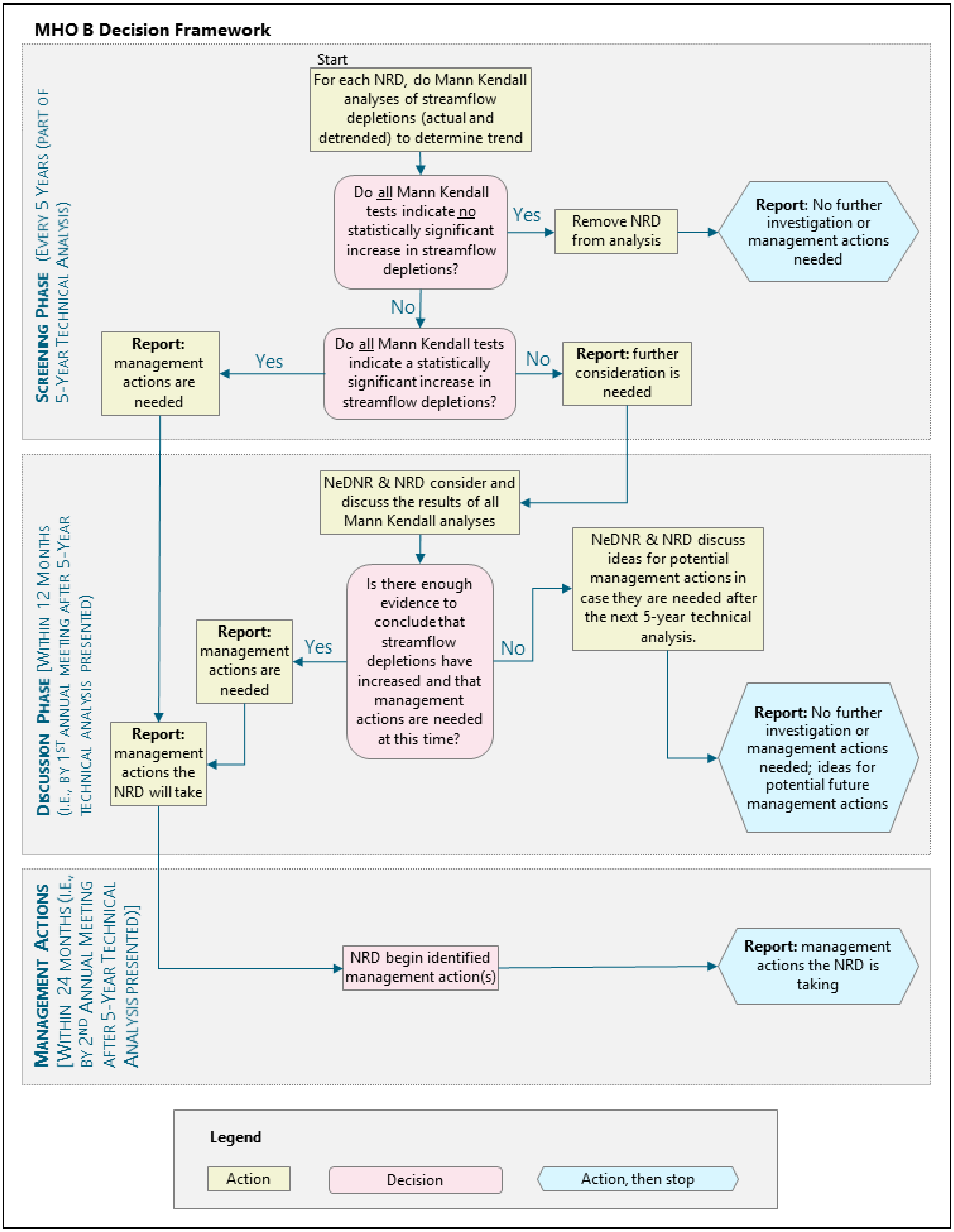

Figure 27. Decision framework for MHO B, outlining details about each phase of the analysis, including its purpose and timeframe, the decisions that are made during each phase, and what is reported as a result of it.

Appendix B: Written Procedures for MHO C Analysis

DRAFT Supplement to the *Republican River Basin-Wide Plan*

Methodology for MHO C

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Purpose and Background

Statute requires that the *Republican River Basin-Wide Plan* include Measurable Hydrologic Objectives (MHOs) to ensure that reasonable progress is being made toward achieving the goals and objectives of the plan (*Neb. Rev. Stat.* § 46-755). Five MHOs were agreed-upon during the planning process and adopted as part of the basin-wide plan. For MHOs B and C, which are more technically complex than the basin-wide plan's other three MHOs, it was important to members of the Stakeholder Advisory Committee that more specific assessment methodology be developed by the Nebraska Department of Natural Resources (NeDNR) and Natural Resources Districts (NRDs) than was feasible during the stakeholder process. NeDNR and the NRD committed to developing assessment procedures before the basin-wide plan's first annual meeting, to be appended to the basin-wide plan upon completion. This document describes the assessment procedures for MHO C. MHO C is shown in Figure 28, along with contextual information about where it fits within the plan's goals, objectives, and action items.

Goal 1. Maintain Nebraska's compliance with the Republican River Compact and applicable state laws

Objective 1.3. Assess progress toward meeting the goals and objectives of the Plan, and share the results of this assessment with the Public and the Nebraska Legislature

Action Item 1.3.2. Evaluate progress toward each of the Plan's measurable hydrologic objectives at the intermediate dates specified in the Plan for each one

MHO C: Ensure there is always enough groundwater for all groundwater uses within the timeframe of this plan, either by stabilizing groundwater levels or managing declining groundwater levels

Figure 28. MHO C is one of the *Republican River Basin-Wide Plan*'s Measurable Hydrologic Objectives (MHOs).The MHOs are part of Action Item 1.3.2, Objective 1.3, and Goal 1.

Introduction

MHO C is to "Ensure there is always enough groundwater for all groundwater uses within the timeframe of this plan, either by stabilizing groundwater levels or managing declining groundwater levels." Developing methodology for MHO C requires setting parameters for how the terms in MHO C will be evaluated.

Groundwater Levels and Observation Well Data

Groundwater levels in the basin are evaluated using spring average groundwater observation well data that have been exchanged between the NRDs and NeDNR or are publicly available through the USGS or University of Nebraska-Lincoln Conservation and Survey Division databases. For MHO C, each observation well is initially evaluated individually to determine whether groundwater levels have declined.

For each well, each year's spring average groundwater observation well data are calculated for by averaging any spring groundwater level observations collected from that well between February 24 and May 15. This date range was selected based on historical observation frequency and known data collection practices. Calculating an average value for each year allows continuous, non-continuous, and intermittent observations to be assessed in the same manner as each other, across all observation wells. Using only spring data is a common practice for evaluating long-term groundwater level trends. This is because spring groundwater levels are less affected than fall groundwater levels by the short-term effects of groundwater pumping, which can vary considerably from year-to-year depending on irrigation water requirements.

Note that while in most locations, spring groundwater level observations are usually the best option for evaluating long-term groundwater level trends, as described in the preceding paragraph, there are situations that make spring groundwater levels at certain observation wells unsuitable for use for this analysis. Examples would include observation wells located very near a site where groundwater is either being extracted or recharged during the winter or spring months. Any observation wells determined by NeDNR and the NRDs to be unsuitable for the use of spring observation well data, due to their location, are excluded from this analysis.

Stable Groundwater Levels or Managed Declining Groundwater Levels

MHO C provides for two ways in which NRDs can comply with the objective of ensuring there is enough groundwater for all uses within the plan's timeframe: 1) stable groundwater levels, or 2) managed declining groundwater levels. This assessment takes a multi-phased approach. In the first phase, we evaluate each well to determine which observation wells have stable groundwater levels and which wells have had consistently declining groundwater levels over the time period of the analysis. During the second and third phases we further investigate the areas containing wells with consistently declining groundwater levels to determine which of those wells have groundwater levels that are declining at such a rate that there will not be enough groundwater available for all groundwater uses within the timeframe of the plan.

The assessment period begins from 2008 for Upper Republican NRD, Middle Republican NRD, and Lower Republican NRD, and from 2013 for Tri-Basin NRD. These assessment periods for MHO C were selected for consistency with the assessment periods for MHO B. The analysis of "stable groundwater levels" examines trends in groundwater levels observed during all years within the assessment period. The analysis of "managing declining groundwater levels" considers expected water availability at the end of the basin-wide plan's timeframe (i.e., 2044).

Statistical Trend Analysis

Groundwater levels are assessed for stability by the trend analysis statistics discussed in this section. These are the same statistical methods used to determine trends in groundwater depletions to streamflow for MHO B. The statistics are applied to each groundwater level observation time series for each observation well evaluated.

Mann-Kendall Trend Test

The trend test used for this analysis is the **Mann-Kendall Trend Test**[6,7] (MK test). The MK test is a nonparametric test for monotonic, linear or non-linear trends. "Non-parametric" means that no assumptions need to be made about the distributions of the observation well data. "Monotonic" means that the trends detected will be consistently increasing or decreasing. "Linear or non-linear" means that the test will detect changes that are well represented by a line or are step changes. In addition to these features of the MK test, it has the advantage of not being dependent on the magnitude of the groundwater level changes, i.e., the presence of a trend will not be skewed by the magnitude of any extreme groundwater level values. A limitation of the MK test is that, as with many other statistical trend tests, statistical confidence increases with size of the dataset; however, the MK test is one of the few statistical trend tests that is recommended for use on small datasets like those being analyzed here.

The MK test is calculated by pairwise comparisons of each annual spring average groundwater level to each previous annual spring average groundwater level. If the later groundwater level is greater than the earlier groundwater level, 1 is added to the MK test statistic. If the later groundwater level is less than the earlier groundwater level, 1 is subtracted from the MK test value. If the pair of groundwater levels are the same, the MK test value does not change. If after comparing all pairs, the MK test value is a large positive number, then an upward trend in groundwater levels is shown. If the MK test value is a large negative number, then a downward trend in groundwater levels is shown. If the MK test value is near 0, then no trend is shown.

The significance of the MK test value depends on the number of years in the test. If the number of years is less than or equal to 10, then the MK test value is compared directly to a table of probabilities.[8] If the number of years is greater than 10, then the variance of the MK test value is calculated as a function of the number years and the number of identical groundwater levels. The MK test statistic is then calculated as a function of the MK test value and the variance of the MK test value. The MK test statistic is then compared to the corresponding Z value for the desired significance.[9] For the MHO C assessment, a p-value of 0.05 is used as the threshold to determine significance. Example MK test results are shown in Figure 29.

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[6] *Statistical Methods in Water Resources* by D.R. Helsel and R.M. Hirsch, chapter 12 'Trend Analysis'. Book 4 in the Hydrologic Analysis and Interpretation Series by USGS (https://pubs.usgs.gov/twri/twri4a3/twri4a3.pdf).

[7] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)

[8] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)

[9] Pacific Northwest National Laboratory Visual Sample Plan (VSP) 6.0 documentation, Mann-Kendall Test For Monotonic Trend (https://vsp.pnnl.gov/help/Vsample/Design_Trend_Mann_Kendall.htm)

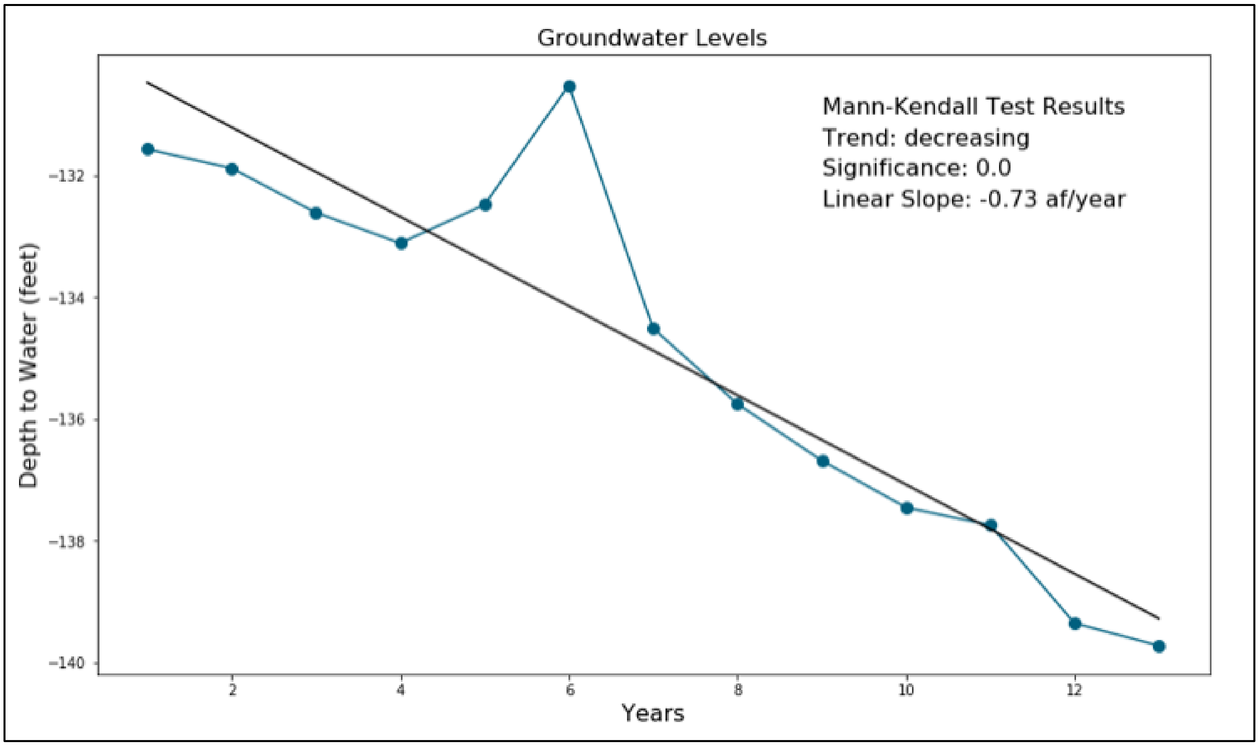

Figure 29. Example Mann-Kendall test results using made-up data.

In addition to indicating which observation wells have declining groundwater levels, the results of the MK test also include the slope of the trend observed. For each well that is identified by the MK test as having consistently declining groundwater levels, the linear trend of those observations can be projected to 2044 to estimate groundwater availability at the end of the plan's timeframe.

Future Work

NeDNR is working with NRDs to share and combine well attribute and groundwater observation data in order to more quickly and easily update records for MHO C assessments.

Assessment of Whether Management Actions are Needed

As described in the basin-wide plan, if NeDNR and the NRDs determine that an MHO is not being achieved, they will determine what actions to take to achieve that MHO in the future. The process described below summarizes the decision framework that is followed to determine whether an NRD needs to take management actions as a result of this analysis of MHO C. The full decision framework is shown in Figure 30.

There are four phases in the decision framework for MHO C: three screening phases, and management actions. Figure 30 includes details about each phase, including its purpose and timeframe, the decisions that are made during each phase, and what is reported as a result of it.

The first screening phase takes place as part of each five-year technical analysis for the basin-wide plan. During the first screening phase, NeDNR and the NRDs use the MK test to determine which observation wells have experienced a statistically significant decline in groundwater levels. Wells that have not experienced a statistically significant decline are meeting MHO C because they have experienced stable or increasing groundwater levels; therefore, no further analysis of these wells is needed after the first screening phase. For wells that have experienced a statistically significant decline in groundwater levels, the MHO C analysis moves to the second screening phase.

It is not possible to set one basin-wide, meaningful, numerical trigger to determine whether MHO C is being met, because what constitutes "enough groundwater for all groundwater uses" varies considerably from one area to the next depending on factors such as groundwater demands and hydrogeologic conditions. For this reason, the second and third phases of this decision framework provide a guide for evaluating each area with declining groundwater levels individually to determine whether MHO C is being met or management actions are needed.

The second screening phase takes place within approximately one year of when the five-year technical analysis results are presented. During this phase, NeDNR and the NRDs expand their focus to include a large enough geographic area to provide context for interpreting the observation well results. NeDNR and the NRDs determine whether it is obvious that the decline indicated by the MK test does not indicate a potential limit to groundwater availability by 2044, or whether a more in-depth investigation is needed. For areas where the NRDs and NeDNR determine that more investigation is needed, the MHO C analysis moves to the third screening phase.

The third screening phase takes place within approximately two years of when the five-year technical analysis results are presented. During this phase, NeDNR conduct an in-depth evaluation of projected groundwater availability and groundwater demands and determine whether there will be insufficient groundwater availability in 2044.

If the third screening phase identifies that an NRD needs to take management actions because MHO C is not being achieved, the NRD will begin the selected management action or actions no later than the annual meeting that takes place three years after presentation of the five-year technical analysis.

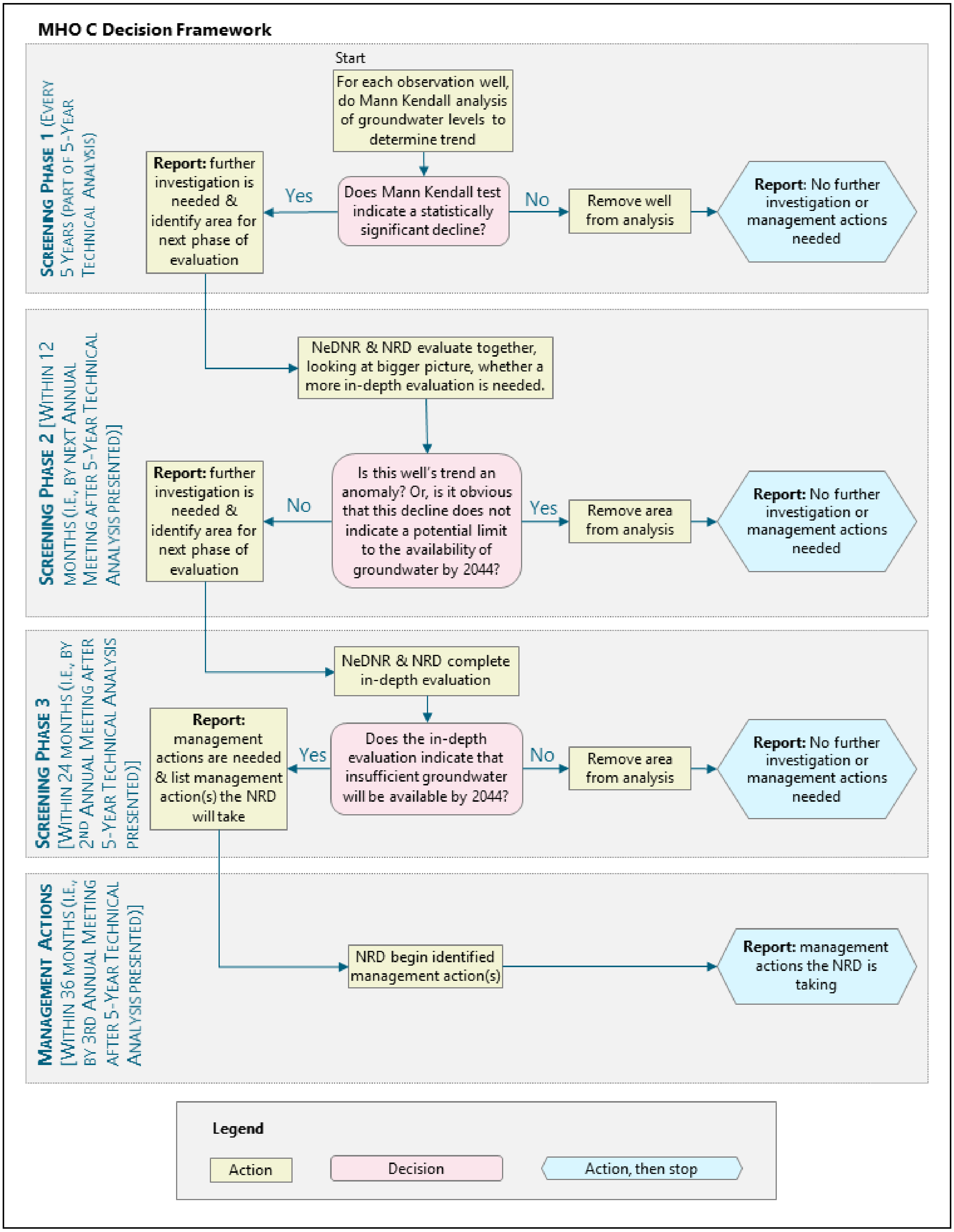

Figure 30. Decision framework for MHO C, outlining details about each phase of the analysis, including its purpose and timeframe, the decisions that are made during each phase, and what is reported as a result of it.