**BEFORE THE OFFICE OF ADMINISTRATIVE HEARINGS**
**STATE OF KANSAS**

| | |
|---|---|
| IN THE MATTER OF THE APPLICATION OF THE CITIES OF HAYS, KANSAS AND RUSSELL, KANSAS FOR APPROVAL TO TRANSFER WATER FROM EDWARDS COUNTY PURSUANT TO THE KANSAS WATER TRANSFER ACT | OAH Case No. 23AG0003 AG |

**MEMORANDUM IN SUPPORT OF MOTION BY WATER PROTECTION ASSOCIATION OF CENTRAL KANSAS AND EDWARDS COUNTY, KANSAS TO STRIKE REBUTTAL TESTIMONY OF DAVID BARFIELD, P.E.**

## I. INTRODUCTION

The law is quite explicit regarding the prerequisites for expert testimony. K.S.A. 60-456 mandates that a witness, in order to offer such testimony, must possess the relevant knowledge, skill, experience, training, or education. Furthermore, the testimony offered must be premised upon sufficient facts or data and be the product of reliable principles and methods. It is essential that the witness demonstrate his capacity to apply these principles and methods in a reliable manner to the circumstances of the case at hand.

Mr. Barfield's involvement in the Cities' efforts to transfer water from the R9 Ranch dates to his service as the presiding officer, the factfinder, in the earlier change of use proceeding. In that role he was bound to serve as an impartial arbiter. Kan. Att'y Gen. Op. No. 79-276 (Dec. 6, 1979). Mr. Barfield has now been asked by the Cities to assume the role of an advocate to counter expert testimony from Intervenor's expert Mr. Larson who is critical of Mr. Barfield's decision making in the change of use proceeding. The optics could hardly be worse. But beyond appearances, Mr. Barfield by his own admission lacks the skill or experience to offer the opinions the Cities seek. Moreover, his opinions are not grounded in sufficient facts or data.

## II. LEGAL STANDARD

### A. EXPERT TESTIMONY GENERALLY

Admission of expert testimony lies within the presiding officer's discretion. *Kansas Gas & Elec. Co. v. State Corp. Comm'n of State of Kan.*, 14 Kan. App. 2d 527, 537, 794 P.2d 1165, 1173 (1990). Pursuant to K.S.A. 60-456 a witness may only offer expert testimony if (1) the testimony is based on sufficient facts or data; (2) the testimony is the product of reliable principles and methods; and (3) the witness has reliably applied the principles and methods to the facts of the case. K.S.A. 60-456. The Cities have the burden to show Mr. Barfield's testimony is admissible. *Endorf v. Bohlender, 26 Kan. App. 2d 855, 865, 995 P.2d 896, 903 (2000).*

This tribunal must serve as a gatekeeper to ensure that the requirements of K.S.A. 60-456 are met before allowing expert testimony. *In re Cone*, 435 P.3d 45, 49-50 (Kan. 2019). Though true that a presiding officer need not be bound by technical rules of evidence and should give the parties reasonable opportunity to be heard and to present evidence, a witness who is not qualified as an expert should not be allowed to offer testimony in the form of an opinion. Allowing incompetent evidence creates a danger of unfair prejudice.

### B. THE AMBIGUITY FOSTERED BY MR. BARFIELD'S PREVIOUS ROLE

It is arguable that Mr. Barfield is statutorily precluded from serving as an expert witness here. "Except as otherwise provided by law, in any proceeding under this act, a person shall not be eligible to act as presiding officer, and ***shall not provide confidential legal or technical advice*** to a presiding officer in the proceeding, if that person: (1) Has served in an investigatory or prosecutorial capacity in the proceeding or a proceeding arising out of the same event or transaction." K.S.A. 77-514 (emphasis added). That prohibition is not an unfamiliar concept. A similar rule prevails in relation to federal agency matters. *Pork Motel, Corp. v. Kansas Dep't of Health & Env't*, 234 Kan. 374, 383, 673 P.2d 1126, 1135 (1983) ("The APA says specifically: 'An employee or agent engaged in the performance of investigative or prosecuting functions for an agency in a case may not, ***in that or a factually related case***, participate or advise in the decision.'")(emphasis added). Mr. Barfield's participation is suspect under those standards.

## III. ARGUMENT

### A. BARFIELD IS NOT QUALIFIED TO OPINE ON HYDROLOGICAL MODELING

In his written testimony, Mr. Barfield explains the scope of his assignment: "I have been asked to review and provide an evaluation of Mr. Larson's expert report as further supplemented by his direct testimony for this proceeding." *Barfield Direct Testimony* at 4. He was not asked to critique the GMD5 groundwater model[1] and, indeed, as hereinafter explained is in many respects unqualified to do so. Notwithstanding his circumscribed role and the limits of his expertise, Mr. Barfield in his report and testimony expands his portfolio to opine on perceived shortcomings within the GMD5 model.

Mr. Larson's report is critical of the BMcD report's model. But in attacking Mr. Larson's critique Mr. Barfield strays from his professional moorings. He is not versed in the development of groundwater models. Tellingly, his limited expertise in relation to groundwater modeling was revealed by his candid admissions when earlier deposed where he conceded during questioning by counsel for the Cities that he was not qualified to develop a groundwater model.

> ***Q. So if you know so much about models, why***
> ***did you hire somebody else? I mean, aren't you an***
> ***expert modeler?***
> ***A. I'm not an expert at developing***

[1] The groundwater model developed for the Big Bend Groundwater Management District Number 5 ("GMD5 Model")

***groundwater models. I consider myself more an***
***expert in the application of groundwater modeling***

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***to our resource problems*** so Sam -- Doctor Perkins
Q. Other than it takes a lot of time and
effort that you don't have, but I mean isn't it
true that somebody -- that it takes a particular
and significant training and understanding to
actually develop those -- a model from -- from
either a starting point with somebody else's or
from ground up? That would be fair wouldn't it?
A. Yes.
***Q. Are you qualified to do that?***
***A. To build a groundwater model?***
***Q. Right.***
***A. No.***

*Barfield deposition, p. 150:20-25, p. 151:-1-14*

To draw a more commonplace analogy, Mr. Barfield may be able to follow a cookbook, executing the instructions to create the desired dish, but he lacks the expertise to create the recipe.[2] An expert who "possesses knowledge as to a general field" but "lacks specific knowledge does not necessarily assist the jury." *City of Hobbs v. Hartford Fire Ins. Co.*, 162 F.3d 576, 587 (10th Cir. 1998).

The core of Mr. Barfield's objection to Mr. Larson's opinion seems to rest on his assertion that Mr. Larson considered issues not addressed by the GMD5 Model. This is most markedly demonstrated in the following declaration from Mr. Barfield:

> Mr. Larson is correct with respect to BMcD not accounting for 'enhanced' precipitation recharge due to irrigation, but that omission was reasonable

[2] "For a witness to testify as an expert on a particular subject, the witness must have skill or experience in the business or profession to which the subject relates....This witness had no experience as a mill operator or feed mixer. In fact, he admitted that he didn't pass himself off as an expert in any of these fields. He was an entomologist and administrative director of several programs within the agriculture board. The trial court did not err in restricting the scope of his testimony." *Choo-E-Flakes, Inc. v. Good*, 224 Kan. 417, 419, 580 P.2d 888, 890 (1978).

> because the GMD5 model does not include that feature... Mr. Larson disregards the fact that the GMD5 Model Report, as used by BMcD, remains the best tool we have to simulate the long-term impact of the Cities' proposed water transfer and is superior to Mr. Larson's proposed alternative methodology.

*See Barfield Written Testimony*, page 5:3-7. But David Romero, president and a hydrologist at the firm that developed by the GMD5 Model, has endorsed Mr. Larson's conclusions regarding the effect of cessation of irrigation on aquifer recharge. Mr. Romero concurs with Mr. Larson's assertion that, given the model's premise of increased groundwater recharge due to precipitation on irrigated land, any valid assessment of the proposed transfer, consistent with the GMD 5 Model, must account for a decrease in groundwater recharge when irrigation ends. *Romero's Written Testimony*, page 3:52-62.

The situation here is steeped in a profound irony that cannot be ignored. Mr. Barfield, who once deemed Mr. Larson's expertise reliable and valuable enough to engage him in a pivotal peer review role for the GMD 5 Model, is now in his compensated role critical of Mr. Larson’s work and expertise. In his deposition, Mr. Barfield acknowledged Mr. Larson’s knowledge and abilities.

> A. And actually from that collaborative
> model development process, I sort of spearheaded
> bringing those concepts to our intrastate model
> development, and that actually began with the Mid
> Ark model that was a precursor to the GMD 5 model,
> so we formed a modeling committee and had not only
> a committee, as the model was being developed,
> comment on it and ***make it a better model including***
> ***a peer review modeler, Steve Larson, our expert in***
> ***the interstate litigations both the Republican and***
> ***the Ark River, was on that committee as well.***
> Q. And Steve Larson is with?
> A. He's with a firm called Papadopoulos and
> Associates but he's -- ***he's the state of Kansas***
> ***sort of expert in these interstate conflicts in***
>
> Page 150

1 ***both cases.***

*Barfield deposition, p. 149:11-25 and p. 150, 1.*

Mr. Barfield argues that "[I]n sum, Mr. Larson's method to determine the reduction in recharge under non-irrigated conditions is not reliable, is not based on sound methodology, and leads to a significant overstatement of the expected reduction in recharge from natural precipitation on the Ranch." Yet, it is noteworthy that this is a conclusion from the same person who, in his tenure as Chief Engineer for the State of Kansas, retained Mr. Larson because Mr. Barfield lacked the methodological proficiency necessary to independently construct groundwater models.

Hydrological modeling requires specialized expertise that Mr. Barfield admittedly does not possess. As Mr. Barfield has testified, Mr. Larson does. Mr. Barfield is not situated to assess Mr. Larson's analysis and his report and testimony should be stricken on that basis.

### B. BARFIELD'S TESTIMONY IS BASED ON INACCURATE, OUTDATED FACTS

While lacking the requisite expertise, Mr. Barfield also relies upon dated predictions shown to be unreliable by actual observed data. "As part of the pretrial evaluation, the trial court ... must determine whether the expert opinion is 'based on facts that enable the expert to express a reasonably accurate conclusion as opposed to conjecture or speculation....'" *See Smart v. BNSF Ry. Co.*, 52 Kan. App. 2d 486, 497, 369 P.3d 966, 974 (2016). In the present case, the facts presented by Barfield do not support such a reasonable conclusion.

Mr. Barfield's report focuses on a modified version of the GMD5 Model calibrated several years ago by the Cities' engineering consultants, Burns and McDonnell.

> Hydrological models are used to analyze whether changes in water rights will affect existing rights. However, the acceptability of a hydrological model will be based upon the "number and strengths of confirming observations," and will always rest upon a subjective judgment as to the quality of the model in representing any particular hydrologic system.

NAT'L JUDICIAL COLLEGE, HYDROLOGIC MODELING BENCHBOOK: DIVIDING THE WATERS 8 (2010), *available at* https://www.judges.org/dividing_the_waters/hydrological-modeling-bench-book/ [hereinafter, MODELING BENCH BOOK].

In prior appropriation states, petitioners use hydrologic models to examine whether changes in water rights will impair other existing water rights or otherwise deplete aquifers. *See, e.g., Montgomery v. Lomos Altos, Inc.*, 150 P.3d 971, 971 (N.M. 2006); *see also* Final Report of the Special Master with Certificate of Adoption of RRCA Groundwater *Model, in Kansas v. Nebraska and Colorado*, 124 S.Ct. 461 (2003) attached as Exhibit E. [hereafter, SPECIAL MASTER'S REPORT].

The existing hydrologic model of GMD5, like other hydrogeological models, predicts how groundwater and surface water flows within GMD5 based on mathematical formulas. Those predictive calculations are calibrated to predict groundwater depletion and stream flow based on observable criteria like soil type, the amount of water absorbed by different kinds of vegetation, river flows, amounts diverted for irrigation, rainfall, and return flows to the aquifer. *See* MODELING BENCH BOOK at 13. Modelers then compare predicted outcomes with actual observed data taken from metering performed by government agencies to assess the quality of predictions.

> Calibration parameters are physical, climatic, and/or aquifer properties that can be adjusted to so that the mathematical representation of a groundwater model better represents actual conditions. Selection of final values for calibration parameters requires consideration of the match

> between model outputs and calibration targets, and whether such values are reasonable considering geologic, climatic, and other conditions in the [basin]. Calibration parameters may vary in a spatial context to reflect different physical and/or geographic conditions. *The two principal calibration parameters used in application to the RRCA Model are hydraulic conductivity and precipitation recharge.*

SPECIAL MASTER'S REPORT at 46 (emphasis supplied).

The version of the GMD5 Model relied upon by Mr. Barfield ignored calculations and calibrations in the GMD5 Model designed to account for how growing native grasses impacts existing water rights in the geographic area of the GMD5 Model that includes the R9 Ranch. The Cities' edition of the GMD5 Model also omitted actual streamflow data from the 2008-2022 period for the area of the GMD5 Model known as Zone 9, the area where the R9 Ranch is located. When examining observed changes in Zone 9 recharge data during the 2008-2022 period, Balleau Groundwater Inc. found that actual and predicted recharge aligned almost exactly with observations made by Mr. Larson. (compare Pages 15 and 16 of Exhibit D, KORA response).

Data for the 2008-2022 period thus proves that Barfield erred in relying upon the Burns and MacDonnell work product. What's more, because actual observed recharge levels in the largely irrigated lands of Zone 9 was almost exactly as calculated by Mr. Larson, such calculations suggest that even less recharge will occur at the R9 Ranch due to the higher water consumption of native grasses planted there by the Cities. *See* Barfield Rebuttal Testimony at 40 ("Deep, silt loam-type soils are best, whereas shallow, sandy-type soils are poorest for storing water. Crops, too, have an effect. Perennial crops and grass use the most water because they are actively growing during a longer portion of the year.") Mr. Barfield's testimony is thus predicated upon projections shown to be demonstrably unreliable, as shown by fresh data for Zone 9 of the GMD5 Model and the

Koelliker study that he references throughout his report. Such information categorically refutes Mr. Barfield's testimony regarding the projected amount of recharge to the aquifers underlying the R9 Ranch in Zone 9, as well as the version of the GMD5 Model developed by Burns and McDonnell.

## IV. CONCLUSION.

The Barfield report and testimony fails to meet the requisite standards for admissibility. Inclusion of either in the proceedings would contravene the interests of justice, undermine the integrity of this case, and unduly prejudice the parties. Accordingly, Intervenors respectfully request that the Court grant this Motion and strike the entirety of David Barfield's report and rebuttal testimony.

DATED: July 17, 2023
Overland Park, Kansas

Respectfully Submitted,

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I hereby certify that on July 17, 2023, the foregoing was electronically served to all counsel of record by email as follows:

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# EXHIBIT A

**BEFORE THE OFFICE OF ADMINISTRATIVE HEARINGS**

**STATE OF KANSAS**

**IN THE MATTER OF**

| | | |
|---|---|---|
| **THE APPLICATION OF THE CITIES OF HAYS, KANSAS AND RUSSELL, KANSAS FOR APPROVAL TO TRANSFER WATER FROM EDWARDS COUNTY, KANSAS PURSUANT TO THE KANSAS WATER TRANSFER ACT.** | **)<br>)<br>)<br>)<br>)<br>)<br>)** | **OAH NO. 23AG0003 AG** |

Pursuant to K.S.A. Chapter 77.

**REBUTTAL TESTIMONY OF DAVID W. BARFIELD, P.E.**

**ON BEHALF OF**

**THE CITIES OF HAYS AND RUSSELL, KANSAS**

## I. INTRODUCTION AND SUMMARY

**Q. Please state your name and present position.**

A. David W. Barfield, P.E., Owner and Principal of Kansas Water Resources Consulting, LLC.

**Q. On whose behalf are you submitting testimony?**

A. The City of Hays, Kansas and the City of Russell, Kansas (the "Cities").

**Q. Please describe your educational background, employment experience, and duties and responsibilities of your current position.**

A. I graduated with a Bachelor of Science in Civil Engineering in 1978 and a Master of Science in Water Resource Engineering in 1991—both from the University of Kansas. I am a licensed Professional Engineer in Kansas.

My career in water resources now exceeds 40 years. I was employed for 36 years with the Division of Water Resources, which included 15 years as lead of Kansas' technical team dealing with interstate water matters, working principally to resolve concerns related to the Republican River Compact and Kansas-Colorado Arkansas River Compact.

From June 2007 until my retirement from State service in 2020, I was Kansas Chief Engineer, responsible for directing the staff of the Division in fulfilling their broad responsibility over the state's water resources including administration of four interstate water compacts, more than 30,000 active water rights, and the safety of thousands of dams and other water structures. As Chief Engineer I supported the passage and implementation of legislative initiatives to extend the useful life of the Ogallala Aquifer, lead Kansas' efforts to protect to its entitlements under the Republican River Compact, negotiated agreements with Colorado implementing the U.S. Supreme Court's Final Decree on the Arkansas River, negotiating the State first tribal water right settlement, and more. My educational and professional experience has involved extensive use of groundwater models to determine sustainable yield of aquifers, address groundwater-related impairment concerns, make complex groundwater related decisions, and to support interstate water litigation for Kansas.

Since retirement from the State, I have worked as a consultant, assisting two of the State's groundwater management districts (GMDs) in implementing water conservation in the Ogallala Aquifer; and assisting municipalities, industry, investment and irrigation interests on water rights matters, including water right reviews, investigating new sources of water for expansion, assisting in water right conversions and changes, evaluating water rights for purchase, and investigation of impact of neighboring changes on a client's water rights.

My educational background, employment experience, and current duties and responsibilities are set forth in more detail in my CV, which is Attachment 1 to my report, and is incorporated into my testimony as if set forth in full.

**Q. Has this direct testimony been prepared by you or under your direct supervision?**

A. Yes, it has.

**Q. Have you previously testified before the Kansas Department of Agriculture–Division of Water Resources or any other regulatory agency or any litigation in the past?**

A. Yes, I have:

- *In re Designation of an Intensive Groundwater Use Control Area in Wallace, Logan, Gove, and Trego Counties, Kansas* (Feb. 1987).
- *Franklin v. Atwood Township*, (Rawlins Cnty.) (Regarding Atwood Lake and the 1989 Flood).
- *Kansas v. Nebraska and Colorado*, No. 126 Orig. 538 U.S. 720 (initiated Oct. 21, 2008 pursuant to decree of May 19, 2003), and related arbitration trials, which included testimony relating to:
    - Ensuring Future Compliance by Nebraska (Jan. 2009);

- Requirements for Nebraska's Compliance with the Republican River Compact (Jan. 2009);
- Kansas' Responsive Expert Report Concerning Haigler Canal and Groundwater Modeling Accounting Points (Feb. 2009);
- Kansas' Expert Response to Nebraska's Expert Report, "Estimating Computed Beneficial Use for Groundwater and Imported Water Supply under the Republican River Compact" (Feb. 2009);
- Colorado Compliance Pipeline (June 2010);
- Ensuring Compliance by Nebraska (November 2011);
- Nebraska Rock Creek Proposal (July 2013);
- Expert Report on the Nebraska Plan for Alternative Water-Short Year Administration (July 2013);
- Pre-filed Direct Testimony of Kansas Expert David W. Barfield, P.E. (Aug. 2013);
- Colorado's Compact Compliance Pipeline Proposal and Bonny Reservoir Accounting Proposal (July 2013);
- Pre-filed Direct Testimony of Kansas Expert David W. Barfield, P.E. (Sept. 2013)
- Nebraska N-CORPE Augmentation Plan Republican River Compact (Jan. 2014);
- Pre-Filed Testimony of David W. Barfield (Feb. 2014).

- *Cochran v. Kan. Dep't of Agric. and the City of Wichita, Kansas*, (2014) (deposed and testified in an administrative hearing on remand from District Court to Agency to allow the Cochrans the opportunity to challenge DWR's approval of the six permits. The administrative hearing held on January 8, 2014, January 9, 2014, and May 14, 2014).

**Q. Are you sponsoring any exhibits with your rebuttal testimony?**

A. Yes. I Sponsor Exhibit DWB-01, which is my rebuttal report titled "Rebuttal Report to SSPA's 'Revaluation of Burns & McDonnell's R9 Ranch Modeling Results' as supplemented by Mr. Larson's direct testimony," and which is incorporated into my testimony as if set forth in full.

**Q. What is the purpose of your direct testimony?**

I have been asked to review and provide an evaluation of Mr. Larson's expert report as further supplemented by his direct testimony for this proceeding.

**Q. In summary, what did you conclude?**

A. In general, Mr. Larson's criticisms of Burns & McDonnell's groundwater model report are overly simplistic, lack a reasonable scientific basis, are greatly exaggerated, and are not based on valid scientific methodology.

In short, Mr. Larson alleges a deficiency in the modeling of Burns and McDonnell (BMcD) supporting both the City's application for change of the water rights appurtenant to the R9 Ranch as well as for the water transfer proceedings, specifically asserting that "the BMcD evaluation failed to consider how groundwater recharge on irrigated land would change when the land was no longer irrigated." To remedy this alleged deficiency, Mr. Larson reduced the recharge on the Ranch by the difference between the "pre-1970 conditions," which he refers to as the "non-irrigated" curve, and the post-1970 curve, which he calls the "irrigation curve." Both curves are from Figure 32 of the June 2010 Balleau Groundwater, Inc. ("BGW") Hydrologic Model of Big Bend Groundwater Management District No. 5 for "Zone 9" shown in Figure 33 of the BGW Report which covers a large portion of GMD5 including the R9 Ranch. Mr. Larson's approach produced a 44% reduction in precipitation recharge after the Cities stopped irrigation on the Ranch as compared to the BMcD report. He then illustrates the effects of this reduction in recharge, comparing it to BMcD's modeling report.

Mr. Larson is correct with respect to BMcD not accounting for "enhanced" precipitation recharge due to irrigation, but that omission was reasonable because the GMD5 model does not include that feature. And Mr. Larson ignores the fact that the GMD5 Model Report, as utilized by BMcD, is still the best tool available for simulating the impact of the Cities' proposed water transfer over the long-term, and is superior to the alternative method proposed by Mr. Larson for multiple reasons, including:

- Mr. Larson incorrectly asserts that the GMD5 Model Report "was premised on the concept of increased groundwater recharge from precipitation on irrigated lands."
- Mr. Larson's method for estimating the purported irrigation "enhancement" to recharge is overly simplistic, opaque, and unsupported by either the GMD5 Model Report or its supporting documentation.
- Mr. Larson overstates the extent to which post-irrigation recharge is reduced on the R9 Ranch because he ignores the fact that the soils on the Ranch are excessively drained sandy soils, resulting in high permeability and very low water-holding capacity compared to the rest of Zone 9.
- Based on my extensive experience as Chief Engineer of the Division of Water Resources, even assuming the accuracy of Mr. Larson's unsupported claims, the difference in water levels after 51 years of the Cities' continuously pumping their maximum authorized quantity of water from the Ranch water rights is practically negligible and well within the acceptable levels of water use by both irrigators in the area of the Ranch, municipalities, and other water users across the State of Kansas.

In sum, Mr. Larson's method to determine the reduction in recharge under non-irrigated conditions is not reliable, is not based on sound methodology, and leads to a significant overstatement of the expected reduction in recharge from natural precipitation on the Ranch. Even if his report could be accepted at face value, the effects Mr. Larson shows from this reduction in recharge are largely contained on the Ranch, even under the worst-case scenario of 4,800 acre-feet per year for 51 years, and generally has negligible long-term impacts on the Ranch and, in particular, other water right users.

**Q. Please describe how you arrived at your conclusions.**

A. My work consisted of a careful review of Mr. Larson's report, as well as a review of pertinent portions of BGW's GMD 5 Model Report and its attachments as they relate to Mr. Larson's opinions. The model documentation is clear that while there are two sets of recharge curves for pre- and post-1970 periods, nowhere in the model documentation is the difference in these curves ascribed to irrigation alone and nowhere are the two curves applied specifically to irrigated vs. non-irrigated lands. Rather, the model documentation shows that the factors affecting the difference in the curves reflect a list of land-use changes including various soil and water conservation practices including dams and farm ponds, terraces, conservation tillage of various kinds, and irrigation.

In addition, Mr. Larson's methods are not consistent with the Model Report's Appendix H which illustrates the use of the groundwater model to determine the effects of reduced groundwater pumping.

Unlike other groundwater models that have specifically been developed and calibrated with a recharge enhancement on irrigated lands, the GMD5 Model Report provides ***no*** mechanism to estimate the difference in precipitation recharge between irrigated and non-irrigated cases across the entire GMD 5 Model boundary or in any particular Recharge Zone identified in the GMD 5 Model Report, or based on the difference between the specific soil types that exist at the R9 Ranch itself and the rest of "Zone 9" as defined by the GMD5 Model Report.

Due to the purported impact that soil-type has on precipitation recharge and in Larson's evaluation, I also completed a review of soils information for the Ranch. Soil type has a significant effect on precipitation recharge and the potential for its enhancement on irrigated lands. I reviewed available soils information for the R9 Ranch specifically for their implications to precipitation recharge and its potential enhancement on irrigated land and found the soils on the Ranch have low available water capacity and high permeability to the degree that do not support Mr. Larson's conclusion of the very significant irrigation-enhancement for recharge, approaching an average of 5 inches/year.

**Q. Does that conclude your direct testimony?**

A. Yes, it does.

## VERIFICATION

STATE OF Kansas )
)
COUNTY OF Douglas )

I David Barfield, being duly sworn, on oath state that I have read the foregoing and know the contents thereof, and that the facts set forth therein are true and correct to the best of my knowledge and belief.

By: [signature]
David Barfield, P.E.

The foregoing was subscribed and sworn to before me this 28th day of June, 2023.

[signature]
Notary Public

My Commission Expires:

06/17/2024

CAMERON NORTON
Notary Public-State of Kansas
My Appt. Expires 06/17/2024

State of Kansas
County of Douglas.

Kansas Water Resources Consulting
David Barfield, P.E.
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Lawrence, Kansas 66049

**Rebuttal Report to**
**SSPA's "Revaluation of Burns & McDonnell's R9 Ranch Modeling Results"**
**as supplemented by Mr. Larson's direct testimony**
**June 28, 2023**

## Introduction and Background: occasion for work, work scope

I have been asked to serve as an expert on the application of groundwater modeling and Kansas water administration and regulation in light of my education, technical expertise, and professional experience as a licensed Professional Engineer in Kansas, a long-time employee and former Chief Engineer of the Kansas Department of Agriculture, Division of Water Resources, as well as my on-going work as a water-resources consultant. This work has involved the use of groundwater models to determine sustainable yield of aquifers, address groundwater-related impairment concerns, make complex groundwater related decisions, and to support interstate water litigation for Kansas.

Specifically, I have been asked to review and provide an evaluation of the expert report by Steven P. Larson, titled "Revaluation of Burns & McDonnell's R9 Ranch Modeling Results," dated February 1, 2023, as further supplemented by his direct testimony for this proceeding.

All of my opinions in this report are presented within a reasonable degree of scientific and professional certainty.

In short, Mr. Larson alleges a deficiency in the modeling of Burns and McDonnell (BMcD) supporting both the City's application for change of the water rights appurtenant to the R9 Ranch as well as for the water transfer proceedings, specifically asserting that "the BMcD evaluation failed to consider how groundwater recharge on irrigated land would change when the land was no longer irrigated." To remedy this alleged deficiency, Mr. Larson reduced the recharge on the Ranch by the difference between the "pre-1970 conditions," which he refers to as the "non-irrigated" curve, and the post-1970 curve, which he calls the "irrigation curve." Both curves are from Figure 32 of the June 2010 Balleau Groundwater, Inc. ("BGW") Hydrologic Model of Big Bend Groundwater Management District No. 5 for "Zone 9" shown in Figure 33 of the BGW Report which covers a large portion of GMD5 including the R9 Ranch.

Mr. Larson's approach produced a 44% reduction in precipitation recharge after the Cities stopped irrigation on portions of the Ranch as compared to the BMcD report. He then illustrates the effects of this reduction in recharge, comparing it to BMcD's modeling report.

Mr. Larson is correct with respect to BMcD not accounting for "enhanced" precipitation recharge due to irrigation, but that omission was reasonable because the GMD5 model does



EXHIBIT
DWB-01

not include that feature.  And Mr. Larson ignores the fact that the GMD5 Model Report, as utilized by BMcD, is still the best tool available for simulating the impact of the Cities' proposed water transfer over the long-term, and is superior to the alternative method proposed by Mr. Larson for multiple reasons, including:

- Mr. Larson incorrectly asserts that the GMD5 Model Report "was premised on the concept of increased groundwater recharge from precipitation on irrigated lands."
- Mr. Larson's method for estimating the purported irrigation "enhancement" to recharge is overly simplistic, opaque, and unsupported by either the GMD5 Model Report or its supporting documentation.
- Mr. Larson overstates the extent to which post-irrigation recharge is reduced on the R9 Ranch because he ignores the fact that the soils on the Ranch are excessively drained sandy soils, resulting in high permeability and very low water-holding capacity compared to the rest of Zone 9.
- Based on my extensive experience as Chief Engineer of the Division of Water Resources, even assuming the accuracy of Mr. Larson's unsupported claims, the difference in water levels after 51 years of the Cities' continuously pumping their maximum authorized quantity of water from the Ranch water rights, which is not anticipated, is practically negligible and well within the acceptable levels of water use by both irrigators in the area of the Ranch, municipalities, and other water users across the State of Kansas.

In sum, Mr. Larson's method to determine the reduction in recharge under non-irrigated conditions is not reliable, is not based on sound methodology, and leads to a significant overstatement of the expected reduction in recharge from natural precipitation on the Ranch. Even if his report could be accepted at face value, the effects Mr. Larson shows from this reduction in recharge are largely contained on the Ranch, even under the worst-case scenario of 4800 acre-feet per year for 51 years, and generally has negligible long-term impacts on the Ranch and, in particular, other water right users.

**Work undertaken:**

My work consisted of a careful review of Mr. Larson's report, as well as a review of pertinent portions of BGW's GMD 5 Model Report and its attachments as they relate to Mr. Larson's opinions.

The GMD5 Model Report provides ***no*** mechanism to estimate the difference in precipitation recharge between irrigated and non-irrigated cases across the entire GMD 5 Model boundary or in any particular Recharge Zone identified in the GMD 5 Model Report, or based on the difference between the specific soil types that exist at the R9 Ranch itself and the rest of "Zone 9" as defined by the GMD5 Model Report.

Due to the purported impact that soil-type has on precipitation recharge and in Larson's evaluation, I also completed a review of soils information for the Ranch and other areas in Zone 9.

**Professional background and qualifications**

A copy of my curriculum vitae (CV) is attached to this report **as Attachment 1**.

In short, I continue my 40+ year career in water resources. I graduated with a Bachelor of Science in Civil Engineering in 1978 and a Master's Degree in Water Resources Engineering in 1992, both from the University of Kansas. My education includes training in the engineering property of soils and graduate level work in groundwater modeling.

I was employed for 36 years with the Kansas Deportment of Agriculture, Division of Water Resources, which included 15 years as lead of the Kansas technical team dealing with interstate water matters, working to resolve concerns related to the Republican River Compact and the Kansas-Colorado Arkansas River Compact in litigation before the U.S. Supreme Court.

From June 2007 until my retirement from State service in 2020, I was Kansas Chief Engineer of the Division of Water Resources, responsible for directing the staff of the Division in fulfilling their broad responsibilities for regulation and administration of the State's water resources, including administration of four interstate water compacts, more than 30,000 active water rights, and the safety of thousands of dams and other water structures. As Chief Engineer, I supported the passage and implementation of legislative initiatives to extend the useful life of the Ogallala Aquifer, lead Kansas' efforts to protect its entitlements under the Republican River Compact, negotiated agreements with Colorado implementing the U.S. Supreme Court's Final Decree on the Arkansas River, negotiated the State's first tribal water right settlement, and more.

Since retirement from the State, I have worked as a consultant, assisting two of the State's groundwater management districts (GMDs) to implement water conservation in the Ogallala Aquifer; and assisting municipalities, industry, investment and irrigation interests on water rights matters, including water right reviews, investigating new sources of water for expansion, assisting in applications for new water rights and applications to change existing water rights, evaluating water rights for purchase, and investigation of impact of neighboring changes on a client's water rights.

My experience related to groundwater modeling includes:

- Work on various groundwater modeling projects both before and during my tenure as Chief Engineer, some of which involved work with Mr. Larson. For example, we worked together on Kansas v. (Colorado and) Nebraska, No. 126, Orig, related to the Republican River Compact, where I hired Mr. Larson on behalf of DWR and worked with him extensively in leading up to Kansas filing its original action in 1998. We also worked together extensively from 2009-2014 when Kansas was forced to return to the U.S. Supreme Court to enforce the State's 2002 settlement with Nebraska.

- I encouraged the development of Kansas groundwater models and worked with others at DWR, the KGS, and the GMDs to implement the use of a robust model development process for Kansas groundwater models. I oversaw DWR's use of groundwater models for our decisions related to the safe yield of the Ozark Plateau Aquifer of Southeast Kansas, the Lower Arkansas River, and northwest Kansas tributaries to the Republican River. I worked with staff to develop mapping and spreadsheets to make groundwater model results more understandable and accessible to assist in our decision-making on new applications and change applications and support enhanced groundwater management.

- I wrote and presented the paper "*Collaborative Groundwater Model Development*" at the American Society of Civil Engineers' World Environmental & Water Resources Congress, during May 2009.

- I oversaw the use of the GMD 5 groundwater model to evaluate the impairment claim of the U.S. Fish and Wildlife Service regarding its Quivira Wildlife Refuge water rights and to evaluate potential options to address that impairment.

- I also I oversaw DWR's evaluation of the BMcD Report and DWR's use of the GMD 5 groundwater model to evaluate the change applications filed by the Cities of Hays and Russell and the impairment claims made by Water PACK and others. The process and the results of that evaluation are set out in the Master Order and the documents referenced therein.

**<u>Groundwater models.</u>**

Groundwater Models are the best tools available for analyzing ground-water systems, but they are not capable of predicting the future with precision. Groundwater models simulate a portion of a complex natural world that is always a simplification of the true hydrogeologic system, which is impossible to characterize completely. Each of the modeling efforts in this case were prepared by competent professional modelers. BGW's GMD 5 model is well done and both BMcD and Larson rely on and build on that foundation. But the results must be read and used with some caution.

**<u>Summary of Larson's opinions</u>**

Mr. Larson's chief concern is summarized in Section 2 of his report: "The BMcD projected future scenarios did not account for the reduction in groundwater recharge associated with changing the status of lands on the R9 Ranch from irrigated to nonirrigated."

To be clear, Mr. Larson is NOT referring to ***irrigation*** return flows, the removal of which were already accounted for in BMcD's modeling as it is part of the "net pumping" Term.[1] Instead, Mr. Larson's criticism relates to his assertion that "enhanced" recharge from precipitation on irrigated lands is significant and must be quantified when evaluating the Cities' Water Transfer Application.

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[1] *See, e.g.*, Paul A. McCormick, *R9 Ranch Modeling Results Summary,* 3-8 (May 26, 2023) ("Return flow for non-irrigation wells is zero.").

In Section 3 of his report, Mr. Larson describes his attempt to "correct" the purported deficiency. His approach involved substituting a recharge estimate using the pre-1970 conditions for the Ranch rather than using the recharge estimate based on post-1970 conditions used by BMcD and BGW in their modeling. The Ranch is in recharge Zone 9, which is by far the largest zone in GMD 5. Mr. Larson assumes that the difference is due solely to the absence of irrigation before 1970.

**Attachment 2** provides Figures 32 and 33 of BGW's model report showing the precipitation-recharge curves and BGW's recharge zones. These curves show the difference in the applicable Zone 9 curves, for pre-1970 and post-1970 conditions discussed below. Mr. Larson utilized these curves in performing his analysis.

Mr. Larson claims that "[b]y comparing the post-1970 curve to the pre-1970 curve for a given amount of groundwater recharge, SSP&A was able to determine the amount of reduction in recharge [from natural precipitation] that would occur when land conditions change from irrigated to non-irrigated."

Mr. Larson then compares his pre-1970s recharge calculation to BMcD's modeling results via a series of model runs and concludes that recharge on the Ranch should be reduced by 44%. Notably, other than Figure 7, Larson's Report does not provide water budgets or other information needed to confirm those results.

**<u>Evaluation of Mr. Larson's Review</u>**

**Larson's Assertion No. 1:** *"The BMcD projected future scenarios did not account for the reduction in groundwater recharge associated with changing the status of lands on the R9 Ranch from irrigated to nonirrigated."*

With respect to recharge, the dominant difference in irrigated and non-irrigated on any particular tract of land is irrigation return flow. In the GMD 5 model and BMcD's implementation of that model, irrigation pumping is input as "net pumping"; i.e., the difference between pumping and irrigation return flows. Thus, when the "net pumping" is removed, the irrigation return flows are removed.

Here, Mr. Larson is asserting that BMcD's simulations over-estimate future recharge because of a purported enhancement of precipitation recharge associated with irrigation. In other words, Mr. Larson argues that there will be less precipitation recharge under municipal pumping conditions because irrigation saturates the soil, which causes more water to infiltrate down into the aquifer. Specifically, Mr. Larson claims that 44% less water will percolate down into the aquifer under municipal pumping conditions than under irrigation conditions.

I reviewed the BMcD's modeling report and confirmed that while irrigation return flows are removed as is evidenced by Tables 1 & 2 of the BMcD report, precipitation recharge is the same for all scenarios except Scenario 6, the projected drought operations with 2% drought.

**Larson's Assertion No. 2:** "*The BGW groundwater model was premised on the concept of increased groundwater recharge from precipitation on irrigated lands. To be consistent with this premise when evaluating a transfer, the groundwater recharge on irrigated land must be reduced when that land is no longer irrigated."*

Mr. Larson provided no citation to support his claim that the GMD5 model was "premised" on enhanced recharge due to irrigation. In fact, Mr. Larson is mistaken.

It appears that Mr. Larson assumes that because of increased irrigation after 1970, the **sole** cause of the difference between the two curves is irrigation vs. no irrigation. This assumption is not supported by the GMD 5 model documentation; in fact, it is refuted by it. While there are two sets of recharge curves for pre- and post-1970 periods, nowhere in the model documentation is the difference in these curves ascribed to irrigation alone and nowhere are the two curves applied specifically to irrigated vs. non-irrigated lands. There is no statement or suggestion in the BGW model documentation that that model was "premised" on irrigation "enhanced" recharge.

This is also illustrated in Appendix H to the GMD 5 Model Report where BGW discusses the use of the groundwater model to respond to proposed management decisions. Specifically, an illustrative case is shown where all wells subject to administration of minimum desirable streamflows are turned off, 11,296 AF of pumping, but recharge remains unchanged in the BGW modeling (see Table 1), which is precisely what BMcD did in their modeling.

If the BGW model was "premised on the concept of increased groundwater recharge from precipitation on irrigated lands," as Mr. Larson contends, that concept would have been incorporated into BGW's discussion of how the model should be used to respond to proposed management decisions. It was not. Moreover, when Mr. Larson conducted his peer review of the BGW model, he did not criticize BGW for a failure to account for a decrease in recharge caused by removal of those lands from irrigation that he now alleges will occur on the R9 Ranch.

**Larson's Assertion No. 3:** "*The curves on Figure 32 of the BGW report illustrate two curves for estimating recharge in zone 9, one curve for pre-1970 (non-irrigated) and one curve for post-1970 (irrigated). By comparing the post-1970 curve to the pre-1970 curve for a given amount of groundwater recharge, SSP&A was able to determine the amount of reduction in recharge that would occur when land conditions change from irrigated to non-irrigated."*

It was error for Larson to assume that the difference in the pre-1970 curve versus post-1970 curves for Zone 9 was entirely attributable to irrigation. A careful read of the GMD 5 Model Report shows that the increase in recharge rates between pre-1970 and post-1970 was driven by a number of profound changes in land use, with irrigation being only one such factor. The GMD 5 Model Report provides no guidance on how to determine the differences in precipitation recharge due to post-1970 land-use changes or how such changes should be reasonably applied to land management decisions (such as, e.g., converting irrigated farmland to a municipal wellfield)—much less how such changes would simulate recharge relative to the

Ranch or any other specific tract in Zone 9, all of which have experienced non-uniform land-use changes after 1970.

Page 38 of the GMD 5 Model Report, begins the discussion of Land Use and Recharge/Runoff Trends, with the following statement:

> The historical progress of land development in the study area has altered the patterns of runoff and recharge from prairie/rangeland through dry-land agriculture, with progressive soil and water conservation, to irrigation in increasingly efficient forms. The process is described in Koelliker (1998) "Effects of Agriculture on Water Yield in Kansas" (Appendix B) as an increase in runoff and baseflow due to clearing land in the decades from statehood to about WWII, followed by decreases due to retaining water on farm from expanded watershed management and irrigation development.

I have attached the GMD 5's Model Report's Appendix B, Koelliker's referenced paper, as **Attachment 3**.

Page 39 of the GMD 5 model report goes on to state:

> **Recharge is treated in the Big Bend GMD No. 5 model as a monthly variable around an historical trend due to land-use changes**. The pre-development recharge was characteristically low, a few tenths of an inch. **The historical change in recharge is based on a land-use trend as scheduled by Koelliker** (1998, Figure 7.3) where initial baseflow from year 1860 nearly doubled due to land clearing into the 1960s, then declined after "development of ground water resources". The decline of baseflow in recent decades results from net pumping (return flow minus pumping) being negative despite a large increase in recharge from agricultural returns. Total recharge currently may be many times more than the pre-development recharge rate. That process is accounted for to attribute historical change in baseflow to its cause.

(Emphasis added.)

More specific to Mr. Larson's assertion that the pre- and post-1970's recharge curves can be used to estimate the reduction in recharge that would occur when land conditions change from irrigated to non-irrigated, Pages 57-58 of the GMD 5 model report provides the specifics on model inputs for recharge, runoff, and ET.

> Figure 32 shows two sets of curves for Zones 7, 8 and 9, which are located in much of Big Bend GMD No. 5. **The second set of curves represent post-1970 conditions that reflect the land-use change associated with water retained on farm areas**.

(Emphasis added.)

BGW did not give irrigation-enhanced recharge the importance ascribed to it by Larson and, as noted above, Larson did not raise this issue during his peer review of the BGW model. Rather, it is appropriately characterized as just one factor in the difference between pre- and post-1970 recharge in the BGW report.

With respect to the **land-use changes driving the different curves** for the pre- and post-1970 periods noted above, BGW relied on Koelliker work, who states in the Model Report's Appendix B:

> The contributions of the various soil and water conservation practices are estimated with time on the graph. **Dams** are stock watering and erosion control structures that create features commonly known as **farm ponds**. These farm ponds in aggregate collect runoff from over one-third of the watershed. **Terraces** have been installed on nearly one-half of the cropland in the watershed to reduce water erosion and to improve moisture conservation. Here, **residue** refers to a variety of agricultural-management practices to keep the soil surface partially or totally covered with plant residue to reduce potential for water and wind erosion. **Conservation tillage** of various kinds is the most widely used practice. Irrigation is used to describe the effects of withdrawals of ground water from the alluvial aquifer. Nearly all the water withdrawn is subsequently lost as evapotranspiration from the irrigated areas.

(Emphasis added.) Koelliker's Figure 7.3 is pasted below.

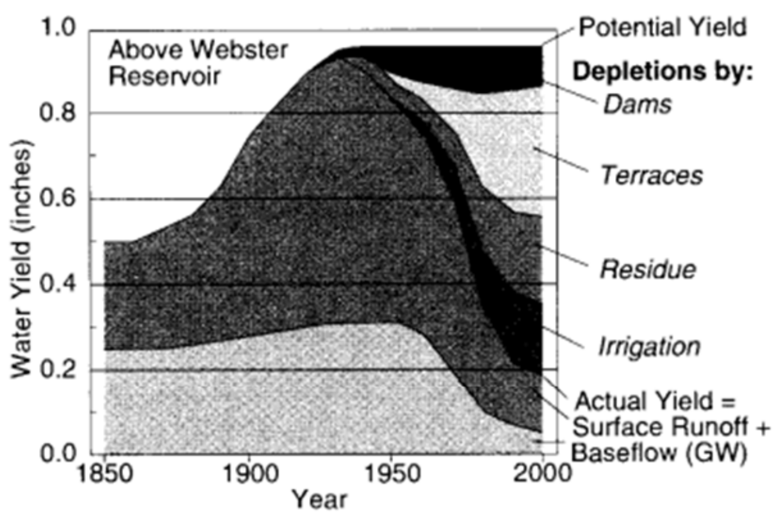


FIGURE 7.3—HISTORICAL PERSPECTIVE OF THE EFFECT OF AGRICULTURAL TECHNOLOGY ON WATER YIELD ABOVE WEBSTER RESERVOIR showing increases caused by conversion to cropland and depletions caused by various soil- and water-conservation practices and changes in agricultural technology (adapted from Koelliker, 1984).

While Figure 7.3 and the specific fractions mentioned in the quoted text are for the South Fork Solomon River above Webster Reservoir, these same practices are in place in GMD 5 Zone 9.

So while irrigation is among the factors affecting the difference in the pre- and post-1970 recharge, the post-1970 curves are applied to all lands, not just irrigated lands, and the significant differences in the two curves reflect the list of land-use changes noted in the Koelliker quote above. In the GMD 5 modeling, these pre-1970 and post-1970 curves are applicable to all district lands, of which only 18% is irrigated.

Taken together, these references demonstrate that Mr. Larson is incorrect in assigning all the differences in the pre- and post-1970 recharge curves to irrigated vs. non-irrigated lands, thus exaggerating the effect that removing irrigation has on recharge.

**Mr. Larson's conclusions are unsupported.**

Consistent with BMcD's report, Mr. Larson states that precipitation recharge averaged about 4,732 acre-feet per year or about 5.1 inches per year "*over the area of the R9 ranch*." These values correspond to about 11,100 acres (4,732 AF / 5.1 inches * 12 inches/foot), approximately the area of BMcD's R9 Hydrostratigraphic Unit (HSU), used in BMcD's Report.[2]

Mr. Larson states that applying the pre-1970 curve to the Ranch HSU instead of the post-1970 curve results in an average precipitation recharge of 2,655 AF/year or about 2.8 inches/acre. This results in a reduction of 2,077 AF/year in precipitation recharge. As an average of approximately 5,200 acres were irrigated historically, his analysis ascribes an increase in precipitation recharge on the irrigated land of 4.8 inches per acre. Mr. Larson's total precipitation recharge on irrigated lands is 7.6 inches (4.8 inches + 2.8 inches), which is in addition to an average of 1.5 inches per acre of irrigation return flows. Based on my experience reviewing groundwater model results, irrigation return flows are normally the largest positive water budget component associated with irrigation. Thus it is remarkable that Mr. Larson's analysis estimates the enhancement to precipitation recharge on irrigated lands at a more than three times irrigation returns flows.

Moreover, Mr. Larson asserts that the "the lack of irrigation to increase and maintain soil moisture impacts the amount of incident precipitation that can recharge the groundwater." As discussed below, Mr. Larson did not explore or address the unique nature of the soils on the R9 Ranch compared to the soil types in Zone 9, discussed below. The soils on the R9 Ranch have very limited capacity to hold moisture, whether from irrigation or natural precipitation. Mr. Larson also fails to account for the fact that any irrigation-enhanced precipitation recharge occurs only during the growing season. These conditions do not support Mr. Larson's extraordinary increases in precipitation recharge noted above.

Mr. Larson's approach of simply subtracting the post-1970 curve from the pre-1970 curve, is overly simplistic and not in accord with accepted scientific principles.

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[2] *See* Paul A. McCormick, *R9 Ranch Modeling Results Summary,* 4-1–4-2 and Figure 3-1 (May 26, 2023).

**Groundwater Models' treatment of precipitation recharge**

The GMD 5 model does not provide a method to estimate enhanced recharge from precipitation on irrigated lands.

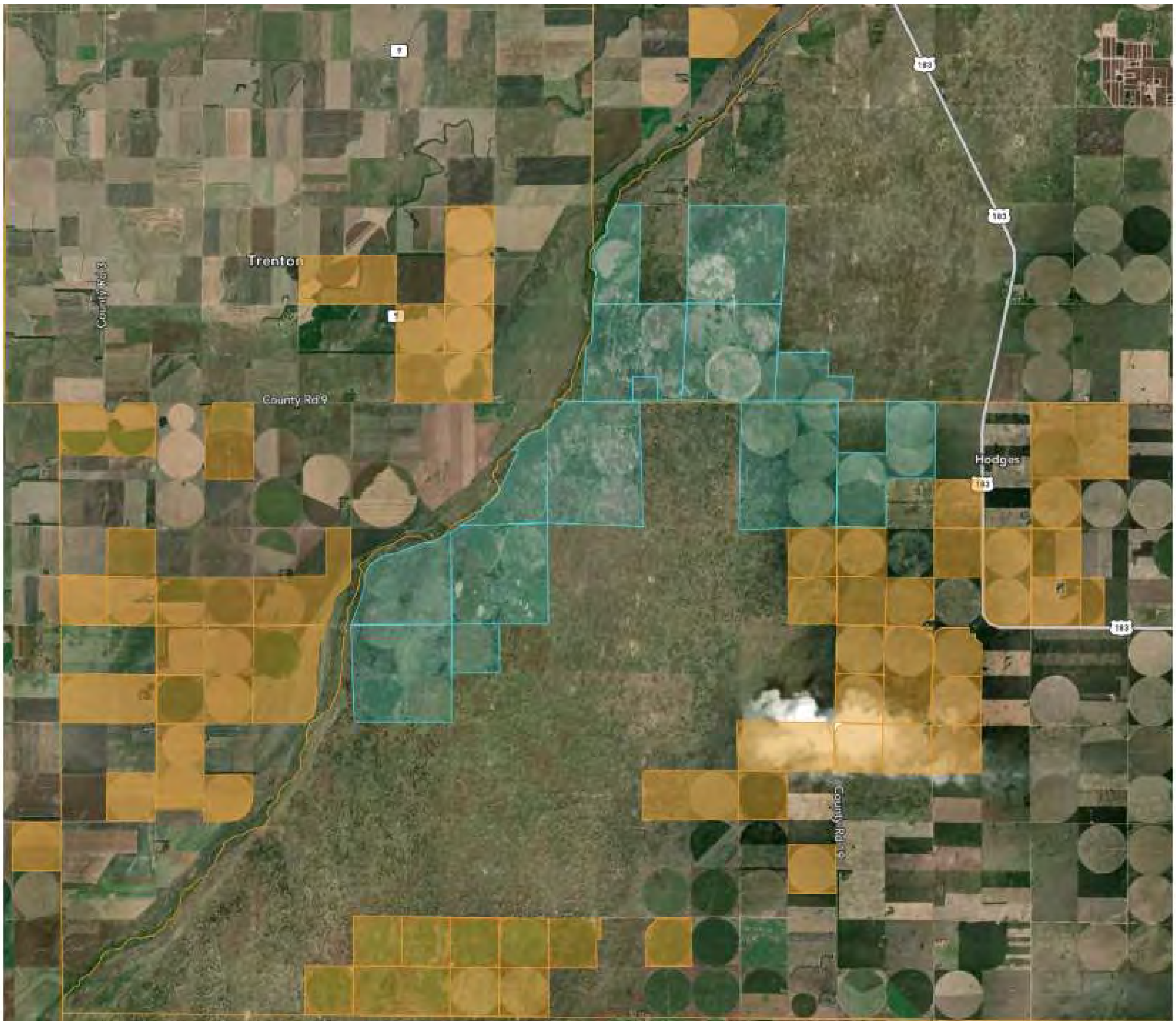
I have been involved in a number of Kansas model development projects by the Kansas Geological Survey for Kansas Groundwater Management Districts (GMDs). In some cases, no enhancement of precipitation recharge was included (the 2006 Middle Arkansas River Model and 2022 GMD 2 model). In other cases (the 2010 GMD 3 model, the 2016 GMD 1 model, and the 2021 GMD 4 model) an enhancement was included, but it was an explicit part in the model development and calibration process.

In this case, because the GMD 5 Model was not developed and calibrated to include such a recharge enhancement, and provided no specific basis for adding that factor, it was error for Mr. Larson to criticize BMcD's modeling on that basis.

**Review of soils information for the R9 Ranch and its implications to the magnitude of enhanced precipitation recharge with irrigation.**

Mr. Larson assumes the soil types on the Ranch are identical to all other soils in Zone 9 of the BGW Model Report. But soil type has a significant effect on precipitation recharge and the potential for its enhancement on irrigated lands. I reviewed available soils information for the R9 Ranch specifically for their implications to precipitation recharge and its potential enhancement on irrigated land and found the soils on the Ranch to be dramatically different than Mr. Larson's assumptions with respect to any purported irrigation-enhancement for recharge.

Below, for general reference, is a map showing the outline of the R9 Ranch in light green and area irrigated lands by WaterPACK members outlined in tan highlighting. It illustrates the contrast of the soils of the Ranch versus lands in the vicinity. The R9 Ranch is in the "sandhills" just east of the Arkansas River. The USDA Soil Survey, published in September 1973, states: "Most of the irrigated acreage in Edwards County, about 15,000 acres, is East of the sandhills and in the Arkansas River Valley. The area east of the sandhills has a large supply of good water and ***a large acreage of soils well suited to irrigation***. This area has good potential for further irrigation development." Soil Survey, p. 30 (emphasis added).




**My detailed review is provided in Attachment 4,** "Review of Soils information for the R9 Ranch," in which I reviewed USDA's 1973 soils survey of Edwards County, Kansas, related to soils identified to be on the Ranch. I subsequently reviewed the NRCS's Web Soil Survey for Edwards County available at: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. Based on my review, it appears that the 1973 Report's soils classifications are the same as the on-line version, with the same basic descriptors.

Using the Web Soil Survey, I created an outline of the R9 Ranch and extracted reports on key soil attributes that influence the magnitude of precipitation recharge, and in particular, the magnitude of differences in such on irrigated versus non-irrigated lands. The attached review includes these reports and is summarized below.

- The Ranch is dominated by two soils, which represent about 85% of the Ranch:
  - Pratt-Tivoli loamy fine sands ("Pt" on soil survey; # 5941 on on-line version) and
  - Tivoli fine sand ("Tf" on soil survey; # 5972 on on-line version).
- These soils have the following descriptors: well-drained or excessively drained sandy soils, rapid permeability and low or very low available water capacity, on slopes. They both have capacity classes that indicate severe or very severe limitations to cultivation.

- Specifically for these two soil types:
    - The capacity of the most limiting layer to transmit water (Ksat) is High to Very High (6.00 to 20.00 in/hour).
    - Available water, 0-60 inches, is low (3.4, and 6 inches).

The soil survey clearly indicates that the soils of the Ranch are not suitable for cultivation because of low available water capacity, and high permeability. Soil water capacity and relatively limited permeability are prerequisites for significant enhancement of recharge from precipitation during irrigation. To the degree that soils do not have the capacity to hold irrigation water, it is unlikely that they will support significantly enhanced precipitation recharge during irrigation.

Thus, the specific soils on the Ranch further undercut Mr. Larson's conclusion that irrigation-enhanced recharge is a significant factor in recharge on the Ranch.

**Review of Mr. Larson's computed effects on the R-9 Ranch and vicinity**

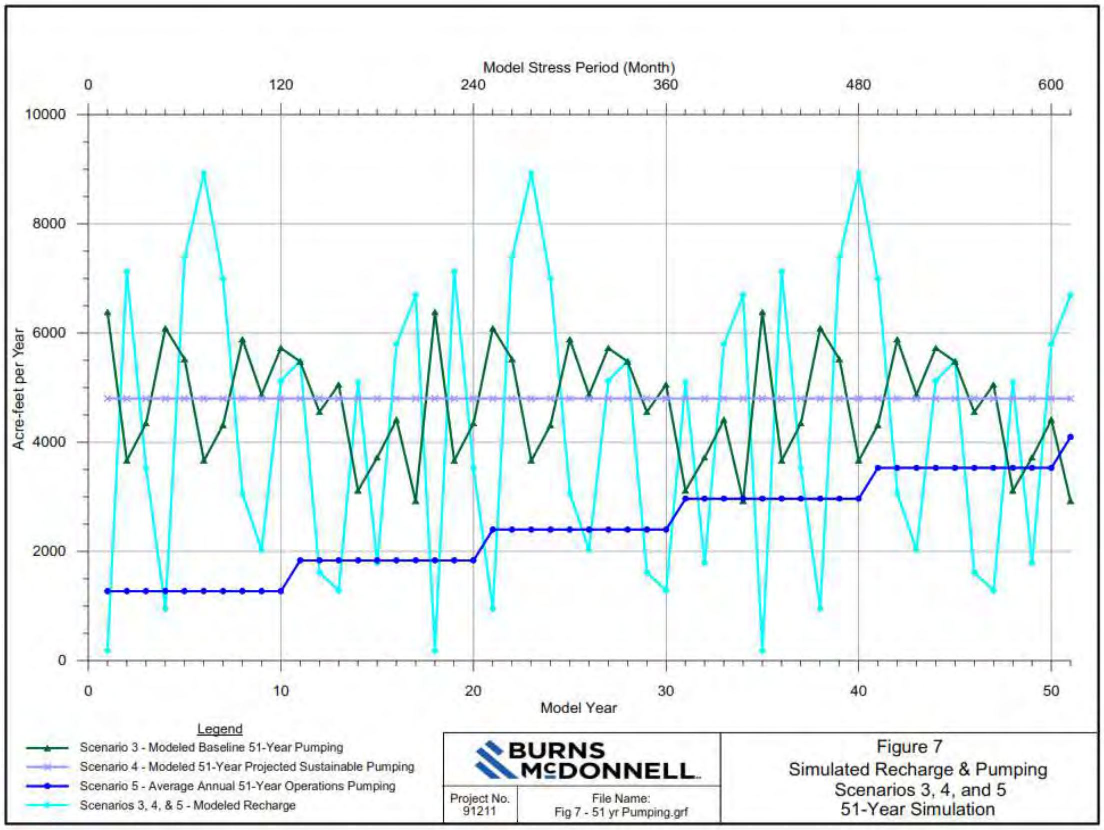
Even given the reduction in recharge from natural precipitation from Mr. Larson's analysis, the effects on the Ranch and vicinity are quite limited.

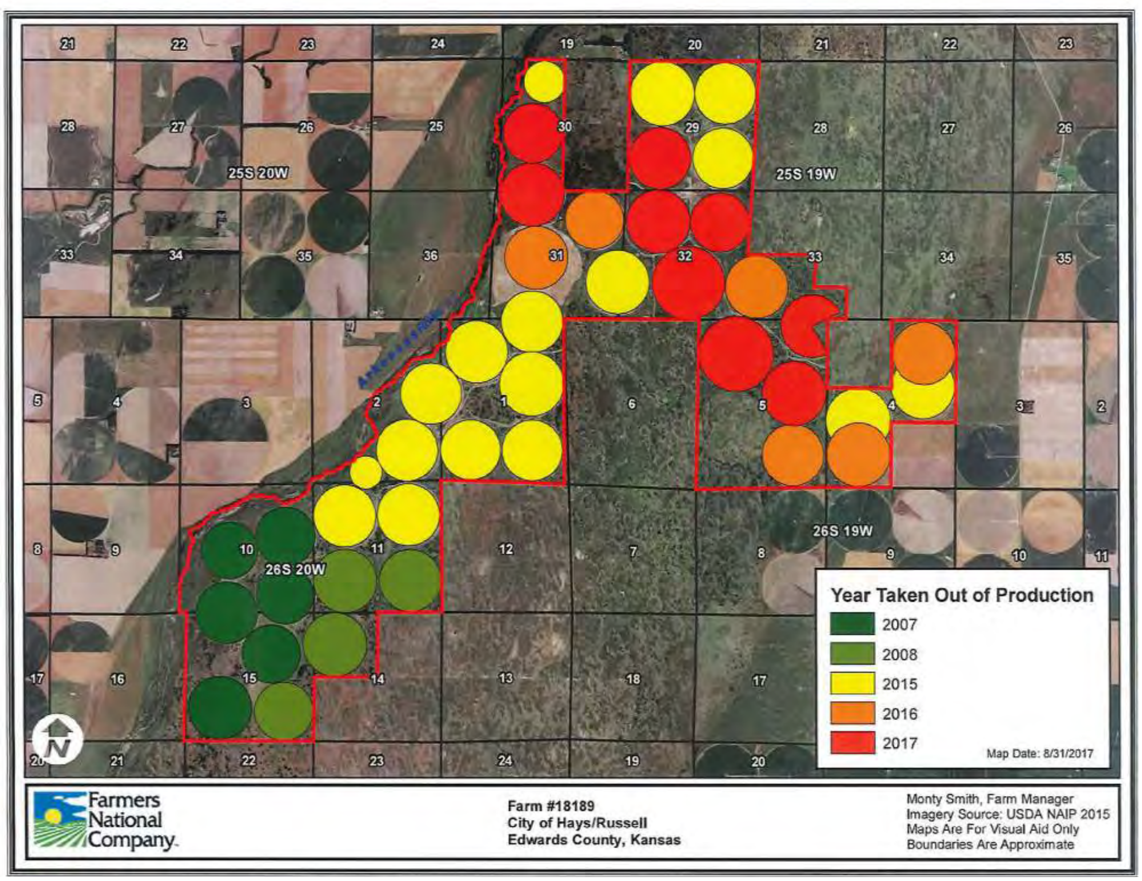
At my request as Chief Engineer, BMcD ran several future simulations to show the anticipated and potential effects of the change from irrigation on the Ranch to the proposed municipal use. Figure 7 from BMcD's modeling report below, shows the proposed pumping under three of those scenarios:

- Scenario 3, continued irrigation use (the baseline);
- Scenario 4, maximum municipal use (4,800 acre feet/year), and
- Scenario 5, anticipated future operations, with a gradual increase in use over the coming 5 decades.

While Mr. Larson displays and explains the results from the various scenarios, his conclusions reference Scenario 4, the maximum-use scenario. This includes his Exhibit 7 which is a tabulation of the individual wells located within specific amounts of lowered groundwater levels that he projects to occur at the end of 51 years of Scenario 4, maximum-use scenario pumping 4,800 acre-feet per year.

These results do not consider the improved conditions on the Ranch as a result of the retiring of the wells from irrigation use, some going back as far as 2007, with all wells out of production since 2017 (see the map below), nor do they acknowledge the fact that the Cities will not be pumping the maximum authorized quantity of water available from the Ranch, 24 hours a day, 7 days per week, for 51 continuous years. Rather, the Cities will develop the Ranch wellfield in phases, and the anticipated operation of the Ranch as a municipal water supply will begin small—less than 1,800 acre-feet per year for the first decade, with a gradual increase in pumping as the Cities' populations are expected to grow over time. It also bears noting that the Cities continue to have access to their existing water supplies, and their use of the Ranch is planned to occur in conjunction with use of those sources—not in place of them.


Model Stress Period (Month)
0
120
240
360
480
600
10000
8000
6000
4000
2000
0
Acre-feet per Year
0
10
20
30
40
50
Model Year
Legend
Scenario 3 - Modeled Baseline 51-Year Pumping
Scenario 4 - Modeled 51-Year Projected Sustainable Pumping
Scenario 5 - Average Annual 51-Year Operations Pumping
Scenarios 3, 4, & 5 - Modeled Recharge
BURNS McDONNELL
Project No. 91211
File Name: Fig 7 - 51 yr Pumping.grf
Figure 7
Simulated Recharge & Pumping
Scenarios 3, 4, and 5
51-Year Simulation


25S 20W
25S 19W
26S 20W
26S 19W
Year Taken Out of Production
2007
2008
2015
2016
2017
Map Date: 8/31/2017
Farmers National Company
Farm #18189
City of Hays/Russell
Edwards County, Kansas
Monty Smith, Farm Manager
Imagery Source: USDA NAIP 2015
Maps Are For Visual Aid Only
Boundaries Are Approximate

Even ignoring these realities and assuming, as Mr. Larson does, that the Cities will undertake 51 consecutive years of maximum authorized municipal use, the greatest impact to the closest irrigation well at the end of the simulation is just 2.8 feet—well under 5% of the remaining saturated thickness of the aquifer.

Based on my extensive experience as Chief Engineer of DWR, such use is well within acceptable and standard declines within the State of Kansas—including near and surrounding the Ranch. DWR routinely grants change applications even though planned water use will result in a reasonable lowering of the static water level at and surrounding the relevant place of use. This is entirely consistent with Kansas law and DWR regulations—many of which were implemented during my tenure as Chief Engineer. Denial or curtailment of the quantity available to the Cities from the Ranch water rights in the quantities and for the reasons suggested by Mr. Larson would ignore Kansas law and would be fundamentally unfair and would treat the Cities differently than every other water user in the State.

**Summary of Opinions**

- While BMcD's modeling does not adjust precipitation recharge with the removal of irrigation lands in its evaluations, this is consistent with BGW's discussion on the use of its model and its example of a reduced pumping future scenario in Attachment H to the GMD 5 model report.

- Mr. Larson's assertion "*that the curves on Figure 32 of the BGW report illustrate two curves for estimating recharge in zone 9, one curve for pre-1970 (non-irrigated) and one curve for post-1970 (irrigated)*" is inconsistent with the GMD 5 Model Report.

- A careful read of the GMD 5 Model Report shows that the increase in recharge rates between pre-1970 and post-1970 curves are driven by a number of profound changes in land use described by Koelliker and relied upon by BGW, including dams creating farm ponds and erosion control structures, terraces, a variety of residue management practices including conservation tillage, and irrigation. Mr. Larson's ascribing the difference between the pre-1970 and post-1970 recharge curves as an estimate of the precipitation recharge enhancement ignores these critical factors and is thus unreliable and over-estimated.

- The BGW model provides no way of quantifying the existence or extent of precipitation-enhanced recharge.

- A review of the soils of the Ranch, shows the Ranch is dominated by soils that are well-drained or excessively drained sandy soils, with rapid permeability and low or very low available water capacity. These characteristics are unlikely to support significant enhanced precipitation recharge with irrigation versus non-irrigated lands.

- To the extent that irrigation did enhance recharge on the Ranch, it occurred only during the irrigation season, not year around, and only on those areas of the Ranch on which irrigation occurred.

- Even given Mr. Larson's exaggerated and unsupported estimates of the reduced recharge, it shows the impact of a limited amount of reduced recharge is not detrimental to the Cities' proposal as the main effects are within the boundaries of the Ranch. Even in the immediate vicinity, Mr. Larson's unsupported worst-case-scenario effects appear to be under three feet of drawdown to the closest well, well under 5% of the remaining saturated thickness of the area, with significantly reduced effects as one moves away from the Ranch. Even given the drastic reduction in precipitation recharge estimated by Mr. Larson's methods, the effects outside the Ranch are practically negligible. Based on my extensive experience as Chief Engineer of DWR, such use is well within acceptable and standard declines within the State of Kansas

**Attachments**

1. David Barfield Curriculum Vitae
2. Figures 32 and 33 of Balleau Groundwater model report (in references below), cited in Mr. Larson's report.
3. APPENDIX B from BGW's GMD 5 Model document, KOELLIKER, J.K. , EFFECTS OF AGRICULTURE ON WATER YIELD IN KANSAS; CHAPTER 7, IN SOPHOCLEOUS, M., ED., 1998, PERSPECTIVES ON SUSTAINABLE DEVELOPMENT OF WATER RESOURCES IN KANSAS: KANSAS GEOLOGICAL SURVEY BULLETIN 239
4. Review of Soils information for the R9 Ranch

**References:**


1. HYDROLOGIC MODEL OF BIG BEND GROUNDWATER MANAGEMENT DISTRICT NO. 5, June 2010, Balleau Groundwater, Inc.
2. APPENDIX H from BALLEAU GROUNDWATER, INC., JUNE 10, 2010, TECHNICAL MEMORANDUM: ILLUSTRATIVE RESPONSE TO MANAGEMENT ACTION
3. Big Bend GMD 5 Model Peer Review, SSPA (Steve Larson), February 2011
4. R9 Ranch Modeling Results – Revision 2, Burns and McDonnell

Barfield Rebuttal Report
Attachment 1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**Education**

| | |
|---|---|
| Master of Science, Water Resources Engineering | 1991 |
| University of Kansas | Lawrence, Kansas |
| Bachelor of Science, Civil Engineering | 1978 |
| University of Kansas | Lawrence, Kansas |

**Registrations**

Professional Civil Engineer, Kansas — License # 9866

**Professional Experience**

**Water Resources Consultant** — 2020-present
**Kansas Water Resources Consulting, LLC**

Water right consulting and assisting groundwater management districts in water conservation, particularly in the development and implementation of Local Enhanced Management Areas (LEMAs). Clients include municipalities, industry, irrigators, and groundwater management districts.

Projects include:

- assisting the Western Kansas Groundwater Management District (GMD) No. 1 in its Local Enhanced Management Area (LEMA) development and implementation including:
    - Assisted in developing the hearing record for GMD 1's Wichita County LEMA and its implementation, 2020-21
    - Assisted the GMD Board and its manager in data development; developing and evaluating options for a LEMA allocation method; writing the LEMA plan; developing the hearing record; and providing testimony at hearing related to the District's Four County LEMA plan, 2021-23;
- assisting the Northwest Kansas GMD No. 4 in developing its hearing record and testimony for its 2022 renewal hearings for the Sheridan 6 LEMA and its District-wide LEMA;
- assisting municipalities and industry in developing and evaluating potential sources of water for expansion;
- assisting water right holders in making application to change their water rights;

- assisting municipalities in evaluating the sufficiency of their existing water rights; identifying best solutions to meet future needs; and developing strategies to perfect their water rights; and
- evaluating the effect of neighboring water right changes on client water rights.

**Chief Engineer** 2007 – 2020
**Division of Water Resources** Topeka, Kansas
**Kansas Department of Agriculture**

Oversaw the staff of the Division with its broad responsibility over the State's water resources including the administration of over 33,000 active surface and ground water rights; regulation of dams, other water structures, and floodplains for public safety and to protect public property; represented the State on its' four interstate water compacts; approved actions of special water districts including Groundwater Management Districts, Watershed Districts, and others for consistency with Kansas law and the public interest; provided legislative testimony regarding statutes administered by the Division including interstate matters; and worked with Kansas' Groundwater Management Districts, which included in part, considering proposed regulations and changes to their management plans and collaborating with them to develop groundwater models.

- Member, Kansas-Colorado Arkansas River Compact Administration
- Kansas Commissioner, Republican River Compact Administration
- Ex officio member, Kansas-Nebraska Big Blue River Compact Administration
- Commissioner, Kansas-Oklahoma Arkansas River Compact Commission
- Member, (Kansas) State Conservation Commission
- Ex officio member, Kansas Water Authority
- Governor-appointed representative for Kansas, Missouri River Recovery Implementation Committee
- Governor-appointed representative, Western States Water Council
- Past President, Association of Western State Engineers

**Selected accomplishments**
- Conducted hearings and issued orders related to the review of the Burrton and McPherson Intensive Groundwater Use Control Areas (IGUCAs) of GMD No. 2, 2020.
- Quivia National Wildlife Refuge Impairment Complaint – Following the US FWS request, conducted an impairment investigation, finding in 2016 that the Refuge's water right was being impaired by upstream junior groundwater pumping. Worked with the Service and GMD No. 5 to explore options for a suitable remedy for the impairment.
- Hays/Russell R9 Ranch change applications – Following significant public input and discussions with the applicants, contingently approved the Cities' change applications to convert the water rights of the R9 Ranch from irrigation use to municipal use, 2019.

- Conducted Hearings and issued orders to establish the State's second Local Enhanced Management Area for the majority of the Northwest Kanas GMD No. 4, 2017-18.
- Kickapoo Water Right Settlement – following years of litigation and disputes with the Kansas Attorney General's Office, the Tribe, and its consultants, negotiated a quantification and settlement of the Tribe's reserve water right signed on September 8, 2016.
- Republican River Compact agreements, 2016 – After more than two years of discussions and interim agreements, on behalf of Kansas, approved two long-term agreements related to Colorado's and Nebraska's compliance activities in the Republican River basin, aligning their actions with Kansas water users' needs in both the upper basin and main stem of the Republican River of Northcentral Kansas.
- Assisted with the development of legislation to allow for Water Conservation Areas (WCA) passed by the Legislature in 2015; worked with staff on implementation of the statute including developing standards of review and processing procedures. Approved over 25 plans covering more than 75,000 acres.
- Oversaw the transition of Division's office to Manhattan, Kansas, 2014
- Prepared expert reports and provided testimony in arbitration trials on five issues of dispute between the states regarding augmentation plans and other matters of administration of the Republican River Compact, 2013-14
- Prepared expert reports and provided testimony in Kansas case against Nebraska in the U.S Supreme Court concerning Nebraska's 2005-06 violations of the Republican River Compact's Final Settlement Stipulation, August 2012
- Conducted Hearings and issued orders to establish the State's first Local Enhanced Management Area for Sheridan County, 2012-13.
- Worked with Northwest Kansas GMD No. 4 to develop proposed legislation to allow Local Enhanced Management Areas, fall 2011; passed by the 2012 Legislature.
- Drafted legislation to provide for significantly expanded use of Multi-Year Flex Accounts (MYFAs), fall 2011, passed by the Legislature in 2012. Extensive use by water users beginning in 2012.
- Kansas-Colorado Arkansas River Compact – Oversaw negotiations and agreement on changes to the H-I Model to reflect Colorado groundwater irrigation improvements, September 15, 2011
- Development of Drought Emergency Term Permit program to provide drought relief for 2011 while preventing increased long-term use, summer 2011
- Oversaw DWR's use of a USGS groundwater model of the Lower Arkansas river basin to update methods to determine safe yield of the aquifer based on best science available.
- Oversaw use of the RRCA Groundwater Model and development of criteria to evaluate water right applications in areas "Substantially Hydrologically Connected" to the tributaries of the Republican River in northwest Kansas.
- Ozark Aquifer Safe Yield Determination using a USGS groundwater model, December 2010.
- Evaluate and make decisions on a series of ongoing groundwater impairment investigations initiated under my predecessor.

- Work with State's five groundwater management districts to improve data, analysis, and management of the Ogallala-High Plains Aquifer including the GMD No. 1 closure to new application; a GMD No. 2 meter order; and encouraging and participation in the development groundwater models in each of the GMDs.

**Significant regulation development**
- Impairment regulations for groundwater investigations, K.A.R. 5-4-1 & 5-4-1a Effective 10/29/10
- Intensive Groundwater Use Control Area hearing regulations (new) K.A.R. 5-20-1 and 5-20-2, Effective 9/18/09

**Interstate Water Issues Technical Team Leader** 1992 – 2007
**Division of Water Resources** Topeka, Kansas
**Kansas Department of Agriculture**

Managed and developed, along with various inside and outside experts, technical and engineering positions with regard to interstate water rights administration and litigation for <u>Kansas v. Colorado</u> regarding the Arkansas River Compact and <u>Kansas v. Nebraska and Colorado</u> regarding the Republican River Compact. Supervised the work of technical staff of the interstate water issues program and technical consultants for Kansas; developed budget for the program; and performed the following functions:

Republican River Compact:
- Engineering committee representative for Kansas on the Republican River Compact 1994-2007
- Developed proposals and supporting data for Kansas presentation to the Compact Administration.
- Lead technical representative on the facilitated negotiations, 1995-97
- Provided technical data in support of Kansas filing in Kansas v. Nebraska and Colorado.
- Acted as custodian of records for Kansas in Kansas v. Nebraska and Colorado; assisted team in document discovery of other states and the federal government.
- Lead technical representative in settlement discussions, 2001-02. Co-author of the Accounting Procedures adopted in the settlement.
- Member, Modeling committee in settlement discussions, 2002-03.
- As Engineering Committee representative since the settlement, participated in its work to implement its comprehensive review and minor fixes to the Accounting Procedures, development of the accounting spreadsheet.
- Worked with other committee members toward development of the annual accountings and resolution of differences.

Kansas-Colorado Arkansas River Compact:
- Lead technical representative for Kansas in negotiations with the state of Colorado to resolve John Martin Reservoir accounting disputes.

- Acted as Kansas representative to oversee study to develop methods to quantify transit losses between John Martin Reservoir and the Kansas-Colorado stateline on the Arkansas River and to determine methods for computing Colorado deliveries.

Missouri River:
- Reviewed the Corps of Engineers' Missouri River Mainstem Reservoirs Master Manual Revisions for impacts to Kansas interests.
- Assisted and, at times, represented the Chief Engineer in matters related to the Missouri River Basin Association (MRBA)
- Member of the MRBA technical committee.
- Participated in negotiations among the states on recommendations to the Corps of Engineers on revised navigation rule curves that they ultimately adopted in their Revised Master Manual.
- Acted as Kansas representative on the Spring Rise Plenary work group and lead the hydrology technical work group, 2005-2006.

Other duties:
- Participated in the Middle Arkansas River groundwater model technical advisory committee.
- Participated in the Groundwater Management District No. 4 groundwater model technical advisory committee.

**Head of Dam Safety Unit** 1987-1992
**Division of Water Resources** Topeka, Kansas
**Kansas Department of Agriculture**

Supervised and participated in the work of Dam Safety Unit in reviewing plans for proposed dams, construction inspections, and on-going safety inspections of high and significant hazard dams in Kansas. Reviewed and responded to questions and complaints of the public. Worked with local Watershed Districts to create, review, modify and approve general plans as well as approve specific projects.

**Engineer, Technical Services Section** 1984-1987
**Division of Water Resources** Topeka, Kansas
**Kansas Department of Agriculture**

Conducted hydrologic analysis and investigations, wrote reports, and made public presentations to assist in the determination of administrative policy for intensive groundwater use control areas. Supervised consulting engineers contracted to inspect points of water diversion. Developed micro-computer applications for the section. Resolved technical problems with municipal, industrial, and agricultural water use reporting.

**Regional Engineer** — 1981-1984
**Central Region** — Rep. of Bophuthatswana,
**Bophuthatswana Dept. of Works and Water Affairs** — Southern Africa

Supervised the operation and maintenance of public water supplies for a region of 300,000 people. Duties included: management of 200 staff; design and selection of pumping plant and small distribution systems; budget and inventory control; field investigations of water problems within the region; and government representative on various projects.

**Project Engineer** — 1978-1980
**RCM Associates** — Hopkins, Minnesota
**(now part of SEH of St. Paul, MN)**

Conducted feasibility studies related to municipal wastewater treatment options for communities in Minnesota and Iowa, plan and specification preparation related to waste water treatment plant improvements, and construction inspections.

## Awards and Honors

Headgate Award, 2008, Four States Irrigation Council

## Publications

Collaborative Groundwater Model Development, American Society of Civil Engineers' World Environmental & Water Resources Congress, Barfield, David W., May 2009

Proposed Smoky Hill River and Hackberry Creek Intensive Groundwater Use Control Area Above Cedar Bluff Reservoir, Division of Water Resources 87-1, Barfield, David W., Feb. 1987

Availability of Water in the South Fork Solomon River and Its Valley Alluvium Above Webster Reservoir, Division of Water Resources 84-9, Bagley, James O. P.E.; Barfield, David W. P.E., Oct. 1984

Availability of Water in the North Fork Solomon River and Its Valley Alluvium Above Kirwin Reservoir, Division of Water Resources 84-10, Bagley, James O. P.E.; Barfield, David W. P.E., Oct. 1984

Availability of Water in Sappa Creek, Its Tributaries and Their Alluviums, Division of Water Resources 84-8, Barfield, David W. P.E.; Bagley, James O. P.E., Oct. 1984

Availability of Water in the Solomon River, Its Tributaries and Their Valley Alluviums, Division of Water Resources 84-7, Bagley, James O. P.E.; Barfield, David W. P.E., Jul. 1984

Availability of Water in Big Creek, Its Tributaries and Their Alluviums, Division of Water Resources, Report 84-4, Bagley, James O. P.E.; Barfield, David W. P.E., Jun. 1984

Availability of Water in the South Fork Solomon River, Its Tributaries and Their Alluviums in the Reach Between Webster Res. & Waconda Lake, Division of Water Resources 84-5, Barfield, David W. P.E.; Bagley, James O. P.E., Jun. 1984

Availability of Water in the North Fork Solomon River, Its Tributaries and Their Valley Alluviums in the Reach Between Kirwin Res. & Waconda Lake, Division of Water Resources 84-6, Bagley, James O. P.E.; Barfield, David W. P.E., Jun. 1984

**Expert Testimony or Depositions**

*WATER PROTECTION ASS'N OF CENTRAL KANSAS, vs. DAVID BARFIELD, P.E, AS CHIEF ENGINER,* regarding approval of the Hays/Russell R9 Ranch Water Right Change Application, deposition, January 28, 2020.

*Cochran v. Kansas Department of Agriculture and the City of Wichita, Kansas* - deposed and testified in an administrative hearing on remand from District Court to Agency to allow the Cochrans the opportunity to challenge DWR's approval of the six permits. The administrative hearing held on January 8, 2014, January 9, 2014, and May 14, 2014.

Non-Binding Arbitration pursuant to Decree of May 19, 2003, 538 U.S. 720 Kansas v. Nebraska & Colorado No. 126, Orig., U.S. Supreme Court, regarding Nebraska N-CORPE Augmentation Plan. Testimony and the following expert reports:

- *Report on the Nebraska N-CORPE Augmentation Plan Republican River Compact, Response to report prepared by State of Nebraska, David W. Barfield, P.E., 1/24/2014*
- *Pre-Filed Testimony of David W. Barfield, 2/24/2014*

Non-Binding Arbitration pursuant to Decree of May 19, 2003, 538 U.S. 720 Kansas v. Nebraska & Colorado No. 126, Orig., U.S. Supreme Court, regarding Colorado's Compact Compliance Pipeline Proposal and Bonny Reservoir Accounting Proposal. Testimony and the following expert reports:

- *Expert Report on Colorado's Compact Compliance Pipeline Proposal and Bonny Reservoir Accounting Proposal,* 7/29/2013
- *Pre-filed Direct Testimony of Kansas Expert David W. Barfield, P.E.*, 9/18/2013

Non-Binding Arbitration pursuant to Decree of May 19, 2003, 538 U.S. 720 Kansas v. Nebraska & Colorado No. 126, Orig., U.S. Supreme Court, regarding Nebraska Rock Creek Proposal and Nebraska Plan for Alternative Water-Short Year Administration. Testimony and the following expert reports:

- *Expert Report on Nebraska Rock Creek Proposal*, 7/1/2013

- *Expert Report on the Nebraska Plan for Alternative Water-Short Year Administration*, 7/1/2013
- *Pre-filed Direct Testimony of Kansas Expert David W. Barfield, P.E.*, 8/21/2013 on both matters

Kansas v. Nebraska & Colorado No. 126, Orig., U.S. Supreme Court. Testimony and the following expert report:

- *Ensuring Compliance by Nebraska*, November 18, 2011

Non-Binding Arbitration initiated August 21, 2009 pursuant to Decree of May 19, 2003, 538 U.S. 720 Kansas v. Nebraska & Colorado No. 126, Orig., U.S. Supreme Court. Testimony and the following expert report:

- *Responsive Expert Report of David W. Barfield, regarding the Colorado Compliance Pipeline*, June 22, 2010

Non-Binding Arbitration initiated October 21, 2008 pursuant to Decree of May 19, 2003, 538 U.S. 720 Kansas v. Nebraska & Colorado No. 126, Orig., U.S. Supreme Court. Testimony and the following expert reports:

- *Ensuring Future Compliance by Nebraska*, Jan. 2009
- *Requirements for Nebraska's Compliance with the Republican River Compact*, Jan. 2009 (co-author)
- *Kansas' Responsive Expert Report Concerning Haigler Canal and Groundwater Modeling Accounting Points*, Feb. 2009 (co-author)
- *Kansas' Expert Response to Nebraska's Expert Report, "Estimating Computed Beneficial Use for Groundwater and Imported Water Supply under the Republican River Compact,"* Feb. 2009 (co-author)

Franklin vs. Atwood Township; District Court of Rawlins County, Kansas; regarding Atwood Lake and the 1989 flood; April 1994.

Administrative Hearing in the Matter of the Designation of an Intensive Groundwater Use Control Area in Wallace, Logan, Gove, and Trego Counties, Kansas, February 26, 1987.

**Additional training**

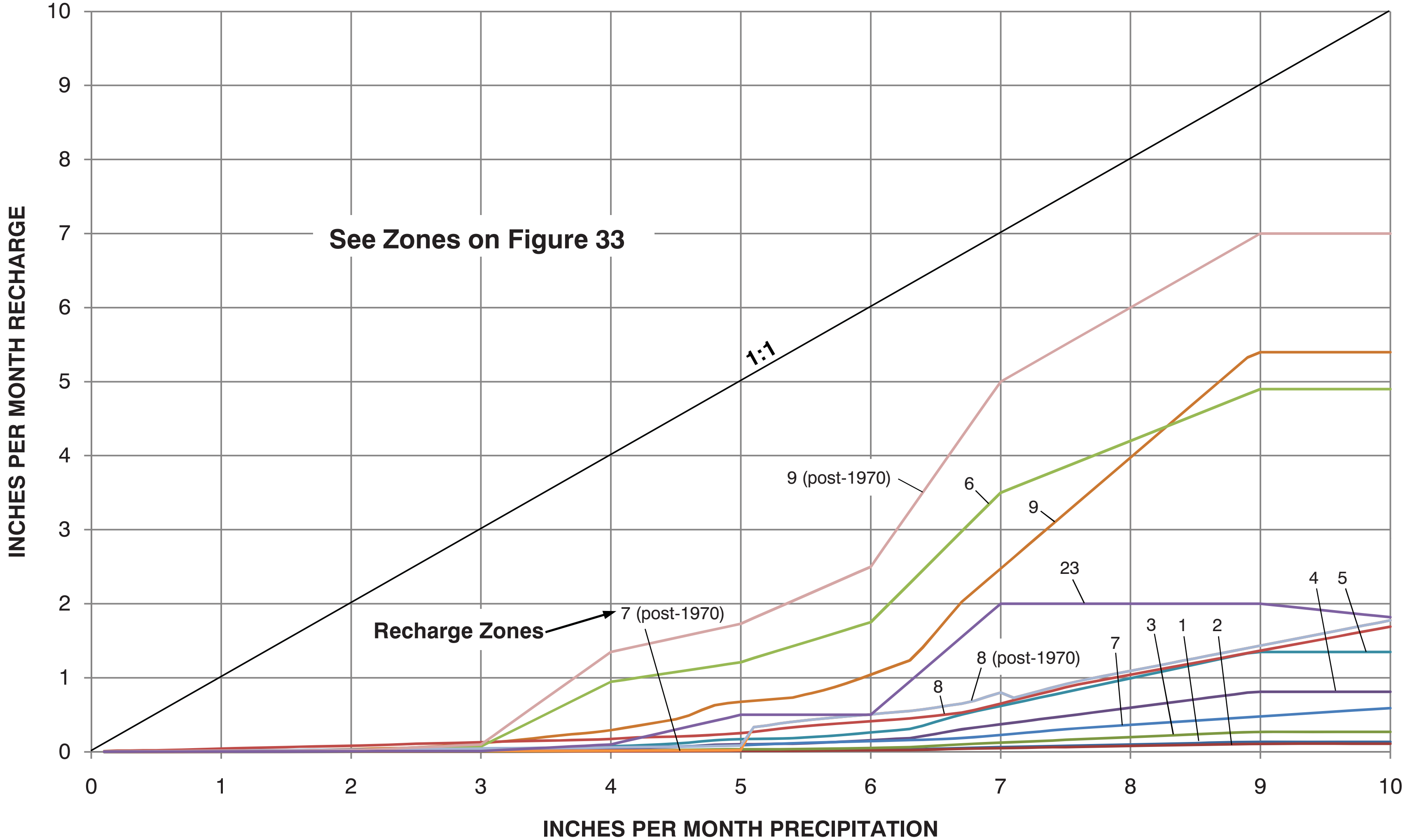
Fundamentals of Hydraulics and Hydrology for Runoff Computations, May 21-25, 1990

Revised: June 2023

Barfield Rebuttal Report
Attachment 2



## FIGURE 32
## MONTHLY PRECIPITATION-RECHARGE RELATIONSHIPS

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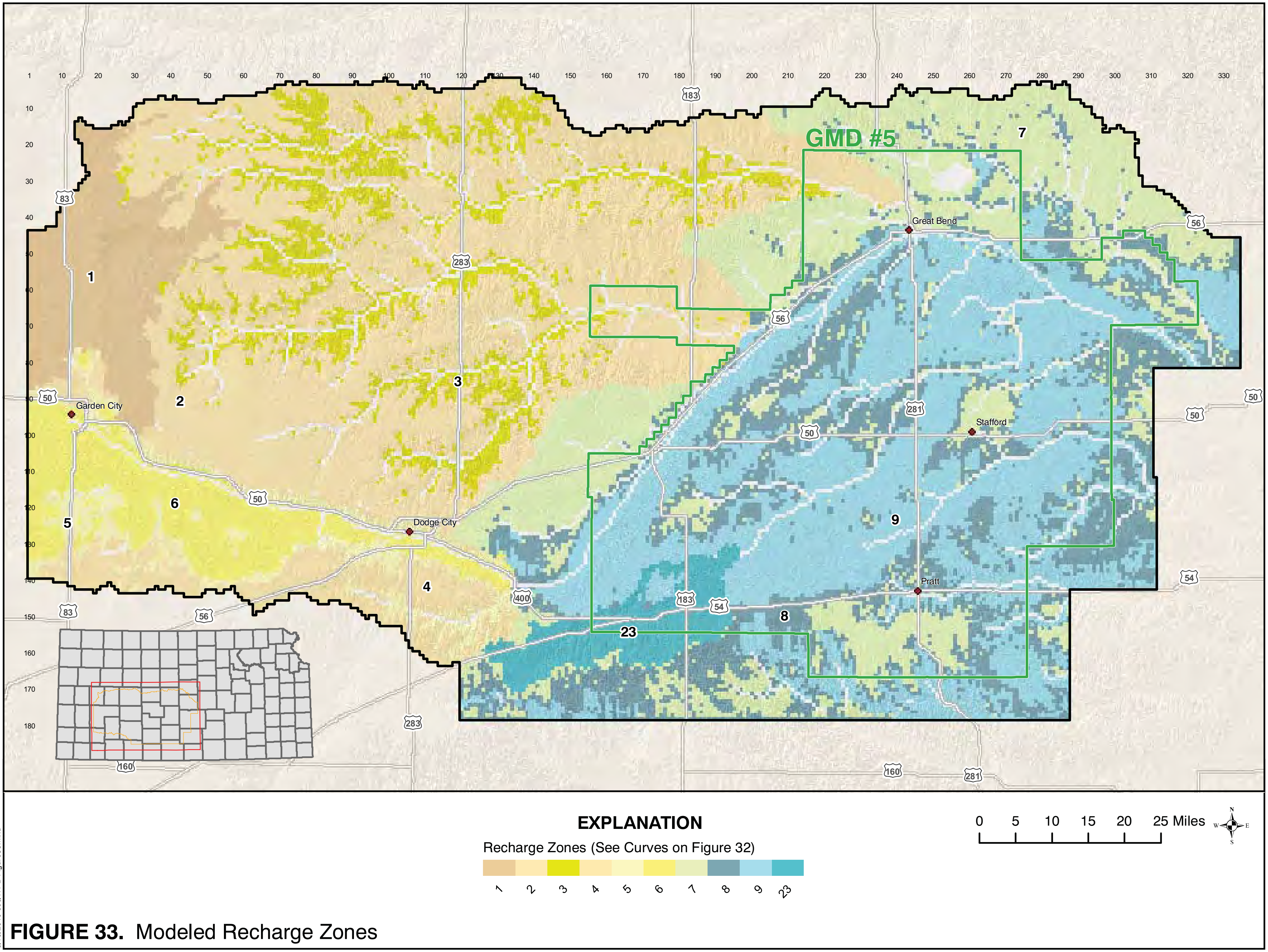


**FIGURE 33.** Modeled Recharge Zones

**APPENDIX B**

**KOELLIKER, J.K.**
**EFFECTS OF AGRICULTURE ON WATER YIELD IN KANSAS;**
**CHAPTER 7, *IN* SOPHOCLEOUS, M., ED., 1998,**
**PERSPECTIVES ON SUSTAINABLE DEVELOPMENT OF WATER RESOURCES**
**IN KANSAS: KANSAS GEOLOGICAL SURVEY BULLETIN 239**

# CHAPTER 7

## *Effects of Agriculture on Water Yield in Kansas,*

*James K Koelliker*
*Kansas State University, Manhattan, Kansas*

Most of the land area of Kansas (over 90%) is used for agricultural purposes. Nearly all of the potential water supply for Kansas (98%) comes from precipitation onto the land surface.. The amount of precipitation averages about 28 inches (70 cm) per year over the state. The primary source of water resources available over the long term for other users in the state is runoff and percolation from the precipitation that falls on agricultural land within the state. Therefore, the activities of agriculture to use and manage the land play a role in affecting the amount and quality of water available for water-resource purposes. Effects of agriculture on water yield are of particular interest because the prior appropriation doctrine is used to allocate water rights. Therefore, understanding how agricultural activities influence the quantity of water lost from agricultural lands is crucial to account for the effects of more efficient use of water from precipitation as well as to decide how much water is potentially available for appropriation by other users.

Effects of agriculture on water yield have been of interest for many years. In much of the state, natural ecosystems, particularly prairies, have been converted to agricultural production Of cultivated crops. Two important changes occur. First, surface runoff is increased because the potential for loss by runoff is increased from soil that is bare or partially bare during the cropping cycle. Bare soil
has a lower rate of infiltration than the same soil covered with growing plants or crop residue. Second, actual evapotranspiration is decreased because annual crops are actively growing for a shorter period of the year than perennial plants. This increases the potential for percolation and subsequent recharge. The exact effects of these changes depend upon the interactions of the climate, soil, and agricultural-management practices including those of soil and water conservation at a particular location.

In most of the state, water supply is limited because precipitation usually is less than potential evapotranspiration for much of the growing season. The success of dryland agricultural technology hinges on its ability to use precipitation as effectively as possible by a combination reducing runoff and increasing the amount of water used as evapotranspiration through useful crops. Additionally, where ground water is available, making use of it is usually very desirable.

The necessity to control wind and water erosion and improve water management was soon recognized in Kansas agriculture. Conservation techniques began to emerge in the 1930’s following the disastrous drought. National programs to reduce erosion soon were developed. Kansas has been a leader in the adoption of soil- and water-conserving techniques including terracing, conservation tillage, farm ponds, and watershed dams. A terrace is a broad channel, bench, or embankment constructed across the slope to intercept runoff and to detain the water or to channel the excess water to protected outlets for disposal from the field. Conservation tillage is a practice that uses mechanical or chemical means to control weeds and/or plant crops such that plant residues cover at least 30% of the soil surface to promote wind- and water-erosion control and moisture conservation.

To quantify the effects of agriculture, several factors that, interact must be considered—climate, soil, and agricultural-management practices which include type of land use, production practices, and conservation practices. Ideally, there would have been field experiments conducted to determine these effects. However, few have been done, and the length of time the experiments were operated were often insufficient to understand the interactions of all of the factors. Thus, simulation-modeling techniques have been required to obtain estimates of effects and to explain the effects on the availability of water resources in the state. The remainder of this chapter focuses on the development of a model, the results from a specific study, and a broader interpretation of those results for the entire state.

### Background for Computer-simulation Modeling

In the 1960’s, the U.S. Department of Agriculture Soil Conservation Service (SCS), now known as the Natural Resources Conservation Service (NRCS), and Agricultural Research Service (ARS) used a joint task force to develop procedures to assess the effects of land and watershed treatment on streamfiow. Land and watershed treatment include change in land use from cropland to permanent cover crops such as native or tame grasses, structural measures such as terraces, tillage and surface-residue management, irrigation, farm ponds and watershed darns. The result was a rational approach based upon annual amounts of precipitation, a climatic variable, extent of land-use changes and conservation practices and other factors. At the time this work was done, however, the effectiveness of residue management was uncertain and the extent of future use of land treatment and other conservation practices was not well known. The procedure, however, has been used by the NRCS, and it did serve as a good basis for future work on the effects of land treatment on water yield. One major limitation of the procedure, however, was that the effects of land treatment and conservation practices on a continuous basis on water yield could not be determined easily. In particular, the variability from year to year in climate could not be accounted for very well with the rational technique.

Continuous computer-simulation modeling allows questions about effects of changes in land use, crops, and management practices to be assessed at various locations over a simulation period of many years. While direct comparison with measured results from field experiments are not possible because such measurements have not been made on whole watersheds, results can be compared with measured streamfiow if conditions in a drainage area are simulated for a period of time. In the late 1960's, water yield into several flood-control and irrigation-supply western Kansas reservoirs that had been built in the 1950's was much less than expected. When well-above-average amounts of precipitation that occurred in the early 1970's did not result in expected inflows to these reservoirs, the Bureau of Reclamation began a study of the Solomon River basin in Kansas to identify what was happening to the water supply. Speculation implicated changes in land use and soil-and water-conservation practices, changes in the precipita tion regime, and increased use of ground water from alluvial aquifers were involved. Work began at Kansas State University to develop a method to assess the effects of land use and soil- and water-conservation practices on water yield on a watershed basis.

## Potential Yield Model

When a method was needed to assess the effects of land use and conservation practices on large watersheds for the Bureau of Reclamation, a continuous computer simulation model, called the Potential Yield (POTYLD) (Koelliker et al., 1981, Koelliker et al., 1982), was developed for this purpose. POTYLD simulates the daily change in the water budget for different climatic and landuse conditions to estimate the dispensation of precipitation as interception, runoff, actual evapotranspiration, percola tion, and change in water content in the soil. The model utilizes values of runoff curve numbers (RCN) to predict the split between runoff and infiltration for land uses from daily amounts of rainfall and snowmelt (See chapter 1 for more information on RCN values). Individual land uses and conservation-practice conditions can be described by a RCN, and the RCN technique is used widely to predict runoff from design storms. It follows that the RCN method can predict runoff over a period of time provided the antecedent moisture condition (AMC), how wet the soil was at the time of each storm, can be determined. This technique to assess runoff through a computer- simulation model is now used widely in watershed-simulation models. Recently, POTYLD has been modified to include additional refinements and to include irrigation; consequently, the name was changed to Potential Yield Revised (POTYLDR) (Koelliker, 1994a, 1994b). This model simulates the water budget on a daily basis for different land uses and estimates the water yield on a monthly or annual basis for a drainage area. A more comprehensive description of **POTYLDR** can be found in Appendix 7.A of this chapter.

The POTYLDR model is useful to estimate effects of land-use changes and agricultural soil-water conservation practices on surface-water yield and on percolation. Exact comparisons with data from the field are difficult because such data are very limited. The following section does provide the results of a comprehensive study to combine all impacts on water yield into Webster Reservoir along with estimates of the effects across the state. Extended use of the POTYLDR model for other studies, too, provides evidence that it reasonably documents real effects that have been and are being experienced in Kansas.

## Results of Modeling Water-yield Changes

Several studies have been done with POTYLD. The most extensive was for the South Fork of the Solomon River basin above Webster Reservoir in northwest Kansas (Koelliker et al., 1981). Webster Reservoir, located on the South Fork of the Solomon River in Rooks County, has a watershed of 1,150 mi2 (2,980 kin2; fig. 7.1). It was completed in 1956, primarily to serve as a water supply for an 8,400-acre (3,400-ha) irrigation district and to control flooding and to provide recreation. After about 1975, however, the irrigation district seldom received a full delivery of water, and in several years no water was delivered. At streamflow-gaging stations in the region with 30 or more years of records, average streamfiow during the 1970's was less than 25% of the long-term average. A report by the Bureau of Reclamation (1984) concluded that phreatophytes, water-loving plants, and changes in the nature of precipitation events were not important contributors to the declining streamflow. That same report did, however, conclude that withdrawal of ground water from the alluvial aquifer was an important contributor. The largest effect by far upon declining streamflow was that of soil- and water-conservation practices, a finding substantiated by POTYL

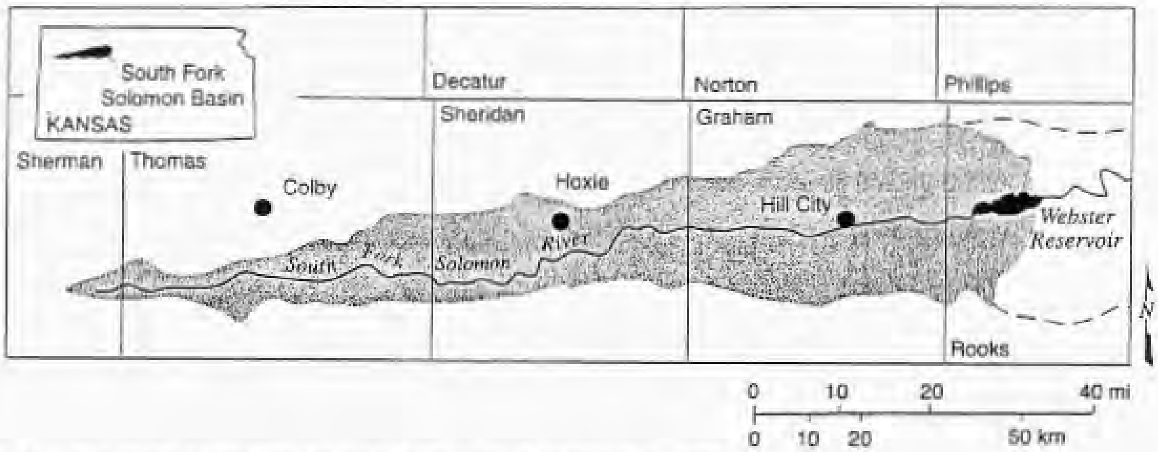


FIGURE 7.1—MAP OF THE SOUTH FORK SOLOMON RIVER BASIN (Koelliker et al., 1981).

Figure 7.2 shows streamflow for two conditions along with measured streamflow into Webster Reservoir for a period when both daily precipitation and streamflow were available for the study. The curve labeled “1950” represents the expected streamflow into Webster Reservoir if conditions above the reservoir had remained unchanged after 1950 Until the end of the simulation period in 1978. The curve labeled “changing” accounted for changes in land use, conservation practices, and ground-water withdrawals during the period simulated. A 3-year moving average is used because of limited availability of continuous weather records to represent the area. Rainfall is spatially quite variable because of the continental-type climate in the area. Because long-term changes were of interest, averaging shows the trend more clearly.

The results of the study showed that by 1980, the expected water yield into Webster Reservoir was predicted to be less than half the historic inflow (1920—1955) of 50,900 acre-feet/year (62.8x106 m3/yr). The Bureau of Reclamation reported the inflow to Webster Reservoir for the period, 1979—1988, averaged 13,300 acre-feet/year (16.4x106 m3/yr; Kutz, 1990), which further substantiated the results obtained by the use of POTYLD.

Fluctuations in all three curves in fig. 7.2 are caused by temporal changes in amounts of precipitation and the ability of that precipitation to produce runoff. Amounts of individual rainfall events and their timing and aerial distribution are critical tO the production of runoff. Continuous simulation is very helpful to evaluate fluctuations in streamflow because it can account for conditions in the watershed when precipitation occurs. By aggregating results from several sub-basins for a stream, the aerial distribution also can be accounted for partially. This is very helpful to describe the impact of precipitation on yield. A study of the Upper Republican River basin of northeastern Colorado, southern Nebraska, and northwest ern Kansas was done using POTYLD as a major component of the work (Koelliker et al., 1983). While changes in precipitation regime appear to be occurring in the Great Plains, the length of record (1920—1978) available for that study did not show it. When POTYLD was used with 1950 basin conditions held constant, essentially no

decrease in water yield with time was expected. A more recent study to estimate the future water supply for the Cheyenne Bottoms Wildlife Refuge, which comes from streamflow originating in west-central Kansas, showed a difference attributable to precipitation. For the period 1973—1988, the ability of precipitation to produce streamflow from this drainage basin was about 27% below that for the earlier period 1948—1972 (Koelliker, 1991).

An historical view of land use and development of agricultural technology on streamflow can be done by simulating for many years with conditions in the water shed fixed at given points in time. Then, the average of the results can be graphed against time to see if there are trends and effects. Such an analysis was done for the South Fork of the Solomon River above Webster Reser voir. In addition, the effects of changes in land use, conservation practices, and ground-water withdrawals during the period show the estimated impact of agriculture on water yield (fig. 7.3) (Koelliker, 1984). Initially, the watershed was all rangeland before 1850. Figure 7.4 shows the important changes with time that have occurred in the watershed. Agriculture was started around 1860 and by about 1930, 70% of the watershed was cropland. Drought and erosion has caused some cropland to be put

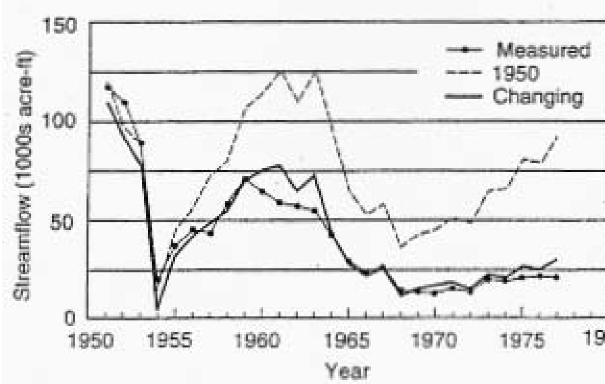


FIGURE 7.2—COMPARISON OF THE THREE-YEAR MOVING AVERAGE ACTUAL STREAMFLOW ABOVE WEBSTER RESERVOIR with streamflow predicted with changing conditions, and when 1950 conditions were held constant (adapted from Koelliker et al., 1981).

back to grass since 1930. Development and adoption of conservation practices have progressed since the 1930's. From the early 1950's, development of ground-water resources has reduced baseflow in the stream. In the future, amounts of surface-water yield will be less than the amount estimated for conditions before agricultural development began.

In fig. 7.3, the line labeled POTENTIAL YIELD represents an estimate of the total streamflow from the watershed jf agricultural land use and practices in the 1930's had remained in place. That period is chosen only because it was the set of conditions in the last 150 years that produced the greatest streamflow. Records from that period also probably influenced the design conditions that were used for the development of Webster Reservoir and its original operations plan. The line labeled ACTUAL YIELD represents the expected amount of streamflow into the reservoir as affected by the changing conditions in the watershed. This line does not imply that water yield does not fluctuate from year to year. It shows an expected average for a given date that would have resulted if the precipitation from 1920 to 1978 had occurred on the watershed when it was in a particular set of conditions that were in place on that date. The split of the actual yield into surface runoff and ground water is an estimate based upon the types of land use with time and the effects of withdrawals of ground water for irrigation.

The contributions of the various soil- and water-conservation practices are estimated with time on the graph. Dams are stockwatering and erosion control structures that create features commonly known as farm ponds. These farm ponds in aggregate collect runoff from over one-third of the watershed. Terraces have been installed on nearly one-half of the cropland in the water shed to reduce water erosion and to improve moisture conservation. Here, residue refers to a variety of agricultural-management practices to keep the soil surface partially or totally covered with plant residue to reduce potential for water and wind erosion. Conservation tillage of various kinds is the most widely used practice. Irrigation is used to describe the effects of withdrawals of ground water from the alluvial aquifer. Nearly all the water withdrawn is subsequently lost as evapotranspiration from the irrigated areas.

The latest conditions in the watershed above Webster Reservoir have not been studied with POTYLDR. Further evidence of the effects of agriculture on water yield appeared from the flood of 1993. This flood and the precipitation that caused it were remarkably similar to the flood year of 1951 (see chapter 1 comparison of 1951 and 1993 floods). Although the reservoir was not completed in 1951, the streamflow-gaging station just upstream was operational and estimates of the inflows to the reservoir had the lake existed have been made for that period by the Bureau of Reclamation. Figure 7.5 shows the precipitation and inflow to Webster Reservoir on a monthly basis for both floods. The amount of inflow in 1993 was essentially half the amount in 1951. This points out that even in years with high precipitation, the effects of agriculture on watersheds in the western half of Kansas can be and are substantial.

At the same time that runoff is reduced, more water is added to the soil to aid subsequent crop production and to add to percolation. At Webster Reservoir, the amount of baseflow into the reservoir appears to be higher than in 1951. Some of the water that did not leave as runoff is' slowly seeping from the watershed and reaching the reservoir. Much more of the seepage water may be being 'used to satisfy ground-water withdrawals in the alluvial aquifers that are above the reservoir.

The impact of agriculture on available water resources for other uses above Webster Reservoir has been substantial. At the same time, however, the water that was lost previously has been converted into more production on the land where it fell. This fact is based upon yield of wheat on dryland in the Northwest Crop Reporting District, which

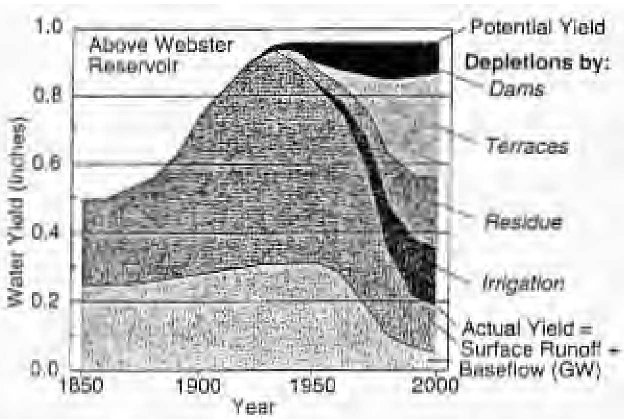


FIGURE 7.3—Historical perspective of the effect of agricultural technology on water yield above Webster Reservoir showing increases caused by conversion to cropland and depletions caused by various soil- and water-conservation practices and changes in agricultural technology (adapted from Koelliker, 1984).

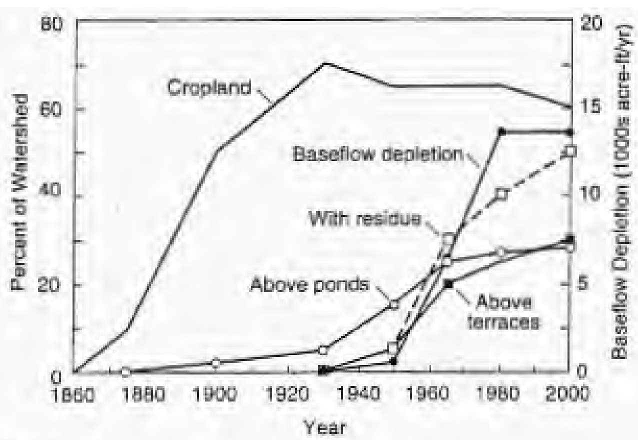


FIGURE 7.4—Historical amounts of cropland, conservation practices, and baseflow depletions in the South Fork Solomon Basin above Webster Reservoir (adapted from Koelliker, 1984).

includes the watershed above Webster Reservoir (fig. 7.6) (State Board of Agriculture, 1989, and previous). Wheat yields have increased steadily since the 1930's. This is the result of better agricultural technology, which includes better varieties, fertilizer and herbicides, and management practices. All of these factors, however, are benefited by more available water. In this area, the USDA ARS estimates that about 40% of the total increase in agricultural production can be attributed to-better water conservation.

There is a tradeoff here between more agricultural production on dryland and water resources available for users downstream. This work points out that the availability of water resources may not be constant over time. It will be necessary to make adjustments in water use-so that the demand is more in line with the supply. As Robert Ingersoll, a 19th century orator from Kansas, stated, "In nature there are no rewards or punishments—there are consequences."

## General Procedure to Estimate the Magnitude of Land-use Changes on Water Yield

Agriculture and agricultural land-use changes are affected by location in the state. The POTYLDR model has been used for several studies in Kansas, and from those general results, inferences can be drawn about the effects of agriculture on water resources in the state. One of the most important aspects that influences the magnitude of land-use changes is that the climate at a particular location can be described by the moisture deficit (MD). The MD is defined as the difference between the average annual lake evaporation and the average annual precipita tion at a location. Figure 7.7 shows a map of the average in each county (DWIR, 1994). There is a substantial difference in MD across the state (see also fig. 1.12 of Chapter 1). MD is greatest in the southwest corner of the state where lake evaporation is greatest and precipitation is near the lowest in the state. The MD is smallest along the eastern border of the state where lake evaporation is lowest and precipitation is more abundant. This variable is one that correlates well with many of the important effects that climate plays on agriculture. The greater the MD the more arid the climate while the lower the MD the more humid is the climate.

The greater the MD the greater the potential to reduce total runoff if the soil can hold the extra water that infiltrates it so that it will be lost later by evapotranspiration. As MD decreases, the potential of percolation increases because the soil cannot hold all of the water that infiltrates during extended wet periods. Soil type is important, particularly the soil's ability to store water that is available for later use by plants. Deep, silt-loam-type soils are best, whereas shallow, sandy-type soils are poorest for storing water. Crops, too, have an effect. Perennial crops and grass use the most water because they are actively growing during a longer portion of the year. Annual or summer crops use less because they are growing for a shorter period of the year. Fallowed soils do not use water, although water is lost from fallowed soil by evaporation. The least water loss is from fallow land with good crop-residue cover, provided no plants are allowed to grow.- Protecting the soil surface on fallowed land with residue decreases runoff, decreases evaporation, and may increase the potential for percolation during wetter years.

Further, experience with the results from the POTYLD model for many locations in Kansas shows that its results are in general agreement with what is observed. The depth of the amount of reduction in surface runoff increases with decreasing MD where conservation practices are added. The effect, however, as a percentage

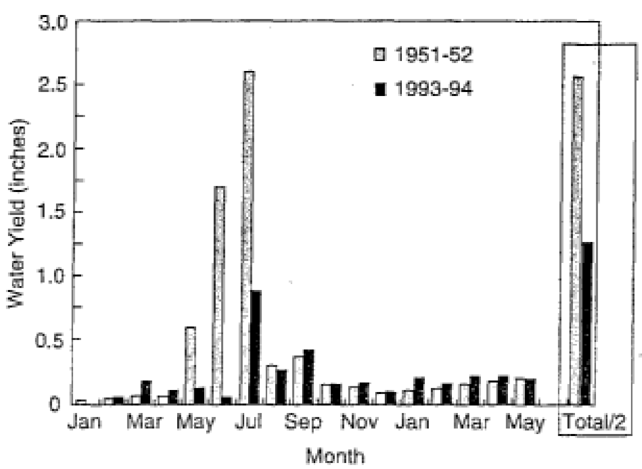


FIGURE 7.5—Comparison of monthly inflow to Webster Reservoir for the floods of 1951 and 1993.

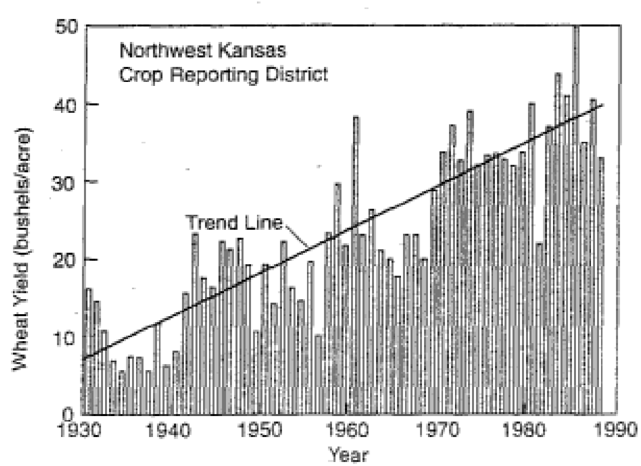


FIGURE 7.6—Dryland wheat yields in the Northwest Kansas Crop Reporting District (data from Kansas State Board of Agriculture).

of total yield decreases as the MD decreases. With decreasing MD, more percolation results from conservation practices. Finally, the effect of conservation practices on total water yield is greatest in areas where the MD is moderate. To illustrate the effect of MD on water yield across Kansas, results of simulating a change in continuous wheat production caused by changing from a condition of little conservation practices to good conservation practices are discussed in Appendix 7.A. The change is expressed primarily in a decrease in the RCN by five and a slight increase in the residue factor that reduces the rate of surface evaporation. Figure 7.8 shows how the general amount of total water yield (surface runoff + percolation), decrease in surface-runoff, increase in percolation, and the total de crease in water yield are affected by the MD. The reader is cautioned to notice that the “average annual” is a log scale in fig. 7.8. In areas where the MD is high, most of the surface runoff prevented by better conservation practices because of more infiltration is stored as soil moisture which is subsequently lost as evapotranspiration because the climatic demand for water is large. With moderate amounts of MD; a larger amount of water yield occurs because there is more potential surface runoff to affect. Some increase in percolation results because not all of the extra water can be stored in the soil during wetter periods. In areas where the MD is low, runoff is still reduced, but nearly all of the extra water that enters the soil becomes percolation. Here, the ability of the atmosphere to increase evapotranspiration during wet periods is insufficient to cause much of the additional water that does not become surface runoff to become evaporation. Also, practices that are effective at reducing runoff require residue cover on the surface. The residue cover also decreases evaporation from the soil. Thus, the total amount of water yield is affected very little in areas where the MD is low. In some cases, water yield may actually be increased in eastern Kansas, particularly
during wet periods because evaporation is decreased. In eastern Kansas, if water is not lost by evapotranspiration, it will eventually become streamflow. There is just not enough storage in the soil to hold all of it for later use.

When the maximum potential for agricultural soil- and water-conservation practices to reduce surface runoff are added together they can have a substantial effect. Figure 7.9 shows a generalized map of these aggregate effects to reduce runoff from the amounts of strearnflow that were reported for conditions around 1930. By the late 1990’s, a substantial amount of these effects of agriculture are occurring. The numbers on fig. 7.9 show the percent reductions that were experienced during the 1980’s for various locations in western Kansas.

The above information is for one set of conditions described previously. Results for a wide variety of land uses and conservation practices found across Kansas have been produced with POTYLDR by making simulations at five locations (Koelliker, 1994a). Predicted average annual depth of runoff and percolation are included in table 7.1 from the representative RCN value for a Soil Conservation Service Group B/C soil (silt loam soil). For all locations, the same planting and harvest date for row crops (grain sorghum, May 10 and October 15) and small grain (winter wheat, October 10 and June 25) were used. The fallow shown is for a combination of wheat-fallow rotation with the wheat having an RCN equivalent to the small grain practice shown earlier in the table. Pasture/ range growing season was March 15 through October 31. These results can be generalized to other locations by relating the values to the MD at a particular location. The MD for three of the locations (Horton, Great Bend, and Garden City) were adjusted somewhat because the stations have more or less annual precipitation than is typical for the MD each one was most representative of across the state. Figure 7.10 shows there is a general relationship

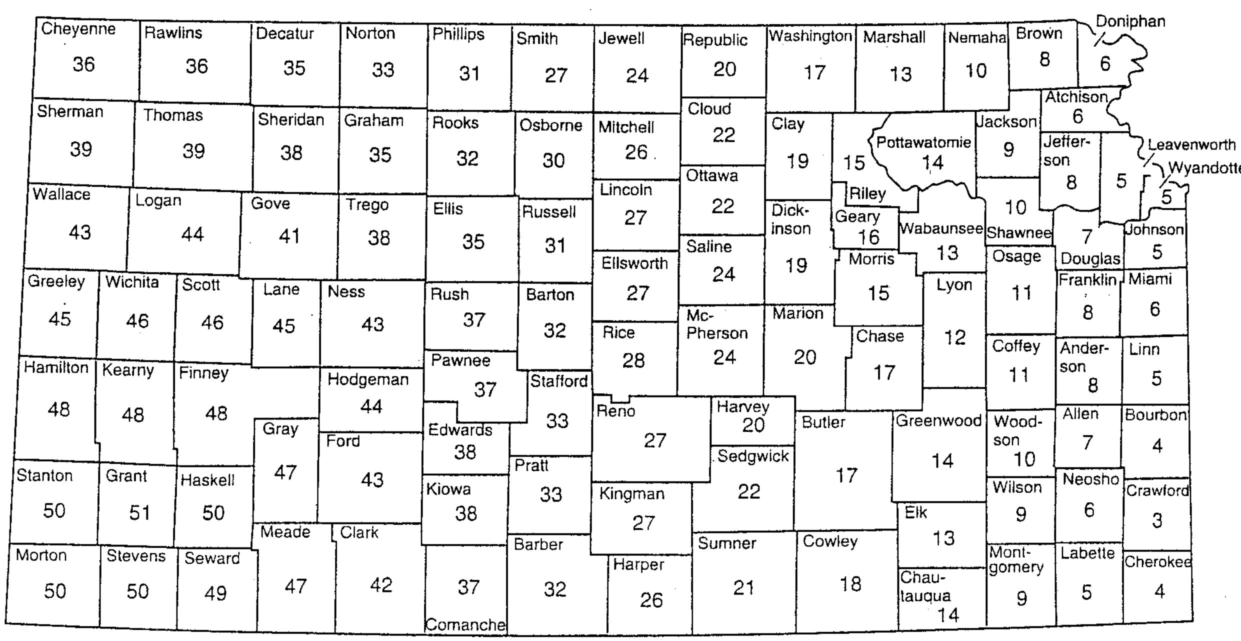


FIGURE 7.7—POTENTIAL NET Evaporation For KANSAS counties (Division of Water Resources, 1994).

between runoff and percolation and the adjusted MD across the range of conditions simulated. The transmission loss factor *(TLF)* is the ratio of runoff estimated upstream to the amount of runoff actually measured at a gaging station downstream. If the value of the *TLF* at each location as shown for each station in table 7.1 is used along with the amount of runoff shown in table 7.1, then the estimated effect of an agricultural practice change on surface streamflow can be calculated by dividing the runoff by the *TLF*.

With the values in table 7.1, it is possible to compare the effect of a change in land use and/or conservation practice from one condition to another condition and to estimate the effect on long-term average amount of runoff and percolation. Consider the effects of changing from an initial land use of annual cropping with row crops with straight row conservation practice (line 1 in table 7.1) to a second condition of pasture/range (line 29) that might result if highly erodible cropland were placed into the Conservation Reserve Program at Great Bend. Predicted

$$Y = (I - F) \cdot P / (TLF \cdot 100) \qquad \text{(eq. 7.1)}$$

average annual runoff for initial conditions, *I*, is 3.19 inches (81 mm) and for final conditions, *F*, is 1.52 inches (39 mm). Essentially no change in percolation is expected. The *TLF* is 1.15 for Great Bend. Further, consider if 4.0% *(P)* of the watershed were to be changed. To estimate the decrease in average annual water yield (Y) use,
The result is, *Y*= 0.06 inches (1.5 mm). At Great Bend, water yield averages about 1.5 inches/year (38 mm/year). So, total water yield. would be reduced by about 4%.

As agriculture developed, much pasture/range was converted to cropland and later conservation practices were added to cropland to reduce erosion and/or to improve moisture conservation. The impact of these changes depends upon the amount of the watershed affected and the magnitude of the change in runoff. Figure 7.11 shows a comparison of surface-water yield from
small grain production with various conservation practices to the surface-water yield from pasture/range across the amounts of MD found in Kansas. Straight row was the earliest agricultural practice. Later, contouring and conservation tillage or residue management were added. along with terraces as conservation practices. The line "Best Management Practice" includes the applicable type of terrace, conservation tillage, and contouring at each of the five locations simulated. The graph shows that the amount of surface runoff from small grain production can be reduced to that expected from pasture/range across Kansas with good management.

The effect of conservation practices on reducing runoff as a percent of the total water yield increases with increasing MD. When MD = 15 inches (38 cm) as found in eastern Kansas, the reduction from straight row to best management practice is about 30%. With MD = 40 inches (100 cm) as is the case in most of the western half of Kansas, the reduction in water yield is about 60%, similar to the results shown in fig. 7.9.

In summary, this section shows that effects of conser vation practices and land-use changes in Kansas on water yield can be Substantial, particularly in areas where the MD is large. Conservation practices have the ability to hold much of the potential runoff, which is then lost as evapotranspiration. These practices are most effective during drier years when streamflow is limited, which further aggravates the problem of allocating limited water resources to other users. The simulation method described in this chapter provides a way to determine the magnitude of these effects on a continuous basis so that effects with time on water yield and water availability can be evalu ated. Other measures such as watershed projects and irrigation withdrawals from alluvial aquifers along streams add further to potential depletions of streamflow. The impact on ground-water recharge is positive in the central portion of the state where several good aquifers store and transmit the additional water to potential ground-water users. In eastern Kansas where the potential to increase percolation is even better, there is limited opportunity to

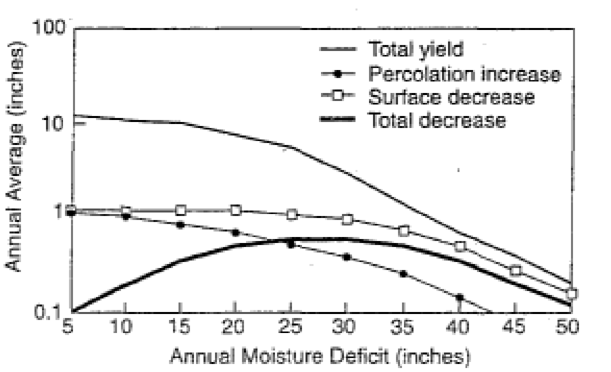


FIGURE 7.8—Simulated effects on aspects of the water budget when the RCN value for continuous wheat is reduced from 75 to 70 on a silt loam soil as related to the MD across Kansas.

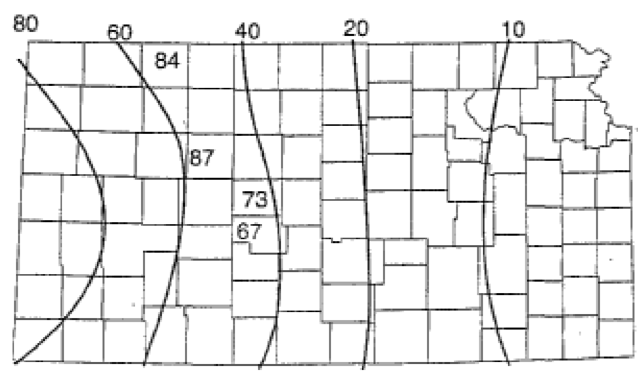


FIGURE 7.9—Generalized potential of soil and water conservation practices and agricultural technology to reduce streamflow below the amount measured in the 1930–1950 period, by percent.

TABLE 7.1—SIMULATED RESULTS FROM POTYLDR FOR AVERAGE ANNUAL RUNOFF AND PERCOLATION, IN INCHES, FOR VARIOUS LAND USES AND CONSERVATION PRACTICES (Koelliker, 1994b).

| LOCATION | HORTON | MANHATTAN | GREAT BEND | COLBY | GARDEN CITY |
|---|---|---|---|---|---|
| Period of record simulated | 1935–1975 | 1958–1986 | 1948–1988 | 1940–1980 | 1948–1988 |
| Lake evaporation inches | 48.90 | 51.13 | 61.47 | 55.63 | 64.03 |
| Precipitation, inches | 35.60 | 32.89 | 25.54 | 19.31 | 17.97 |
| Moisture deficit, inches | 13.30 | 18.24 | 35.93 | 36.34 | 46.06 |
| Adjusted moisture deficit, inches | 15.30 | 18.24 | 28.93 | 36.84 | 42.66 |
| Transmission-loss factor | 1.02 | 1.03 | 1.15 | 1.25 | 1.43 |

| No. Land use | Conservation practice | RCN AMC II | Runoff | Perc. | Runoff | Perc. | Runoff | Perc. | Runoff | Perc. | Runoff | Perc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. row crops | straight row | 81 | 7.61 | 2.39 | 6.37 | 1.17 | 3.19 | 0.07 | 1.92 | 0.02 | 1.27 | 0.00 |
| 2. row crops | contoured | 78 | 6.24 | 3.73 | 5.19 | 2.20 | 2.54 | 0.28 | 1.55 | 0.07 | 0.99 | 0.03 |
| 3. row crops | level terrace | 74 | n/a | n/a | n/a | n/a | 1.97 | 0.55 | 1.20 | 0.14 | 0.74 | 0.05 |
| 4. row crops | lev. terr., cl.-end | 64 | n/a | n/a | n/a | n/a | n/a | n/a | 0.57 | 0.42 | 0.30 | 0.14 |
| 5. row crops | conserv. tillage | 77 | 5.81 | 4.63 | 4.86 | 2.90 | 2.39 | 0.52 | 1.45 | 0.11 | 0.95 | 0.04 |
| 6. 2 | graded terrace | 75 | 5.19 | 4.97 | 4.30 | 3.19 | 2.04 | 0.58 | 1.27 | 0.14 | 0.79 | 0.05 |
| 7. 2 + 3 | | 72 | n/a | n/a | n/a | 3.88 | 1.61 | 0.82 | 1.01 | 0.23 | 0.60 | 0.07 |
| 8. 2 + 4 | | 62 | n/a | n/a | n/a | n/a | n/a | n/a | 0.46 | 0.50 | 0.23 | 0.18 |
| 9. 2 + 5 | | 75 | 5.24 | 5.19 | 4.38 | 3.36 | 2.11 | 0.67 | 1.28 | 0.15 | 0.82 | 0.05 |
| 10. 2 + 3 + 5 | | 70 | n/a | n/a | n/a | n/a | 1.46 | 1.05 | 0.90 | 0.29 | 0.54 | 0.09 |
| 11. 2 + 4 + 5 | | 61 | n/a | n/a | n/a | n/a | n/a | n/a | 0.43 | 0.55 | 0.21 | 0.22 |
| 12. 6 + 5 | | 74 | 5.16 | 5.28 | 4.29 | 3.43 | 2.04 | 0.71 | 1.24 | 0.16 | 0.80 | 0.05 |
| 13. 1 + | irrigated | 81 | 9/05 | 4.58 | 8.09 | 3.26 | 4.78 | 0.86 | 3.15 | 0.41 | 2.50 | 0.09 |
| 14. 1 + 5 + | irrigated | 77 | 6.78 | 6.93 | 6.14 | 5.23 | 3.56 | 1.65 | 2.31 | 0.80 | 1.81 | 0.35 |
| 15. small grain | straight row | 78 | 6.08 | 3.80 | 4.87 | 2.34 | 2.33 | 0.18 | 1.36 | 0.03 | 0.90 | 0.02 |
| 16. small grain | contoured | 75 | 5.03 | 5.01 | 4.00 | 3.31 | 1.88 | 0.44 | 1.10 | 0.14 | 0.71 | 0.04 |
| 17. small grain | level terrace | 71 | n/a | n/a | n/a | n/a | 1.44 | 0.74 | 0.85 | 0.29 | 0.51 | 0.06 |
| 18. small grain | lev. terr., cl. end | 63 | n/a | n/a | n/a | n/a | n/a | n/a | 0.45 | 0.56 | 0.23 | 0.17 |
| 19. small grain | conserv. tillage | 74 | 5.03 | 5.55 | 3.99 | 3.74 | 1.90 | 0.60 | 1.15 | 0.24 | 0.72 | 0.04 |
| 20. 16 | graded terrace | 74 | 4.98 | 5.39 | 3.92 | 3.61 | 1.84 | 0.56 | 1.09 | 0.22 | 0.68 | 0.04 |
| 21. 16 + 17 | | 70 | n/a | n/a | n/a | n/a | 1.32 | 0.90 | 0.78 | 0.39 | 0.46 | 0.08 |
| 22. 16 + 18 | | 60 | n/a | n/a | n/a | n/a | n/a | n/a | 0.39 | 0.65 | 0.19 | 0.18 |
| 23. 16 + 19 | | 74 | 5.04 | 5.60 | 4.08 | 3.78 | 1.91 | 0.62 | 1.15 | 0.25 | 0.72 | 0.04 |
| 24. 16 + 17 + 19 | | 68 | n/a | n/a | n/a | n/a | 1.19 | 1.08 | 0.73 | 0.50 | 0.42 | 0.12 |
| 25. 16 + 18 + 19 | | 59 | n/a | n/a | n/a | n/a | n/a | n/a | 0.36 | 0.78 | 0.17 | 0.23 |
| 26. 20 + 19 | | 71 | 4.16 | 6.46 | 3.26 | 4.47 | 1.52 | 0.86 | 0.92 | 0.39 | 0.55 | 0.08 |
| 27. 15 + | irrigated | 78 | 6.84 | 6.02 | 5.77 | 4.49 | 3.25 | 1.79 | 2.06 | 1.17 | 1.57 | 0.54 |
| 28. 15 + 19 + | irrigated | 74 | 5.54 | 7.43 | 4.69 | 5.70 | 2.56 | 2.33 | 1.65 | 1.54 | 1.21 | 0.83 |
| 29. pasture/range | | 73 | 4.53 | 2.57 | 3.51 | 1.07 | 1.52 | 0.06 | 0.81 | 0.00 | 0.46 | 0.00 |
| 30. 29 | improved | 70 | 3.38 | 3.78 | 2.54 | 1.93 | 1.07 | 0.18 | 0.56 | 0.01 | 0.20 | 0.00 |
| 31. hay (alfalfa) | | 76 | 4.61 | 1.74 | 3.54 | 0.36 | 1.53 | 0.02 | 0.80 | 0.00 | 0.48 | 0.00 |
| 32. 31 + irrigated | | 76 | 6.58 | 4.76 | 5.52 | 3.31 | 3.42 | 0.98 | 1.94 | 0.73 | 1.76 | 0.21 |
| 33. fallow-wheat | straight row | 86 | n/a | n/a | n/a | n/a | 3.69 | 0.72 | 2.37 | 0.25 | 1.70 | 0.04 |
| 34. fallow-wheat | contoured | 83 | n/a | n/a | n/a | n/a | 3.01 | 1.26 | 1.92 | 0.52 | 1.35 | 0.13 |
| 35. fallow-wheat | level terrace | 79 | n/a | n/a | n/a | n/a | 2.28 | 1.92 | 1.46 | 0.90 | 0.96 | 0.29 |
| 36. fall.-wheat | lev. terr., cl. end | 68 | n/a | n/a | n/a | n/a | n/a | n/a | 0.71 | 1.54 | 0.38 | 0.72 |
| 37. fall.-wheat | conserv. tillage | 81 | n/a | n/a | n/a | n/a | 2.94 | 1.74 | 1.87 | 0.81 | 1.29 | 0.24 |
| 38. 34 | graded terrace | 80 | n/a | n/a | n/a | n/a | 2.59 | 1.71 | 1.65 | 0.79 | 1.10 | 0.22 |
| 39. 34 + 35 | | 77 | n/a | n/a | n/a | n/a | 1.94 | 2.25 | 1.27 | 1.10 | 0.81 | 0.43 |
| 40. 34 + 36 | | 67 | n/a | n/a | n/a | n/a | n/a | n/a | 0.63 | 1.64 | 0.33 | 0.78 |
| 41. 34 + 37 | | 79 | n/a | n/a | n/a | n/a | 2.72 | 1.94 | 1.73 | 0.93 | 1.18 | 0.31 |
| 42. 34 + 35 + 37 | | 75 | n/a | n/a | n/a | n/a | 1.85 | 2.76 | 1.19 | 1.37 | 0.75 | 0.61 |
| 43. 34 + 36 + 37 | | 66 | n/a | n/a | n/a | n/a | n/a | n/a | 0.61 | 1.89 | 0.31 | 0.96 |
| 44. 38 + 37 | | 79 | n/a | n/a | n/a | n/a | 2.47 | 2.17 | 1.59 | 1.06 | 1.06 | 0.40 |

Notes: Soil is silt loam which fits SCS hydrologic group B/C and SCS Irrigation Class 3; unless noted otherwise, good hydrologic condition assumed.

make the additional percolation become usable ground water. It may seep out gradually to enhance the dry weather flow for a few weeks following wet periods.

The procedure described to estimate change in the surface runoff portion of water yield has been studied more intensely than that for percolation and the potential for ground-water recharge from such percolation. The operation of POTYLD, however, also estimates the amount of percolation as shown in fig. 7.7. An aspect of recharge that is important to understand when considering sustainable yield is that for many locations, particularly in drier areas, recharge occurs infrequently. The section following in the inset Boxed section 7.1 illustrates this phenomenon.

## Conclusion

Agriculture has made substantial changes to the land charge. In the western half of the state, in particular, use in Kansas for more than 150 years. Sustainable crop streamflow has been reduced from the amounts measured production by agriculture without irrigation, in large part, before about 1950 by a combination of agricultural has been a matter of developing management practices that practices including withdrawal of ground water for increase the effectiveness of use of the limited water irrigation along streams. Reductions of streamflow by as supply and that protect the soil resource from excessive much as 50% or more have been experienced. In the erosion. Adoption of conservation practices that decrease eastern half of the state, the effect has been limited runoff

and reduce evaporation losses have been important. because of the difference in climatic conditions. As ways In much of the state, the effectiveness of these practices to use water more efficiently are developed and adopted has resulted in more efficient use of water for grain and for Kansas conditions, this means less for nonagricultural• forage production. Since water use by agriculture is a uses, particularly in the drier regions of the state. In the consumptive use that results in evaporation of water from future these effects will probably result in a further the land surface, more effective use means that less water decrease in the amount of water available for appropriation is left to become runoff or potential ground-water re- by other users.

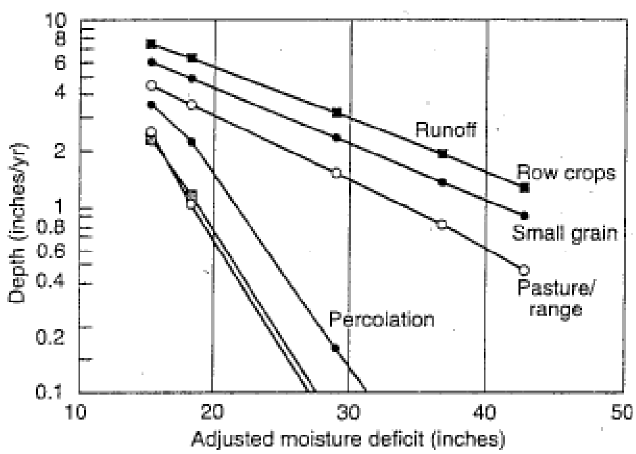


FIGURE 7.10—SIMULATED AVERAGE ANNUAL DEPTH OF RUNOFF AND PERCOLATION FROM ROW CROPS AND SMALL-GRAIN PRODUCTION WITH STRAIGHT-ROW CONSERVATION PRACTICE COMPARED WITH PASTURE/RANGE AS AFFECTED BY MOISTURE DEFICIT (Koelliker, 1994b).

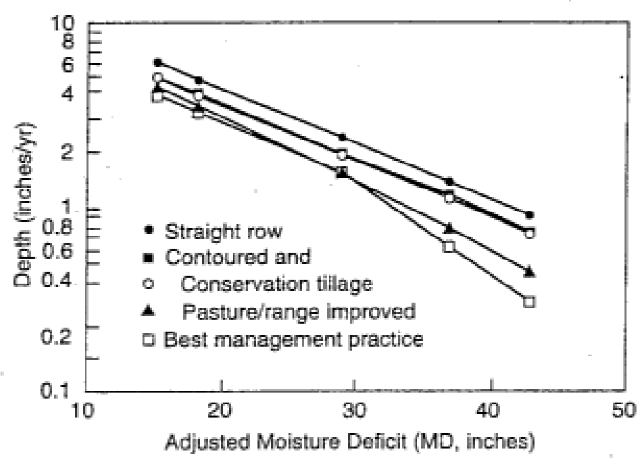


FIGURE 7.11—COMPARISON OF SIMULATED AVERAGE ANNUAL RUNOFF FROM SMALL-GRAIN PRODUCTION WITH VARIOUS CONSERVATION PRACTICES TO PASTURE/RANGE AS AFFECTED BY MOISTURE DEFICIT (Koelliker, 1994b).

Under average conditions, evapotranspiration demand for water exceeds that supplied by precipitation. So, on average the soil should not become so saturated with water that percolation occurs. Average conditions, however, seldom occur in the continental climate that prevails in Kansas (see also Chapter 1). There are periodic episodes when drought and wet periods occur. Much of the percolation that results in ground-water recharge occurs in extended wet periods.

To illustrate this point, a 44-year simulation for Great Bend was made with POTYLDR. Great Bend (MD 35 inches [89 cm]) is representative of that part of the state where agricultural practices have important effects on water yield, and aquifers benefit from increase in percolation. Representa tive RCN values for a Soil Conservation Service Group B/C soil (silt loam soil) for Great Bend are shown in table B7.1.l. The planting and harvest date for grain sorghum were May 10 and October 15, respectively, and for winter wheat they were October 10 and June 25, respectively. The results of the conditions simulated for Great Bend produced average amounts of runoff and percolation as shown in table B7. 1.1. Percolation

TABLE B7.1.1 SIMULATED RESULTS FROM POTYLDR FOR AVERAGE ANNUAL RUNOFF AND PERCOLATION, IN INCHES, FOR VARIOUS LAND USES AT GREAT BEND ON A SILT LOAM SOIL

| Predicted annual average, inches | | |
|---|---|---|
| Land use | Runoff | Percolation |
| pasture/range, good condition | 1.1 | 0.2 |
| pasture/range, fair condition | 1.5 | 0.1 |
| continuous wheat | 1.8 | 1.2 |
| wheat-fallow | 2.5 | 2.6 |
| irrigated wheat | 2.5 | 3.6 |
| grain sorghum, conventional | 2.3 | 0.4 |
| grain sorghum, conservation tillage | 2.1 | 0.7 |
| irrigated grain sorghum | 3.2 | 2.2 |

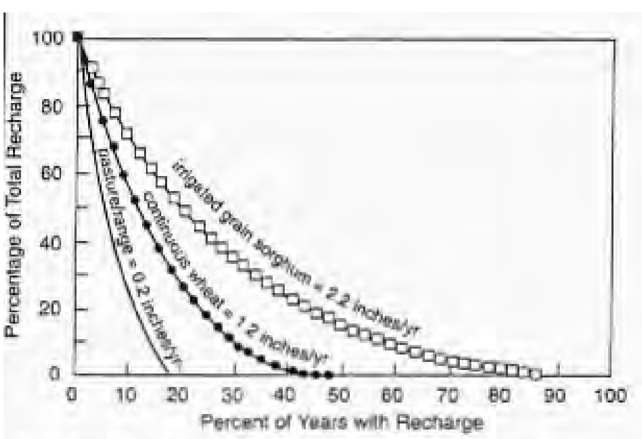


FIGURE B7.1.1—Summary of simulated percent of accumulated percolation from three land uses at Great Bend on a silt loam soil versus the percent of years with percolation.

or recharge is least from pasture/range which has a long growing season and is greatest from irrigated crops.

Here, the average amount of net irrigation water applied to the soil in 2.0-inch (5-cm) increments when the available soil moisture decreased to 50% was 9.0 inches (23 cm) and 13.0 inches (33 cm) for wheat and grain sorghum, respectively.

Figure B7. 1.1 was prepared from the annual results from three of the simulations to show the distribution of percent of years with percolation within the simulation period for three of the land uses. For pasture/range in good condition, recharge was estimated to occur in less than 20% of the years and half of the recharge occurred in less than 5% of the years. For continuous wheat, recharge was predicted to occur in less than half of the years and half of the total occurred in about one year in eight on average. Irrigated grain sorghum showed some recharge in about seven out of eight years; however, half of the total recharge occurred in about one year out of five. The example above is for one location only. Where recharge is most needed in western Kansas, the climate has a greater moisture deficit. There, recharge is even less than for the example above, and more of the recharge occurs in a lower percentage of the years. While runoff events are rather widely spaced in time, recharge events are even more widely spaced in time. Providing a sustainable yield from an aquifer that must be periodically replenished, the event nature of recharge must be taken into account. The time between years with recharge for the Great Bend example for pasture/range is illustrated in fig. B7. 1.2. Here, three periods with lengths of eight years or longer between recharge events were predicted in the 44-year simulation for the range/pasture land use.

Sustainable yield from ground water must include estimates of total recharge as an upper limit as well as the distribution of recharge in time and space over the aquifer. Using average annual values is risky, especially if the storage capacity of the aquifer is limited.

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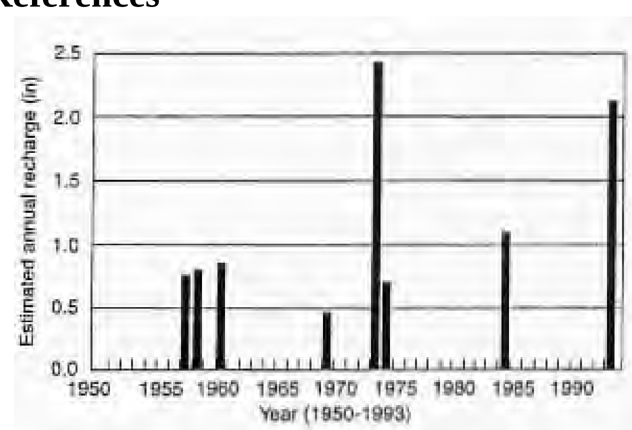


FIGURE B7.1.2—Summary of predicted annual amount of recharge (percolation) from range/pasture at Great Bend on a silt loam soil.

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# Appendix 7.A
# POTYLD MODEL DESCRIPTION

Continuous watershed-simulation modeling was budgets for various land areas where the runoff was common by the mid-1970's. Zovne et al. (1977) devel- applied according to some management scheme. The oped a continuous water-budget simulation model that model utilized runoff curve nufnbers (RCN) values to worked on daily time steps for use in assessing the predict the split between runoff and infiltration for the performance of open feedlots to control runoff from feedlot and areas where runoff was applied to daily feedlots. The model predicted runoff from 'the feedlot amounts of rainfall and snowrnelt (See Chapter 1 for more drainage area, operation of a storage pond, and water information on RCN values). The model named

FROMKSU was designed to be physically based, to use readily available information to describe conditions in an area of interest, and to be capable of being applied anywhere in the continental US. Its detailed description is contained in Zovne and Koelliker (1979).

The Potential Yield (POTYLD) model simulates a continuous water budget for land uses with different conditions in a watershed on a daily basis (see fig. 7.A1). Up to 18 different land-use combinations can be simulated in one run of the model. Estimates of the upstream runoff and percolation that would result from various land uses and conservation practices are provided. A RCN value for antecedent moisture condition (AMC) II is needed for each land use and conservation practice based upon soil characteristics, land cover, conservation practice, and management practice. Soil characteristics are assumed to fall into one of 12 irrigation group classifications for Kansas (USDA—SCS, *1975)*, which define the water-holding characteristics of the soil layers and soil-water evaporation characteristics. A continuous water-budget simulation produces estimates of water content in the soil. AMC values are adjusted based upon available soil moisture (ASM) in the upper 1.0 ft (30 cm). AMC I holds below 50% ASM, AMC III holds above 90% ASM, and AMC II holds in the intermediate range of ASM.

The water budget is driven by daily precipitation and minimum and maximum temperature for a single station representative of the area under study. Large areas are divided into sub-areas which are modeled separately, then combined for better representation of the entire watershed. Long-term monthly average values of percent sunshine, relative humidity, solar radiation, windrun, and average temperature are used to estimate potential evapotranspira tion (PET) by the Penman combination equation after Gray (1973). Long-term monthly values are obtained by triangulation from published values for first-order weather stations (Water Information Center, 1974). Geographical coefficients, Brunt a and b (Brunt, 1944) are used to

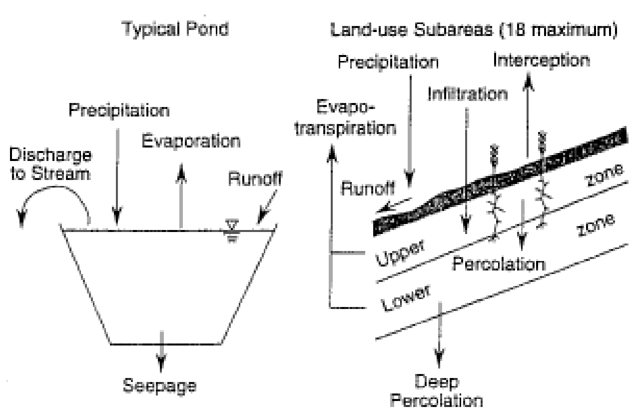



FIGURE 7.A1—Schematic of POTYLD water-budget model (adapted from Zovne and Koelliker, 1979).

calibrate Penman's PET such that predicted average annual lake evaporation at a location agrees with published values (Zovne and Koelliker, 1979). Actual water use by crops is simulated by multiplying daily PET by a monthly Blaney—Criddle crop coefficient (Blaney and Criddle, 1962) and a coefficient based upon ASM.

The crop coefficients are calculated by pre-programmed equations in the program which require the user to provide planting and harvest dates. The soil-moisture coefficient is 1.0 forASM greater than 30%; below 30% it decreases linearly to zero when ASM is zero. When crops

•are not growing, bare soil and fallow water loss is simu lated by a decay-rate equation (Ritchie, 1972) and adjusted for assumed amount of surface residue. Water loss by percolation from the rooting zone is assumed to cascade from the lower layer whenever the ASM in the lower zone exceeds 90%. POTYLD simulates the complete daily water budget for a "typical" pond. The pond is defined by assigning a stage-storage and stage-surface area relation ship along with a seepage loss rate. The model treats the pond as an inverted frustum of a pyramid which can match most actual relationships fairly well. Runoff into the typical pond is determined by routing runoff from speci fied areas of the various land-use subareas which would be typical of the drainage area for a pond in the particular study area. Modeled results of predicted depletions of surface water caused by ponds have compared closely with depletion effects described by Sauer and Masch (1969) for watershed flood-control dams in Texas. Figure 7.A2 shows the general relationship from Sauer and Masch and the average results found for typical ponds above Webster Reservoir (Koelliker et al., 1981).

Substantial revisions have been made to the model and the name changed to POTYLD (Revised) (Koelliker, 1994a, 1994b). Enhancements to the PET routine to reflect greater daily and annual variation based upon daily minimum and maximum temperature and a function to simulate annual variation in heat storage and dissipation at the surface have been made. Also, RCN between AMC I and AMC III is varied linearly with ASM between 50 and 90%. AMC II holds when ASM is 70%.

## COMPARING MODEL RESULTS WITH ACTUAL STREAMFLOW

Results from POTYLD must be adjusted by estimates of transmission losses and the effects of depletion from or additions to strearnflow in order to compare with actual streamfiow records. In addition, because agricultural effects on upstream yield are changing with time, changes must be accounted for in output from POTYLD by making successive runs with the inputs that represent conditions applicable over the period of the streamflow record. Once all of these changes are accounted for, then modeled results can be compared directly with reported streamflow records.

Transmission loss refers to the ratio of annual volume of upstream runoff to downstream streamflow. It accounts for natural losses caused by infiltration, evaporation, and detention storage. The value of the transmission loss factor *(TLfl* was originally predicted by a technique developed by Sharp et al. (1966). This loss is related to the ratio of PET (Thornthwaite's values) to annual amount of precipitation. Our work shows that annual moisture deficit (MD), defined as lake evaporation minus precipitation, is an effective characteristic of the climate that can be used estimate the *TLF* (Koelliker et al., *1995).* In dry years when runoff is low and MD is higher, the *TLF* is larger and in wet years when MD is lower *TLF* approaches 1.0 as shown in Figure 7.A3.

Finally, estimates of depletions or additions to streamflow from ground-water use, importation, exportation, return flows, etc. must be accounted for to compare POTYLD modified results with reported streamflow records.

Average MD for each county (DWR, 1994) is shown in fig. 77. There is a substantial difference in MD across the state. MD is greatest in the southwest corner of the state where lake evaporation is greatest and precipitation is near the lowest in the state. MD is lowest in the far eastern part of the state where lake evaporation is lowest and precipitation is more abundant. This variable is one that correlates well with many of the important effects that climate plays on agriculture. The greater the MD the more arid the climate while the lower the MD the more humid is the climate. In Kansas this helps explain why northeast Kansas is in the western end of the Corn Belt even though it receives less precipitation than southeastern Kansas which has a larger MD than the northeast. Predicted effects of land use and conservation practices on water yield based upon MD are shown in table 7.1.

Results from POTYLD for an entire watershed provide evidence that various practices and land use effects when aggregated together are useful to assess or estimate combined effects of individual practices. When the model, FROMKSU, was used to study feedlots in different parts of the United States, it was noted that the water yield from the runoff disposal areas using published RCN values (USDA, SCS, 1972) generally agreed reasonably well with values reported for streamflow. In more arid areas, however, water yield was overestimated as expected because transmission losses and effects of ground-water withdrawals have important effects on streamflow. This provided reasonable confidence it the applicability of RCN values to larger watersheds. When POTYLD was developed, however, RCN values were not available to account for levels of residue management, particularly on wheat-fallow. Work reported by Rawls et al. (1980) on effects of residue and tillage on RCN values was influential for predicting how much RCN values for important practices in the area could be reduced when residue management was used. Field simulations in the area were run by Steichen (1983) and those results substantially agreed with predicted amounts that RCN values could be reduced as predicted by Rawis et al. (1980). Finally, field data for runoff from bare fallow and stubble mulch were available for Alliance, Nebraska (Fenster et al., 1977). Those results were simulated with POTYLD and showed the RCN value for stubble mulch with good residue management was six less (73 vs. 79) than for bare fallow on the same soil (Koelliker et al. 1981).

The reference list at the end of Chapter 7 contains several references to work where POTYLD has been used. Also, a copy of the user's manual, computer code, and diskettes are available from the author.

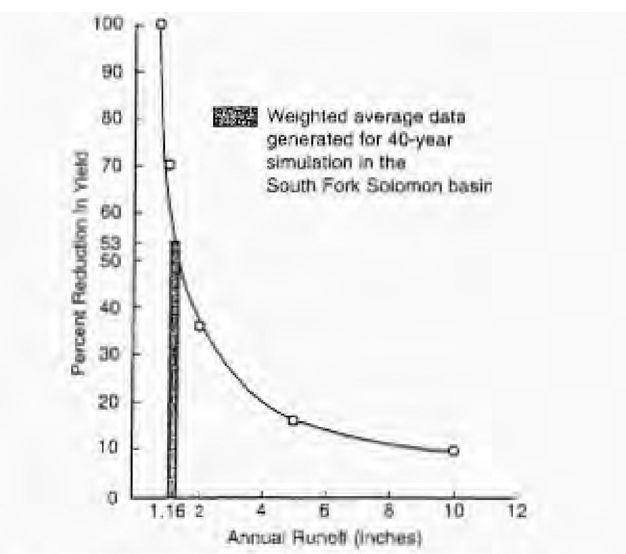



FIGURE 7.A2—Function of percent reduction in watershed yield due to ponds as a function of annual runoff in the watershed.

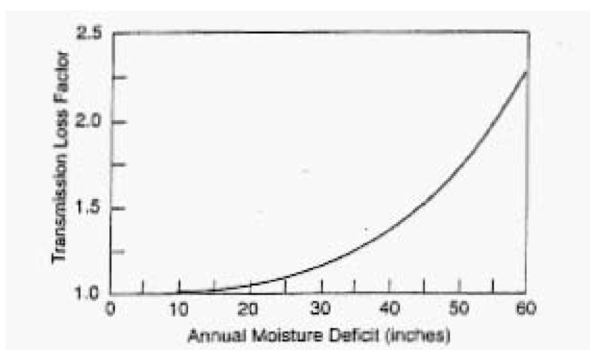



FIGURE 7.A3—Transmission loss factor for reducing upstream runoff to compare with measured runoff at a downstream streamflow gaging station [adapted by Koelliker et al. (1995) from Sharp et al. (1966)].

## Attachment 4: Review of Soils information for the R9 Ranch

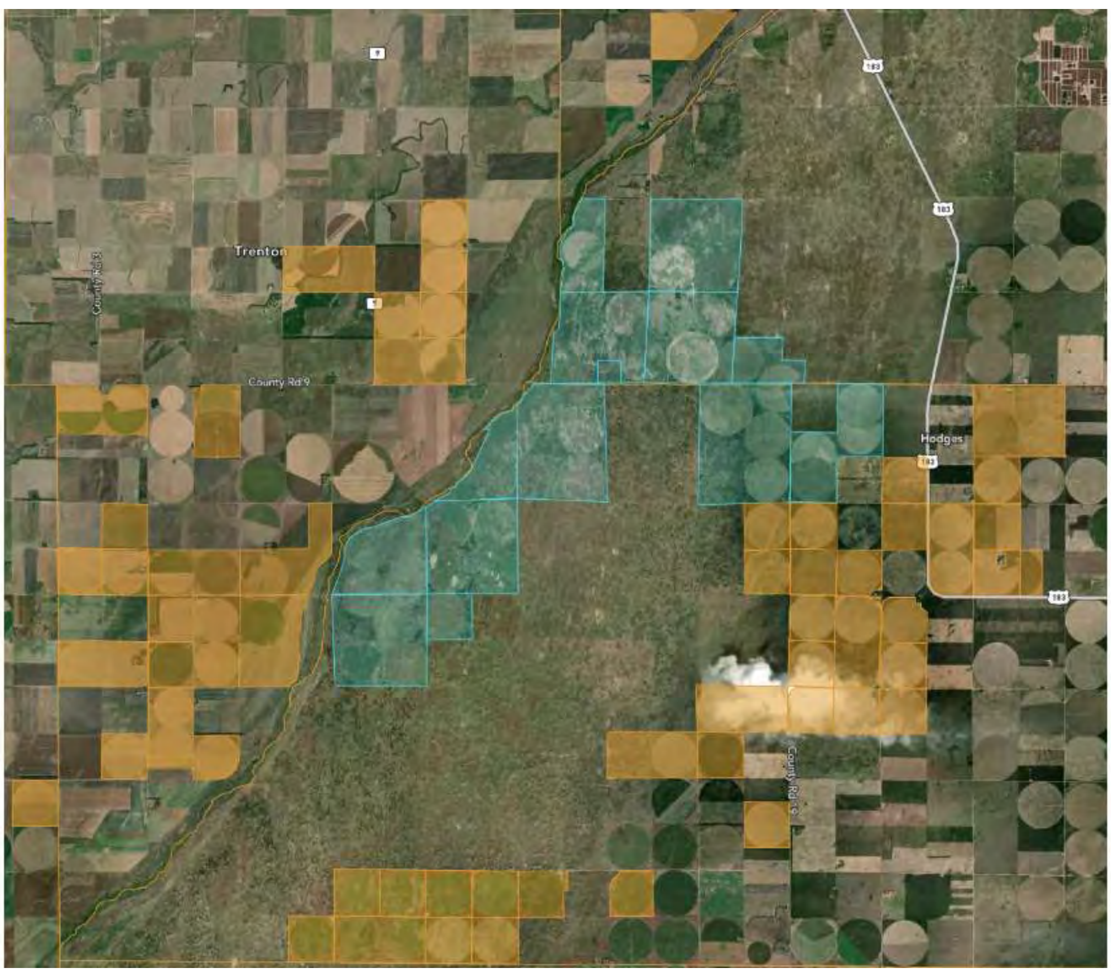
**Introduction and overview**

In this document, I summarize my review of readily available soils information for the R9 Ranch. This consisted of review of two resources from the NRCS:

- its September 1973 Soil Survey of Edwards County Kansas and
- its Web Soil Survey at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

It appears the 1973 Report's soils classifications are the same as the on-line version, with the same basic descriptors. As the Web Soil Survey review has more helpful outputs, it is presented first, in Part 1. My review of the 1973 Soil Survey is in Part 2 below. As is noted below, attached are several outputs of the Web Soil Survey on specific soil attributes of the R9 Ranch.

Inserted below, for general reference, is a map showing the outline of the R9 Ranch in light green and area irrigated lands by WaterPACK members in tan. It illustrates the contrast of the soils of the Ranch versus irrigated lands in the vicinity.



**Part 1: Review of the NRCS's Web Soil Survey related to soils information for the R9 Ranch**

Data from web site: https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

General procedure: Selected Kansas and Edwards County; Zoomed to R9 Ranch Area; On Area of Interest (AOI) tab, I made an approximate polygon of the R9 Ranch.

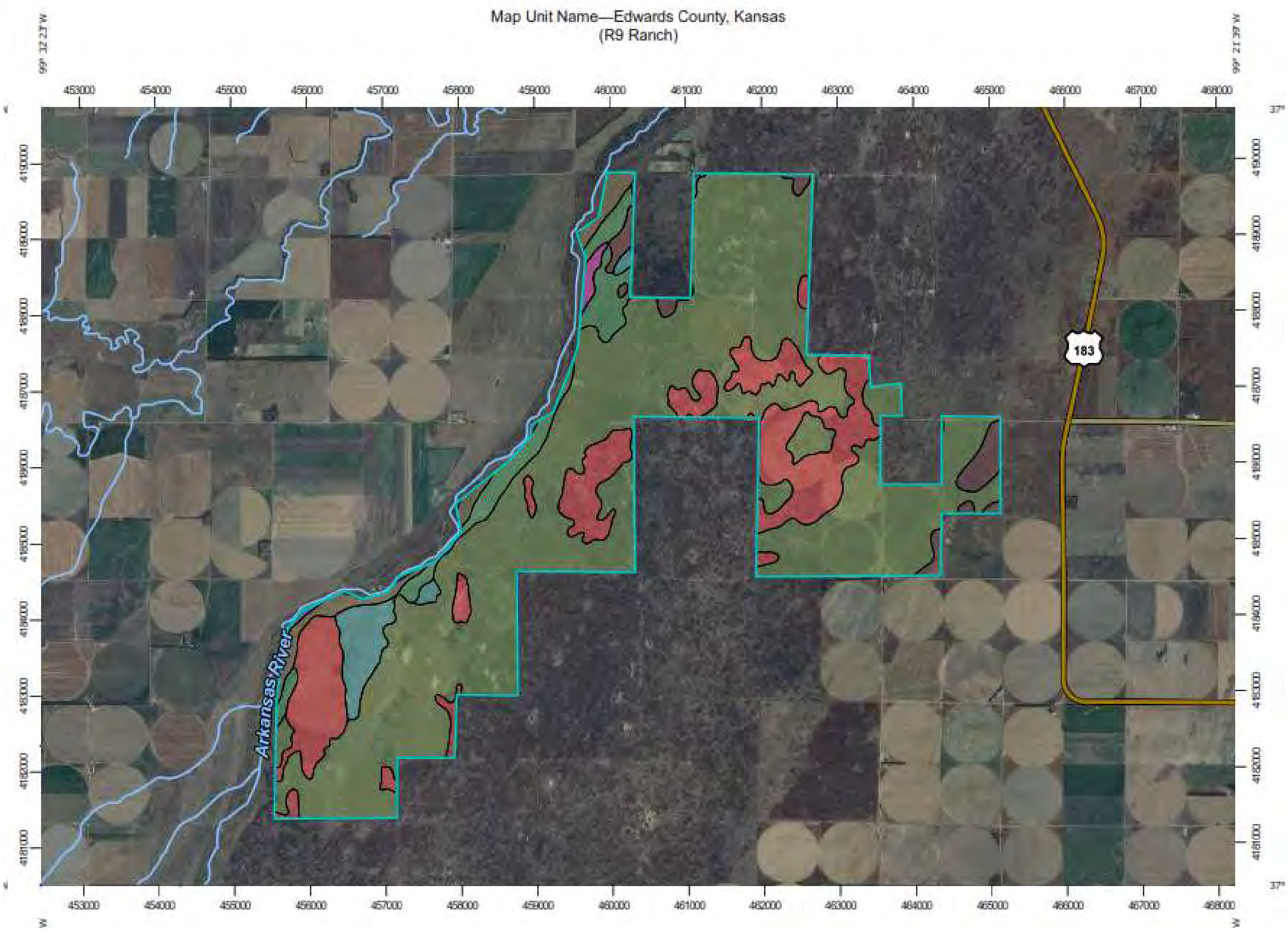
The **Soil Map Tab** was used produce the map inserted below, the summary table below of the soils of the Ranch, as well as enclosed **Exhibit 1**: **"**Map Unit Name: R9 Ranch.pdf."

This "Map Unit Name" map **confirmed that the soil types on the on-line version appear to be the same as the 1973 soil surveys.** The Map Unit Name map color codes the soil type, allowing easier comparison with the original soil survey (i.e. shows the same shapes of the interior Tivoli fine sands when surrounded by the dominant Pratt Tivoli loamy fine sands).

**Summary table**

| Map Unit Symbol | Map Unit Name | Acres in AOI | Percent of AOI |
|---|---|---|---|
| 1183 | Las Animas loamy fine sand, occasionally flooded | 197.0 | 3.0% |
| 5632 | Platte soils, occasionally flooded | 165.4 | 2.5% |
| 5670 | Waldeck fine sandy loam, occasionally flooded | 319.1 | 4.9% |
| 5671 | Waldeck loam, occasionally flooded | 29.0 | 0.4% |
| 5928 | Pratt loamy fine sand, 1 to 5 percent slopes | 177.8 | 2.7% |
| 5941 | **Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes** | 4,425.4 | **67.6%** |
| 5961 | Solvay loamy fine sand, 0 to 2 percent slopes | 0.7 | 0.0% |
| 5972 | **Tivoli fine sand, 10 to 30 percent slopes** | 1,216.5 | **18.6%** |
| 9994 | Rivers | 12.9 | 0.2% |
| Totals for Area of Interest | | 6,543.9 | 100.0% |

**The two soils highlighted make up about 85% of the Ranch**.




The detailed descriptors of these two dominate soil types (all others less than 5%) are attached as **Exhibit 2 and 3**.

- Description_Pratt-Tivoli_loamy_fine_sands_5_to_15_percent_slopes--Edwards_County_Kansas.pdf, **shown in green above**, and
- Description_Tivoli_fine_sand_10_to_30_percent_slopes--Edwards_County_Kansas.pdf, **shown in red above**.

These documents indicate for these dominant soils of the Ranch:

- Capacity of the most limiting layer to transmit water (Ksat) is High to Very High (6.00 to 20.00 in/hour).
- Available water, 0-60 inches is low (3.4, and 6 inches).

At the **Soil Data Explorer Tab** and the following maps with descriptions were developed from the Ranch outline:

- **R9Ranch_Soil_Health_-_Available_Water_Capacity.pdf** - Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants. Available water capacity is an indicator of a soil's ability to retain water and make it sufficiently available for plant use. The two dominant soils of the Ranch have AWC's on the lower end of the spectrum.
- **R9Ranch_Saturated_Hydraulic_Conductivity_Ksat_Standard_Classes.pdf** – This map shows a measure of the saturated hydraulic conductivity of the soil. The two dominant soil types of the Ranch have **"very high" conductivities**.
- **R9_Ranch_Representative_Slope.pdf -** This map shows that the two dominate soils have s**lopes of 5-15% and 15-45% respectively**.

These three reports are attached as **Exhibits 4, 5, and 6** respectively.

**<u>Part 2: Summary of September 1973 Soil Survey of Edwards County Kansas regarding dominate soils of the R9 Ranch</u>**

Below are excerpts from the 1973 soil survey of Edwards County regarding the most common soil types on the Ranch, in order of acres.

**<u>Pratt-Tivoli loamy fine sands</u>** (Pt on soil survey; # 5941 on on-line version). Part of the Pratt series. From table 1, 26,160 acres in the county (6.7%)

**Pratt Series** "*The Pratt series* consists of deep, **well-drained sandy soils** that formed in eolian sands. Slopes range from 1 to 15 percent.

In a representative profile the surface layer is grayish-brown loamy fine sand about 13 inches thick. The subsoil is friable, brown heavy loamy fine sand about 17 inches thick. The substratum is pale brown loamy fine sand.

Pratt soils have **rapid permeability and low available water capacity**.

These soils are suited to wheat, sorghum, and native grasses. They are medium in fertility. They are highly susceptible to blowing. The native vegetation is chiefly mid and tall grasses.

Specifically on PT from p. 19 of soil survey:

*"**Pratt-Tivoli loamy fine sands** (**5 to 15 percent slopes**) (**Pt**). - This mapping unit is on uplands. It is about 65 percent Pratt loamy fine sand and 35 percent Tivoli loamy fine sand. Pratt soils are **on slopes**, and Tivoli soils on ridgetops. The Tivoli soil has a surface layer of loamy fine sand. Otherwise each soil has a profile similar to the one described as representative for its respective series.*

*Included with these soils in mapping were areas of Carwile soils and Tivoli fine sand. Small blowouts are shown on the map by spot symbols. Each symbol represents an area about 2 to 10 acres in size.*

*Nearly all the acreage of this mapping unit is in native grasses.*

*Soil blowing is the main limitation.* ***Capability unit VIe-3****, dry land;* ***no irrigated capability unit****;* ***Sands range*** *site; Sandy Upland windbreak group.*

**Tivoli fine sand** (**Tf** on soil survey; # 5972 on on-line version). From table 1, 12,040 acres in the county (3.1%)

Part of **Tivoli Series** described as "*The Tivoli series consists of deep,* ***excessively drained****, sandy soils that formed in eolian sands.* ***Slopes range from 5 to 20 percent****.*

*The surface layer is brown fine sand about 8 inches thick. The underlying material is light yellowish-brown fine sand about 52 inches thick.*

*Tivoli soils have* ***rapid permeability and very low available water capacity****.*

*These soils are well suited to native grasses. They are low in fertility and are susceptible to blowing. The native vegetation is chiefly mid and tall grasses.*

Specifically, **Tivoli fine sand** is described as: "***(10 to 20 percent slopes)*** *(****Tf****). - This soil is on uplands. Included in mapping were small areas of Pratt and Las Animas soils and Blown-out land. Small blowouts are shown on the map by spot symbols. Each symbol represents an area about 2 to 10 acres in size.*

*Nearly all the acreage of this Tabler soil is in native grasses.*

*The main limitation is soil blowing.* ***Capability unit VIIe-1****, dryland; Choppy Sands range site; no irrigated capability unit or windbreak group."*

**Pratt loamy fine sand**, *undulating (1 to 4 percent slope) (****Pg****).* From table 1, 26,540 acres in the county (6.8%).

Described as -*This soil is on wetlands. It has the profile descr1becl as representative for the Pratt series.*

*Included with this soil in mapping were small areas of Attica and Carwile soils and areas of Pratt soils where slopes are 4 to 10 percent. Small depressional areas and limy spots are shown on the map by spot symbols. Each symbol represents an area about 1 to 5 acres in size.*

*Most of the acreage of this Pratt soil is in wheat and sorghum. Small acreages in native grasses occur within areas of nonarable soils.*

*Controlling soil blowing and maintaining the supply of organic matter are the main concerns in management Capability unit IIIe-3, dryland; capability unit IIIe-1, irrigated; Sands range site; Sandy Upland windbreak group.*

***Blown-Out Land.*** *Only 400 acres in county. D*escribed as: "*(0 to 20 percent slopes) (**Bd**) is in the sandhills. It consists of hills, ridges, and cone-shaped dunes of fine sand. About 85 to 95 :percent of the acreage has a cover of annual weeds and thickets of sandhill plum. The areas have not been stable long enough for native grasses to become established. About 5 to 15 percent of the acreage consists of barren active dunes that are continually shifted by the wind.*

*Blown-out land is excessively drained, has very low available water capacity, and has rapid permeability.*

*Blown-out lands used chiefly as ,range, but it has little value for grazing. It has low fertility and is highly susceptible to blowing. Capability unit VIIe-1, dry land; Choppy Sands range site; no irrigated capability unit or windbreak group."*

**Las Animas loamy fine sand** is part of the Las Animas Series. Only 1,480 acres in county. It is described as "*( 0 to 1 percent slopes) (**La**) - This soil is on stream terraces. Included with this soil in mapping were small areas of Waldeck, Platte, and Tivoli soils.*

*Nearly all the acreage of this Las Animas soil is in native grasses.*

*Low available water capacity, wetness, and soil blowing are the main limitations. Capability unit IVs-1, dryland; capability unit IVs-1, irrigated; Sandy Terrace range site; Wet Loamy and Sandy Lowland windbreak group."*

**Capacity Groupings**

CAPABILITY CLASSES, the broadest groups, are designated by Roman numerals I through VIII. The numerals indicate progressively greater limitations and narrower choices for practical use, defined as follows:

- Class I soils have few limitations that restrict their use.
- Class II soils have moderate limitations that reduce the choice of plants or that require moderate conservation practices.
- Class III soils have severe limitations that reduce the choice of plants, require special conservation practices, or both.
- Class IV soils have very severe limitations that reduce the choice of plants, require very careful management, or both.
- Class V soils are subject to little or no erosion but have other limitations, impractical to remove, that limit their use largely to pasture, or range, woodland, or wildlife habitat.
- **Class VI soils** have **severe limitations** that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife habitat.

- **Class VII soils** have **very severe limitations** that make them unsuited to cultivation and that restrict their use largely to pasture or range, woodland, or wildlife habitat.
- Class VIII soils and landforms have limitations that preclude their use for commercial crop production and restrict their use to recreation, wildlife habitat, or ·water supply, or to esthetic purposes.

**Pratt-Tivoli loamy fine sands is a Capability unit VIe-3.** The Soil survey has the following to say about it:
*Capability unit Vle-3, dryland - This unit consists of deep,* ***well drained to excessively drained soils*** *of the Pratt, Brazos, and Tivoli series. The surface layer of these soils is loamy fine sand. It is underlain by loamy fine sand to sand. Slopes are 0 to 15 percent.*

*These. soils have low and medium fertility,* ***very low to low available water capacity, and rapid permeability****.*

*Because the erosion hazard is severe, these soils are best suited to native grasses (fig. 9). They are also suited to trees and to the development of wildlife habitat.*

*The proper range use and deferred grazing help in controlling erosion and in maintaining or increasing the more desirable native grasses. Proper location of fences, salt and water helps distribute the livestock so that the range is grazed uniformly. Blowouts should be fenced off from livestock. Native grasses can be seeded in areas where a protective cover to sorghum or weeds is established.*

**Tivoli fine sand has a Capability unit VIIe-1.** The soil survey has the following to say about it:

*The deep, excessively drained Tivoli fine sand and Blown-out land are in this unit. The texture is fine sand in all horizons.*

*These soils have low fertility,* ***very low available water capacity, and rapid permeability****. Erosion and regulation of grazing are the chief management concerns.*

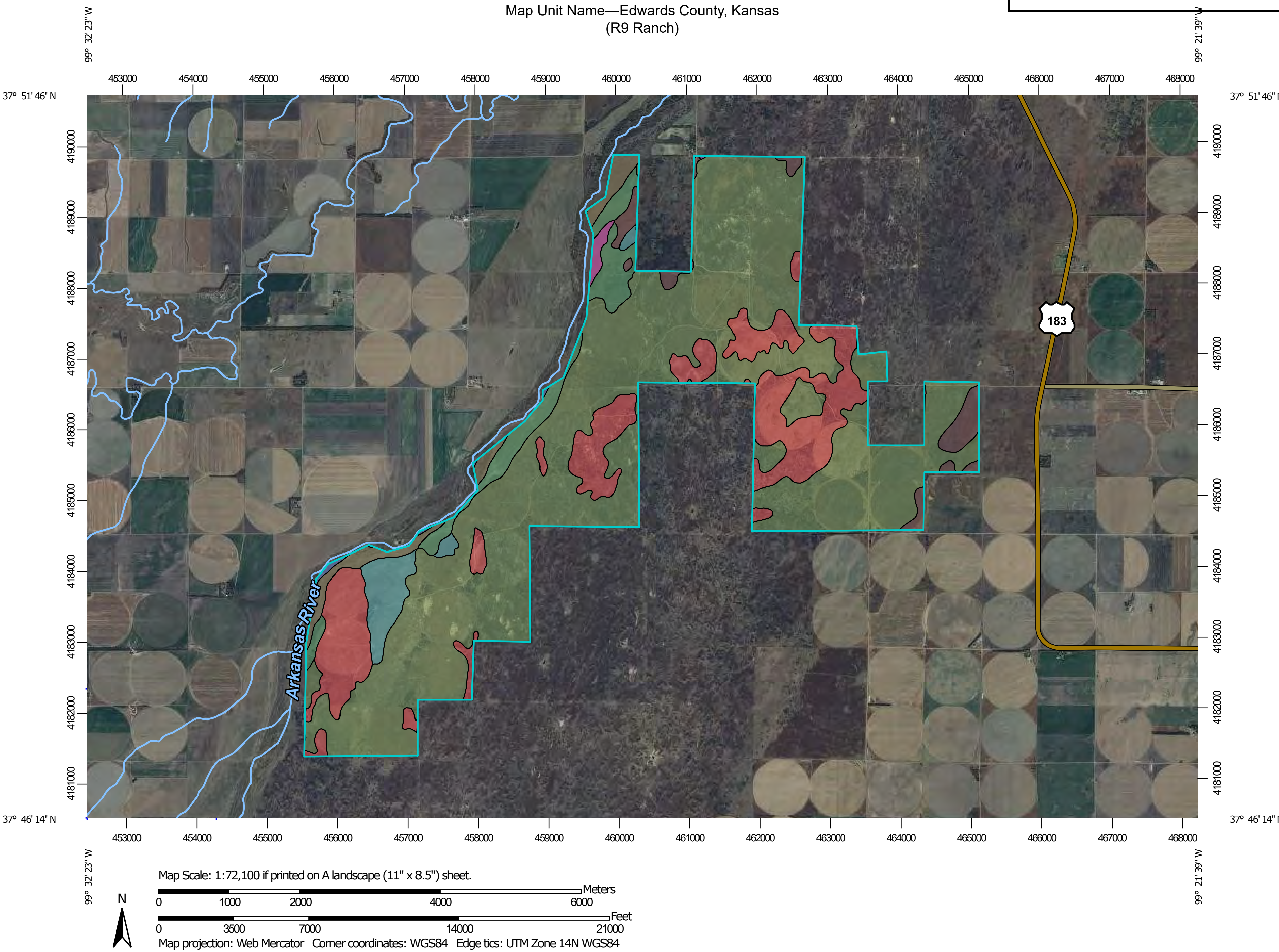
*Proper range use and deferred grazing help in controlling erosion and in maintaining or increasing the more desirable native grasses. Proper location of fences, salt, and water helps distribute the livestock so that the range is grazed uniformly. Blowouts should be fenced off from livestock. Native grasses can be seeded in areas where a protective cover of sorghum or weeds is established.*

**Exhibits:**

1. Map Unit Name: R9 Ranch.pdf.
2. Description_Pratt-Tivoli_loamy_fine_sands_5_to_15_percent_slopes--Edwards_County_Kansas.pdf and
3. Description_Tivoli_fine_sand_10_to_30_percent_slopes--Edwards_County_Kansas.pdf
4. R9Ranch_Soil_Health_-_Available_Water_Capacity.pdf
5. R9Ranch_Saturated_Hydraulic_Conductivity_Ksat_Standard_Classes.pdf
6. R9_Ranch_Representative_Slope.pdf

Barfield Rebuttal Report
Exhibit 1 to Attachment 4

Map Unit Name—Edwards County, Kansas
(R9 Ranch)



## MAP LEGEND

**Area of Interest (AOI)**

- Area of Interest (AOI)

**Soils**

**Soil Rating Polygons**

- Las Animas loamy fine sand, occasionally flooded
- Platte soils, occasionally flooded
- Pratt loamy fine sand, 1 to 5 percent slopes
- Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes
- Rivers
- Solvay loamy fine sand, 0 to 2 percent slopes
- Tivoli fine sand, 10 to 30 percent slopes
- Waldeck fine sandy loam, occasionally flooded
- Waldeck loam, occasionally flooded
- Not rated or not available

**Soil Rating Lines**

- Las Animas loamy fine sand, occasionally flooded
- Platte soils, occasionally flooded
- Pratt loamy fine sand, 1 to 5 percent slopes
- Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes
- Rivers
- Solvay loamy fine sand, 0 to 2 percent slopes
- Tivoli fine sand, 10 to 30 percent slopes
- Waldeck fine sandy loam, occasionally flooded
- Waldeck loam, occasionally flooded
- Not rated or not available

**Soil Rating Points**

- Las Animas loamy fine sand, occasionally flooded
- Platte soils, occasionally flooded
- Pratt loamy fine sand, 1 to 5 percent slopes
- Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes
- Rivers
- Solvay loamy fine sand, 0 to 2 percent slopes
- Tivoli fine sand, 10 to 30 percent slopes
- Waldeck fine sandy loam, occasionally flooded
- Waldeck loam, occasionally flooded
- Not rated or not available

**Water Features**

- Streams and Canals

**Transportation**

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

**Background**

- Aerial Photography

## MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Edwards County, Kansas
Survey Area Data: Version 22, Sep 13, 2022

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Nov 7, 2021—Nov 8, 2021

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

# Map Unit Name

| Map unit symbol | Map unit name | Rating | Acres in AOI | Percent of AOI |
|---|---|---|---|---|
| 1183 | Las Animas loamy fine sand, occasionally flooded | Las Animas loamy fine sand, occasionally flooded | 197.0 | 3.0% |
| 5632 | Platte soils, occasionally flooded | Platte soils, occasionally flooded | 165.4 | 2.5% |
| 5670 | Waldeck fine sandy loam, occasionally flooded | Waldeck fine sandy loam, occasionally flooded | 319.1 | 4.9% |
| 5671 | Waldeck loam, occasionally flooded | Waldeck loam, occasionally flooded | 29.0 | 0.4% |
| 5928 | Pratt loamy fine sand, 1 to 5 percent slopes | Pratt loamy fine sand, 1 to 5 percent slopes | 177.8 | 2.7% |
| 5941 | Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes | Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes | 4,425.4 | 67.6% |
| 5961 | Solvay loamy fine sand, 0 to 2 percent slopes | Solvay loamy fine sand, 0 to 2 percent slopes | 0.7 | 0.0% |
| 5972 | Tivoli fine sand, 10 to 30 percent slopes | Tivoli fine sand, 10 to 30 percent slopes | 1,216.5 | 18.6% |
| 9994 | Rivers | Rivers | 12.9 | 0.2% |
| **Totals for Area of Interest** | | | **6,543.9** | **100.0%** |

## Description

A soil map unit is a collection of soil areas or nonsoil areas (miscellaneous areas) delineated in a soil survey. Each map unit is given a name that uniquely identifies the unit in a particular soil survey area.

## Rating Options

*Aggregation Method:* No Aggregation Necessary

*Tie-break Rule:* Lower

# Edwards County, Kansas

## 5941—Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes

### Map Unit Setting

*National map unit symbol:* 2ww14
*Elevation:* 1,660 to 2,610 feet
*Mean annual precipitation:* 25 to 33 inches
*Mean annual air temperature:* 55 to 57 degrees F
*Frost-free period:* 180 to 200 days
*Farmland classification:* Farmland of statewide importance

### Map Unit Composition

*Pratt and similar soils:* 60 percent
*Tivoli and similar soils:* 35 percent
*Minor components:* 5 percent
*Estimates are based on observations, descriptions, and transects of the mapunit.*

### Description of Pratt

#### Setting

*Landform:* Dunes on paleoterraces
*Down-slope shape:* Linear, convex
*Across-slope shape:* Linear, convex
*Parent material:* Eolian deposits

#### Typical profile

*A - 0 to 8 inches:* loamy fine sand
*Bt - 8 to 24 inches:* loamy fine sand
*E and Bt - 24 to 43 inches:* loamy fine sand
*E and Bt - 43 to 64 inches:* fine sand
*C - 64 to 79 inches:* fine sand

#### Properties and qualities

*Slope:* 5 to 15 percent
*Depth to restrictive feature:* More than 80 inches
*Drainage class:* Well drained
*Runoff class:* Low
*Capacity of the most limiting layer to transmit water (Ksat):* High to very high (6.00 to 20.00 in/hr)
*Depth to water table:* More than 80 inches
*Frequency of flooding:* None
*Frequency of ponding:* None
*Calcium carbonate, maximum content:* 2 percent
*Maximum salinity:* Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
*Available water supply, 0 to 60 inches:* Low (about 6.0 inches)

#### Interpretive groups

*Land capability classification (irrigated):* None specified
*Land capability classification (nonirrigated):* 6e

*Hydrologic Soil Group:* A
*Ecological site:* R079XY121KS - Sand Plains
*Hydric soil rating:* No

### Description of Tivoli

#### Setting

*Landform:* Dunes on paleoterraces
*Down-slope shape:* Linear, convex
*Across-slope shape:* Linear, convex
*Parent material:* Eolian deposits

#### Typical profile

*A - 0 to 7 inches:* loamy fine sand
*AC - 7 to 18 inches:* fine sand
*C - 18 to 79 inches:* sand

#### Properties and qualities

*Slope:* 5 to 15 percent
*Depth to restrictive feature:* More than 80 inches
*Drainage class:* Excessively drained
*Runoff class:* Very low
*Capacity of the most limiting layer to transmit water (Ksat):* High to very high (6.00 to 20.00 in/hr)
*Depth to water table:* More than 80 inches
*Frequency of flooding:* None
*Frequency of ponding:* None
*Maximum salinity:* Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
*Available water supply, 0 to 60 inches:* Low (about 3.4 inches)

#### Interpretive groups

*Land capability classification (irrigated):* None specified
*Land capability classification (nonirrigated):* 7e
*Hydrologic Soil Group:* A
*Ecological site:* R079XY103KS - Choppy Sands
*Hydric soil rating:* No

### Minor Components

#### Carway

*Percent of map unit:* 5 percent
*Landform:* Depressions on interdunes on paleoterraces
*Down-slope shape:* Concave, linear
*Across-slope shape:* Concave, linear
*Ecological site:* R079XY133KS - Wet Subirrigated
*Hydric soil rating:* Yes

## Data Source Information

Soil Survey Area: Edwards County, Kansas
Survey Area Data: Version 22, Sep 13, 2022

# Edwards County, Kansas

## 5972—Tivoli fine sand, 10 to 30 percent slopes

### Map Unit Setting

*National map unit symbol:* 2ww15
*Elevation:* 1,660 to 2,610 feet
*Mean annual precipitation:* 25 to 33 inches
*Mean annual air temperature:* 55 to 57 degrees F
*Frost-free period:* 180 to 200 days
*Farmland classification:* Not prime farmland

### Map Unit Composition

*Tivoli and similar soils:* 92 percent
*Minor components:* 8 percent
*Estimates are based on observations, descriptions, and transects of the mapunit.*

### Description of Tivoli

#### Setting

*Landform:* Dunes on paleoterraces
*Down-slope shape:* Linear, convex
*Across-slope shape:* Linear, convex
*Parent material:* Eolian deposits

#### Typical profile

*A - 0 to 7 inches:* fine sand
*AC - 7 to 18 inches:* fine sand
*C - 18 to 79 inches:* sand

#### Properties and qualities

*Slope:* 10 to 30 percent
*Depth to restrictive feature:* More than 80 inches
*Drainage class:* Excessively drained
*Runoff class:* Very low
*Capacity of the most limiting layer to transmit water (Ksat):* High to very high (6.00 to 20.00 in/hr)
*Depth to water table:* More than 80 inches
*Frequency of flooding:* None
*Frequency of ponding:* None
*Maximum salinity:* Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
*Available water supply, 0 to 60 inches:* Low (about 3.4 inches)

#### Interpretive groups

*Land capability classification (irrigated):* None specified
*Land capability classification (nonirrigated):* 7e
*Hydrologic Soil Group:* A
*Ecological site:* R079XY103KS - Choppy Sands
*Hydric soil rating:* No

**Minor Components**

**Pratt**

*Percent of map unit:* 3 percent
*Landform:* Dunes on paleoterraces
*Down-slope shape:* Linear, convex
*Across-slope shape:* Linear, convex
*Ecological site:* R079XY121KS - Sand Plains
*Hydric soil rating:* No

**Carway**

*Percent of map unit:* 3 percent
*Landform:* Depressions on interdunes on paleoterraces
*Down-slope shape:* Concave, linear
*Across-slope shape:* Concave, linear
*Ecological site:* R079XY133KS - Wet Subirrigated
*Hydric soil rating:* Yes

**Langdon**

*Percent of map unit:* 1 percent
*Landform:* Dunes on paleoterraces
*Down-slope shape:* Linear, convex
*Across-slope shape:* Linear, convex
*Ecological site:* R079XY103KS - Choppy Sands
*Hydric soil rating:* No

**Plev, occasionally flooded**

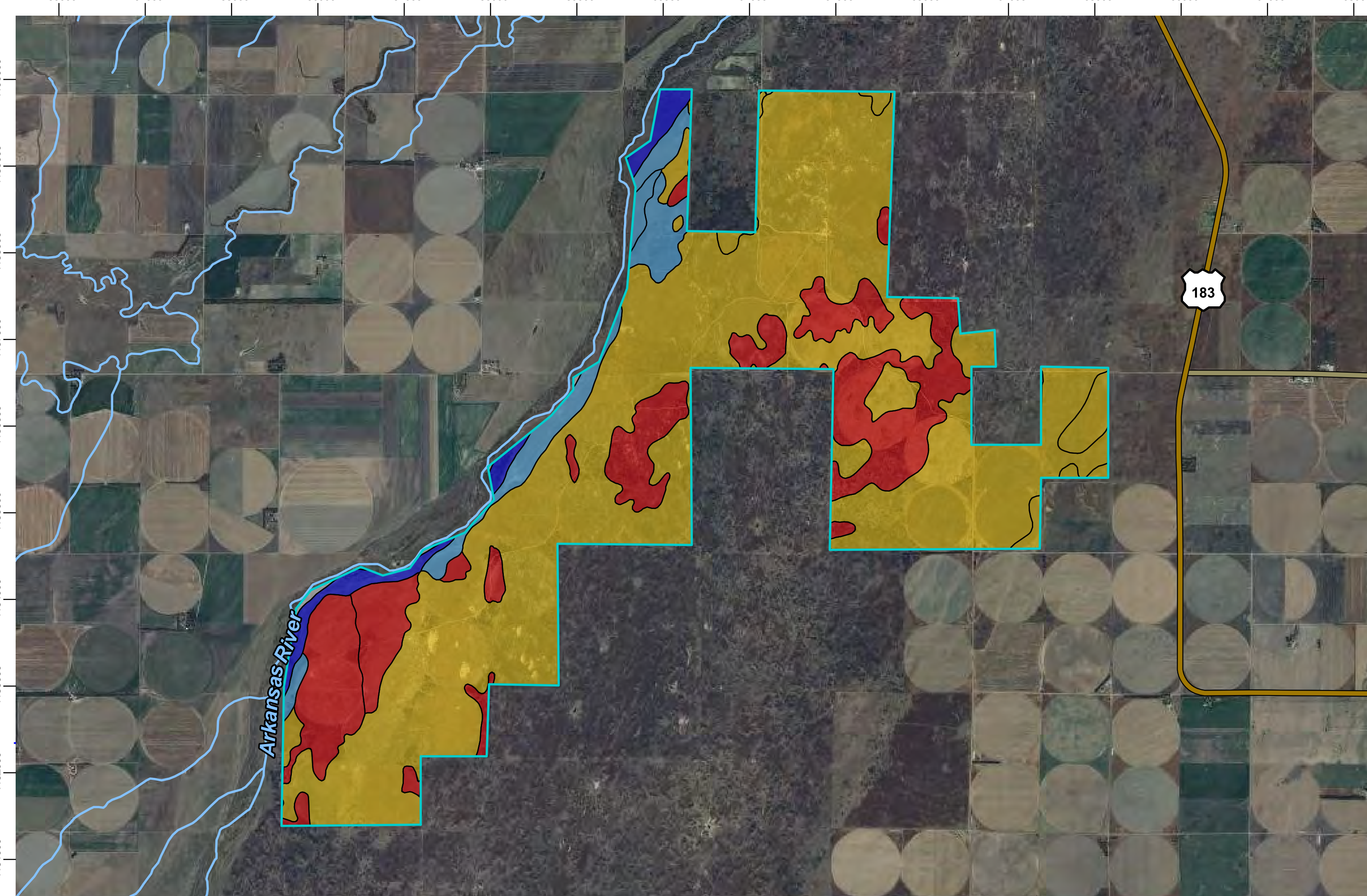
*Percent of map unit:* 1 percent
*Landform:* Depressions on interdunes on paleoterraces
*Down-slope shape:* Concave, linear
*Across-slope shape:* Concave, linear
*Ecological site:* R079XY133KS - Wet Subirrigated
*Hydric soil rating:* Yes

## Data Source Information

Soil Survey Area: Edwards County, Kansas
Survey Area Data: Version 22, Sep 13, 2022

Barfield Rebuttal Report
Exhibit 4 to Attachment 4

# Soil Health - Available Water Capacity—Edwards County, Kansas
(R9 Ranch)




Map Scale: 1:72,100 if printed on A landscape (11" x 8.5") sheet.

N

Meters: 0, 1000, 2000, 4000, 6000

Feet: 0, 3500, 7000, 14000, 21000

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 14N WGS84

## MAP LEGEND

**Area of Interest (AOI)**

Area of Interest (AOI)

**Soils**

**Soil Rating Polygons**

- <= 0.08
- > 0.08 and <= 0.12
- > 0.12 and <= 0.13
- > 0.13 and <= 0.14
- > 0.14 and <= 0.16
- Not rated or not available

**Soil Rating Lines**

- <= 0.08
- > 0.08 and <= 0.12
- > 0.12 and <= 0.13
- > 0.13 and <= 0.14
- > 0.14 and <= 0.16
- Not rated or not available

**Soil Rating Points**

- <= 0.08
- > 0.08 and <= 0.12
- > 0.12 and <= 0.13
- > 0.13 and <= 0.14
- > 0.14 and <= 0.16
- Not rated or not available

**Water Features**

Streams and Canals

**Transportation**

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

**Background**

Aerial Photography

## MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Edwards County, Kansas
Survey Area Data: Version 22, Sep 13, 2022

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Nov 7, 2021—Nov 8, 2021

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

# Soil Health - Available Water Capacity

| Map unit symbol | Map unit name | Rating (centimeters per centimeter) | Acres in AOI | Percent of AOI |
|---|---|---|---|---|
| 1183 | Las Animas loamy fine sand, occasionally flooded | 0.08 | 197.0 | 3.0% |
| 5632 | Platte soils, occasionally flooded | 0.16 | 165.4 | 2.5% |
| 5670 | Waldeck fine sandy loam, occasionally flooded | 0.14 | 319.1 | 4.9% |
| 5671 | Waldeck loam, occasionally flooded | 0.14 | 29.0 | 0.4% |
| 5928 | Pratt loamy fine sand, 1 to 5 percent slopes | 0.12 | 177.8 | 2.7% |
| 5941 | Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes | 0.12 | 4,425.4 | 67.6% |
| 5961 | Solvay loamy fine sand, 0 to 2 percent slopes | 0.13 | 0.7 | 0.0% |
| 5972 | Tivoli fine sand, 10 to 30 percent slopes | 0.07 | 1,216.5 | 18.6% |
| 9994 | Rivers | | 12.9 | 0.2% |
| **Totals for Area of Interest** | | | **6,543.9** | **100.0%** |

## Description

Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants. It is expressed in centimeters of water per centimeter of soil for each soil layer.

Significance:

Available water capacity is an indicator of a soils ability to retain water and make it sufficiently available for plant use. In areas where daily rainfall is insufficient to meet plant needs, the capacity of soil to store water is very important (USDA-NRCS, 2008). Water held in the soil is needed to sustain plants between rainfall or irrigation events and provide a buffer against periods of water deficit. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure, with corrections for salinity and rock fragments. Available water capacity determinations are used to develop water budgets, predict droughtiness, design and operate irrigation systems, design drainage systems, protect water resources, and predict yields (Lowery et al., 1996). They also are an important factor in the choice of plants or crops to be grown. The available water capacity can be increased by applying soil management that maximizes the soils inherent capacity to store water. Improving soil structure and ameliorating compacted zones can improve both the storage capacity of the soil itself and increase the depth to which plant roots can penetrate.

Factors Affecting Available Water Capacity:

Inherent factors.Available water capacity is affected by soil texture, amount of rock fragments, and a soils depth and layers. It is primarily controlled by soil texture and structure. Soils with higher silt contents generally have higher available water capacities, while sandy soils have the lowest available water capacities. Rock fragments reduce a soils available water capacity proportionate to their volume, unless the rocks are porous. Soil depth and root-restricting layers affect the total available water capacity since they can limit the volume of soil available for root growth.

Dynamic factors.Available water capacity is affected by soil organic matter, compaction, and salt concentrations. Organic matter can increase a soils capacity to store water, on average, equivalent to its weight in available water (Libohova et al., 2018). Indirectly, organic matter improves soil structure and aggregate stability, resulting in increased pore size and volume. These soil improvements result in increased infiltration and movement of water through the soil. Greater amounts of water entering the soil can then be used by plant roots. Compaction reduces the available water capacity by reducing the total pore volume. Soils with high salt concentrations have a reduced available water capacity. Solutes in soil water attract water (osmotic potential), making it difficult for plant roots to extract or uptake the water.

Measurement:

Available water capacity is determined in the lab by measuring the water content at field capacity (33 kPa) and wilting point (1500 kPa) and calculating the difference (Soil Survey Staff, 2014). Pressure plates or membranes are used to bring the soil sample to a desired matric potential (33 kPa or 1500 kPa). When at equilibrium, the soil sample is removed and dried to determine its water content.

References:

Libohova, Z., C. Seybold, D. Wysocki, S. Wills, P. Schoeneberger, C. Williams, D. Lindbo, D. Stott, and P.R. Owens. 2018. Reevaluating the effects of soil organic matter and other properties on available water-holding capacity using the National Cooperative Soil Survey Characterization Database. Journal of Soil and Water Conservation 73(4):411-421.

Lowery, B., M.A. Arshad, R. Lal, and W.J. Hickey. 1996. Soil water parameters and soil quality. In: J.W. Doran and A.J. Jones (eds.) Methods for assessing soil quality. Soil Science Society of America Special Publication 49:143-157.

Soil Survey Staff. 2014. Kellogg Soil Survey Laboratory methods manual. Soil Survey Investigations Report No. 42, Version 5.0. R. Burt and Soil Survey Staff (eds.). U.S. Department of Agriculture, Natural Resources Conservation Service.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2008. Soil quality indicatorsAvailable water capacity.

## Rating Options

*Units of Measure:* centimeters per centimeter

*Aggregation Method:* Dominant Component

*Component Percent Cutoff: None Specified*

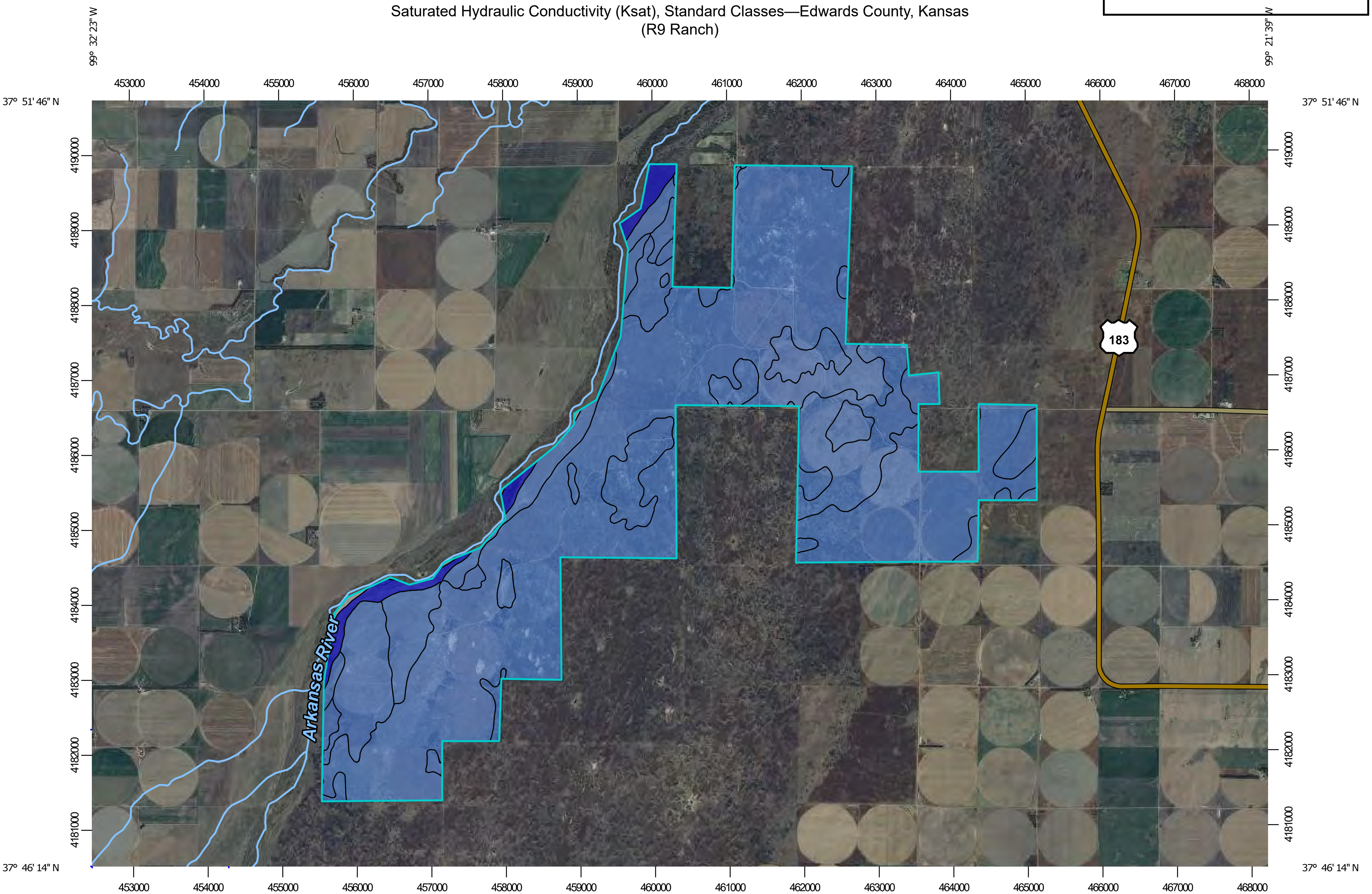
*Tie-break Rule:* Higher

*Interpret Nulls as Zero:* No

*Layer Options (Horizon Aggregation Method):* Surface Layer (Not applicable)

Barfield Rebuttal Report
Exhibit 5 to Attachment 4

Saturated Hydraulic Conductivity (Ksat), Standard Classes—Edwards County, Kansas
(R9 Ranch)




Map Scale: 1:72,100 if printed on A landscape (11" x 8.5") sheet.

Meters: 0, 1000, 2000, 4000, 6000

Feet: 0, 3500, 7000, 14000, 21000

N

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 14N WGS84

## MAP LEGEND

**Area of Interest (AOI)**

- Area of Interest (AOI)

**Soils**

**Soil Rating Polygons**

- Very Low (0.0 - 0.01)
- Low (0.01 - 0.1)
- Moderately Low (0.1 - 1)
- Moderately High (1 - 10)
- High (10 - 100)
- Very High (100 - 705)
- Not rated or not available

**Soil Rating Lines**

- Very Low (0.0 - 0.01)
- Low (0.01 - 0.1)
- Moderately Low (0.1 - 1)
- Moderately High (1 - 10)
- High (10 - 100)
- Very High (100 - 705)
- Not rated or not available

**Soil Rating Points**

- Very Low (0.0 - 0.01)
- Low (0.01 - 0.1)
- Moderately Low (0.1 - 1)
- Moderately High (1 - 10)
- High (10 - 100)
- Very High (100 - 705)
- Not rated or not available

**Water Features**

- Streams and Canals

**Transportation**

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

**Background**

- Aerial Photography

## MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Edwards County, Kansas
Survey Area Data: Version 22, Sep 13, 2022

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Nov 7, 2021—Nov 8, 2021

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

# Saturated Hydraulic Conductivity (Ksat), Standard Classes

| Map unit symbol | Map unit name | Rating (micrometers per second) | Acres in AOI | Percent of AOI |
|---|---|---|---|---|
| 1183 | Las Animas loamy fine sand, occasionally flooded | 53.1733 | 197.0 | 3.0% |
| 5632 | Platte soils, occasionally flooded | 325.9200 | 165.4 | 2.5% |
| 5670 | Waldeck fine sandy loam, occasionally flooded | 53.6000 | 319.1 | 4.9% |
| 5671 | Waldeck loam, occasionally flooded | 53.6000 | 29.0 | 0.4% |
| 5928 | Pratt loamy fine sand, 1 to 5 percent slopes | 92.0000 | 177.8 | 2.7% |
| 5941 | Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes | 92.0000 | 4,425.4 | 67.6% |
| 5961 | Solvay loamy fine sand, 0 to 2 percent slopes | 17.7400 | 0.7 | 0.0% |
| 5972 | Tivoli fine sand, 10 to 30 percent slopes | 92.0000 | 1,216.5 | 18.6% |
| 9994 | Rivers | | 12.9 | 0.2% |
| **Totals for Area of Interest** | | | **6,543.9** | **100.0%** |

## Description

Saturated hydraulic conductivity (Ksat) refers to the ease with which pores in a saturated soil transmit water. The estimates are expressed in terms of micrometers per second. They are based on soil characteristics observed in the field, particularly structure, porosity, and texture. Saturated hydraulic conductivity is considered in the design of soil drainage systems and septic tank absorption fields.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

The numeric Ksat values have been grouped according to standard Ksat class limits. The classes are:

Very low: 0.00 to 0.01

Low: 0.01 to 0.1

Moderately low: 0.1 to 1.0

Moderately high: 1 to 10

High: 10 to 100

Very high: 100 to 705

## Rating Options

*Units of Measure:* micrometers per second

*Aggregation Method:* Dominant Component

*Component Percent Cutoff: None Specified*

*Tie-break Rule:* Fastest

*Interpret Nulls as Zero:* No

*Layer Options (Horizon Aggregation Method):* Depth Range (Weighted Average)

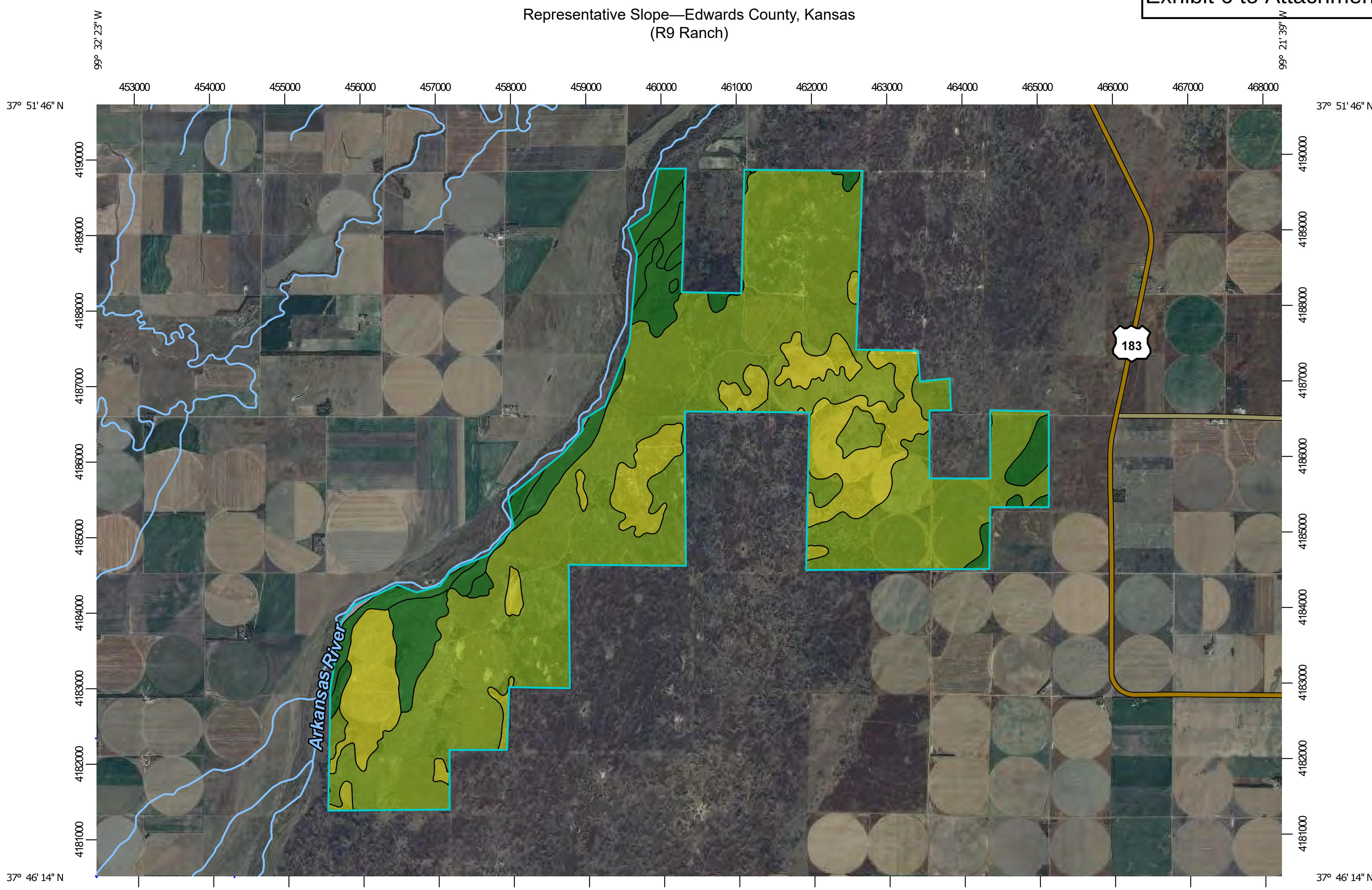
*Top Depth:* 0

*Bottom Depth:* 150

*Units of Measure:* Centimeters

Barfield Rebuttal Report
Exhibit 6 to Attachment 4

# Representative Slope—Edwards County, Kansas
(R9 Ranch)




Map Scale: 1:72,100 if printed on A landscape (11" x 8.5") sheet.

N

Meters: 0 1000 2000 4000 6000

Feet: 0 3500 7000 14000 21000

Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 14N WGS84

## MAP LEGEND

**Area of Interest (AOI)**

Area of Interest (AOI)

**Soils**

**Soil Rating Polygons**

0 - 5

5 - 15

15 - 45

45 - 60

60 - 100

Not rated or not available

**Soil Rating Lines**

0 - 5

5 - 15

15 - 45

45 - 60

60 - 100

Not rated or not available

**Soil Rating Points**

0 - 5

5 - 15

15 - 45

45 - 60

60 - 100

Not rated or not available

**Water Features**

Streams and Canals

**Transportation**

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

**Background**

Aerial Photography

## MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Edwards County, Kansas
Survey Area Data: Version 22, Sep 13, 2022

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Nov 7, 2021—Nov 8, 2021

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

# Representative Slope

| Map unit symbol | Map unit name | Rating (percent) | Acres in AOI | Percent of AOI |
|---|---|---|---|---|
| 1183 | Las Animas loamy fine sand, occasionally flooded | 1.0 | 197.0 | 3.0% |
| 5632 | Platte soils, occasionally flooded | 1.0 | 165.4 | 2.5% |
| 5670 | Waldeck fine sandy loam, occasionally flooded | 1.0 | 319.1 | 4.9% |
| 5671 | Waldeck loam, occasionally flooded | 1.0 | 29.0 | 0.4% |
| 5928 | Pratt loamy fine sand, 1 to 5 percent slopes | 3.0 | 177.8 | 2.7% |
| 5941 | Pratt-Tivoli loamy fine sands, 5 to 15 percent slopes | 10.0 | 4,425.4 | 67.6% |
| 5961 | Solvay loamy fine sand, 0 to 2 percent slopes | 1.0 | 0.7 | 0.0% |
| 5972 | Tivoli fine sand, 10 to 30 percent slopes | 20.0 | 1,216.5 | 18.6% |
| 9994 | Rivers | | 12.9 | 0.2% |
| **Totals for Area of Interest** | | | **6,543.9** | **100.0%** |

## Description

Slope gradient is the difference in elevation between two points, expressed as a percentage of the distance between those points.

The slope gradient is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

## Rating Options

*Units of Measure:* percent

*Aggregation Method:* Dominant Component

*Component Percent Cutoff: None Specified*

*Tie-break Rule:* Higher

*Interpret Nulls as Zero:* No

# EXHIBIT B

Page 1

IN THE TWENTY-FOURTH JUDICIAL DISTRICT
DISTRICT COURT, EDWARDS COUNTY, KANSAS

WATER PROTECTION ASS'N OF
CENTRAL KANSAS,
Plaintiff,

vs. Case No. 2019-CV-000005

DAVID BARFIELD, PE, in His Official Capacity as Chief Engineer, Division of Water Resources, Kansas Department of Agriculture,
Defendant,

vs.
THE CITY OF HAYS, KANSAS, et al.,
Intervenors.

DEPOSITION OF
DAVID BARFIELD, P.E.

Page 2

taken on behalf of the Plaintiff, pursuant to Notice to Take Deposition, beginning at 9:03 a.m. on the 28th day of January, 2020, at the Kansas Department of Agriculture, 1320 Research Park Drive, in the City of Manhattan, County of Riley, and State of Kansas, before Ksenija M. Zeltkalns, RPR, Kansas CCR No. 1461.

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.
.
ALSO PRESENT:
.
Mr. Jon Quinday
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WITNESS


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EXHIBITS






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DAVID BARFIELD, P.E.
called as a witness on behalf of the Plaintiff, having been duly sworn, testified as follows:

DIRECT-EXAMINATION
BY MR. SCHWALB:

**Q. All right. Thank you, Mr. Barfield. If you could just tell us what your name is, even though I already said it.**
A. David W. Barfield.
**Q. How do you spell your last name, sir?**
A. B as in boy, A-R, field, F-I-E-L-D.
**Q. Okay. What's your current role, sir?**
A. I am chief engineer of the Division of Water Resources of the Kansas Department of Agriculture.
**Q. And I know even though we're sitting at your business address, if you could still let us know what it is just for the record.**
A. 1320 Research Park Drive in Manhattan, Kansas.
**Q. All right. And have you ever done a deposition before?**
A. I have.
**Q. Okay. Tell me about that.**
A. Well, I've done a number of them in

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connection with our interstate dispute with Nebraska. Most of them have been in connection with trial and/or arbitration trials.
**Q. Okay.**
A. I've done at least, I've done one on the Cochran case, sort of an internal matter, and possibly another one or two.
**Q. Okay. And so I'm guessing you're kind of familiar with the ground rules for depositions?**
A. I believe I am.
**Q. No head shakes or anything like that.**
A. I understand. Yes.
**Q. All right.**
A. It has to be on the record.
**Q. Yep. And let's just make sure we're audible otherwise, you know, the gesticulations won't show up, so grunts, nods, that sort of thing, you know, please just speak for Ksenija here and then we'll kind of cook along here and hopefully we can get out of here early. And if -- I'll try not to interrupt you but I can't make any guarantees, and if you need any breaks, you know, just let us know, or if you need me to restate a question that's okay too. Just stop me and I'll rephrase.**

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**What did you, just to get started here, what did you do to prepare for the deposition?**
A. Mostly I attempted to review pertinent parts of the master order.
**Q. Um-hm.**
A. A bit of the modeling report, our staff review of water level documents, you know, sort of assembled this notebook that I spoke to you about before we went on the record.
**Q. Okay.**
A. Some of the key documents related to the decision.
**Q. Okay. And so you're talking about the decision a little bit. Can you kind of walk me through maybe a little bit of the time line of maybe from change applications to present date, kind of what the major processes look like from your perspective?**
A. This is where the web page that I made a copy of --
**Q. Um-hm?**
A. -- in my notebook here gives me a little bit of help with, with respect to the overall.
**Q. Okay.**
A. Large time frame, which I assume is what

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you're speaking about.
**Q. Yes, sir.**
A. Right. Well --
MR. TRASTER: One thing. I don't have -- I don't know what document you're looking at. Could you identify it before you testify?
THE WITNESS: Yes, I certainly can.
MR. TRASTER: Just the document you're look at.
THE WITNESS: Right. And it's a copy of our web page with respect to the City of Hays R9 Water Right Change Applications. At the end of that page is a time line, it's not comprehensive but it has some of the key -- key dates with respect to this process.
MR. SCHWALB: Okay.
MR. TRASTER: So it's a time line that's posted on the web page?
THE WITNESS: That's correct.
MR. TRASTER: Thank you very much. Sorry.
MR. SCHWALB: Can we mark that one as an exhibit, please. Thank you. We can just get that one marked as Exhibit 1.
(THEREUPON, the court reporter marked

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Barfield Deposition Exhibit No 1 for identification.)
BY MR. SCHWALB:
**Q. All right. So if you can just kind of walk me through the time line of events here, maybe from the original applications all the way through present day, kind of major milestones from your perspective? I think that will help.**
A. Okay. Well, the cities purchased the ranch in the mid 1990's. City of Hays and Russell submitted their applications to change the water rights from irrigation to municipal use in -- on June 26th, 2015. On January 6th, 2016, the cities provided application for the proposed water transfer. We had some back and forth with the city in 2016 and beyond with respect to discussions about necessary conditions for the change applications. The next major event listed is in 2018 the cities provided their modeling report, and that was posted on our website. On May 7th, 2018, we transmitted drafts of the proposed master order with exhibits to GMD5 for review and posted that on our website. On June 21st, 2018, we held a public informational meeting to discuss the change applications in Greensburg,

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Kansas.

**Q. Uh-huh.**

A. That followed by a period of accepting public input on the proposed changes. We received comments from GMD5 on the change applications on August 30 of 2018 and supplemental comments on the change applications from GMD5 on September 14th of 2018. The cities provided an updated modeling report on October 5, 2018. I issued my contingent approvals of the change applications on March 27, 2019, then we've had the judicial review process -- well, I guess secretarial review.

**Q. Yep.**

A. Fairly shortly thereafter he declined and then that started the judicial review process from there.

**Q. Okay. And have you been keeping an eye on the -- the judicial review since that time?**

A. How do you define keeping an eye on?

**Q. Is it reflected on this Exhibit 1 in some way, shape or form?**

A. The judicial -- there's a number of documents. We've attempted to keep the website up to date with the pleadings, at least the major pleadings with respect to that. I have not

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necessarily studied them.

**Q. Okay.**

A. It's been a fairly wild period of time here on many issues.

**Q. Understood. Have you looked at any of the -- the recent orders or memos back and forth on this deposition in particular?**

A. Yes. I mean, I've -- I've not studied them but I'm generally aware of the parameters surrounding this.

**Q. Okay. All right. In terms of -- thanks for kind of going through all that. In terms of these different milestones, as a general matter who's been involved in terms of the parties or the commentors or folks that have weighed in on this proceeding to date?**

A. In total?

**Q. Yeah.**

A. Well, obviously I've been involved in discussions with the city and its consultants, both legal and technical.

**Q. Uh-huh.**

A. And some of the city, you know, Toby Dougherty and those types in terms of -- so they've been quite involved. G5 obviously has had

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a role. I've mentioned their specific interests. They've not only provided recommendations but comments on -- on the technical work and work by various parties, Water PACK has weighed in, obviously, with comments and its -- its consultants' analysis.

**Q. Okay.**

A. And other individuals in the area that believe they're being affected by the change, obviously through the public comment period have provided oral comments at the public meeting and written comments as well.

**Q. So folks around the ranch?**

A. Folks around the ranch, yes.

**Q. Okay.**

A. Those are the major ones that come to mind.

**Q. Any communications with state officials, either governor's office or legislators?**

A. A limited amount. You know, yes.

**Q. Okay.**

A. A limited amount. And we can speak to that in more detail if you like.

**Q. Yeah. Sure. Go ahead.**

A. So what do you want to know specifically?

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**Q. Which legislators have you chatted with or members of the governor's staff or what was the -- well, let's start with that and then we can dig into the conversation.**

A. So which one do you want me to start with?

**Q. Legislators is fine.**

A. Legislators, the only one that has requested a visit specifically, Representative Phelps requested that we come and sort of brief him on the matter early in 2019. So we had a discussion with him and he was -- he was actually a mayor or city commissioner back in when they purchased the ranch.

**Q. Um-hm.**

A. And he was -- he was essentially wanting a status update, what's the status of the matter.

**Q. Okay.**

A. Senator Billinger, I don't recall any specific -- I mean I bump into him once in a while. I don't recall him asking specifically about it, but Lane Letourneau, my program manager, is more engaged in legislative matters and sees him from time to time, and he's told me that he's asked for status updates from time to time as

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well.
**Q. Okay.**
A. Those are the only specific ones that I recall.
**Q. Okay. In terms of legislators, how about either staff or governor at the time, governor or the executive.**
A. So I believe -- I believe I had a discussion with Governor Colyer at some point in his tenure just again, in briefing him on different water issues, this is one of them. Again, status of the matter. And then Governor Kelly in January of '19, I went over and met her and spoke to her on a sort of the status of several of the major issues, but this was one of particular interest to her and gave her essentially a, again, a status update in terms of where we were at that time.
**Q. Okay.**
A. With respect to the process.
**Q. Anybody encourage you to push this thing along at the governor's office?**
A. I don't recall specifically but I, you know, I do believe that that was some of the sense, yes, that, you know, it wasn't seeking to

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determine my decision but just let's get this done.
**Q. Um-hm.**
A. I've been encouraged in that way, certainly.
**Q. Get this done meaning let's get it over and done with and approved or?**
A. Let's, you know, I had made some commitments to get the decision made in the fall of 2018.
**Q. Um-hm.**
A. And I did not get that done. Several other pressing matters, in particular Quivira, but not just Quivira, Wichita's aqua storage and recovery issue just got bigger than I expected and so I wasn't able to meet those commitments.
**Q. Uh-huh.**
A. To work through the record and to make a decision, and that resulted in some impatience by elected officials.
**Q. Okay. Mainly the ones you've talked about?**
A. Them and elected officials in Hays.
**Q. Okay.**
A. As well.

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**Q. Tell me about those -- those conversations and what those entailed.**
A. So again, those occurred sort of January-February of 2019.
**Q. Uh-huh?**
A. And I had made some, you know -- I had talked to the city early in the year is my recollection, 2019, about how to get the process on track to -- to get it done but to give me time to go through the record and make an informed decision. We'd sort of agreed upon a schedule that had me going through March but with some milestones along the way. Somehow the communication between Mr. Dougherty and the mayor/city council, they weren't entirely on board with that schedule and they just were -- were wanting to make sure that I was giving this adequate priority.
**Q. Okay.**
A. In terms of juggling all the responsibilities that I was still dealing with at the time, so.
**Q. Okay. But there was sort of an agreed upon date in March?**
A. Yes.

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**Q. Okay. I'll pass this one over here and let me give that to you, Ksenija. What I'm going to put in front of you, and if you don't mind passing a copy of this, here. I've got it marked as Exhibit 19 for Water PACK purposes but I think we can just mark it as Exhibit 2 for depo purposes. That is a series of articles from the Hays Daily News. You'll see at the top there, I think, that pretty much all of these are from the Hays Daily News.**
MR. TRASTER: Aaron, or I'm sorry, Micah?
MR. SCHWALB: Yes, sir.
MR. TRASTER: So you've marked them with deposition exhibit numbers but you want to change the numbers?
MR. SCHWALB: Yeah. I think it will just be easier to have it be sequential as we'll introduce it. I didn't know what the sequence was going to be relative to what Mr. Barfield was talking about.
MR. TRASTER: So this is what?
MR. SCHWALB: That will be Exhibit 2 for deposition purposes. And I'm sorry if that's confusing.
MR. TRASTER: All right. Very good.

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Thank you.
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 2 for identification.)
BY MR. SCHWALB:
**Q. Okay. Just take some time to review that and there's some highlighting in there that you'll see.**
A. What level of review do you want me to do, here.
**Q. Oh, just the -- if you just want to look at the titles of the articles, the dates and the highlighted portions.**
MR. TRASTER: Micah, one of these doesn't seem -- most of these are Hays Daily News but there's one in the middle that I can't tell, Hays Post. Never mind. I see it now.
MR. SCHWALB: Yep. That will be on page eight, I believe, of that exhibit.
A. All right. I believe I've perused them as you requested.
BY MR. SCHWALB:
**Q. All right. Thank you, sir. If I can summarize what's in here, between February 15th and February 22nd, there's a series of articles**

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**within this Exhibit 2 that describe conversations between Hays representatives, governor's office, legislators, as well as I believe there's a reference to a lobbyist in here. Did you have communications with the governor's office after these February dates or in the same time frame, February 15th to February 22?**
A. I don't recall any communications with the governor's office. Again, I briefed the governor on the issue in later January. My, you know, I -- I have regular updates with the secretary of ag being the current one and previous one, and the secretary updates the governor.
**Q. Uh-huh.**
A. So obviously I'm updating, so they're getting updates that way.
**Q. Through the secretary?**
A. Through the secretary.
**Q. And then are you hearing back feedback through the secretary?**
A. I can at times.
**Q. Okay.**
A. Yeah.
**Q. Was there any feedback in this February period from Secretary Beam regarding the order?**

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A. I don't recall anything specific. You know, these statements here about putting pressure on me to get it done by next Friday are just not -- not the reality of what I got back. Again, I sort of laid out what I needed to get this done.
**Q. Uh-huh.**
A. To complete the review, to draft the master order, to be able to push out a product that I could stand behind --
**Q. Uh-huh.**
A. -- early on, and I pretty much stuck with that schedule.
**Q. Okay. Other than the shift from fall of '18?**
A. Right. Right.
**Q. Through March of '19?**
A. Correct.
**Q. Okay. Were you aware that Hays had hired a -- or had a lobbyist working on this?**
A. I don't believe I was until I --
MR. TRASTER: Object to the form of the question. States facts not in evidence.
BY MR. SCHWALB:
**Q. You can go ahead and answer.**
A. Not that I was aware of before reading

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the article.
**Q. Okay. Thank you. All right. So let's -- do you need some water?**
A. I've got it here.
**Q. Okay.**
A. I'm good.
**Q. Let's -- earlier in your testimony you referenced meetings with the City of Hays, City of Russell, their representatives, engineers, what have you. Were these meetings posted somewhere publicly?**
A. No.
**Q. Okay. All right. Other than the Greensburg meeting?**
A. Correct.
**Q. Okay. Let's talk about the Greensburg meeting for a little bit. What was the intended purpose of that meeting?**
A. Well, it was to inform interested, affected water right holders, landowners of the area about this significant package of change applications that were under consideration.
**Q. Uh-huh**
A. And to seek to inform them about what was being requested, and by that point we had

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developed a draft proposed approval documents.
**Q. Okay.**
A. That we thought would help them to understand specifically what was being proposed and to -- to facilitate public feedback on those documents.
**Q. How'd you get the word out for the meeting?**
A. It was obvious on our web page. I believe we did a press release, at least that's my recollection. Obviously informed GMD5 and Water PACK.
**Q. Any other folks in the vicinity of the ranch?**
A. I don't recall.
**Q. Okay.**
A. Specifically what we did beyond that.
**Q. Okay. Do you recall the general topics that were covered by you at that -- at that meeting?**
A. Well, I'm looking at the copy of my presentation. So the outline of the meeting was a welcome and overview by me that provided just a general overview of the change applications, that it was a second water transfer in state history

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and the first undercurrent requirements, generally what they were proposing with respect to the changes from municipal -- from irrigation use to municipal. There was a presentation by the city on -- on what they were seeking to accomplish in the change and its importance to them.
And then I came back and basically walked through a summary of the draft proposed approval documents, again stepping through sort of the major provisions of those documents and then had a time of questions and answers, a break, and then an opportunity for public comment to be received.
**Q. Okay. You mentioned the major topics there. What are the major regulations or statutes here that you might have touched on?**
A. Well, change applications are provided for in K.S.A. 82a-706b that allows water right holders to make changes in place of use, point of diversion, or use made of water or any combination thereof, so obviously the statutory requirements that are provided in 708b and then obviously we have a large body of regulations that are also in play.
**Q. Okay.**
A. That I'm -- that are also considered that

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govern things like changes in use made of water, consumptive use requirements, as well as spacing and then many other attributes.
**Q. Okay. So you referenced I think 708b?**
A. Correct.
**Q. Is that right?**
A. Yeah.
**Q. Can you maybe focus on 708b(a)(2), to the extent that it's in your new presentation, here. Can you read for me just into the record?**
A. Certainly.
MR. OLEEN: I'm going to object, or actually I will ask for clarification, Micah. Are you asking him to read his paraphrasing of 708b or are you asking him to actually read the statute?
MR. SCHWALB: Whatever's in the presentation.
MR. TRASTER: Whatever's in what?
MR. KITE: The presentation. He's asking him to read the section of 708b.
MR. TRASTER: Okay.
A. Okay. I'll read what's in the presentation which is in fact the full statement of what's in the statute as well, so. K.S.A. 82a-708b, paragraph (a)(2): Demonstrate to the chief

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engineer that any proposed change is reasonable and will not impair existing rights.
BY MR. SCHWALB:
**Q. Okay. In the context of the Greensburg meeting, do you recall any sort of conversation or statements around impairment of existing rights that may have occurred?**
MR. TRASTER: I'm going to I guess not really object but for the record note that the transcript of the informational meeting on June 21st, 2018, is in the record and so it can -- it says what it is.
MR. SCHWALB: We'll get there.
A. So can you restate the question.
BY MR. SCHWALB:
**Q. Sure. Do you recall any discussion of impairment of existing rights or any sort of statements you might have made in the Greensburg meeting?**
A. Well, I did state that no decision had been made and that we were getting public inputs to ensure that the proposed changes that the draft proposed documents met statutory requirements, but there could have been a statement that we believed that those documents did meet the requirements of

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82-708b.
**Q. Okay. With respect to impairment?**
A. With respect to impairment.
**Q. Is an impairment viewed, at least by you, on an annualized basis or over some period of time beyond a year?**
A. Repeat the question again.
**Q. Okay. So from your perspective when you're, as chief engineer and you're thinking about impairment, are you looking at it over on an annualized basis or over some longer period of time, like when you have to say an existing right is impaired like what it says here are you looking at it within a one year period or something longer than that?**
A. Well, with respect to the change evaluation.
**Q. Uh-huh?**
A. Which I assume is the context of which --
**Q. Yes?**
A. Because -- because we have to do -- we have to deal with impairment with respect to real-time water administration.
**Q. Uh-huh?**
A. That's a different sense of impairment in

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my view than the impairment requirement here.
**Q. Why is that different?**
A. Well, when I make an application, a decision with respect to impairment in a new application or a change, I'm essentially saying am I -- does -- is my approval ensuring that the impairment will not occur, and that includes the ability to administer water rights as needed.
**Q. Um-hm?**
A. You know, we approve, for example, surface water rights that -- that have conditions in it so that I can curtail that use when it's interfering with a senior appropriator.
**Q. Okay.**
A. So my approval includes my ability to administer that right as needed. But to answer your initial question, you know, we have to look at both, but the principal looking at it I guess with respect to this impairment requirement in 82a-706b, you know, in a -- in this groundwater decision, the long-term sort of dominates the considerations.
**Q. Okay. So multi-year?**
A. Multi-year.
**Q. Okay. What do you think a policy is here**

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**with this impairment language in this statute? What is it -- what is it driving towards?**
MR. OLEEN: I object. I think it calls for a legal conclusion. You may answer.
MR. TRASTER: I object on the -- I don't understand the question.
BY MR. SCHWALB:
**Q. Why are you looking at impairment for a change application?**
A. Well, people are allowed to change their water rights, place of use, point of version, use made of water or any combination thereof. That's their entitlement under 708b.
**Q. Um-hm?**
A. Subject to change being feasible and not interfering with existing water rights, so I need to make sure that as we let people make those changes.
**Q. Um-hm?**
A. We're not creating a problem for neighboring existing rights that's not addressed in the approval.
**Q. Okay. Are you looking at senior rights?**
A. Well, senior rights obviously are the principal concern but this language says existing

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rights.
**Q. Which refers to who?**
A. Other water rights besides senior.
**Q. So junior?**
A. Junior.
**Q. Okay. Thank you. The consideration of senior and junior rights that you just referred to, was that described at the meeting in Greensburg or discussed at the meeting in Greensburg?**
A. I don't recall specifically.
**Q. Okay. Would it help you if I handed you a transcript of the --**
A. It might.
**Q. All right. Let's get this one in, I think as, are we up to Exhibit 3?**
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 3 for identification.)
BY MR. SCHWALB:
**Q. So I'll ask you to turn to page four, should be highlighted at the bottom.**
A. Page ... the fourth page?
**Q. Sorry. It's the fourth page of the one you've got in front of you. It should be, the**

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**internal pagination is page 12.**
A. Okay. Okay.
**Q. So in essence what did you say?**
MR. TRASTER: I'm going to object -- no, I'm not. Withdraw the objection.
MR. SCHWALB: Okay.
A. So I believe the summary is, I mean I'm speaking about juniors and senior water rights. Seniors are allowed to interfere with juniors or juniors cannot interfere with seniors as a general matter. But with respect to a change in conditions, I have to consider all water rights.
BY MR. SCHWALB:
**Q. What do you look at when you're considering all water rights? What are the -- what are the factors that you -- that you consider?**
A. To -- I mean I'm basically try to ensure that the change does not expand use.
**Q. What kind of use?**
A. Well, expand use of the water rights. You know, we speak about consumptive use is a part of that consideration of impairment.
**Q. Okay.**
A. It's not the whole of it. I mean, we

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consider well spacing is, withdraw rates, just the actual physical condition and I'll -- I have reference to that in the master order in my findings with respect to when considering all of these factors, I found that these changes do not -- would not be expected to lead to impairment of the neighboring water rights.
**Q. The junior water rights?**
A. Well, all.
**Q. All water rights?**
A. All water rights.
**Q. And you mentioned net consumptive use or just consumptive use?**
A. Well, that's one of the pieces that -- one of the sets of conditions that allows me to get to that conclusion.
**Q. Okay. What are some of the other conditions that you look at?**
A. Well, again, spacing.
**Q. Um-hm?**
A. Is -- maintaining sufficient spacing is very critical to reducing, ensuring that there's not inappropriate interference between wells, pumping rates, again, just the physical -- the particulars of the physical system.

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**Q. Okay. Did you discuss this consideration of impact on adjacent users with the cities?**
MR. TRASTER: In what time frame?
BY MR. SCHWALB:
**Q. Just in general. I mean, we've talked about meetings.**
A. So are you asking if I discussed my impairment analysis with the cities?
**Q. Correct, with juniors, seniors, this consumptive use assessment.**
A. You know, I don't recall any detailed discussions of that evaluation. I'm certainly -- we had some general discussions, I am sure, along the way. A lot of my evaluation of the potential for impairment came as I waded through the record from the public meeting and the various critiques that were received from -- from Doctor Keller and Balleau Groundwater so I formulated that evaluation largely in that setting.
**Q. Okay. But no direct discussions of junior impairment with the cities?**
A. We've had a lot of discussions so I can't say definitively. I just don't recall any substantive discussions with them on that subject, so.

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**Q. What about within the context of the consumptive use?**
A. Again, I'm not recalling any specific discussion that weighed into my decision here.
**Q. Okay. Let's focus on consumptive use for a little bit. What do you look at when you're considering consumptive use? What are some of the data points?**
A. Well, we have a body of regulations that lays out specifically what we consider in our consumptive use evaluations.
**Q. Okay.**
A. Which in the case of changes in use made to water looks at the maximum acres that were irrigated under a particular water right.
**Q. Um-hm?**
A. Times the net irrigation requirement for the crop that's irrigated.
**Q. Okay. Where do you get the data for the crop that was irrigated?**
A. Well, the default is corn in the regulation.
**Q. Um-hm?**
A. So we'll use corn, but the regulations do provide for us to consider other crops if a record

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demonstrates that there was a crop that was irrigated that was other than corn and had a higher consumptive use value.

**Q. Okay. Was that determined here, that there was something higher?**

A. In many of the water rights alfalfa was irrigated.

**Q. Okay. And what was your data point? What was the evidence supporting that?**

A. So one of my staff in Stafford field office went through the records to determine, you know, what was reported.

**Q. Um-hm?**

A. And according to how we do that and she -- she reviewed the records and determined what the crop was in the year of record.

**Q. Reported by the irrigator?**

A. Correct.

**Q. Okay. Did the cities provide any additional data on this?**

A. I'm not recalling it.

**Q. Would it be helpful if I could provide you with some of that data?**

A. You might.

**Q. All right. This is a federal one. I**

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**believe that will be Exhibit 4. Please take a moment to take a look through that.**

(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 4 for identification.)

BY MR. SCHWALB:

**Q. I will represent to you that that was included as an appendix to one of the change applications -- well, it has the change application that's the front page and then as an exhibit to that we've cut out some interweaving pages but there is an exhibit there that shows FSA cropping records from 1985.**

MR. OLEEN: Micah, which page did you say we're looking at here?

MR. SCHWALB: If you would turn to.

MR. BULLER: Might be helpful to refer to the Bates number.

MR. SCHWALB: For sure. So if you want to, at the very bottom it's marked KDA2265 and it's a Report of Acreage. And if you look in the upper left hand corner, it shows a program year of 1985, and then beneath that you will see different crops identified and the column headers, and that continues through Bates stamp 2269.

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MR. OLEEN: Does it also have a Hays Bates number, the first page?

MR. SCHWALB: It does. It's Hays 4907 through 4911.

MR. BULLER: Yeah. I believe the bottom of the -- the bottom -- the KBA Bates number might be cut off on some of these pages.

MR. SCHWALB: Oh, on the print-out. Oh, my apologies.

MR. BULLER: Which is why the Hays Bates number is also helpful.

MR. SCHWALB: Okay. Thank you.

BY MR. SCHWALB:

**Q. Have you had a chance to review?**

A. Generally.

**Q. Okay. Based on your quick review was there something other than corn and alfalfa grown in program year 1985?**

MR. TRASTER: Object to the form of the question as what are we talking about when, where and how? I mean, I don't know what we're asking about.

BY MR. SCHWALB:

**Q. Within pages 4907, I'm using the Hays Bates stamps here, through 4911, is there any**

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**indication that something other than alfalfa or corn was grown?**

A. Just generally?

**Q. Yes, sir?**

A. Yeah. I mean there's some wheat indicated, possibly, in some rotation, and alfalfa. Am I answering your question?

**Q. Yes, sir.**

A. Okay.

**Q. Thank you. And then on the page with Hays Bates stamp 4907, at the very bottom do you see that Section II Operator's Certification, the bottom left hand corner?**

A. I believe so.

**Q. Okay. Would you mind reading that into the record?**

MR. OLEEN: I object to this line of questioning. I think it's outside the scope of this limited deposition. You may answer.

A. Are you asking me to read the -- attempt to read the operator's signature?

BY MR. SCHWALB:

**Q. No, just the certification language there underneath Section II.**

A. Oh. I certify to the best of my

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knowledge and belief that the acreage of crops and land uses listed herein are true and correct. Further, my signature constitutes authority for ASCS personnel to enter my farm for making any program determinations.
**Q. Thank you. Did you review these records in connection with processing the change applications?**
A. I didn't personally.
**Q. Do you know if your staff did?**
A. Well, I've relied on my staff to evaluate the records to make these determinations as is typically done.
**Q. Um-hm?**
A. So I relied on that work.
**Q. Okay.**
A. I believe their work is -- was provided as part of the agency record.
**Q. Okay. So I think we talked about how this record refers to wheat. Does wheat use more water or less water to grow than corn?**
A. Well, it would typically require less. Often wheat is done as part of rotation with other crops.
**Q. What about milo? Does milo use less**

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**water or more water than corn or alfalfa?**
A. My understanding is typically less.
**Q. Okay. Do you know if the -- these other crops were accounted for in the consumptive use analysis?**
A. Well, again, I relied on staff to -- to do this determination pursuant to the normal procedures.
**Q. Okay. You mentioned you have a copy of the master order in front of you.**
A. Um-hm.
**Q. Would you turn to, I believe it's table B?**
A. Table B? As in boy?
**Q. I think so. Yep?**
A. Do you know where it is?
**Q. It has the gray at the top there. Right there. Maybe that's, I'm sorry, Appendix B, Table 1.**
A. Yes.
**Q. Is there any reference in this table to wheat or milo?**
A. I don't see any.
**Q. Okay. So if there's no wheat or milo here, what would be the reason for that?**

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MR. OLEEN: Again, renew my objection. This line of questioning is outside the scope as this deposition was limited by the court. You may answer.
A. I'm not certain.
BY MR. SCHWALB:
**Q. Okay. Now, in connection with putting together this consumptive use analysis you mentioned the input of Doctor Keller; is that correct?**
A. Well, he provided his comments and suggestions on consumptive use.
**Q. Okay. Was that in the form of a report of some kind?**
A. It was.
**Q. Did you have a chance to review that report?**
A. I did.
**Q. Do you remember if that report showed any discrepancies between the growing crops in the master order and the records that he reviewed?**
A. He, as I recall, I believe he did believe there were some differences.
**Q. Okay. Do you recall what those differences were?**

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A. I don't recall now.
**Q. Would it be helpful if I provided that to you?**
A. It would.
**Q. All right. This is Exhibit 5.**
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 5 for identification.)
BY MR. SCHWALB:
**Q. You're right there on the right page. It's marked KDA 967 is the table I'd like to focus on just for a little bit and I believe that carries over to KDA 968, so it should just be the two pages there, and the highlighted portions in particular that are highlighted in yellow. Please take a moment just to review that.**
A. Okay.
**Q. And then I believe, just to be clear, there's a notation at the bottom on the second page of the table, it says values in red were assumed. Have you had a chance to look at that?**
A. Well, I've just generally perused it. It depends on your question whether I need more time.
**Q. Okay. So I think you'll see at the top of the columns Doctor Keller has identified**

**different column headers, the circle number, the number of acres for GIS. What does GIS stand for?**
A. Geographic Information System.
**Q. Okay. And then the next column I think is chief engineer acres, and as you go through it kind of describes the different data points that Doctor Keller was looking at. As you look at this table are there any differences between what's labeled chief engineer crop, 1984 FSA crop, metric Ks, I don't know what that means, 1985 FSA crop, are there any differences there between what the FSA data showed and what's listed as chief engineer crop?**
A. There are some differences, yes.
**Q. Okay. Are they the highlighted rows -- or, yes, highlighted rows?**
MR. TRASTER: I'm going to object to the form of the question. These -- these all state -- the questions are assuming facts not -- withdraw the objection.
A. Yes, there are differences with respect to the highlighted rows.
BY MR. SCHWALB:
**Q. Okay.**
A. In chief engineer crop versus other



records.
**Q. Okay. Let's focus just for a second on circle No. 15 which I think is the third highlighted row. If you go off to the right there under 1984 FSA crop, what does that say?**
A. Not farmed.
**Q. Okay. And then 1985 FSA crop?**
A. N/A, which I assume means not available.
**Q. Okay. So according to this were any fields fallow in 1984?**
A. That's what would be indicated.
**Q. Okay. Did you review this table in connection with your consumptive use analysis?**
A. Again, I don't know to what extent staff reviewed this table.
**Q. Okay. But earlier you testified that the Table 1, Exhibit B, just shows corn and alfalfa?**
MR. OLEEN: Objection. Where in the table? Maybe you could say which water right we're talking about.
BY MR. SCHWALB:
**Q. Is there anything other than corn or alfalfa indicated as the growing crop in any of these fields?**
MR. OLEEN: For which table, please.



MR. SCHWALB: I'm sorry. Table 1, that was in Appendix B to the master order.
A. I don't see anything other than a blank for water right 30-44.
BY MR. SCHWALB:
**Q. Okay. Let's focus on that one in particular. If nothing's there in that field, is there a net consumptive use?**
A. I believe this one may only have additional rate attached to it or -- there's something unique about this water right that I don't remember the details anymore.
**Q. Okay.**
A. So.
**Q. So let's keep going with this consumptive use question. Earlier you testified, if I can rephrase just for a second, that you look at impairment over a multiyear period for a change application with respect to junior users; is that correct?**
A. Yes.
**Q. And are you also looking at a multiyear period for impairment of senior users in connection with a change application?**
A. Yeah. We're looking at is this going to



create a problem in the long-term future.
**Q. Um-hm. And that ties to the consumptive use?**
A. Consumptive use is a part of the analysis to essentially reduce the water right to -- as one piece to make sure that impairment will not occur.
**Q. Okay. Does that consumptive use analysis account for a change in the cropping or movement of water off the point of diversion in the change application?**
A. No. Repeat the question. I didn't follow.
**Q. Okay. When you're looking at the change application and you're thinking about the consumptive use over a longer period of time, are you accounting for the change in crops that will be grown after, assuming the change application is approved?**
A. I'm still not quite sure what you're getting at. So here we're looking at a change from irrigation.
**Q. Um-hm?**
A. To something else.
**Q. And the irrigation accounts for the crop that was grown in the year of perfection?**

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A. Correct.
**Q. Okay. If the crop will change at --**
MR. TRASTER: I'm going to object to the form of the question. Misstates the statute. Go ahead.
BY MR. SCHWALB:
**Q. If the crop will change, does the consumptive use analysis account for that changed crop post approval?**
A. Again, I'm just not following what you're asking.
**Q. Okay. We've looked at corn. We've looked at alfalfa. We've looked at wheat. We've looked at milo. You testified that crops have different consumptive uses; is that correct?**
A. Yes.
**Q. Okay.**
A. That's right.
**Q. For lands that are converted to grassland, would that have a different consumptive use, depending upon what's grown there? The type of grassland?**
A. Well, we do not consider the post change use, if that's what you're asking. So our consumptive use is designed to -- to provide water

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usage for making a change, the ability to change a reasonable quantity of water. This is a property right.
**Q. Um-hm?**
A. And so -- and we look at, you know, certificate represents the maximum they can divert in any calendar year. We look at the maximum acres that was irrigated during the perfection period.
**Q. Um-hm?**
A. And apply the NIR to it to determine what's reasonable to change with respect to consumptive use, so.
**Q. Is that referred to as the net consumptive use?**
A. I believe so.
**Q. Okay. And so earlier you testified that you don't look at what happens after.**
A. Yeah. We never have.
**Q. Okay. But your -- you testified earlier that you're considering impairment on junior users over some period of time?**
A. As we do the evaluation I must find that it does not impair. That's right.
**Q. Okay. And you said that it's a property**

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**right relative to the change application. What about the property rights of the adjacent users?**
MR. OLEEN: Object to the form of the question.
A. And again? Ask it again.
BY MR. SCHWALB:
**Q. Okay. You testified earlier that the water right is a property right and you're looking at the change application?**
A. Um-hm.
**Q. As a property right?**
A. Um-hm.
**Q. When you're considering the change application and its impact on junior users, they have a property right as well?**
A. Um-hm.
**Q. What is that property right relative to the changed application?**
MR. OLEEN: I again object to the form of the question. You may answer.
A. Okay. Well again, the senior can interfere with the junior's use as a general matter.
BY MR. SCHWALB:
**Q. Um-hm?**

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A. That's what our law provides, but I do need to ensure that the change does not impair that junior use.
**Q. The existing use.**
A. The existing use.
**Q. Okay. By engaging in a consumptive use analysis?**
A. Yeah. By the overall terms and conditions that are applied, that includes the reduction of consumptive use. That's certainly not the only consideration.
**Q. Okay. So if they're growing alfalfa before, there's one consumptive use before the change application?**
A. Um-hm.
**Q. And if they're growing alfalfa after, it's probably the same consumptive use?**
A. After a change from irrigation to some other use?
**Q. Say you have a partial change in the water right on -- on a given -- on a given ranch. You're growing alfalfa but you're permitting some portion of the water to be taken away and moved somewhere else, the consumptive use for the alfalfa there on the ground would be the same?**

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A. For the part that remains?
**Q. Correct.**
A. I presume so.
**Q. Okay. What if they convert it to grassland? Is that a different consumptive use?**
A. We -- I don't follow. We don't do changes of that nature.
**Q. Okay. Does the model account for any sort of change, all this modeling work that was done, a change from irrigation to a grassland use?**
A. Well, the modeling work, you're talking about the modeling work to support the long term --
**Q. The net consumptive use.**
A. Now what modeling work -- the modeling work that was done was to determine the long-term yield of the ranch.
**Q. Um-hm?**
A. As a ten-year average constraint.
**Q. Um-hm?**
A. That wasn't directly a consumptive use analysis.
**Q. But you did a consumptive use analysis using the model?**
A. We did. Our consumptive use analysis was

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pursuant to our rules.
**Q. Okay. What about the model? Was the model -- use of the model pursuant to your rules?**
A. The groundwater model?
**Q. Yes.**
A. The use of the groundwater model was done to determine the reasonable long-term yield for the ranch that I used as a limitation on our approvals.
**Q. Okay. Who helped prepare that model?**
A. Well, Burns and McDonnell's, the cities' consultants.
**Q. Um-hm?**
A. Did the modeling work.
**Q. Okay. And where did they get the inputs for the model, for their modeling work?**
A. Well, they used the GMD 5 groundwater model that was developed by Balleau Groundwater.
**Q. Okay. And that -- sorry. Just have to get through who's -- where all this comes from. Where did Balleau's -- what is the genesis of Balleau's model? What's the basis for it?**
A. Balleau Groundwater developed the model for GMD 5's use.
**Q. Did he rely upon any, to your knowledge,**

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**other models to develop his specific model?**
A. He looked at past modeling work that had been done in the -- in the area as he developed the model, but that -- the firm developed, I mean, it's its own model. They obviously looked at all the previous work as part of their process to develop the model.
**Q. Previous work within GMD 5?**
A. Yeah. Really a broader area than that. The model goes well beyond GMD 5 in terms of geographic extent, so.
**Q. What else does it cover?**
A. It goes to the west a considerable distance to areas that contribute.
**Q. So --**
A. As --
**Q. How far west are we talking? To the extent you know.**
A. Not to the state line but well into GMD 3. I mean, 50 to 100 miles, I suppose.
**Q. So you've reviewed this model?**
A. Yeah. I was part of the -- there's a modeling committee that was established to sort of provide input to Balleau as he built the model, and I was on that modeling committee.

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**Q. Who else was on that modeling committee?**
A. I'm pretty sure Jeff Lanterman of our field office was. I don't recall whether Doctor Perkins was on staff at that point. I was also part of a modeling committee for a precursor model, the Min Ark model that the Kansas Geologic Survey did for part of the area, so.
**Q. Okay. Has this model ever been approved for use in connection with a change application?**
A. What do you mean by approved for use?
**Q. Is there any regulation that says that this, this model is the standard that's used to determine groundwater flows in connection with a change application?**
A. We don't -- we don't do that, I guess.
**Q. Okay. So the answer is no?**
A. Well, we don't do it one way or the other.
**Q. Okay.**
A. I mean.
**Q. Okay.**
A. We don't have an approved list of tools.
**Q. Okay. And there's not an approved list of tools for change applications?**
A. Correct.

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**Q. Okay. Is there any sort of -- let me rephrase.**
**What form does this model take? Is it a written report, is it software?**
A. It is software. It's a model built on a U.S. Geological Survey, has a modeling platform called MODFLOW that is used extensively in groundwater model development, so it is an application of the U.S.G.S. MODFLOW program to this specific hydrogeologic setting.
**Q. Okay. And Balleau, in consultation with the modeling committee, modified it for this setting?**
A. Right. Or built it for this setting. Yeah.
**Q. Is there any description of how he did that?**
A. Certainly.
**Q. Okay.**
A. He has a modeling report.
**Q. Okay. Have you reviewed this modeling report?**
A. I have.
**Q. Do you recall if this modeling report accounts for soil recharge rates?**

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A. It does. Yeah. It has recharge functions that are functions of soils.
**Q. Okay. Does it account for soil recharge rates predevelopment?**
A. How do you define predevelopment?
**Q. Before 1970.**
A. I believe so.
**Q. Okay. What about post development?**
A. Well, as I recall he does. In that change there's these recharge functions that are sort of curves, amount of precipitation versus recharge, and there are changes that he implemented over time based on land use practice changes, for example.
**Q. Okay. So are there differences between pre and post development for recharge rates?**
A. Well, there's changes over time, so I -- I guess the answer is yes.
**Q. Okay. Do you recall seeing, you mentioned this graph would it be helpful to have a copy of it?**
A. Certainly.
**Q. All right.**
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 6 for

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identification.)
BY MR. SCHWALB:
**Q. Please take a second to review that.**
MR. TRASTER: Okay. What are we numbering this one?
MR. SCHWALB: Six.
MR. TRASTER: Six?
MR. KITE: Yes, sir.
A. Okay.
BY MR. SCHWALB:
**Q. All right. If you would turn to page two of Exhibit 6 marked KDA3402. Do you see the two lines for Region 9?**
A. Yes.
**Q. Okay. Now, along the Y axis there, I think that says inches per month recharge; is that correct?**
A. Yes.
**Q. And then along the X axis, that says inches per month precipitation; is that correct?**
A. That's correct.
**Q. And then we see the two Region 9 lines, one of them says post 1970; is that correct?**
A. Yes.
**Q. And then another one does not; is that**

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**correct?**
A. That is correct.
**Q. The one that doesn't have post 1970 on it, does that show a lower or a higher rate of recharge based on this graph?**
A. So it would have for the same precip a lower recharge value.
**Q. Okay. So for predevelopment it's showing a lower recharge value. Is that --**
A. That's right.
**Q. Okay.**
A. Than post development.
**Q. Okay.**
A. So these conservation practices tend to hold water and create more recharge.
**Q. The conservation practices or the -- what they're -- sorry. Conservation practices post development or pre?**
A. Post development.
**Q. Okay. They hold more water?**
A. They --
**Q. In the crop?**
A. They hold more water in the soil and create more recharge.
**Q. But predevelopment what sort of crops**

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**would be there?**
A. Well, as I understand it, a lot of this happens to do with land treatment practices on nonirrigated land. Again, terraces and whatnot are put in place to reduce soil erosion.
**Q. Um-hm?**
A. But they tend to also retain more moisture on the land and enhance recharge.
**Q. Okay. But earlier you said that these conservation practices post change are not accounted for; is that correct?**
A. We weren't talking about conservation practices earlier.
**Q. I'm sorry. Grassland is not accounted for, conversion to grassland?**
MR. OLEEN: Object to the form of the question.
A. And I guess I'm lost with respect to the context of your earlier discussion but what's your question right now?
BY MR. SCHWALB:
**Q. I guess the question is this graph is showing predevelopment lower recharge rates. The -- and post development, I guess, higher recharge rates. Is it your testimony that the conservation**

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**practices are going to result in higher net water in the soils?**
MR. TRASTER: I'm going to object to the form of the question and to the line of inquiry because there's -- there are a lot of factors that go into this that may or may not be accounted for in the question or on the document, for example, recharge post development, you know, there's more water, it's not just inches of rain, it's that the irrigation water that's being placed on it so -- on there. So you can't really -- I would suggest that it's possible that you can't really correlate the two and I -- and there's no evidence in the record that nine is the region or the, what do we call it here? That nine is has anything to do with the ranch or anything else for that matter, but go ahead.
MR. SCHWALB: I'll withdraw the question.
BY MR. SCHWALB:
**Q. Do you know if this graph was considered in any of the modeling work that was done by your staff?**
A. Well, this modeling work is part of the model. I mean, this is -- the model uses these recharge curves.

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**Q. Um-hm?**
A. To estimate how much recharge gets into the groundwater system.
**Q. Okay. Do you know if it was used by Burns and McDonnell?**
A. Yes.
**Q. Okay. Let's turn to the Burns and McDonnell report real quick. Did you have a chance to review that in advance of this deposition?**
A. Very briefly.
**Q. Okay. Do you recall if the Burns and McDonnell report says anything about native grassland?**
A. I don't recall that it does.
**Q. I'm sorry?**
A. It do not recall that it does.
**Q. Would it be helpful to review it real quick?**
A. Apparently.
**Q. Okay. And can we have your copy marked as an exhibit, please?**
A. Sure.
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 7 for

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identification.)
MR. TRASTER: Are you going to provide copies?
MR. SCHWALB: Yep.
MR. TRASTER: I wanted a copy of the exhibit that you're going to use.
MR. SCHWALB: Let's use the exhibit that I'm going to use then.
MR. TRASTER: I mean I'm not -- it may be the same, I don't know.
MR. SCHWALB: Mine has highlighting on it.
MR. TRASTER: Okay. I'd like to have a copy of the version that you're going to ask about.
BY MR. SCHWALB:
**Q. All right. Please take a moment to review that exhibit which is marked as Exhibit 7.**
MR. TRASTER: This going to be 7?
MR. SCHWALB: 7.
A. What do you want me to review?
BY MR. SCHWALB:
**Q. Just the highlighted portions within the text and then the charts at the end.**
MR. TRASTER: While you're doing that,

just for the record, many, in fact most of these exhibits are just excerpts and portions; they're not complete documents but they are in the record.
MR. SCHWALB: Correct.
MR. TRASTER: And so the full document is in the record, but just so we know that.
THE WITNESS: Okay.
BY MR. SCHWALB:
**Q. All right. Please refer to KDA 345, the first page of that exhibit and the highlighted portion. Do you see there where it says that the revised groundwater model report does not address the alternative approaches to groundwater modeling?**
A. Yes.
**Q. Okay. What does that generally refer to in your view, the alternative approaches?**
A. I would guess it principally addresses not reducing recharge.
**Q. Not reducing recharge based on what?**
A. Based on Doctor Keller's analysis that said recharge would be reduced under native grass.
**Q. Thank you. Let's jump to Figure 6, which I believe is KDA 368 at the bottom. Are you familiar with this graphic?**



A. Yes.
**Q. Okay. What does this graphic depict?**
A. So it depicts the difference in groundwater levels in the aquifer, as modeled, between Scenario 1, which was sort of the historic pumping, irrigation pumping, and Scenario 2 which was the irrigation pumping at 4,800 acre foot per year.
**Q. Which is the proposed pumping rate for the city's change application?**
A. That's the --
**Q. Or the TYRA limitation.**
MR. TRASTER: Object to the form of the question.
A. Right. That's the limitation that we've -- the ten-year limitation that would be placed on diversions.
MR. TRASTER: That's the quantity, not the rate.
THE WITNESS: The quantity, yes.
BY MR. SCHWALB:
**Q. All right. On this graphic are there little blue dots there?**
A. There are little blue dots, yes.
**Q. Okay. What do those little blue dots**



**depict?**
A. Those are irrigation wells in the region.
**Q. Okay. Any distinction between senior or junior relative to the ranch depicted here?**
A. No.
**Q. Okay. Towards the middle of the graph you'll see that there are some changes in color. What do those changes depict?**
A. So are you talking about the green dots being the proposed municipal well, or something different?
**Q. No. I'm referring to the gradations in, I guess it's purple or royal blue. What does that depict?**
A. Well, they're contours that depict the differences between the two runs.
**Q. Okay.**
A. Right. So for example, there's a generally at the boundary of the ranch -- the ranch is depicted with the irregular shape, looks like a green boundary.
**Q. Okay.**
A. So, you know, they vary but, you know, on the order at the ranch, you know, three tenths of a foot, some places half of a foot difference.



**Q. Okay.**
A. Some places less.
**Q. A difference in what?**
A. Difference in the water levels between the two runs.
**Q. Okay.**
A. Irrigation, baseline and the municipal maximum.
**Q. So less water based on municipal use?**
A. The water levels are, you know, three tenths of a foot less at the end of the 17-year simulation.
**Q. Okay.**
A. Or however -- yes. At the end of the simulation.
**Q. All right. Let's jump to the next page. That would be KDA 371 depicted as Figure 9. What is this graphic describing or depicting?**
A. Again, it's similar but at different runs, so it's subtracting the water level contours at the end of 51 years in this case, between a historic baseline that repeated the '91 to 2007 record for irrigation three times, versus the irrigation -- I mean versus the municipal 4,800 maximum as well. Again showing the difference in

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head between -- that exists between those two model runs at the end of the 51 year simulation.
THE REPORTER: 51 year?
THE WITNESS: 51 year simulation.
BY MR. SCHWALB:
**Q. With respect to the blue dots that also appear on this graphic.**
A. Um-hm.
**Q. Are they being shown as getting less water or is it stable with no change?**
A. Well, it shows the difference in head, the difference in level being, again, on the order of four tenths of a foot or less different at the end of the 51 year simulation, so it's a -- it's how deep is the water. It's not getting to how much water they can take.
**Q. Okay.**
A. But it's a very small difference.
**Q. But there is a difference between historic pumping versus proposed pumping depicted here?**
A. By these very small amounts.
**Q. Okay.**
A. My characterization.
**Q. That's fine. Let's jump down to Figure**

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**12 which is labeled KDA 374. What does this depict?**
A. So again, similar overall graphic. This is looking at a difference in runs.
**Q. And there's a dark blue line. What does that depict?**
A. I think the dark blue line is the Ark River. Is that the one you're talking about?
**Q. Oh, I'm sorry. We're looking at different things, 374 at the very bottom, Figure 12.**
A. Right. Okay. So strike what I was saying a moment ago. I was looking at the wrong graphic. So Figure 12 is again from the Burns and Mac model and it's depicting the amount of pumping in the two different runs. No, I'm sorry. It's depicting recharge in light blue and then the pumping for this drought simulation run, Scenario 6.
**Q. Does the light blue line ever fall underneath the dark blue line?**
A. Certainly at -- it does once in a while but during the drought simulation throughout most of the period.
**Q. Is there any averaging line that shows**

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**you the overall trend for the light blue, the modeled recharge?**
A. There is no line.
**Q. Okay. But the lines that are depicted, are these anchored to years along the X axis?**
A. They are.
**Q. Okay. Did you discuss this with Burns and Mac?**
MR. TRASTER: Discuss what?
BY MR. SCHWALB:
**Q. This graph.**
A. Well, I don't remember specifically discussing this graphic with them. We had a number of discussions with respect to what model run should be done as part of the overall evaluation, including the drought scenario.
**Q. Okay. Let's talk about the drought scenario just for a minute. During droughts, in your experience do farmers pump more or less?**
A. They pump more when it's dry.
**Q. Okay. What about --**
A. In a general matter. As a general matter.
**Q. What about municipalities?**
A. They would as well.

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**Q. Okay. Thank you.**
A. As a general matter.
**Q. Okay. All right.**
THE REPORTER: Are you at a good spot for a break?
MR. SCHWALB: I sure am. Why don't we take a break and everybody can tend to their business or take cough medicine or anything along those lines.
(THEREUPON, a recess was taken.)
BY MR. SCHWALB:
**Q. All right. We are -- everybody ready? Okay. We are back on the record in Water PACK vs. the deponent. I'd like to come back to the exhibit that we were just reviewing which I believe is Exhibit 7, the Burns and McDonnell report, and I'd like to call your attention, Mr. Barfield, to, again, that highlighting on the first page, but just beneath it there's a list of numbered paragraphs here. The first one refers to 4,800 acre feet of municipal pumping does it not?**
A. Yes.
**Q. Okay. Can you describe the -- why that number is used here in this report?**
A. Well, 4,800 acre feet is the -- is the

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average use that's allowed pursuant to the ten-year limitation of 48,000 acre feet in a ten year period.

**Q. Okay. Can you expound upon that ten-year rolling average I think is how it's referred to in the master order?**

A. What do you want to know about it specifically?

**Q. What's the -- what is the rationale for including that in the order?**

MR. TRASTER: Let's go off the record for a second.

(THEREUPON, an off the record discussion was held.)

BY MR. SCHWALB:

**Q. All right. We're back on the record and I was just asking about the rationale behind the 4,800 acre foot ten year rolling average that's in the master order.**

A. Right. So, and again, there's a significant section in the master order with respect to the TYRA limitation, ten year rolling average, rolling aggregate limitation and what it is and why it is. It's unique to these change approvals. Due to the unique nature of the change

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approvals I required the cities to use the model to determine the long-term yield of the ranch and to limit it, their use, to that long-term amount.

**Q. Initially they wanted a higher amount; is that correct?**

A. Well, they would have chosen not to have this limitation, but to only be constrained by the consumptive use determination.

**Q. Did they initially ask for something above 7,000 acre feet though?**

MR. OLEEN: Sorry to interrupt. Could you -- do you mean as a -- as a TYRA limitation figure or a maximum annual authorized quantity figure.

MR. SCHWALB: Maximum authorized annual quantity.

A. I'm looking to this summary document that we used for the public meeting. So the cities originally asked for 7,640 seven acre feet of water to be changed from municipal use to irrigation use, so they later amended their request and now asked for 6,756.3 acre feet.

BY MR. SCHWALB:

**Q. Okay. That's on an annual basis?**

A. On an annual basis, yes.

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**Q. And then there's an additional requirement, the TYRA, that's dropping it to 4,800?**

A. That's -- that's a limitation that's imposed by the -- by what I approved.

**Q. Okay.**

A. Yes.

**Q. So there's -- you approved, or you contingently approved?**

A. Contingently approved, yes.

**Q. Okay. So you went from 7,600 acres feet on an annualized basis to a rolling average of 4,800?**

A. Well, right.

MR. TRASTER: Object to the form of the question.

A. On an annual basis they can use the consumptive use determination, the 6,756.

BY MR. SCHWALB:

**Q. Okay.**

A. In any year or sequence of years, but it's further limited by the 48,000 acre feet limitation over ten years.

**Q. Okay. Why a limitation of 4,800 acre feet per year, the rolling average?**

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A. Well, the rationale I used to require this is that the change must be reasonable and so -- and again the city didn't -- cities didn't completely agree with this but were willing to agree to it, that it wasn't reasonable to approve more than they could take out of the ranch long term.

**Q. Okay. So does the 4,800 result from the model?**

A. It is from the modeling analysis, yes.

**Q. Okay. And so the initial request, just to be clear, was for 7,600 acre feet, the 4,800 is written by the model. Is that a big difference, the 7,600 to 4,800?**

MR. TRASTER: Object to the form of the question.

A. I'd say it's significant, yes.

BY MR. SCHWALB:

**Q. Okay. Is it almost half of the original amount?**

A. Well, it's somewhat more than half.

**Q. It's two-thirds maybe?**

A. That would be closer.

**Q. Okay. The original 7,600 number, was that driven off of the model?**

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A. That's essentially the authorized quantity.
**Q. Okay.**
A. The sum of the authorized quantity.
**Q. Okay. But still it's a pretty big difference?**
A. Yes.
**Q. Okay. So why no site specific analysis with that big of a difference?**
MR. TRASTER: Object to the form of the question. Misstates facts not in evidence.
BY MR. SCHWALB:
**Q. I think the master order is part of the record so let's just refer to that.**
A. Well, I think the modeling analysis was site specific in terms of what does the model say about the terms and conditions under which this approval was granted and how would that affect the ranch and its immediate vicinity.
**Q. But your regulations contemplate a site specific analysis, do they not, for change applications? If there's -- if you get unreasonable numbers?**
A. So you're speaking, I mean you're speaking to specifically to the consumptive use

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piece of this analysis, right?
**Q. Yep.**
A. And it allows for a site specific determination under certain conditions.
**Q. Okay. And what are those conditions?**
A. Well, I wonder if we can go to the regulation. I've got a copy of it here if you don't already have it as an exhibit.
**Q. I don't think we've entered it into the record here, but let me see if I've got a couple here.**
MR. OLEEN: Off the record.
(THEREUPON, an off the record discussion was held; WHEREUPON, the court reporter marked Barfield Deposition Exhibit No 8 for identification.)
BY MR. SCHWALB:
**Q. And I believe it's 5-5-9(c) that gets into the authorized annual quantity. Does that section use the word unrealistic?**
A. Just give me a moment to review.
**Q. Sure.**
A. Okay. Okay. So what was your question?
**Q. All right. Within 5-5-9(c), and I think it's subparagraph -- no, it doesn't have a**

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**subparagraph. It refers to methods set forth in subsection (A) and it says if the methods set forth in subsection (A) produce an authorized annual quantity of water which appears to be unrealistic, and could result in impairment of other water rights, the chief engineer shall make a site specific net consumptive use analysis to determine the quantity of water which was actually beneficially consumed under the water right. Is that an accurate restatement?**
A. I think you read it well.
**Q. Thank you. So let's focus on the word unrealistic here. The initial request from the cities was for 7,600 per year?**
MR. TRASTER: Objection. States facts not in evidence.
BY MR. SCHWALB:
**Q. Over 7,600 acre feet which is referenced in the master order is it not?**
A. Their original request? It may be.
**Q. Okay. And the TYRA limitation, also defined in the master order, limits withdrawals to a rolling average of 4,800 acre feet per year does it not?**
A. It does.

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**Q. Okay. Is that -- and you testified earlier that the, I believe the initial request was based on modeling of net consumptive use; is that correct?**
A. The initial request of 7,600? I don't --
**Q. Is that wrong?**
A. I don't have any knowledge it was based on modeling?
**Q. Okay. What about the 4,800 acre feet? Is that based on modeling?**
A. It is.
**Q. Okay. And that's substantially lower than 7,600 acre feet?**
A. It is lower.
**Q. Is that an unrealistic difference?**
A. I don't -- I don't know what you're asking.
**Q. Is it a huge difference?**
A. We've said it's a significant difference.
**Q. Okay. In terms of, let's jump to the next part of this regulation where it says: And could result in impairment of other water rights. You testified earlier that you're assessing impairment of seniors and juniors, correct?**
A. With respect to the change in -- with

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respect to the change, yes.
**Q. With respect to the change. Okay. Referring back to the Burns and Mac report which I believe is Exhibit 7?**
A. That's correct.
**Q. Figure 6, I believe. That figure shows surrounding water users outside the boundaries of the ranch getting less water over time does it not?**
A. No. It shows that there's on the order of a tenth of a foot to a third of -- to three tenths of a foot of difference in elevation in the aquifer. I wouldn't expect that small difference to produce anything but a de minimus reduction in what they can pump.
**Q. Over that period of time?**
A. Yes.
**Q. Okay. Jumping back down to Figure 12 in that same report, this is the simulated recharge rate. Those light blue lines there show reduced recharge relative to operations do they not?**
A. Yes. And throughout there's reduced recharge.
**Q. Okay. So if there's reduced recharge during drought. What about the years prior to**

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**that? Are you seeing reduced recharge there?**
A. No.
**Q. What does the light blue line show then?**
A. Well, it goes up and down with the normal variation in precip.
**Q. Okay. Are there any drops below the dark blue line of that light blue line?**
A. There are some minor ones, but yes.
**Q. Okay. So there's modeled recharge falling below, based on modeled precip and operation of the well field?**
A. Yes. And many, many years of significantly more.
**Q. Um-hm. So in those years where it's dropping, are junior users seeing more return flows or fewer?**
A. Say that again.
**Q. In the years below the dark blue line --**
A. Um-hm.
**Q. -- do the junior users, based on this model, or this figure, I should say, see more recharge or less?**
A. Less.
**Q. More return flows or less?**
A. Less return flows.

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**Q. Thank you.**
A. But that doesn't follow to a reduced ability to pump. I mean, that's what an aquifer, that's the benefit of an aquifer versus a surface water system. There's significant storage by which they can continue to operate.
**Q. Did you make any specific findings of fact as to specific junior users in that regard?**
A. Not to specific junior users but certainly they're findings with respect to this modeling demonstrating that the neighboring water rights are not impaired.
**Q. With respect to the junior users?**
A. Well, with respect to all users.
**Q. Okay. And your staff specifically examined whether or not this proposed change application would impact junior users?**
A. Well, the modeling work assesses the degree to which, you know, the -- what are the impacts of the change.
**Q. Right.**
A. To the area.
**Q. Okay.**
A. That's what these maps demonstrate in my view. There is -- the change does not have any

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appreciable effect on the neighboring water rights.
**Q. Okay.**
A. Which is what we're after.
**Q. Was that modeling work provided to the public, the actual model, after that report is based upon for Exhibit 7, I believe, the November 28 Burns and McDonnell report?**
A. The modeling report was posted on our website, the modeling files were provided to GMD 5 and Water PACK.
**Q. When were those provided to GMD 5 and Water PACK?**
A. I don't have that date in front of me but there is a transmittal letter that we found. Before -- well, actually it may be on our website here. Just a second. Well, we posted the model report in February of 2018. I guess I don't see, but I know we found in our records when we sent a thumb drive with the model data files to both GMD 5 and to Water PACK. It was certainly well before the public meeting that we had to allow them to review those, and in fact Balleau did that review and found some minor -- minor problems with the model as a result of their review.

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**Q. Okay. So there's a thumb drive provided to the district, GMD 5?**
A. Correct.
**Q. Prior to the Greensburg meeting?**
A. Yes.
**Q. The Greensburg meeting occurs on June 21st, 2018, correct?**
A. Correct.
**Q. And then there is input from the GMD received, I believe you testified earlier, August 30th of '18?**
A. Correct.
**Q. And then revised input from the GMD on September 14th of 2018?**
A. I believe that's what I said, yes.
**Q. Okay. Did that revised input result to in any changes to the modeling work?**
A. It did.
**Q. Okay. And did that -- did those changes to the modeling work result in this report from Burns and McDonnell?**
A. The revised report, yes.
**Q. What's the date of that revised report, if you don't mind me asking?**
A. September 24, 2018.

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**Q. Okay. Was there any provision of their adjustments to the model to the public, to the GMD or to -- well, let's just focus on the public first.**
A. So what was the question?
**Q. They do the analysis and reproduce the report on September 28th you said?**
A. Yes.
**Q. And then they do that based upon modifications to the model. Were the modifications to the model provided to the public?**
A. Not to my knowledge. We would have if it had been requested.
**Q. Okay. Were they provided to the GMD?**
A. I believe they were. Again, I didn't go back to the records but I'm fairly sure that we provided it both before the public meeting and the final model as well.
**Q. Okay. Were they provided to Water PACK?**
A. They were offered to Water PACK. Again, I remember sending the thumb drive to both.
**Q. Before the Greensburg meeting?**
A. You know, my recollection may not be right. It may have been after and the before might have been from Burns and Mac straight to

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those two entities.
MR. TRASTER: For the record, attached to the Hays response, one of the Hays briefs, is a March 9, 2018, letter addressed to the GMD signed -- which you signed, it's Exhibit 7, and it says with this letter I'm also sending one USB drive to Richard Wenstrom. There were two sent to the GMD. That's March 9th, 2018.
THE WITNESS: Okay. So that was the model?
MR. TRASTER: And that's the original model, not the revised model, but that's in the court file.
A. Okay. So the USB was before the public meeting.
BY MR. SCHWALB:
**Q. Does what Mr. Traster just said conform to your recollection of what happened more or less?**
A. It helps my recollection of what happened, so yes, we sent a thumb drive before the meeting with the model.
**Q. Okay.**
A. I guess I would have expected we would have sent the final model to them as well in the

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same way but I don't -- I may be remembering wrong, so.
**Q. All right. So does all modifications to the model appear in the administrative record?**
A. I'm not certain.
**Q. What about the model runs? Do those appear in the administrative record?**
MR. OLEEN: I would object to the form. What do you mean by appear?
BY MR. SCHWALB:
**Q. Are the model runs in the administrative record post the Greensburg meeting?**
MR. OLEEN: Like actual model mathematical equations, reports about such, which?
BY MR. SCHWALB:
**Q. And adjustments to the model that were made after the Greensburg meeting. Do those appear in the administrative record outside of the Burns and McDonnell report?**
MR. TRASTER: I didn't hear the response. What -- you asked about model runs or reports. I mean but what are you asking about?
MR. SCHWALB: I want to know if the model runs, the adjusted model runs undertaken by Burns and Mac, not the report, but the model runs appear

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in the administrative record?

MR. TRASTER: What form do the model runs take? I mean what is it that you're asking? I mean that's -- I don't know what you mean by model runs. Are you asking about the software itself or are you talking about, I mean, what is a model run? That's, I guess I'm having a little problem understanding what you're asking about.

MR. SCHWALB: Sure. Let me clarify.

BY MR. SCHWALB:

**Q. The specific adjustments to the model that were made within the software and the specific results therefrom, not the reports, but the results, do those modifications and results appear in the record outside of the Burns and Mac report?**

MR. TRASTER: But what form? I mean results. What -- what are you asking about? Are you asking about the model document itself? Are you -- I mean the results, how are results reported other than in the report. And I'm really asking. I'm not trying to play games, here.

MR. SCHWALB: Sure.

MR. TRASTER: Because I don't -- I'm not sure what the, you know, what their answer is to

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that question but I -- we need to get -- have a clear question on the table so that he can -- he probably knows a hell of a lot more, excuse me, he probably knows a little bit more about the modeling than we do.

MR. SCHWALB: Fair enough. Let me rephrase.

BY MR. SCHWALB:

**Q. We have a thumb drive, according to Mr. Traster, from March that has a data set?**

MR. TRASTER: Object to the form of the question. It's not according to me, it's according to the document that's attached to the -- to a -- I mean it's the document. I'm not -- I didn't sign the document, I just provided it.

BY MR. SCHWALB:

**Q. We have a thumb drive that goes out from you in March of '18, correct?**

A. Yes.

**Q. That thumb drive has what on it?**

A. So it has the model data files, the input files that are necessary to run the MODFLOW model to produce the outputs of the model runs that Burns and Mac developed.

**Q. Okay. And a configuration or other**

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**related files that would allow you to see what changes they made to the model?**

A. So I'm sorry. Repeat that question again. Sorry.

**Q. Is there anything on that thumb drive that shows how they produce those results, either in the form of changes to the model or any other forms of instruction, that describe adjustments made to the model to yield those results?**

A. Right. So there's -- that thumb drive had everything that somebody who had MODFLOW, a modeler who has MODFLOW, needs to replicate the runs that the cities did to support the application. So, you know, there's a set of data files and they include -- they include data files, they include configuration files that specify what model runs and what boundary conditions, everything it takes to take MODFLOW and produce the model runs, that's what's on that USB drive that I caused to be delivered to GMD 5 and Water PACK.

**Q. Okay. So configuration files are on that?**

A. That's right.

**Q. Okay. After that is delivered there are**

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**adjustments made to the model by Burns and Mac, correct?**

A. There were some minor adjustments that were made as a result of the Balleau Groundwater's review. They found some minor errors in the model.

**Q. Okay.**

A. That were made that actually benefitted the cities. It actually made their case a little stronger, but right, there was a -- there were some errors that were corrected subsequent.

**Q. So when you correct errors within MODFLOW does that require changing the configuration files?**

A. It did require changing some of those files.

**Q. Were those change configuration files provided to Water PACK or any of the surrounding users?**

A. And I'm not certain. I can't -- I would think we would have -- we would have certainly made them available. I'm not certain if we did or didn't.

**Q. Okay. Are there any rules that you're aware of that govern adjustments to this model**

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**that are promulgated by DWR?**
A. We don't have any such rules.
**Q. Okay.**
A. We certainly would have provided the model runs to anyone requesting them.
**Q. Okay. I want to come back to some of the original modeling work. Just give me one second, here. Earlier you referred to a series of meetings that occurred between you and the cities and their representatives; is that correct?**
A. That's correct.
**Q. Okay. Is there any documentation of these meetings?**
A. A couple of the meetings resulted in letters from me to the cities summarizing some of the issues that were raised and sort of a path forward with respect to those issues.
**Q. Okay. Was there any correspondence relating to the documents that were exchanged by the cities and DWR? Change applications, models?**
A. Well, there's certainly some as they transmitted a new set of change applications, those are documented in the records.
**Q. Okay.**
A. But.

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**Q. As those change applications came in, what'd you do with them?**
A. Physically?
**Q. No, just what's your process for handling them?**
A. Well, the attorney who is head of our change application unit keeps, keeps a box of them. There's a box of the various ones that he's sort of the custodian of those records as it's shepherded through the processes.
**Q. Okay.**
A. So we also -- again, we developed, at a stage when the public was getting interested and we had a -- we were moving forward a decision, we developed a website where we scanned pertinent information and made them available to the public, so those three sets of applications are posted there.
**Q. Okay. Within those applications was there a consumptive use analysis? The initial applications?**
A. I believe there was.
**Q. Okay. Did anyone complete a review of that consumptive use analysis?**
A. We -- I didn't personally do the

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consumptive use analysis. Again, staff reviewed that and determined the consumptive use appropriate from our rules.
**Q. So they did an initial review?**
A. I'm sure they did. I'm not sure to what extent they relied on that information submitted as opposed to just applying the rules.
**Q. Okay. Does that initial review appear in the administrative record to your knowledge?**
A. Our administrative review of their --
**Q. Did your internal review of the consumptive, the initial consumptive use analysis, does that appear in the administrative record for this case?**
A. Well, they're -- the work of Elizabeth Fitch to sort of determine the acres and cropping is in the administrative record. The result of the consumptive use determination by water right is also in the record.
**Q. But that specific initial analysis, is that in the administrative record to your knowledge?**
A. Which? The one the applicant provided?
**Q. The initial -- correct.**
A. Well, if it's part of the applications,

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which I think it was, it is.
**Q. Your internal review though?**
A. Oh, I'm sorry. Our internal review of what they provided.
**Q. Initially?**
A. Not to my knowledge.
**Q. Okay. Did you rely on that while processing the applications?**
A. I don't think we did. Again, I think we did the determination of acres, appropriated cropping, and then applied the rule.
**Q. Okay. Did the initial consumptive use analysis require any -- did that translate into the model in any way or any of the modeling work?**
A. Not to my knowledge.
**Q. Okay. Did Burns and Mac change the modeling analysis during the course of this proceeding more than once?**
A. Well, we met with them multiple times, as is in the record, to frame the modeling analysis, so certainly it developed over time.
**Q. Okay. Does the modeling analysis account for the specific soil types and conditions at the ranch?**
A. Soil types and what?

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**Q. Soil types and conditions.**
A. Soil types?
**Q. Yeah.**
A. Well, I mean Burns and Mac used Balleau's modeling which has the soil types that are indicated on that map we looked at a little bit ago.
**Q. Does it get down to specific -- well, let me rephrase. What is the level of detail that it gets down to in terms of feet or acres? What's the cell level?**
A. I believe they're a mile square.
**Q. They're a mile square?**
A. I believe.
**Q. Okay. And that would account for the soil types?**
A. That's the level at which they determined it.
**Q. Okay. Let's switch gears just a little bit here. This -- this model feeds the master order and helps you reach conclusions in that master order, correct?**
MR. OLEEN: Object. Could you please clarify which model perhaps?
MR. SCHWALB: I'm sorry. Sure.

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BY MR. SCHWALB:
**Q. The final model referenced in the September 28th, I think, 2018, revised Burns and McDonnell report, did that serve as an input to the master order?**
A. It certainly informed portions of the master order, yes.
**Q. The final master order?**
A. Yes.
**Q. Okay. Did prior versions of the Burns and Mac model inform the draft master order that was initially released to the GMD?**
A. Well, the version that informed it was the model report -- what was the -- so we posted a model report February 19, 2018, of their earlier work which is essentially the same model, the same model runs except for this minor correction that was done.
**Q. Um-hm?**
A. So that's the version of the model that -- that's reported on February 2018 that informed the draft proposed master order, and really the final order as well.
**Q. Okay.**
A. The resort -- the difference in results

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did not change.
**Q. Okay.**
A. In an appreciable way so it didn't affect the final version. The revised modeling didn't change the results in the final order.
**Q. Understood. So thus far we have the draft order and the final order. Were there other versions of the order that were worked on by your office?**
MR. TRASTER: Worked on by what?
MR. SCHWALB: By his office.
A. Yes. There were other versions.
BY MR. SCHWALB:
**Q. Do you have a sense of how many?**
A. No. I mean -- no, I don't know.
**Q. Okay. Who drafted the first version of the master order?**
MR. BULLER: Counsel, can you identify which topic under the court's order that you're currently covering?
MR. SCHWALB: I am on topics E and F, E as in echo, F as in foxtrot.
BY MR. SCHWALB:
**Q. Who drafted the first version of the order?**

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A. Mr. Traster.
**Q. Can you tell me about the -- why did Mr. Traster draft the first version of the order?**
A. Well, he offered at a point in time to -- to provide a draft for us to review, so it was partially just economy of state resources for him to provide initial draft. This is a pretty unique set of circumstances and the city needed some unique things. It's preparing the way for a water transfer process later on where the city has a burden so, you know, they wanted to help sort of shape the document in terms of what -- what they needed to meet their client's needs and all the processes that they would have to go through. So some very unique circumstances.
**Q. Is the version that Mr. Traster drafted in the administrative record?**
A. No.
**Q. Okay. Would you be able to provide that to us -- is it in your records?**
A. I'm sure it's in an e-mail somewhere.
**Q. Okay.**
A. Or in some form.
**Q. All right. Did Mr. Traster provide input on any of the versions, multiple versions, of this**

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**draft order between the version that was reviewed by the GMD and the final order?**
A. What was your question?
**Q. Sorry.**
A. That's all right.
**Q. So earlier you testified we have, I'll refer to these as versions A, B and C.**
A. Okay.
**Q. For purposes of the deposition. Version A is the version that Mr. Traster provided?**
A. Um-hm.
**Q. Version B would be the version that was put forth as the draft master order and reviewed by the GMD**
A. Right.
**Q. Version C is the final order.**
A. Right.
**Q. The contingent order that was published on this website, did Mr. Traster have input on revisions to the order between versions B and C?**
A. So.
MR. BULLER: And I'm going to object. This is beyond the scope of the order relating to the scope of this discovery.
MR. SCHWALB: I'll get there.

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MR. BULLER: So I'm not clear about how the different drafts of the master order relates to the chief engineer's decision to permit the cities to prepare the initial draft of the draft master order, or how it could conceivably be related to that topic.
MR. SCHWALB: We'll get there. Go ahead.
A. So, you know, we took full control of the drafting of the document somewhere in the summer of 2017, well before even the proposed draft master order.
BY MR. SCHWALB:
**Q. Um-hm?**
A. But Mr. Traster did have an opportunity to review what we were doing and had input into it.
**Q. Okay. Were there conclusions within the version B, shall we say, that the master order complied with all laws and regulations?**
A. That's right. There were.
**Q. Were there any conclusions indicating that you were going to reject the order, or the application, I should say?**
A. Did the proposed draft master order have any conclusions that I might -- that was going to

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reject it?
**Q. Correct.**
A. No.
**Q. Okay.**
A. Not to my knowledge.
**Q. And so version B stated that it complied with applicable laws and regulations prior to the publication of version C?**
A. I believe it probably did. I wouldn't have proposed an order that I didn't think met -- was compliant with state law.
**Q. Okay.**
A. And requirements.
**Q. But it presumed that it would be approved in version B?**
MR. OLEEN: Object to the form of the question.
BY MR. SCHWALB:
**Q. Go ahead.**
A. It didn't presume it would be approved without any further changes or additional terms and conditions, but I attempted to draft an order that I thought could be approved. But again, the whole purpose of the public process was to see if I got it right, to see if it could be, or it

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should only be under certain modifications to those terms and conditions, but.
**Q. Was that also the purpose of version A?**
A. Well, version A was just a starting point, sort of a framework for the discussion, so it wasn't a full draft of the document by any means.
**Q. Is it common to let counsel for a water -- in a water transfer act proceeding draft the order?**
A. Well, I've never been offered before.
**Q. Okay.**
A. So it's not common.
**Q. Okay.**
A. So nothing about this set of -- of change applications and subsequent processes is common.
**Q. It's common for the lawyer for the applicant to draft the order?**
A. No. I said.
**Q. It's not?**
A. It's not.
**Q. Okay.**
A. I said it's not. I've never been offered.
**Q. Okay.**

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A. Number one, so, and it's not common.
**Q. Okay.**
A. There's nothing common about this set of change applications.
**Q. What about outside of the context of a water transfer act proceeding? Is it -- has it -- is it common for counsel for the applicant to draft the order?**
A. Not to my experience.
**Q. Has it happened a few times?**
MR. BULLER: Objection. Beyond the scope.
BY MR. SCHWALB:
**Q. Go ahead.**
A. Well, I don't know if in my experience of -- in my limited experience as a chief engineer, I don't know that I've had an attorney offer or draft an order. I mean we've -- we've engaged the applicants on particular conditions that were important to them to determine how those conditions should be drafted. I mean that's -- that's happened before.
**Q. Okay. These conversations around drafting of the order, were any of -- these happened in meetings or telephone calls? What**

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**form did these conversations take to the extent you had them?**
MR. BULLER: Objection. Beyond the scope.
MR. SCHWALB: Okay.
A. So again? Repeat the question.
BY MR. SCHWALB:
**Q. Sorry. So we're talking about the decision to permit the cities to draft version A.**
A. Um-hm.
**Q. And you referenced the fact that this is a unique proceeding; is that correct?**
A. I did.
**Q. And that there was an offer made it sounds like --**
A. Um-hm.
**Q. -- from the cities to draft it. What was the setting for that offer? Was it a meeting? Was it e-mails?**
MR. BULLER: Objection. Beyond the scope.
A. As I recall it was at the end of one of our meetings, face-to-face meetings, Mr. Traster offered to do an initial draft.
BY MR. SCHWALB:

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**Q. Okay. Were these meetings announced to the public?**
MR. BULLER: Objection. Beyond the scope.
A. No. The meetings were not announced.
BY MR. SCHWALB:
**Q. Okay. So let's --**
A. Although Water PACK was privy to at least one of the meetings because they showed up on my doorstep, so.
**Q. So somehow they got word of it.**
A. Somehow they got word of it. I mean we -- we certainly didn't keep it a secret that we were working with the cities on this matter.
**Q. Um-hm?**
A. You know, I, you know, I met with Water PACK on one occasion and updated them on the process, so.
**Q. And they were part of this proceeding in I guess maybe a disjointed fashion?**
A. They were certainly interested in what was going on. So again, I attended one of their annual meetings in, I don't remember exactly when it was in this process, to provide them an update, so we certainly weren't secretly meeting.

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**Q. Fair enough. And so this leads into version B, I think you coined it, and version B was finalized prior to the Greensburg meeting or?**
A. Yes.
MR. BULLER: Objection. Beyond the scope.
BY MR. SCHWALB:
**Q. Okay.**
A. Version B being --
**Q. The draft master order --**
A. -- the draft proposed master order.
**Q. Correct.**
A. We provided that to GMD and the public, put it on our website on February 7, 2018, about six weeks ahead of the public meeting.
**Q. Okay. And did the draft proposed master order serve as -- did you use it for the Greensburg meeting?**
MR. BULLER: Objection. Beyond the scope.
MR. SCHWALB: Item C in the order for discovery.
A. We provided at the annual meeting a summary --
BY MR. SCHWALB:

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**Q. Not the annual meeting, the Greensburg meeting.**
A. Sorry. Yeah, I misspoke. At the public meeting we provided a summary of the draft proposed master order to the public.
**Q. Okay.**
A. To explain to them what this -- what was being proposed, yes.
**Q. All right. Can we jump into your slides from -- from that meeting?**
A. Sure.
**Q. And I forget exactly what exhibit we had those marked for.**
MR. BULLER: Is that the entire set of slides presented at the meeting or just an excerpt selected by counsel?
MR. SCHWALB: It is an excerpt. It appears in the administrative record at KDA 850.
MR. BULLER: And when you say it appears in the administrative record, you mean the entire slide show or just the excerpt?
MR. SCHWALB: Just the excerpts.
MR. BULLER: Let me interpose a running objection to the use of all exhibits that are excerpts and not complete copies of documents as

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they exist in the administrative record.
MR. SCHWALB: All right.
MR. BULLER: If counsel will accept that running objection I won't have to re-make it whenever we refer to or were to use a document excerpt.
MR. SCHWALB: Let's deal with it this way. Would it be okay if we just marked his presentation from that, from the Greensburg meeting, as an exhibit?
MR. BULLER: That would be better, but the objection also applies to other exhibits used during this deposition that are excerpts and not complete copies.
MR. SCHWALB: Fair enough. If we can get that one marked as, I think as Exhibit 9.
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 9 for identification.)
THE WITNESS: Would you like me to have copies made?
MR. SCHWALB: The whole presentation is in the administrative record, I believe.
MR. BULLER: But to the extent you're referring to portions of that slide show in this

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deposition, it would be helpful to have a copy.
MR. SCHWALB: Okay. Well, let's mark those as Exhibit 10 then and it will just be the first page, here.
MR. TRASTER: So 9 is what?
MR. SCHWALB: 9 is Mr. Barfield's version that has all of the slides and No. 10 I guess would be the version that Mr. Buller has objected to that's marked as Depo Exhibit 16 by Water PACK but for purposes of this depo for this deposition would be marked as Exhibit 10.
MR. BULLER: And will you be using Exhibit 10 during this deposition? Is that what you're going to be discussing with Mr. Barfield here?
MR. SCHWALB: Just that one slide, yes.
MR. BULLER: And just to clarify for the record, I'm not objecting to Exhibit 10 for purposes of this deposition.
MR. SCHWALB: Okay.
MR. BULLER: My objection is really just I want to make sure that we're looking at the documents as they exist in the administrative record and not counsel's hand selected excerpts.
MR. SCHWALB: Fair enough. I will just

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represent that this is an accurate extract of Mr. Barfield's presentation as it appears within the administrative record and marked KDA 850.
THE REPORTER: Can we pause?
MR. SCHWALB: Sure.
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 10 for identification.)
MR. OLEEN: May I speak off the record.
(THEREUPON, an off the record discussion was held.)
MR. BULLER: We want a copy of Exhibit 9, a full copy.
MS. NAVINSKY-WENZL: We can work on that over the lunch hour or next break.
MR. TRASTER: That's fine. I don't need it today even, but it will come with the record.
MR. SCHWALB: Sorry. I was trying to save some trees and be more sustainable.
THE WITNESS: Okay.
BY MR. SCHWALB:
**Q. Okay. All right. So we're back on the record. We were talking about the meeting in Greensburg. Mr. Barfield, I'll refer you to the slide in your presentation marked as KDA 850 and**

**for purposes of the Deposition Exhibit 10. The third bullet there refers, I'm sorry, the fourth bullet refers to contingent approval of the change applications does it not?**
A. Yes, it does.
**Q. It does not refer to a rejection does it?**
A. It does not. This is -- this is sort of my closing slide of the presentation that basically informs the public of how we anticipated moving forward. Earlier in the presentation I make a statement that no decision has been made. Worked hard to develop a set of terms that meets the city needs and statutory requirements but -- but so this was -- this was just a statement of the anticipated process ahead, so.
**Q. But the word rejection does not appear on the slide?**
A. That is true.
**Q. Okay. You mentioned some earlier statements that you made and I'm sorry, I can't remember which one of these exhibits it refers to, there's a transcript from -- from the Greensburg meeting that I'd like to jump back to, I think it was marked Depo Exhibit 17. Mr. Barfield's jumping through the pages here. There it is. And**



**which exhibit is that, Mr. Barfield?**
A. 3.
**Q. Exhibit 3. Okay. I'd like to draw your attention to the first page of that. That refers to -- and specifically the highlighted portion, maybe even the sentence above that. That asks, and I'm not sure who it was, it's labeled unidentified speaker, it asks whether or not you concurred with Mr. Meier's definition of sustainability; is that correct?**
A. It does.
**Q. Okay. Whose Mr. Meier?**
A. There's more than one Meier around. It's probably Brian Meier with Burns and Mac.
**Q. Okay. And then in the following sentence it says that for purposes of this process we have -- we have come to an agreement on what it means. What's the "it" in that sentence? Is it sustainability?**
A. There's a lot of unintelligibles in my articulation of my response.
MR. BULLER: And I'm going to interpose an objection to the use of this partial transcript. It really lacks foundation for use in this line of questioning.



A. It is -- I have to -- not that I can object here but it is a little difficult to get the full context of what's going on here with this.
BY MR. SCHWALB:
**Q. Well, the first sentence says do you agree with or concur with Mr. Meier's definition of sustainability?**
MR. BULLER: Objection. Asked and answered.
A. So this is an unidentified speaker raising a question speaking about sustainability. I'm not sure the word sustainability appears in any of our documents.
BY MR. SCHWALB:
**Q. Okay.**
A. I mean that was not the basis of, you know, the ten- year rolling average limitation, so.
**Q. Okay. But the following sentence says we have come to an agreement on what it means. Does it not?**
MR. BULLER: Objection. Lack of foundation. Asked and answered.
A. So again, that are the -- that's the



words on the page, here. I'm not quite sure without more context what I was trying to communicate here.
BY MR. SCHWALB:
**Q. Okay. Was there any agreement on what sustainability means with Burns and Mac?**
A. No. Again, we did modeling work to determine the long-term yield.
**Q. Um-hm?**
A. Which is of the area.
**Q. So does yield equate to sustainability?**
A. No.
**Q. Okay. What does sustainability equate to?**
A. Well, sustainability means the use that can be sustained indefinitely.
**Q. The use sustained by whom?**
A. Well, whatever water user you're determining.
**Q. The cities?**
A. You're asking about a general definition of what does sustainability mean, right?
**Q. Within the context of this order. If we're talking about sustainability, subject to his objection, what does sustainability mean?**

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A. The order doesn't talk about sustainability, this question, or ask the question.

**Q. Okay. And do you have a personal definition of sustainability?**

MR. BULLER: Objection. Lack of foundation. Calls for speculation.

MR. OLEEN: Objection. Outside the scope of the deposition.

MR. BULLER: I join in that objection.

A. Well, sustainable use is that use that can be sustained indefinitely.

MR. SCHWALB: All right. Could we take a quick break. All right? Maybe ten minutes if that works?

THE WITNESS: Do you want a lunch break? It's ten to noon.

MR. BULLER: Yeah, I'd be fine with that. I'm fine with working through lunch, I'm fine with taking a lunch break. Whatever everybody else wants to do is fine with me. Mr. Traster, just for the record, is grasping his midsection.

MR. TRASTER: Let's take at least a short lunch break.

MR. SCHWALB: Maybe 40 minutes?

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Reconvene at 12:30?

MR. TRASTER: That'd be fine. Can we go -- we can go off the record for this discussion.

(THEREUPON, an off the record discussion was held.)

BY MR. SCHWALB:

**Q. Are we back on the record? All right. I want to come back to this notion of information made available to you that was part of the administrative record. You said earlier that the ranch was -- was acquired, I believe in the early 1990's, was it not?**

A. I believe 1995.

**Q. Okay. So mid-'90s?**

A. Right.

**Q. All right. Do you know whether the cities employed any engineers between acquisition of the ranch and the initial change application to assess how much water could be moved?**

MR. BULLER: Objection. Beyond the scope.

MR. OLEEN: I join that.

A. I don't have any knowledge.

BY MR. SCHWALB:

**Q. Did you review any information from any**

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**engineering firms other than Burns and McDonnell relating to the R9 ranch?**

MR. BULLER: Same objection. And vague and ambiguous.

A. And besides Doctor Keller's?

BY MR. SCHWALB:

**Q. Correct. Any of the parties not -- beyond those that you've already referred to.**

MR. BULLER: Same objection.

A. So again, repeat the question just to make sure.

BY MR. SCHWALB:

**Q. Sorry.**

A. No, that's all right. That's fine.

**Q. So I asked you whether or not there were other engineering firms --**

A. Um-hm.

**Q. -- that might have been involved here. Were there any?**

MR. BULLER: Same objection.

A. Again, I'm not aware of it.

BY MR. SCHWALB:

**Q. Okay. So there would not be any reports to your knowledge, other than those provided by Burns and McDonnell, relating to the change**

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**application?**

MR. BULLER: Same objection.

A. Related to the changes or the ranch itself?

BY MR. SCHWALB:

**Q. The change applications as they relate to the ranch.**

A. Yeah. I'm not aware. I mean, there was a reference, I mean one of, I don't remember if it's Balleau or Keller, referenced some earlier assessment of the yield of the ranch.

**Q. Okay.**

A. I can't remember who did that.

**Q. Was that assessment provided to you?**

A. Some summary of it was. I don't recall beyond that, so.

**Q. Okay. Does that summary appear in the record?**

A. Again, there's a reference to that work and its conclusion. I don't know if -- I don't recall the details of the assessment was in the record.

**Q. Okay.**

A. I'm not sure.

**Q. And did you -- so you would not have**

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**reviewed that work in connection with the master order?**
A. No.
MR. SCHWALB: Okay. I think I'm done.
THE WITNESS: All right.
MR. SCHWALB: Thank you.
MR. OLEEN: Off the record for a lunch break.
(THEREUPON, a recess was taken.)
CROSS-EXAMINATION
BY MR. OLEEN:
**Q. Okay. Go back on the record. Mr. Barfield, we're back on the record after a lunch break and you understand that you're still under oath like you were earlier in the day of this deposition?**
A. I understand.
**Q. I want to hand you what I will mark as depo Exhibit 11.**
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 11 for identification.)
BY MR. OLEEN:
**Q. And Mr. Barfield, please take your time to review the first couple pages of Depo Exhibit**

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**11 which appears to be a letter dated April 18, 2016, and let me know when you've had a chance to review that, please.**
A. Okay. I think I've reviewed it sufficiently.
**Q. What's the date of this letter and who purported to sign it?**
A. So the date is April 18th, 2016, it's written by me to Richard and Jane Wenstrom who are members of Water PACK but also neighbors to the ranch.
**Q. Does this -- well, do you recall sending this letter to the Wenstroms?**
A. I do.
**Q. Does this letter include some attachments?**
A. Yes. It includes a letter of April 6th, 2016, to Mr. Traster that responds to one of our meetings that we had and the issues raised.
**Q. And does it also have an -- a water transfer act procedure overview document at the end?**
A. It does.
**Q. Okay. So this package of documents that was sent to the Wenstroms by you in April of 2016,**

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**it contains some references to DWR having had some discussions with the cities about the proposed R9 Ranch change applications doesn't it?**
A. It does, yes.
**Q. In response to this letter, do you recall either Mr. or Mrs. Wenstrom or anybody else with Water PACK objecting to the meetings that were referenced in here?**
A. No, I don't recall any objection or -- of theirs to the meetings, no.
**Q. In response to this letter do you recall them asking to be involved in future meetings?**
A. No, they did not make such a request to my recollection.
**Q. Did they ask to be put on some sort of e-mail list?**
A. You know, I think they -- they wanted to be informed, and as I reference in the letter this is one reason we created the website. Their open record request I think initiated this phase of interest and so we built the website as a way to keep -- keep them and other water users informed of, you know, the most pertinent things going on, so.
**Q. I'm going to hand you another document**

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**which I would like to be marked as Deposition Exhibit 12, please.**
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No. 12 for identification.)
MR. SCHWALB: And I'm sorry. Aaron, before you continue, I just want to object to the admission of this Exhibit 11 on the basis that it's outside the scope of the discovery order.
MR. OLEEN: Okay.
MR. KITE: Just to clarify, this is 12, the one you just handed me?
MR. OLEEN: Yes. We just talked about 11 which was April, the April 16, 2016, letter and now a new one circulating has been marked as Deposition Exhibit 12. And for the record I believe it's relevant to Mr. Schwalb's line of questioning about Water PACK's notice of this or that with respect to this matter.
MR. TRASTER: I have a question about 12. The first page is on Department of -- I'm -- but my signature is on the back and I'm not sure that --
THE WITNESS: That doesn't sound right.
MR. TRASTER: I'm happy to speak for --

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MR. OLEEN: Okay. I see what happened.
MR. KITE: David, I thought you worked for DWR. Isn't that right?
MR. OLEEN: Let's go off the record for a minute.
(THEREUPON, an off the record discussion was held.)
MR. OLEEN: Okay. So for the record, I realized that what I had asked to be marked as Deposition Exhibit 12, I don't think it has actually been marked yet.
THE REPORTER: It does have a sticker on it.
MR. OLEEN: Does it? Okay. Is not the correct document that I wanted to mark, so we are going to get that complete document corrected and come back to it. In the meantime I'll ask you some other questions, Mr. Barfield.
BY MR. OLEEN:
**Q. Earlier Mr. Schwalb asked you a line of questioning about elected officials and what they may have said to you regarding the cities' proposed change -- changes regarding the R9 water rights. Do you recall that line of questioning?**
A. I do.

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**Q. To your recollection were you ever told by any state elected official to reach a particular decision with respect to the cities' pending change application regarding the R9 water rights?**
A. I was not.
**Q. In your opinion are any of the conclusions that you reached -- any of the findings or conclusions that you put in the final issued master order, were they impacted as far as content by any sort of political pressure?**
A. They were not.
**Q. But the timing was certainly something that was encouraged to you as far as something that needed to progress, correct?**
A. That is correct.
**Q. You also earlier made a reference to statute 82a-708b. Do you recall that?**
A. Um.
**Q. If not, that's --**
A. Well, I mean, we've talked about the statute multiple times, so.
**Q. Okay. 708b, statute 708b, that is the statute that primarily governs chain (sic) applications -- change applications, correct?**

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A. That is correct.
**Q. Okay. And so if someone submits a change application purportedly along -- let me rephrase.**
**If someone submits a change application to change a water right, do you view it as DWR's job to consider that application?**
A. Certainly. Yes.
**Q. And render some decision about it?**
A. Yes.
**Q. You -- you -- isn't it true that DWL processes change applications all the time?**
A. Yes.
**Q. Has there ever been a set of change application requests as extensive or complex as the ones that the cities requested regarding the R9 Ranch to your experience here, or knowledge?**
A. Well, not in my tenure as chief engineer that I can think of.
MR. OLEEN: Okay. Now back to -- I guess I'm not -- I'm probably not allowed to delete a deposition exhibit so we will -- I would ask that this be marked as Deposition Exhibit 13, please.
MR. BULLER: I think you can withdraw and replace.
MR. KITE: You can withdraw it.

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MR. BULLER: Just withdraw and replace it.
MR. OLEEN: I want to withdraw what you had originally marked as Deposition Exhibit 12 and ask that you re-mark this document instead.
MR. KITE: No objection.
MR. TRASTER: No objection.
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 12 was re-marked for identification.)
BY MR. OLEEN:
**Q. Regarding what -- regarding the replaced document that's been marked as Deposition Exhibit 12, Mr. Barfield, if you'd please review that letter and let me know when you're done.**
A. Okay.
**Q. Mr. Barfield, what is the date of this letter and who apparently signed it?**
A. Well, it's dated February 19, 2018, and I signed it.
**Q. And is this a letter that you wrote or approved?**
A. It's a letter I wrote and approved.
**Q. And to whom did you send this letter?**
A. It's sent to GMD 5 and Water PACK.

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**Q. And did I ask you the date?**
A. You did.
**Q. Okay. Would you please read for the record the first two sentences of the first paragraph of this letter?**
A. All right. As you're aware we have been in discussions with the cities of Russell, Hays and Russell, regarding their proposed change applications submitted in anticipation of their desired water transfer from the R9 Ranch for municipal use in their region. Our discussions will culminate in a DWR -- in DWR completing a draft master order and draft individual approvals for the proposed changes, which final drafts will be provided to GMD 5 for review and input and posting on our website for the general public.
**Q. Thank you. In response to this letter did you ever hear from Water PACK, some Water PACK representative complaining about these referenced discussions for the referenced draft documents in this first paragraph?**
A. Not to my recollection.
**Q. Did they ever ask -- did anyone from Water PACK, in apparent response to this letter, ever ask to be involved in these referenced**

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**discussions or drafts?**
MR. KITE: Object as outside the scope.
BY MR. TRASTER:
**Q. You may answer.**
A. Not to my recollection.
**Q. I will now hand you what I will ask be marked as Deposition Exhibit 13.**
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 13 for identification.)
BY MR. SCHWALB:
**Q. Mr. Barfield, if you would please review what's been marked as Deposition Exhibit 13 and let me know when you're done.**
A. Okay.
**Q. Do you recall -- did you send out this letter, Mr. Barfield?**
A. Yes, I did.
**Q. Earlier this morning there was a discussion about sending some USB drives containing some modeling files. Do you recall that line of questioning?**
A. I do.
**Q. Given your recollection of that line of questioning, is this letter related to that? And**

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**if so, how or how not?**
A. Well, this is the letter that accompanied the flash drive that I spoke about, the USB drive I spoke about.
**Q. Okay. And this USB drive contained what again?**
A. Well, as the letter indicated, it says backup files. Again, it's the files that are necessary to run the model scenarios that were used, that the city did for their modeling report.
**Q. And this letter, does it indicate whether a copy of the USB drive was sent to Richard Wenstrom with Water PACK or not?**
A. It does say that, that it is, was.
**Q. Earlier there was -- earlier this morning I believe there was a discussion about some corrections to the model that's referenced in this letter. Do you recall that line of discussion?**
A. I do.
**Q. So this document here, Deposition Exhibit 13, which version of the -- well, let me make sure I understand it correctly. This letter refers to a model that was created by whom?**
A. By Burns and McDonnell -- well, right. Burns and McDonnell based on GMD 5's model.

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**Q. Okay. And so at some point Burns and McDonnell made some corrections to the model; is that right?**
A. They did, later.
**Q. After -- after this letter was sent?**
A. After the letter was sent. After the public comment was reviewed, after the error was found by Balleau Groundwater.
**Q. Okay. And I thought you said earlier something about the corrected model favored the cities. Did you say something like that?**
A. Yes, I did say something like that.
**Q. Can you explain what you meant by that?**
A. So the fix of the model produced outputs, results, that had reduced impacts from the change. Let me try again.
I said they favored the city, I meant they supported the cities' contention that the limits that they found in their original work were reasonable. Is that any -- any clearer?
**Q. I think so.**
A. The city did not -- and again there's a -- I could go to the master order. There is a discussion about this in the master order that maybe is more thoughtful than my articulation

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here. It could have supported a slightly higher limits if the city wanted to go back but the city didn't change their limits based on the modeling work, so it supported the cities' contention that the results were reasonable. If you want a clear articulation of that I can find the paragraph in the order that says that better than I just did.

**Q. That's not necessary. I will hand you what I would now like marked as Deposition Exhibit 14, please.**

A. I would note, I'm sorry, there's a word, evolution in this letter here that I think should be evaluation but it's probably not important.

**Q. And which letter are you referring to? Which deposition exhibit?**

A. Exhibit 13, the first sentence says per your request, please find enclosed two copies of a USB drive each containing the MODFLOW modeling files associated with the R9 Ranch evolution regarding the pending application. I think it should be evaluation.

(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 14 for identification.)

BY MR. OLEEN:

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**Q. Mr. Barfield, please review what has been marked as Deposition Exhibit 14 and let me know when you're done.**

A. Okay.

**Q. Tell me what this document is, Mr. Barfield, who signed it, when it was sent out and to whom it was sent?**

A. All right. It was a letter by me dated May 4, 2018, to GMD 5 and cc'd to Water PACK and city officials essentially transmitting the draft proposed master order and individual approvals related to the Hays-Russell R9 Ranch change applications.

**Q. So is this the transmittal letter that you sent out that enclosed what we've referred to as the, quote, draft proposed master order?**

A. It is, yes.

**Q. And would you read to me the last sentence of the third paragraph of this Deposition Exhibit 14?**

A. Nevertheless, these are only draft proposed documents and I have made no official decision about any of these issues.

**Q. At the time you disseminated the draft proposed master order that this letter enclosed,**

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**were you open to changing any terms in that draft proposed master order?**

A. Well, that's what the review process is about, was to provide GMD 5 specifically, as well as the public, an opportunity to review and comment on the sufficiency of that proposed draft master order.

**Q. At the time you transmitted the proposed draft master order that this was a cover letter for, you did your -- well, did you think it complied with applicable laws?**

A. Yes, I did.

**Q. Do you think it would be reasonable to transmit something otherwise?**

A. I do not think it would be reasonable to transmit something otherwise.

**Q. I'll hand you what I will ask be marked as Deposition Exhibit 15.**

(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 15 for identification.)

BY MR. TRASTER:

**Q. Please briefly review that document, Mr. Barfield, and let me know when you're done.**

MR. TRASTER: So this is?

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MR. OLEEN: 15.

MR. TRASTER: 15?

A. Okay.

BY MR. OLEEN:

**Q. So as a result of -- well, let me rephrase. The draft proposed master order was transmitted at least to the entities listed on Deposition Exhibit 14, it was transmitted on May 4th, 2018, correct?**

A. Yes. And then posted on our website as well.

**Q. Okay. And after that there was this public informational meeting that we talked about this morning, correct?**

A. That's correct.

**Q. And at that public informational meeting you essentially heard input on the cities' requested changes and the draft proposed master order; is that right?**

A. That's correct. And then a lot of written comments following, during the period assigned for comments to be received.

**Q. As a result of the comments either oral or written that you received, after disseminating the draft proposed master order, did you make any**

**changes that -- that were shown in the final master order that you issued on or about March 27th of 2019?**
A. Yes. The third to the last bullet is a list of, you know, key revisions from the proposed draft master order to the contingent approval.
**Q. So this Deposition Exhibit 15, what is this document, I should ask?**
A. Yeah. So this is a summary of the contingent approval, somewhat similar to the version that I provided at the public meeting, here is sort of an update that -- that this is the document we put on our website at the time of the contingent approval just to update the public in terms of what had happened and what -- what that approval meant and where the process was going from there.
**Q. And so does the third bullet point from the bottom of Deposition Exhibit 15, does that summarize key revisions that were made as a result of the public input that you had received?**
A. Yeah. That's its intent.
**Q. And what were some of those key revisions?**
A. So the ten-year rolling aggregate



limitation, there was a provision in the draft proposed master order that would allow that to be dropped in the future under certain conditions. That was not part of the approval I did in March of 2019. I added a provision that required a public hearing before there could be any increase to the ten-year rolling aggregate limitation. That was not explicitly required in the draft proposed. We added a water quality component to the cities' monitoring plan and then we corrected errors in the cities' groundwater modeling that were identified in the process.
**Q. This public informational meeting, is it typical to hold a public informational meeting before DWR approves any change application?**
A. It is not typical, but these were not typical applications, as we already said.
**Q. So is it your understanding that DWR would have just issued the final master order without holding such a public information meeting?**
A. There's no explicit requirement.
**Q. And so why -- why did you want to hold this public information meeting?**
A. Well, again, to ensure that what we were proposing, you know, just to provide an



opportunity for -- an expanded opportunity for comments from -- from the public. You know, we do provide notice to the neighborhood, you know, to neighboring water rights and obviously to GMD to get their comments, as is normal part of our process. So this is just an expanded opportunity to understand this complex set of change applications and, you know, some complexity in terms of some of the unique terms and conditions so they could provide meaningful feedback.
**Q. Would you say that you were open to changing any provisions of the draft proposed master order, depending on what information you received as a result of the public informational meeting process?**
A. Any is a pretty strong word there. You know, we had done a lot of work on the document and I mean, I was open to input and carefully evaluated that input to ensure that the pack sent still complied with state law and requirements.
**Q. And the final master order that was issued around March 27, 2019, how much involvement -- well, let me rephrase that.**
**After the public informational meeting, who -- who drafted the -- the changes to the master**



**order that -- these changes that you indicated followed the public informational meeting, how were they drafted? How and who drafted those?**
A. Well again, as I referenced earlier today, we took control of the drafting process well before this, but much of the material added to the order was added by myself that included an overview of the public review process, the places and the input we got from that process generally in the review of the specific pertinent comments that were provided, and then several sections that provide our evaluation, my evaluation, of that. So virtually all of the significant additions to the order that were done were authored by myself.
**Q. Have you read every word of the -- of the issued master order?**
A. I have. Of the master order itself multiple times. I have not read every word of the attached approval documents.
**Q. Did you rely on staff to draft some of those attached approval documents?**
A. The attorney was largely responsible for implementing the individual approval documents that were attached to the master order. But yes, I take full responsibility for the master order.

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**Q. To this day do you believe that it's correctly issued, as it was issued on -- on or about March 27 of 2019?**
A. I do.
**Q. This entire application consideration process, it's gone on since some point in 2015, correct?**
A. June of 2015, yes.
**Q. So, what, about four years or so, say it's about four years from the time that the applications were submitted to the time the master order was -- the final master order was issued?**
A. Most of that, yes.
**Q. Okay. And so a lot of documents can be generated in that amount of time; is that right?**
A. Certainly.
**Q. And were a lot of documents generated as a result of this process?**
A. They were.
**Q. Do you believe that the documents contained in the agency record include the salient -- let me rephrase that.**
**Do you believe that the documents currently in the filed agency record are the primary documents upon which your decision was based, the**

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**decisions that you made in this master order?**
MR. KITE: Object. Outside the scope.
BY MR. TRASTER:
**Q. You may answer.**
A. Well, that was certainly the intent was to build -- you know, that was our intent was to always provide that, yes.
MR. OLEEN: I don't have any further questions.
MR. TRASTER: I have a few. So what exhibit number are we on?
MR. OLEEN: 16.
MR. KITE: 16 is the next exhibit, correct?
MR. OLEEN: That's right. 16 will be the next.
MR. TRASTER: Will you mark this 16? It's just one, yeah.
THE REPORTER: The top?
MR. TRASTER: Yeah. I guess we can ...
(THEREUPON, the court reporter marked Barfield Deposition Exhibit No 16 for identification.)
CROSS-EXAMINATION
BY MR. TRASTER:

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**Q. Mr. Barfield, my name is David Traster. I'm a lawyer with Foulston Siefkin. I represent the City of Hays. Daniel Buller is here with me, he also represents the City of Hays. As you know, Ken Cole represents the City of Russell, and the city manager for the city of Russell, Jon Quinday, is here as well representing Russell.**
**I've handed you what's been marked as Exhibit 16 and I'll represent to you that this is a document that is included in the agency record and it is a letter dated -- undated but received by DWR, according to this stamp, on July 16th of 2018 signed by Richard Wenstrom. Do you know Mr. Wenstrom?**
A. Yes, I do.
**Q. He -- now, you received a number of written and oral comments at the Greensburg meeting and thereafter, correct?**
A. Correct.
**Q. Do you recognize this as being one of the written comments that you received?**
A. Yes. And it is dated July 11. There is a date there.
**Q. It is. Okay. Mr. Wenstrom has a PE after his name. You're aware that he's an**

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**engineer?**
A. I am, yes.
**Q. You've had dealings with him over the years on water rights issues on his farm? Or not?**
A. I actually first came to know him, he had a firm called Pumping Plant Testing that we used to do field inspections of water rights under a program that I managed on behalf of the division, so I got acquainted with him back in 1985, I believe.
**Q. Okay.**
A. I don't know if I've had any specific dealings with his water rights.
**Q. But he's also a member of Water PACK and he's been -- has he been on the board at the GMD, if you know?**
A. Not to my knowledge.
**Q. Okay. You've had but -- he wrote you a two and a quarter, two and a third page letter expressing concern about the master order, the draft master order did he not?**
A. Yes, he did.
**Q. And during your direct examination you were asked about an engineering report for the City of Hays done by the city -- for the city and**

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**you said that there was a summary and I'm -- my guess is, is that that -- that summary that you were asked about is in the middle of the second page. But that's my question, is this the summary that you were referring to?**

A. Well, I didn't refer to it. I was trying to be responsive to a question and I was speculating a bit.

**Q. Okay. I understood you to say that somebody raised the issue and you thought maybe there was a summary and I'm just asking you if this is the summary that -- do you recall receiving or reading this -- that second -- that second paragraph on the second page of the letter where it talks about Bob Vincent's report?**

A. Correct. Yeah. This was my recollection. This might not be the only manifestation of it, but yes.

**Q. Okay.**

A. I think that's correct.

**Q. So did you have a copy of Mr. Vincent's report?**

A. Not to my knowledge.

**Q. Well, when you were considering this master order, it may be someplace buried in files,**

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**but my question really is when you were deciding whether or not to issue, finally issue this master order, did you review Bob Vincent's 1984 or '94 report, if you recall?**

A. I don't recall having a copy to review.

**Q. Okay. There were some questions about the draft initial order that was prepared by my law firm and sent to you. Was it -- was it considered -- did you consider it and use it as a basis for your -- the action of approving the master order?**

A. Repeat that again.

**Q. The question is whether the document that was sent to you in 2016 or '17, that initial draft?**

A. Um-hm.

**Q. Was that something you considered and used as a basis for the decision to issue the master order?**

A. Well, it was a starting point that was used for drafting the master order.

**Q. When you were --**

A. The draft proposed master order.

**Q. When you were --**

THE REPORTER: Hang on. I didn't hear you.

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THE WITNESS: The draft proposed master order.

BY MR. TRASTER:

**Q. After you received all the public comments you closed the record for -- you closed the record and said okay, I'm not taking any more comments. Now I'm going to think about this and I'm going to review all this. Recall that?**

A. That is correct. I did.

**Q. In the process of thinking about all of that and reviewing Deposition Exhibit 16 and other documents, the Keller report and other documents, did you go back and look at the initial order that I sent to you back in 2016 or '17?**

A. No, I did not.

**Q. Thank you. The changes that were made to the -- so as I understand it, Berns and Mac prepared a -- the model, it was sent to GMD and Water PACK for review, both the report and the actual model files. Mr. Balleau identified some minor problems with the -- with the model that Burns and Mac had reconstructed, I don't know exactly the right word to use, but had -- that's reflected in the report. Burns and Mac then**

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**corrected those errors. That resulted, and I'm asking, that resulted in a little more water maybe being available to the cities. Are the changes that were made, you understood -- you understood what -- let me back up.**

**You've dealt with models quite a bit as a chief engineer, correct?**

A. Yes, I have.

**Q. What models are the -- what are the significant models you've had to deal with?**

A. Well, yeah. I've had quite a bit of experience not in developing models, but in using models to make water management decisions. The first significant one was in 2001-2002 where I was part of a modeling committee for the Republican River Compact Administration as we were working to settle our dispute with Nebraska and part of that was the states collaboratively building a groundwater model to quantify depletions to stream flow from groundwater pumping. I was on that modeling committee and worked with our modeling experts and our data experts to make it something that was credible and usable and worked for Kansas.

**Q. Let me ask you, I don't want to -- I want**

**to get your answer. Did Nebraska think it was usable and workable for them too?**

A. All three states, all three states hired expert modelers and data experts to fight one another, and when we went to settle the lawsuit we put them -- put us all in a room and said make one model that's going to work for us and so that's what we did and I was a part of that process.

**Q. Okay.**

A. And actually from that collaborative model development process, I sort of spearheaded bringing those concepts to our intrastate model development, and that actually began with the Mid Ark model that was a precursor to the GMD 5 model, so we formed a modeling committee and had not only a committee, as the model was being developed, comment on it and make it a better model including a peer review modeler, Steve Larson, our expert in the interstate litigations both the Republican and the Ark River, was on that committee as well.

**Q. And Steve Larson is with?**

A. He's with a firm called Papadopoulos and Associates but he's -- he's the state of Kansas sort of expert in these interstate conflicts in



both cases. I've also worked with -- we have an expert modeler on staff, Dr. Sam Perkins, and I've worked with him to take two USGS models, one of the Ozark aquifer and one of the lower Ark, and use it to determine the safe yields of those particular aquifers. I've worked with GMD 4 in northwest Kansas, GMD 4 on adapting the Republican River model to help guide water management decisions such as local enhanced management areas in that GMD. You know, I've worked with GMD 3 has a groundwater model and applications of that model to -- to water management decisions in GMD 3. So yes, I've had extensive experience with using groundwater models.

**Q. So you've hired Mr. Perkins, Doctor Perkins, was he on staff when you became chief engineer?**

A. He -- he joined staff since I became chief engineer and he remains on staff.

**Q. So if you know so much about models, why did you hire somebody else? I mean, aren't you an expert modeler?**

A. I'm not an expert at developing groundwater models. I consider myself more an expert in the application of groundwater modeling



to our resource problems so Sam -- Doctor Perkins is the one that's actually running the model.

**Q. Other than it takes a lot of time and effort that you don't have, but I mean isn't it true that somebody -- that it takes a particular and significant training and understanding to actually develop those -- a model from -- from either a starting point with somebody else's or from ground up? That would be fair wouldn't it?**

A. Yes.

**Q. Are you qualified to do that?**

A. To build a groundwater model?

**Q. Right.**

A. No.

**Q. Okay. So are the changes that were made to the Burns and Mac model adequately documented in the report so that you as a consumer of groundwater models can understand what happened and what changes were made?**

A. I believe so.

**Q. Okay.**

A. Again, you'd have to have some modeling expertise and background.

**Q. To?**

A. To understand it. I mean it's -- the



layperson is not going to understand it.

**Q. They're not going to understand the report or they're not going to understand how the model got --**

A. Well, the changes. I mean, you know.

**Q. Okay.**

A. Again, they were not significant changes really. The foundation that the master order and the ten-year limitation is built on and was the -- remains as it was, in essence.

**Q. Are you aware of any documents that you considered and used as a basis for your decision to issue the master order that are not in the agency record?**

MR. KITE: Object to form. Outside the scope.

A. So as I said before in response to Mr. Oleen's question, you know, we did our best to create a complete record of what we relied upon and what I relied upon to make this decision so again, that doesn't mean there's not a document out there.

BY MR. TRASTER:

**Q. Right.**

A. That got overlooked.

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**Q. Well, the definition of the agency record is narrow and it's -- you have to actually have considered it and relied on it. And are the documents that you actually relied on in the record as far as you know?**
A. To the best of my knowledge.
**Q. Have we asked you, has anybody today asked you any questions about documents other than the draft initial order that I prepared and sent to you, and this -- this -- there were questions about the Hays engineer who evaluated the area back in '94 or -5. Other than those two documents, have you been asked about any documents that are not in the record that you recall? I don't know of any other documents that you were asked about other than those two.**
A. At today's deposition?
**Q. At today's deposition.**
A. That aren't in the record?
**Q. This isn't a trick question.**
A. That's not in the record. Yeah.
**Q. Yeah. Just make sure that if there's something that you've been asked about that oh, yeah, I remember that document now.**
A. No. Nothing's been triggered here like

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oh, I forgot to include this.
**Q. Okay.**
A. If that's your question.
**Q. I'm just trying to --**
A. Okay.
**Q. We want to make sure that the record is complete.**
A. Right.
**Q. And that the documents that you've referred to that aren't in the record, aren't -- by definition shouldn't have been in the record, so. All right.**
MR. TRASTER: No further questions. Okay.
MR. COLE: I may have just one, and I know you've heard that before.
CROSS-EXAMINATION
BY MR. COLE:
**Q. But I was interested in Deposition 14 which is your letter to Big Bend Groundwater Management District No. 5. You have that in front of you?**
A. Yes, I do.
**Q. And that's dated May 4, 2018, which was -- is approximately 11 months prior to the**

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**issuance of the -- of the master order. Would that be correct?**
A. Sounds right.
**Q. Okay. And one of the things that interests me is the last paragraph, first sentence of the last paragraph. Could you read that for the record, please?**
A. The first sentence of the last paragraph?
**Q. Yes.**
A. We look forward to working with you on the significant set of applications and the related draft proposed orders.
**Q. And when you referred to you, who are you referring to?**
A. Well, GMD 5 specifically.
**Q. Right. And a copy of this letter, it seems -- it seems a copy of the letter was sent to Water PACK as well. Would that be true?**
A. Yes.
**Q. And by extension were you offering the same invitation to Water PACK?**
MR. KITE: Object to form. Speculation. Assumes facts not in evidence.
MR. TRASTER: Is somebody saying something?

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MR. KITE: I am. I'm just making objections for the record.
MR. TRASTER: I'm not hearing them.
MR. KITE: Okay.
THE WITNESS: Did you hear him? Talking to the court reporter. She apparently got it.
A. Well, certainly the GMD has a unique role in these matters, so in particular it was -- that statement was targeted to GMD 5 in the role they'd been given, but certainly I also welcomed input from Water PACK.
BY MR. COLE:
**Q. So would it be reasonable to say that you were not only open to input, you were inviting input on the matter?**
A. Yeah. Again the public meetings was -- was a even greater, I think, expression of that.
**Q. And during those 11 months that passed, was there any information provided, by either of these entities, to you with respect to the issuance of the final order that you didn't consider and resolve in making your final order?**
A. Well, carefully -- I read all the input that I received and considered it all as appropriate.

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MR. COLE: Okay. Thank you. No other questions.
MR. BULLER: That was eleven questions. Tenfold. That's not bad.
MR. SCHWALB: But who's counting. Could we take a break?
THE WITNESS: Yeah.
MR. SCHWALB: All right.
(THEREUPON, a recess was taken.)
REDIRECT-EXAMINATION
BY MR. SCHWALB:
**Q. All right. We're back on the record. Mr. Barfield, earlier we -- Mr. Oleen was asking you about some of these exhibits, in particular Exhibit 12. Do you recall that line of questioning?**
A. Yes.
**Q. Okay. And then in the discussion of item 12, I think Mr. Oleen focused on this line about awareness of discussions with the cities of Hays and Russell on line one. Do you recall that --**
A. Yes.
**Q. -- conversation?**
A. Yes.
**Q. Okay. In terms of discussions with the**

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**cities of Hays and Russell in particular, I think you also testified that those meetings were not posted on the DWR website; is that correct? Earlier in the day?**
A. Yeah. That's correct.
**Q. Okay. You also testified that there was no objection to any of those meetings?**
A. Yeah. Nobody ever objected in fact that we were meeting or asked explicitly to be a part of it. The only exception to that that I did have two gentlemen from Water PACK that showed up at a particular meeting.
**Q. Okay.**
A. Fairly early in the process.
**Q. Do you recall who they were?**
A. I don't recall the names --
**Q. Okay.**
A. -- of the individuals.
**Q. Okay. What about at the Greensburg meeting? Did anyone complain about the meeting -- the prior meetings?**
MR. BULLER: And if I may interpose an objection here. My recollection of his testimony is not that he testified that nobody objected to the meetings, it was whether anybody objected to

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these letters -- to this letter in response to this letter.
MR. SCHWALB: Fair enough.
MR. BULLER: I may be misremembering that, but that's my recollection of his testimony.
MR. SCHWALB: You can go ahead.
A. So what was the question again? Sorry. I got sidetracked.
MR. SCHWALB: So did I. Would you mind reading back what I asked?
THE REPORTER: Question: Okay. What about at the Greensburg meeting? Did anyone complain about the meeting -- the prior meetings?
MR. SCHWALB: Okay.
BY MR. SCHWALB:
**Q. Within the context of the Greensburg meeting, do you recall anyone objecting to the process surrounding the change application?**
A. I don't recall anybody complaining about the process.
**Q. Okay. Were there representatives of Water PACK at that meeting?**
A. Certainly.
**Q. Okay. Do you recall who they were?**
A. Well, it's listed in the master order if

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you want me to look at that.
**Q. Sure. Go ahead.**
A. I think I can find that fairly efficiently. Let's see, at the public meeting oral public comments were received from the following: Richard Wenstrom, Kent Wetzel, Pat Wetzel, John Janssen, Pat Janssen, George Hetzel and Kim Gamble.
**Q. Okay. Let's unpack those just a little bit. What's Richard's role with Water PACK?**
A. He's -- I think he's on the board. I think he's been president. He may be the current -- no, he's not the current president. He's on the -- I think he's on the board.
**Q. Okay.**
A. He's one of the principals.
**Q. Okay. And does he own water rights in the vicinity of the ranch?**
A. He does, yes.
**Q. Does he own senior water rights?**
A. He does.
**Q. How about junior water rights?**
A. I'm not certain of the suite of them but he does have water rights that are adjacent to the ranch, to the southeast.

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**Q. Is there any specific analysis of the impact of the change applications on his water rights, junior or senior?**
A. Well, again, the modeling output shows the effect of the change on the whole area including, I mean he's some of those dots that are on the southeast side.
**Q. Any specific findings on a well-by-well basis for his water rights?**
MR. BULLER: Asked and answered.
A. So, well, the report doesn't cite the effect that this particular water right, according to Figure 6 of the model run is Y feet, but the map shows the effect on the neighbor water rights.
BY MR. SCHWALB:
**Q. Okay. Let's stick with other Water PACK members. You mentioned the Wetzels?**
THE REPORTER: Can I get the spelling on that name?
MR. SCHWALB: W-E-T-Z-E-L, I believe.
MR. TRASTER: Say it again?
MR. SCHWALB: W-E-T-Z-E-L.
MR. TRASTER: Thank you.
BY MR. SCHWALB:
**Q. Do they own water rights adjacent to the ranch?**
A. I --
MR. BULLER: I'm going to interpose an objection on the basis of vagueness and the fact that -- and adjoining or adjacent is a legal term so calls for a legal conclusion.
MR. SCHWALB: Let me rephrase.
MR. BULLER: Under Kansas law adjoining is a legal term.
MR. SCHWALB: Okay. Let me rephrase.
BY MR. SCHWALB:
**Q. Do the Wetzles have water rights next to the R9 Ranch?**
MR. BULLER: Same objection.
A. I believe they have water rights on the north side just on the other side of the river, if I'm remembering correctly.
BY MR. SCHWALB:
**Q. Do you know if those water rights are senior or junior?**
A. I'm not certain.
**Q. Were there any specific findings of fact in the master order regarding their water rights and the impact of the change application?**
A. My answer is the same as before.

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**Q. Okay. Are the Wetzels, do you know what their role is with Water PACK?**
A. I don't know.
**Q. Okay. Let's come back to Richard just for a second. You mentioned you've known him since 1985 give or take?**
A. Yes.
**Q. And you also mentioned that he worked for or he had a company called?**
A. Pumping Plant Testing.
**Q. Let's just call it PPT.**
A. PPT. Okay.
**Q. What did Richard do in the context of PPT on behalf of DWR?**
A. Well, his firm -- so at the time we were very behind in issuing certificates and one of the workload challenges we had at the time was not having enough field staff to -- to inspect -- to do the inspection that's part of issuing the certificate. We will go out and actually physically go to the water right and inspect the facility, review the records and prepare what's called a field inspection report and then that is one significant piece of the process of issuing certificates. So we contracted with several engineering firms to actually do that work on our behalf, and his firm was one that did that.
**Q. And you have to be a professional engineer to do that work or no?**
MR. BULLER: So after having heard the chief engineer's response I'm going to object. This is far outside the scope of the topics of examination today.
MR. SCHWALB: Okay. I will respond to that objection just by pointing to letter A. of the judge's order with regard to information made available to the chief engineer and I'll get there.
BY MR. SCHWALB:
**Q. So do you have to be a professional engineer to do that work?**
MR. BULLER: Object to form. Same objection.
A. No, but we did -- we use engineering firms to do that but our own people that do these inspections are not engineers.
BY MR. SCHWALB:
**Q. Okay. And earlier, I forget who, I'm going to say Mr. Traster, introduced this letter from Mr. Wenstrom designated Exhibit 16. Do you**

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**recall that?**
A. Yes, I do.
**Q. Okay. And within Exhibit 16, on page two there was a discussion regarding this report from, I believe it's Bob Vincent. Do you recall that?**
A. Yes.
**Q. And just to confirm, that report was never provided to you by the cities?**
MR. BULLER: Object to form. Misstates the testimony.
BY MR. SCHWALB:
**Q. Was that report ever provided to you by the cities?**
A. I don't recall it being provided.
**Q. Okay. With respect, coming back to Richard just for a minute. He's a professional engineer. Does he have the expertise to -- well, let me back up.**
**You said you don't have the expertise to develop a model independently?**
A. Yes. That's true.
**Q. Okay. I think you also said that a layperson wouldn't understand it?**
MR. BULLER: Object to form. Ambiguous.
A. Well, I was speaking specifically to the

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change that was made to the model.
BY MR. SCHWALB:
**Q. Okay. So a layperson would not understand the changes to the model?**
A. Well, the particular changes that were done to the model.
**Q. Okay.**
A. Yeah. It's a pretty in-the-weeds kind of change.
**Q. Okay.**
A. I'm not -- I guess my hesitation was I'm not saying that the general public can't understand groundwater models at all and understand their basic function and what they do.
**Q. But the specific changes a layperson would not understand?**
A. I think it would take -- my opinion is it would take some expertise to understand.
**Q. Okay.**
A. That particular change.
**Q. Does Richard have that expertise?**
MR. BULLER: Object to form. Lack of foundation. Calls for speculation.
BY MR. SCHWALB:
**Q. Let me back up. You provided this USB**

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**drive to Mr. Wenstrom; is that correct?**
A. Well, to Water PACK via Mr. Wenstrom, yes. Well, I believe it was to Richard -- yes.
**Q. And then Exhibit 13, it says in line, sorry, paragraph three: I am also sending one USB drive to Richard Wenstrom; is that correct?**
A. Yes.
**Q. Okay. And earlier you testified Richard Wenstrom would not have the capacity to understand the changes to that model?**
MR. BULLER: Object to form. That misstates his testimony.
MR. OLEEN: I join that objection.
A. I didn't say Richard -- I didn't speculate about Richard in my statements.
BY MR. SCHWALB:
**Q. Okay.**
A. I was speaking about the -- I thought you were talking about the general public, but.
**Q. Okay.**
A. So what's your question?
**Q. Why'd you only give it to Richard?**
A. I gave it to Water PACK via Richard who was, I believe, the president at the time.
**Q. Okay. What about the Wetzels? Did you**

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**provide them with a copy of it?**
A. No. I provided a copy to Water PACK via Richard Wenstrom.
**Q. Okay. And you did that, I believe this letter says, on March 9th of 2018?**
A. Yes. That's right.
**Q. Okay. And then subsequent to that the draft order was posted May 4th; is that correct?**
A. That sounds right.
**Q. Okay. Was it provided to the public before May 4th?**
A. No. That's when we provided it on our website.
**Q. Okay. But the cities had it before then, correct?**
A. Well, it sort of became final right about that time. I mean we were -- they had a form of it.
**Q. Okay. And then earlier you testified that, coming back to the order, you took control of the draft after this Greensburg meeting?**
A. I said it was like --
**Q. The bulk of it.**
A. Ten months before Greensburg.
**Q. Okay.**

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A. Well, ten months before we issued -- the summer of '17 we took control of it.
**Q. Okay.**
A. So.
**Q. And then coming out of the Greensburg meeting, I think you testified earlier that the maybe not the overwhelming bulk, but you made substantial revisions to the order yourself?**
A. Correct. Substantial additions. Again, that summary of what the public provided and sort of the evaluation of that, including some work I commissioned staff to do and, yes, that's correct.
**Q. Did you make any additions or changes to the appendices?**
A. I'm sure there were some changes, maybe even additions, but I'd have to -- I could take a look if you want me to.
**Q. Do you recall making any of those changes?**
A. I mean there was a -- I'd have to have you take me specifically to what you're asking about.
**Q. I'm just asking if you made any changes to the appendices.**
MR. BULLER: I'm going to interpose an

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objection. This is starting to feel like a fishing expedition.
MR. SCHWALB: What's the specific objection?
MR. BULLER: The objection is is none of this is inside the scope of the court's order. The court specifically limited the questions that are allowed at this deposition to the topics pertaining to his order, the issues identified in that order, and this is far beyond the scope of those issues.
MR. SCHWALB: Okay. Let's see.
BY MR. SCHWALB:
**Q. Okay. Was there any back and forth -- well, I think you already touched on this. I'm sorry. Let's come back to the initial draft that Mr. Traster provided, which I think you touched on when Mr. Traster was asking you a few questions. Are there any regulations that you're aware of that provide for an applicant providing the initial draft and getting feedback?**
A. There's -- no regulation speaks for or against that.
**Q. What about in other regulatory contexts that you're responsible for, LIMAs, for example?**

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MR. BULLER: Object to form. Outside the scope of the topics identified.
MR. OLEEN: I'll join that objection. Sorry to interrupt. You may continue.
A. I'm not aware of any one way or the other.
BY MR. SCHWALB:
**Q. Okay.**
A. As I understand the question anyway.
**Q. Okay. All right. And then last two, here, earlier you testified that you had closed the record at some point after the Greensburg meeting; is that right?**
A. Yes.
**Q. Okay. Did the Burns and McDonnell revisions come in before you closed that record or after?**
A. Well, I didn't start evaluating the record -- the Burns and Mac model came after a date I announced as closing the record. You know, I basically told the public I'll take -- take comment through this period, and I think it was the end of September, if memory serves me correctly.
**Q. Okay.**

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A. And it may not be.
**Q. And the Burns and Mac report is dated, I think?**
A. Early October.
**Q. I think September 28th?**
A. Was it? Okay. Well, maybe.
**Q. Well, is it or is it not?**
A. Well, maybe I'm not -- well, we know that answer. I'd have to dig around to find out when I asked for public comment.
**Q. Okay.**
A. One thing at a time, here. Let me -- so the Burns and Mac report was September 24, 2018.
**Q. Okay.**
A. I guess I'm -- I don't have a document in front of me, it seems like there was a document that said when I wanted comments by.
**Q. Okay. But those comments were required prior to receipt of the revised Burns and Mac report?**
A. Again, I don't have the document in front of me but that's my recollection.
MR. SCHWALB: Okay. Anybody want?
MR. TRASTER: Are you done?
MR. SCHWALB: I'm done.

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MR. TRASTER: I didn't hear no further questions.
MR. SCHWALB: No further questions.
MR. TRASTER: I have another question or two but it's not my turn.
MR. OLEEN: Just a minute.
RECROSS-EXAMINATION
BY MR. OLEEN:
**Q. I do have another question or two. Since -- because we're talking about this updated modeling report, I want to ask you to look at your time line which I think has been marked as Deposition Exhibit 1; is that correct? Time line? Is the time line Deposition Exhibit 1?**
A. Yes. Which is included in the web page.
**Q. Okay. So you just testified that the date of the updated Burns and Mac modeling report is what, to your knowledge?**
A. So, well, it's dated -- yeah. Just a second, here. September 24th, 2018.
**Q. Okay. And this is the same revised modeling report that we talked about earlier -- well, let me phrase it as a question. Sorry.**
**Is this the same revised modeling report that you referred to earlier when you said that the**

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**change did not materially affect the conclusions that you reached in the final master order that you issued?**
A. That is correct.
**Q. So Mr. Schwalb had asked a line of questioning about the timing of when this document came out versus the timing of when you may have closed the record to public comment, right? He asked you -- he was asking you some timing questions?**
A. He was, yes.
**Q. But -- but is it your testimony that the errors corrected by this revised report were minor and did not impact materially the final master order that you issued?**
A. That is correct.
MR. OLEEN: No further questions.
MR. SCHWALB: Just have one follow up here unless you-all want to go.
MR. BULLER: Go ahead.
MR. SCHWALB: All right.
REDIRECT-EXAMINATION
BY MR. SCHWALB:
**Q. Mr. Oleen was referring to this Exhibit 1. Does DWR keep track of versions of**

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**this exhibit as they're posted online?**
A. No.
**Q. Okay.**
A. I mean, do I have a list of every change we made to it? I don't. There may be a -- there may be a log. I don't -- but no.
**Q. So this is the edition of the website as it exists today or?**
A. Yes.
**Q. Okay.**
A. Yes.
MR. SCHWALB: Thank you. No further questions.
MR. TRASTER: So --
THE WITNESS: I'm sorry. Well, the website, there is a date posted that's included so we know when particular documents were posted.
MR. SCHWALB: Fair enough. Okay.
THE WITNESS: And this is today's version of it, or.
MR. SCHWALB: Yesterday's.
THE WITNESS: Yesterday's when I printed it out, yes.
MR. SCHWALB: All right. Thank you.
RECROSS-EXAMINATION

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BY MR. TRASTER:
**Q. So Mr. Schwalb asked you a question about taking control of the document that ended up being the master order and in the course of that question said something about it taking control a few months before the master order was issued, as I heard it. Maybe I'm mistaken. But my understanding is that your testimony is that DWR took control in the summer of 2017, which was months before the draft proposed master order was issued, correct?**
A. That is correct. The summer of '17 we took control, approximately ten months before the proposed draft master order, and we kept control through the rest of the process.
**Q. I'm curious about how you remember it was the summer of 2017 that you took control. I mean, do you have a specific recollection of it being the summer as opposed to the spring of 2017?**
A. Well, Mr. Oleen provided me with that date. He was the one that was really -- I made those additions we talked about from the proposed master order on, but he was really shepherding the document through that period of time, so.
**Q. Very good. So it was certainly at least**

**ten months before the draft proposed master order was released to the public that DWR was in full and complete control?**

A. That's my understanding.

**Q. Do you recall -- never mind.**

MR. TRASTER: No further questions.

MR. COLE: No questions.

MR. TRASTER: We done?

MR. KITE: I would ask that you review and sign your transcript.

THE WITNESS: I'll do that when she gets it to me.

MR. SCHWALB: All right. Well, I guess we didn't need the full eight hours, thank you everybody.

THE WITNESS: Thank you.

(THEREUPON, the deposition concluded at 2:47 p.m.)

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SIGNATURE

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The deposition of DAVID BARFIELD, P.E. was taken in the matter, on the date, and at the time and place set out on the title page hereof.

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It was requested that the deposition be taken by the reporter and that same be reduced to typewritten form.

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It was agreed by and between counsel and the parties that the deponent will read and sign the transcript of said deposition.

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AFFIDAVIT

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STATE OF ____________________________:

COUNTRY/CITY OF ______________________:

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Before me, this day, personally appeared, DAVID BARFIELD, P.E., who, being duly sworn, states that the foregoing transcript of his/her Deposition, taken in the matter, on the date, and at the time and place set out on the title page hereof, constitutes a true and accurate transcript of said deposition, along with the attached Errata Sheet, if changes or corrections were made.

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DAVID BARFIELD, P.E.

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SUBSCRIBED and SWORN to before me this _________ day of __________________, 2020 in the jurisdiction aforesaid.

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My Commission Expires Notary Public

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DEPOSITION ERRATA SHEET

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RE: APPINO & BIGGS REPORTING SERVICE, INC.

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FILE NO.: 56894

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CASE: WATER PROTECTION ASSN. OF CENTRAL KANSAS
vs. DAVID BARFIELD, P.E., ET AL.

.

DEPONENT: DAVID BARFIELD, P.E.

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DEPOSITION DATE: 1/28/20

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To the Reporter:

I have read the entire transcript of my Deposition taken in the captioned matter or the same has been read to me. I request that the following changes be entered upon the record for the reasons indicated. I have signed my name to the Errata Sheet and the appropriate Certificate and authorize you to attach both to the original transcript.

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PAGE:LINE FROM TO REASON

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SIGNATURE:__________________ DATE:__________

DAVID BARFIELD, P.E.

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CERTIFICATE

STATE OF KANSAS

COUNTY OF SHAWNEE

I, Ksenija M. Zeltkalns, a Certified Court Reporter, Commissioned as such by the Supreme Court of the State of Kansas, and authorized to take depositions and administer oaths within said State pursuant to K.S.A 60-228, certify that the foregoing was reported by stenographic means, which matter was held on the date, and the time and place set out on the title page hereof and that the foregoing constitutes a true and accurate transcript of the same.

I further certify that I am not related to any of the parties, nor am I an employee of or related to any of the attorneys representing the parties, and I have no financial interest in the outcome of this matter.

Given under my hand and seal this 12th day of February, 2020.

____________________

Ksenija M. Zeltkalns, C.C.R. No. 1461

AFFIDAVIT

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STATE OF Kansas :

COUNTRY/CITY OF Manhattan :

.

Before me, this day, personally appeared, DAVID BARFIELD, P.E., who, being duly sworn, states that the foregoing transcript of his/her Deposition, taken in the matter, on the date, and at the time and place set out on the title page hereof, constitutes a true and accurate transcript of said deposition, along with the attached Errata Sheet, if changes or corrections were made.

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David Barfield

DAVID BARFIELD, P.E.

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SUBSCRIBED and SWORN to before me this 25th day of February, 2020 in the jurisdiction aforesaid.

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KATIE N. ANDERSON
My Appointment Expires
March 12, 2023

Katie N. Anderson

My Commission Expires Notary Public

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DEPOSITION ERRATA SHEET

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RE: APPINO & BIGGS REPORTING SERVICE, INC.

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FILE NO.: 56894

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CASE: WATER PROTECTION ASSN. OF CENTRAL KANSAS
vs. DAVID BARFIELD, P.E., ET AL.

.

DEPONENT: DAVID BARFIELD, P.E.

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DEPOSITION DATE: 1/28/20

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To the Reporter:

I have read the entire transcript of my Deposition taken in the captioned matter or the same has been read to me. I request that the following changes be entered upon the record for the reasons indicated. I have signed my name to the Errata Sheet and the appropriate Certificate and authorize you to attach both to the original transcript.

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| PAGE:LINE | FROM | TO | REASON |
|---|---|---|---|
| .14:25 | "G5" | "GMD5" | typo |
| .18:14 | "aqua" | "aquifer" | typo |
| .26:1 | "undercurrent" | "under current" | typo |
| .26:17 | "82a-706b" | "82a-708b" | misstatement of legal citation |
| .54:11 | "McDonnell's" | "McDonnell" | typo |
| .56:6 | "Min" | "Mid" | typo |
| .63:17 | "It" | "I" | typo |
| .94:6 | "the attorney" | "Brent Turney" | typo |
| .98:25 | "resort" | "report" | typo |
| .127:10 | "DWL" | "DWR" | typo |
| .130:11 | "BY MR. SCHWALB" | "BY MR. OLEEN" | typo re questioner identity |
| .135:22 | "BY MR. TRASTER" | "BY MR. OLEEN" | typo re questioner identity |
| .139:19 | "pack" | "package" | typo |
| .140:22 | "The attorney" | "Brent Turney" | typo |
| .147:18 | "Berns" | "Burns" | typo |
| .170:25 | "LIMAs" | "LEMAs" | typo |

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SIGNATURE: David Barfield DATE: 2/25/2020

DAVID BARFIELD, P.E.

# EXHIBIT C

**BEFORE THE OFFICE OF ADMINISTRATIVE HEARINGS**
**STATE OF KANSAS**

| | | |
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| IN THE MATTER OF THE APPLICATION OF THE CITIES OF HAYS, KANSAS AND RUSSELL, KANSAS FOR APPROVAL TO TRANSFER WATER FROM EDWARDS COUNTY, KANSAS PURSUANT TO THE KANSAS WATER TRANSFER ACT | ) ) ) ) ) ) | OAH Case No. 23AG0003 AG |

**PREPARED REBUTTAL TESTIMONY OF DAVE ROMERO**
**ON BEHALF OF**
**BIG BEND GROUNDWATER MANAGEMENT DISTRICT NO. 5**

**MAY 28, 2023**

**QUESTION: Please state for the record your name, position, and business address.**

ANSWER: My name is Dave Romero. I am the President of and a hydrologist with Balleau Groundwater, Inc., 901 Rio Grande Blvd. NW, Suite F-146, Albuquerque, NM 87104.

**QUESTION: Mr. Romero, will you please describe your qualifications and experience in the field of groundwater hydrology and groundwater modeling?**

ANSWER: I have 27 years of experience with analyses related to interaction of groundwater and surface-water, development of field programs involving testing of wells and aquifers, water-resource planning and management, and water rights litigation support. I have a Bachelor of Science in Mathematics from the University of New Mexico and a Master of Science in Hydrology from the University of Arizona. I am a Certified Professional Hydrologist (08-HGW-1817) with the American Institute of Hydrology.

I have advised a diverse field of clients throughout my career. I advise cities regarding water-resource planning and management. I have also advised industrial water users, irrigation and conservancy districts, state and federal agencies, Indian tribes, water associations and private water users with matters involving water availability and management. My experience includes development of, adaptation of and working with more than 100 hydrogeologic models involving assessments of source water availability and assessment of hydrologic effects from groundwater development. I specify and analyze aquifer testing programs that are used to recommend operational well yields and pump settings and to characterize well service life in settings with declining regional water levels.

I have engaged in peer review services that involve hydrogeologic analyses for municipal water districts in settings of groundwater pumping, return flow discharge, artificial aquifer recharge and remediation of groundwater contamination. I have presented at conferences involving groundwater hydrology and I have been invited to submit a manuscript describing a groundwater analysis technique for consideration in a Theme Issue of the journal *Groundwater*, which was accepted for publication after peer review.

I have been qualified as an expert in the Superior Court of the State of Arizona and in administrative hearings in New Mexico and Kansas.

Since the mid-2000s, Balleau Groundwater, Inc. (BGW) has advised Groundwater Management District 5 (GMD5) on matters related to water use. Part of that effort involved development of a model in part of the Arkansas river basin focused on the area of GMD5. That model is the model used by Burns & McDonnel (BMcD) in their evaluation of the R9 Ranch transfer application and used by S.S. Papadopulos and Associates, Inc. (SSPA).

**QUESTION: What were you asked to do in this matter?**

ANSWER: Review the pre-filed testimony and reports of Steven P. Larson of SSPA and Paul McCormick, P.E. of BMcD disclosed in this matter and identify any issues with the analysis or use of the model.

**QUESTION: What pre-filed testimony and reports did you review?**

ANSWER: A list is below.

Steven P. Larson testimony: *Prepared Direct Testimony of Steven P. Larson on Behalf Of Water Protection Association Of Central Kansas and Edwards County, Kansas (Collectively "Intervenors")*, dated May 30, 2023.

Steven P. Larson Report (attached to testimony dated May 30, 2023): *Revaluation of Burns & McDonnell's R9 Ranch Modeling Results*, dated February 1, 2023.

Paul McCormick Testimony: *Direct Testimony of Paul McCormick, P.E., Senior Associate Geological Engineer, Burns and McDonnel Engineering Company, Inc.*, dated May 26, 2023.

Paul McCormick Report (attached to testimony dated May 26, 2023): *R9 Ranch Modeling Results Summary*, prepared for City of Hays, Kansas, R9 Ranch Development Edwards County, Kansas.

**QUESTION: Did you identify any issues with the analysis or use of the model?**

ANSWER: Yes.

**QUESTION: What issue or issues did you identify?**

ANSWER: Steve Larson of S.S. Papadopulos & Associates, Inc. writes on Page 3 of his report:

> *"The BMcD projected future scenarios did not account for the reduction in groundwater recharge associated with changing the status of lands on the R9 Ranch from irrigated to non-irrigated. The BGW groundwater model was premised on the concept of increased groundwater recharge from precipitation on irrigated lands. To be consistent with this premise when evaluating a transfer, the groundwater recharge on irrigated land must be reduced when that land is no longer irrigated."*

I agree with Mr. Larson's description of this hydrologic concept and associated reduction of local groundwater recharge at the R9 Ranch. I have not reviewed Mr. Larson's analysis at the level of detail associated with examining the actual input and output associated with the model simulations; however, my review of his reported analysis and the accompanying conclusions set forth in pages 3-7 of his report are compatible with my expectations. To that extent, I agree with Mr. Larson's analysis and conclusions.

**QUESTION: Do you concur with the methodology Larson used to re-run the various simulations of potential future conditions considered by Burns & McDonnell, reducing the amount of recharge on the R9 ranch lands that would not be irrigated under future municipal pumping conditions?**

ANSWER: I have not developed an alternative methodology or reviewed Mr. Larson's analysis at the level of detail associated with examining the actual input and output associated with the model simulations; however, my review of his reported methodology set forth in pages 4-5 of his report are compatible with my expectations. To that extent, I concur with Mr. Larson's methodology.

**QUESTION: Have you included with this testimony a copy of your current curriculum vitae?**

ANSWER: Yes. It is attached as Exhibit 1.

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

FURTHER AFFIANT SAYETH NAUGHT.

DAVE ROMERO

SUBSCRIBED AND SWORN to before me this 28th day of June, 2023.

Notary Public

My commission expires: 05/25/2026

STATE OF NEW MEXICO
NOTARY PUBLIC
LAUNA KITTLE
COMMISSION NUMBER 1138067
EXPIRATION DATE 05-25-2026

Exhibit 1

Curriculum Vitae of Dave Romero

## DAVE M. ROMERO, M.S., P.H.
Hydrologist

**EDUCATION:** Master of Science in Hydrology, 1996, University of Arizona
Bachelor of Science in Mathematics, 1992, University of New Mexico

**CERTIFICATION:** Certified Professional Hydrologist (#1817) by the American Institute of Hydrology (2008)

**PROFESSIONAL SOCIETIES:**
National Ground Water Association
American Geophysical Union
Integrated Groundwater Modeling Center
International Association of Hydrogeologists
American Water Resources Association
New Mexico Geological Society

**PROFESSIONAL EXPERIENCE:**

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| 2012 to Present: | President and Hydrologist, Balleau Groundwater, Inc. |
| 2002 to 2011: | Vice President and Hydrologist, Balleau Groundwater, Inc. |
| 1999 to 2002: | Senior Hydrologist, Balleau Groundwater, Inc. |
| 1996 to 1999: | Hydrologist, Balleau Groundwater, Inc., Albuquerque, NM |
| 1994 to 1996: | Research Assistant, University of Arizona, Tucson, AZ |
| 1992 to 1995: | Staff Research Assistant, Los Alamos National Laboratory, Los Alamos, NM (summers only) |

**SUMMARY OF PROFESSIONAL EXPERIENCE:**

Professional experience in major aspects of hydrology and hydrogeology, with emphasis on numerical modeling of both groundwater and surface-water hydrologic processes and interaction. Water-rights litigation support, development of field-testing programs, wellfield assessment, water-resource planning and management, arid zone hydrology, artificial recharge, and mine dewatering have also been major activities. Developed, adapted or worked with more than 100 hydrogeologic models. Assessed the hydrologic effects of water systems serving cities and water suppliers in New Mexico, California and Kansas. Work activities have specialized in regional source-water assessments and analyzing long-term yield of wellfields. Experience with aquifer characterization including specification of well and aquifer tests and interpretation of test data to determine local and regional properties of aquifer systems. Author on expert reports describing regional water budgets and hydrologic effects associated with applications or proposals that affect area wells and rivers. Qualified as an expert in administrative hearings in New Mexico and Kansas, district court in Arizona and developed technical information which guided the outcome of settled cases.

**PUBLICATIONS/PRESENTATIONS:**

"Upper Santa Ana River Integrated Model – Peer Review Process", invited to speak at $2^{nd}$ Annual Santa Ana River Science Symposium, *Success through Collaboration*, Tuesday, October 22, 2019 at the University of California, Riverside.

"Water Accounting Model Analysis - Two Case Studies", invited to speak as faculty at Law Seminars International, Using Hydrology as Proof in Water Cases, Session: Constructing and Deconstructing Hydrologic Models, July 17, 2017, La Fonda Hotel, Santa Fe, New Mexico.

"Water Accounting Analysis - Understanding Viable Solutions to Water Disputes", invited to speak as faculty at CLE International, Law of the Rio Grande, $15^{th}$ Annual Conference - Live!, Session: Real Wet Water Solutions to Legal Disputes, March 5-6, 2015, La Fonda Hotel, Santa Fe, New Mexico.

"Simulation of Aquifer System in Part of the Española Basin, New Mexico", abstract accepted for presentation at National Ground Water Association Conference on Hydrology and Water Scarcity in the Rio Grande Basin, February 25 - 26, 2014.

"Simulation of the Aquifer System in Part of the Hondo Basin from the Sierra Blanca to Riverside, New Mexico", abstract in Geological Society of America, Rocky Mountain Section – $64^{th}$ Annual Meeting, May 9 – 11, 2012, *Abstracts with Programs,* Vol. 44, No. 6, p.23.

"How Much Have We Got? Sandia Labs and USGS Studies of Regional Water Resources", Focus on the Future: Water and Energy in Southern New Mexico, 2012 Southern New Mexico Conference, invited to give presentation and speak on panel for panel discussion, Ruidoso Convention Center, Ruidoso, New Mexico.

"Effluent Recharge to the Gila Group Aquifer near Silver City, New Mexico", abstract and presentation at 2011 American Water Resources Association Annual Conference, November 7 – 10, 2011, Hyatt Regency, Albuquerque, New Mexico.

"Model Accounting of Water-Use and Availability in Southeastern Union County, New Mexico, Part of Cimarron County, Oklahoma and Parts of Dallam and Hartley Counties in Texas", abstract in 2009 Annual Water Symposium Proceedings, *Managing Hydrologic Extremes*, Arizona Hydrological Society and American Institute of Hydrology, August 30 – September 2, 2009, Westin Kierland Resort & Spa, Scottsdale, Arizona.

"Grid Cell Distortion and MODFLOW'S Integrated Finite-Difference Numerical Solution", National Ground Water Association, Ground Water Journal, Theme Issue: Understanding through Modeling, Vol. 44, No. 6, pgs. 797-802, November-December 2006.

“MODFLOW: A Finite-Difference Groundwater Flow Model or an Integrated Finite-Difference Groundwater Flow Model?” MODFLOW and More 2003: Understanding through Modeling – International Groundwater Modeling Center, Colorado School of Mines, Conference Proceedings (with Thomas Maddock, III).

“IFD: An Integrated Finite-Difference Package for Use with MODFLOW,” Master’s Thesis, Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona, 1996.

"Mechanical and Physical Properties of Perlite from the Geophysical Array for Small-Scale Explosive Experiments in Socorro, New Mexico," Los Alamos National Laboratory, LAUR-95-217, January 1995 (with H.N. Plannerer).

Over 75 other confidential consulting reports.

## SPECIFIC EXPERIENCE IN WATER RESOURCE PROJECTS:

-Southeast, Kansas: Technical evaluation of a proposal to permit lowering of the level from which groundwater credit associated with an aquifer storage and recovery (ASR) project could be diverted from City of Wichita wells. The project involved an Administrative Hearing on the proposal. The evaluation involved reducing an existing analysis into its constituent parts to analyze the proposal. The resulting analysis provided new information that isolated the hydrologic and water quality effects of the proposed change in ASR operations on nearby wells and streams.

-Southern California: Peer review of model development in the Upper Santa Ana River watershed. A regional geohydrologic model was developed based on previous work completed in five areas: the Yucaipa Basin, the San Bernardino Basin, the Rialto-Colton Basin, the Riverside-Arlington Basin and the Chino Basin. The project was a joint effort involving three water districts, two water suppliers, the California Department of Fish and Wildlife and the U.S. Fish and Wildlife Service. The regional model was developed to enhance understanding of groundwater and surface water interaction along the Upper Santa Ana River. The technical work involved an assessment of hydrologic effects associated with proposed projects addressed in a Habitat Conservation Plan associated with an application for an incidental take permit under Section 10 of the Endangered Species Act.

-Southeastern Arizona: Evaluation of proposed augmentation pumping that is part of a Federal Reserved Water Right for the San Pedro Riparian National Conservation Area. The work involved model analysis and development of an augmentation scheme to support river flow during drought conditions and evaluation of local monitor wells developed for observing shallow water-level conditions in areas near the river. Testified in district court.

-Southern California: Peer review of Groundwater Management, Monitoring and Mitigation Plan (Plan) for a water development project. The plan involves development of groundwater from the eastern Mojave Desert and transporting it west to enhance the water supply of certain populated areas in southern California. A general concept of the project is to develop groundwater from the Mojave region that otherwise would evaporate (unused) from the basin lowlands. The peer review involved evaluating whether the Plan was sufficient to ensure that the proposed groundwater pumping would not result in potential adverse impacts that could not be effectively mitigated.

-Southeastern New Mexico: Expansion of municipal water supply for a city. The wellfield is located in the High Plains aquifer. The wellfield was expanded with eight new production wells and seven monitor wells. The project involved coordinating with an engineer on well specifications, overseeing drilling and testing of completed wells, and recommending operational pump settings and well yield for individual wells planned for connection to the existing water system.

-Southeastern New Mexico: Development of a water supply for a cryogenic gas processing facility. The facility is located in an area with water known to be of poor quality in a deep aquifer system within Permian bedrock. Treatment of the area water supply is necessary for facility operations. A key question was whether a suitable quantity of water could be produced from a shallower aquifer with significantly better quality than the deep system. Analysis of geophysical logs in the area suggested the presence of a Triassic bedrock aquifer as a candidate source of water. Exploratory drilling and testing identified good quality water and yield at a quantity suitable to meet facility water demand. The end product was identification of a long-term water supply with reduced cost of treatment and a production well to access that supply.

-Central Kansas: Development and analysis of a river augmentation plan to address low flow conditions for a downstream senior water user. The assessment involved evaluation of candidate wellfield locations in consideration of areas with degraded water quality, fluctuations in seasonal water quantities, and management of augmentation pumping to supply water on a specific schedule of water demand.

-West Texas: Assessment of regional water development potential from a deep Triassic aquifer system. The work involved guiding the specification of 1,000+ feet deep wells, development of a well/aquifer testing program, interpretation of aquifer test results, incorporation of local and regional aquifer test data into a model of the aquifer system. Model development included compilation of a three-dimensional framework of a shallow fresh-water aquifer system with a deeper brackish water system. Results of the analysis provided information to quantify the deep aquifer resource and guide whether additional sources of water would be needed to meet projected demand.

-Santa Ana Basin, California: Scientific peer review of groundwater model development. The project progressed over a two-year period involving development of a work plan, review of previous associated works, development of a lithologic model, development and calibration of a groundwater flow model and development and calibration of a contaminant transport model. The model was developed as part of an integrated regional water planning and management process among agencies in the area of the Upper Santa Ana River Watershed. A key to progress involved facilitating technical discussion amongst members of a technical team in attempt to reach model development decisions through a collaborative process. The work was conducted on behalf of four regional water agencies and one private company involved with local groundwater remediation.

-Upstate New York: Analysis of data and subsurface processes related to coal-tar (DNAPL) transport. Technical evaluation involved team development of an approach to characterize the timing of coal-tar transport originating from an early 20th century manufactured gas plant. Coal-tar migrated from processing plant areas and from a tar disposal pond predominantly through unconsolidated sediments before reaching an adjacent river.

-Bernalillo County, New Mexico: Technical evaluation of the administrative setting for a specific License of water use in the Middle Rio Grande Administrative Area. The License has a requirement for offsetting Rio Grande depletion with either return flow to the river or retirement of existing water rights, but it did not explicitly state how depletion to the river is to be calculated. Through technical coordination with the New Mexico Office of the State Engineer, developed an agreed upon technique for calculating river depletion from well use by the Licensee. The approach provided the Licensee with information necessary to plan future water use within a framework of managing return flow to the river and use of its existing water rights portfolio.

-Quay County, New Mexico: Designed aquifer testing program for production wells completed in the High Plains (Ogallala) aquifer. Interpreted aquifer test data, pertinent geologic publications and local lithologic data. Directed development of an aquifer model to analyze the hydrologic effect of changing the location of two wells. Developed a set of technical exhibits for use in an Administrative Hearing regarding use of the wells. Coordinated with legal counsel on the foundation of the technical approach and on development of a technical opinion regarding the hydrologic effect of moving the two wells.

-Sierra County, New Mexico: Developed technical opinion on serviceability of a well providing a thermal source of water for commercial purposes. Planned field test for the well. Interpreted water-level and thermal data collected during testing. Interpreted aquifer testing program previously conducted by the U.S. Geological Survey in local the thermal water artesian basin. Evaluated historical records of water diversions and records of permitted use. Authored technical report describing future well serviceability within the context of permitted well use.

-Sierra County, New Mexico: Evaluated an aquifer testing program conducted in the McRay bedrock aquifer system. Inspected geologic reports to conceptualize a structure for the regional aquifer system. Directed development of an aquifer model to quantify the hydrologic effect of transferring and using water rights to divert groundwater from a well in the McRae aquifer system. Authored a report for use as technical evidence in an Administrative Hearing. Prior to hearing, attended and presented technical information at a formal mediation session. The mediation involved coordination and discussion amongst the parties and other technical experts. The end result was the Parties reached an agreement and matter was settled.

-Santa Ana Basin, California: Conducted a scientific peer review of a groundwater flow model of the San Bernardino Valley aquifer system. The model represents the Bunker Hill and Lytle Creek geologic basins, including certain Environmental Protection Agency operable units related to the Newmark and Muscoy contamination plumes. The scope of review focused on the model functionality for meeting objectives of a Superfund Consent Decree and for guiding basin-wide water management and planning initiatives regarding artificial recharge, regional wellfield operations, and variable climate effects. Authored a peer-review report and presented recommendations for enhancement of model performance in key management areas. The end result was the model authors moved forward with addressing the proposed recommendations for enhancement and Balleau Groundwater, Inc. was brought into the project as a technical team member to peer review the enhancement work. The work was conducted on behalf of eight regional water agencies.

-Raton Basin, New Mexico and Colorado: On behalf of the City of Raton, analyzed hydrologic impacts to the City's municipal water system from proposed coalbed methane development. The work was initiated by four energy companies that collectively petitioned (the Petitioners) to change the administrative status of groundwater within an area where groundwater pumping affects the City's municipal water supply. Conducted assessment of the conceptual model, hydrologic data, and the numerical model developed by the Petitioners and authored an expert report of comments. The end result was the Petitioners addressed key comments and settled with the City of Raton by agreeing not to request a change in the administrative status of groundwater within a buffer area of the City's municipal watershed.

-Central Kansas: Development of a three-dimensional hydrogeologic flow model that includes the High-Plains aquifer and deeper bedrock in the Great Bend area of Kansas. The Principal stream in the model domain is the Arkansas River. Model aquifer properties are based on results from regional aquifer tests. Aquifer recharge and runoff to streams is linked to regional precipitation patterns over a 68-year historical period. Return flow from irrigation pumping is estimated based on monthly variations in precipitation and crop requirements in conjunction with LANDSAT imagery to identify active irrigation acres. The model represents a component of degraded water quality that rises from deep bedrock to shallow groundwater. The model is in use by the Kansas Department of Agriculture - Division of Water Resources to assess hydrologic effects from proposed water management plans and administration of water rights.

-Mimbres Basin, New Mexico: Developed hydrologic program to assess the fate of treated effluent after infiltration beneath the ephemeral stream bed of San Vicente Arroyo. The approach is based on using the seasonal variability of surface-water temperature as a tracer to track effluent as it percolates through the vadose zone toward the regional water table. The work involved specifying a monitoring system comprised of monitoring wells and of vadose zone instrumentation nests to collect data. Data indicated that subsurface effluent could be tracked as it moves through the vadose zone down to the regional water table. The monitoring program was developed to understand the fate and timing of effluent percolation to the regional water table in the area of the Town of Silver City.

-Union County, New Mexico: Developed aquifer testing program for wells completed in the Jurassic and Cretaceous bedrock aquifers beneath the Tertiary/Quaternary sediments of the Ogallala Formation. The work involved specifying the test procedure, managing data collection and interpretation of test results. The work resulted in characterizing hydrologic properties of the bedrock and Ogallala aquifer system in eastern central Union County in the vicinity of Seneca Creek.

-Grant County, New Mexico: Hydrologic evaluation of regional water budget in area of Silver City, New Mexico. The work involved comparing the flow budget associated with a specific area of influence to the flow budget of designated boundaries in the State of New Mexico Southwestern Regional Water Plan. Provided comments on the distinction between regional availability of source water and the source water available to a particular distribution of wells in Grant County.

-Santa Fe, New Mexico: Assessment of shallow water-table dewatering requirements for a construction project. Designed protocol for shallow aquifer test and interpreted test results. Coordinated development of an associated groundwater flow model to project yield and schedule required for dewatering site prior to beginning construction activities.

-Middle Rio Grande Valley, New Mexico: Assessed hydrologic effects of Bernalillo County Water Utility Authority well diversions. The work involved analyzing stream depletion to specific reaches of the Rio Grande and inspecting the extents of aquifer drawdown resulting from diverting water from municipal wells.

-Union County, New Mexico: Developed hydrologic program of aquifer testing, aquifer system model development and analysis of projected hydrologic effects from development of new irrigation project. The work involved interpretation of aquifer stress and response data, geophysical logs, geologic information, water use patterns, historical model calibration and model scenario development to assess effects from projected levels of groundwater use. The end product was a regional model of the geohydrologic system and of regional water use suitable for assessing the effects of groundwater development. Authored reports for use at State Engineer Administrative Hearing and provided expert witness testimony.

- Clayton, New Mexico: Provided hydrologic support for filing a Declaration of water use with New Mexico Office of the State Engineer. The work involved field inspection of wells and interpretation of historical aerial imagery to inspect water use in categories of dryland farming, surface-water irrigation and irrigation from wells. Potential support for New Mexico Office of the State Engineer Administrative Hearing.

-Estancia Basin, New Mexico: Participated in a four-member Hydrology Committee established to review hydrologic and geophysical interpretations used to assess the future service life of a bedrock wellfield. The Committee was formed as part of a joint stipulation between a confidential client and the New Mexico Office of the State Engineer.

-Middle Rio Grande Valley, New Mexico: Provided technical reports for use at State Engineer Administrative Hearings regarding transfer of water rights from Bernalillo and Socorro Counties to the City of Santa Fe Buckman wellfield. Two transfer applications were submitted to the State Engineer. The work involved analysis of hydrologic effects caused by discontinued well use and commenting on administrative accounting associated with the Buckman wellfield permit. Commented on the hydrologic implications of State Engineer policy regarding Middle Rio Grande water rights transfers. Provided expert witness testimony at State Engineer Administrative Hearing.

-Village of Corrales, New Mexico: Provided a technical report describing hydrologic effects for use at a New Mexico Office of the State Engineer Administrative Hearing on a new groundwater appropriation. The analysis was in the context of State Engineer administrative guidelines for use in assessing water rights transfers. The appropriation was within the hydrologic area of influence that includes major municipal wellfields operated by the City of Albuquerque and City of Rio Rancho.

-Middle Rio Grande, New Mexico: Simulation of multiple model scenarios to investigate depletion effects to the Rio Grande caused by variable groundwater pumping schedules for an industrial water user. The work was done in support of a management plan for eventual cessation of well operations as a transition is made to alternative sources of water. The analysis involved accounting for well diversions, stream depletion, treated return flow and available offset water rights. Model scenarios were developed to analyze alternative schedules of reduced wellfield pumping while maintaining associated residual stream depletion to a level less than or equal to available depletion offsets.

-Estancia Basin, New Mexico: Assessed future water-level drawdown at regional scale to investigate the service life of existing wells. The work involved categorizing existing wells into those with and without future water columns remaining for future public supply use. Future projections of water levels were based on a model of the regional aquifer system that takes into account basin-wide estimates of irrigation, commercial, municipal, domestic and stock water use. The analysis provided a basis for identifying areas where long-term source water from existing wells would be expected for planning purposes.

-Pojoaque River Basin, New Mexico: Provided hydrologic support for an Environmental Assessment of impacts associated with converting the source water for a turf irrigation project from well diversions to treated wastewater reuse. Developed an approach and recommended a method for quantifying the associated hydrologic effects. The work involved compiling regional information regarding water use, existing well and water feature locations, and developing model scenarios appropriate for quantifying hydrologic effects related to the change in source water use. The analysis involved an assessment of the effect to water levels in shallow wells and to a stream system caused by a proposed change in deep well pumping. The analysis was based on a published U.S. Geological Survey model, which was spatially refined to provide larger-scale detail to individual wells and to surface-water points of diversion for irrigation. The results were reported in an environmental assessment document submitted to the U.S. Bureau of Indian Affairs for compliance with the National Environmental Policy Act and related legislation.

-Estancia Basin, New Mexico: Assessed the fate of seepage from septic drainfields situated in basin fill deposited on limestone. Developed an approach and chose method for the analysis. The aquifer system includes groundwater flow through the geologic sequence of basin fill and limestone. The analysis involved characterizing an expected range of hydrologic properties for the basin fill sediment and using a variably saturated model technique to account for migration of drainfield seepage through the vadose zone and ultimately to the water table of the regional groundwater system. The approach provided a method to account for water that supports evaporative losses from the shallow vadose zone. Authored a report describing findings for use at a State Hearing regarding return flow from septic drainfields.

-Middle Rio Grande Basin, New Mexico: Assessed regional groundwater flow model developed by the U.S. Geological Survey and adapted model to include data from an aquifer testing program in the Jemez Basin. The aquifer testing data provided a basis for adjusting Santa Fe Group aquifer properties. A later phase of work involved coupling the groundwater flow model to a surface water model using response functions. Developed technique for derivation of groundwater response functions via the groundwater flow model. Response functions accounted for groundwater withdrawal and injection, seepage from reservoirs, seepage from irrigation canals and deep percolation associated with irrigation return flow. The end result was a hydrologic model of the Jemez Basin that links with a surface-water model of the Rio Grande Basin. The model has been used to assess the effects of Jemez Basin water development on State of New Mexico Rio Grande Compact obligations to Texas.

-Sandia Uplift/Hagan Basin, New Mexico: Developed regional model of the hydrologic system. Model development involved creation of predevelopment, historical and future projection versions of the model. The model provided a tool suitable for analyzing effects to the hydrologic system caused by 50 years of groundwater development and importation of water from an adjacent basin. The model is situated between two regional models used by the New Mexico State Engineer to administer water rights. The model provided a basis to assess the hydrologic effects to water levels and to the regional surface-water system caused by a future planned use of water for a subdivision.

-Middle Rio Grande, New Mexico: Provided hydrologic support for quantifying water consumption associated with development of a managed refuge for the Rio Grande silvery minnow. The Rio Grande silvery minnow is an endangered species under the Endangered Species Act of 1973, as amended. The work involved quantifying the water consumption change associated with clearing Rio Grande Bosque vegetation and replacing it with an open water body. The analysis was based on evapotranspiration data collected from eddy covariance flux towers located in the Middle Rio Grande Bosque. The objective of the work was to estimate the total acreage of Bosque vegetation that would have to be cleared and maintained so that the new open water habitat would not cause more water evaporation than would otherwise occur without the habitat. The approach was required to prevent new depletion to surface water which would affect State of New Mexico Rio Grande Compact delivery obligations to Texas.

-Grant County, New Mexico: Authored a supplemental report to the Town of Silver City 40-year plan. The 40-year planning report serves as the basis for the municipality to acquire and hold unused water rights in the State of New Mexico. The report documents regional geohydrology, the Town's existing wellfield facility, wellfield performance testing, history of water use, permitted water use, projected demand and model analyses that focus on an assessment of future wellfield service life. Modeling was based on a regional groundwater flow model developed by the State Engineer and adapted to reflect individual well details observed during a program of field testing. The analysis accounted for water use by the Town and regional water for mines, irrigation, domestic and stock use.

-Lea County, New Mexico: Developed a model of the Southern High Plains aquifer system to assess source water for an existing wellfield and a planned wellfield. In the area of interest, the Ogallala aquifer overlies less permeable rocks of Cretaceous and Late Triassic age. The objective was to assess the future availability of water that could be accessed as individual wells are affected by pumping water levels, well interference, partial aquifer penetration, reduced performance as the aquifer dewaters and declining yield as individual well water levels reach a threshold required to maintain a suitable net positive suction head. The work involved developing a model with a detailed account of well hydraulics in the context of the regional geologic structure and hydrologic system. Results of the project provided information for consideration in decisions for management action regarding a capital improvement plan for potential expansion of a City water system.

-Middle Rio Grande, New Mexico: Analysis of groundwater seepage from Jemez Canyon reservoir. Results from a U.S. Geological Survey groundwater flow model were interpreted and used to estimate historical seepage from Jemez Canyon reservoir during historical operations.

-Estancia Basin, New Mexico: Analysis of future water availability from a limestone aquifer. The work involved implementing a geophysical technique to characterize the relative change in borehole permeability with depth for a wellfield completed in the Madera Limestone aquifer. The approach involved a geophysical technique of combining thermal log data with well specific capacity to arrive at a method for estimating future well yield as regional water levels decline and the limestone aquifer partially dewaters. The work was done to provide a regional water supplier with information regarding the future availability of water in the area of its existing wellfield.

-Española Basin, New Mexico: Developed model of geohydrologic system to assess the effects of historical water use on a regional scale. The model accounted for historical water use by the County of Los Alamos, the Town of Española, the City of Santa Fe and rural domestic and stock water use. Irrigation operations were simulated along the Rio Chama, the Rio Grande, the Santa Cruz River, the Santa Fe River and Pojoaque River Basin Streams.

-Santa Fe County, New Mexico: Assessed hydrologic impacts associated with a water system for the Pojoaque River Basin and the City of Santa Fe. Impact evaluation included integration of population growth with water use and development of model scenarios. The work was prepared for the U.S. Bureau of Reclamation under the direction of the Aamodt Technical Committee and reported in a Feasibility Study to the 108th Congress of the United States.

-Pecos River Basin, New Mexico: Assessment of hydrologic impacts to Pecos River under degrees of priority enforcement on irrigation wells in the Roswell Basin. The analysis included coupling priority enforcement with direct augmentation pumping to provide flow to the Pecos River. The analysis provided a method to inspect the feasibility of administrative action as a means to provide required deliveries of Pecos River water from New Mexico to Texas under a situation of Compact shortfall. Authored an expert report describing findings for the New Mexico Interstate Stream Commission for use in potential litigation.

-Lincoln County, New Mexico: Evaluation of hydrologic impacts associated with wellfield diversions by the Village of Ruidoso. Authored expert report on hydrologic effects associated with water use transfer. Testified at state administrative hearing.

-Rio Arriba County, New Mexico: Evaluation of hydrologic impacts associated with transfer of water use from state engineer permitted irrigation operations to surface-water storage. Development of hydrologic exhibits for use at State Hearing. Expert testimony at state administrative hearing.

-Albuquerque South Valley, New Mexico: Assessment of hydrogeologic and water quality conditions affecting private domestic well owners. Conducted a degraded water quality vulnerability analysis of domestic wells within the service area of a planned municipal water system expansion. Provided technical input for development of an Environmental Assessment Document for compliance with the National Environmental Policy Act.

-Middle Rio Grande, New Mexico: Developed a geographic information system (GIS) based hydrologic model of the Placitas area. Hydrologic model information was based on data derived from an exploratory drilling and aquifer testing program, and from available data regarding the regional geohydrology of the area. The model coupled the groundwater and surface water system for a complete assessment of hydrologic effects caused by a proposed subdivision.

-Santa Fe, New Mexico: Development of a water-use plan that involved a water source assessment, a water-use and demand study, modeling of hydrologic impacts from planned wells and evaluation of water-use alternatives. Developed technical specifications for planned water supply wells and monitoring wells.

-Middle Rio Grande, New Mexico: Assessment of City of Albuquerque wellfield impacts to Rio Grande and Middle Rio Grande Conservancy District canals and drains. The analysis was conducted with the New Mexico Office of the State Engineer Administrative Groundwater Flow model of the regional groundwater flow system.

-Silver City, New Mexico: Assessment of City wellfield performance. Well pump tests were conducted at each of the City's active wells to determine specific capacity and estimate well service life with model projections. Aquifer properties of the Gila Conglomerate at selected wells were derived from monitoring water-level recovery data after individual wells were shutdown.

-Grant County, New Mexico: Design and conceptualization of numerical model to integrate with existing New Mexico Office of the State Engineer model for use in Gila River Basin administration. Application of the model to a water rights transfer application submitted to the State Engineer. Designed and developed hydrologic exhibits for use at State Hearing. Provided expert witness testimony at State Administrative Hearing.

-Santa Fe County, New Mexico: Application of hydrologic model scenarios to quantify impacts to Pojoaque River Basin streams and to Rio Grande. Presented model results to Aamodt negotiation/settlement team and a presiding Judge. Team participants included State and Federal legal counsel and State and Federal technical staff.

-Santa Fe County, New Mexico: Design of hydrologic modeling program to assess impacts from future development of water use in Pojoaque River Basin. Water use options include comparative analysis of wellfield development versus installation of a regional water system.

-Santa Fe County, New Mexico: Design of observation well monitoring network to quantify long-term local drawdown impacts from Ranney-type radial well collector planned for regional water supply distribution system.

-Middle Rio Grande Basin, New Mexico: Evaluation of aquifer testing program conducted at four sites in Rio Grande alluvium in the vicinity of the City of Albuquerque. Analyzed aquifer test data and commented on applicability of use in localized hydrologic modeling. The tests were conducted as part of the City's investigation of options to divert San Juan Chama Project water for municipal use.

-Middle Rio Grande Basin, New Mexico: Evaluation of hydrologic model conceptualization and results from simulation of San Juan Chama Project water diversion from a Ranney-type well collector in the City of Albuquerque. The model was designed to investigate the hydrologic effect to the Rio Grande and Middle Rio Grande Conservancy District canals and drains from a shallow subsurface diversion.

-Middle Rio Grande Basin, New Mexico: Evaluation of impacts to Rio Grande and Jemez River from City of Rio Rancho groundwater appropriation. Impacts were calculated with the New Mexico Office of the State Engineer Administrative model. Designed and developed hydrologic exhibits for use at State Hearing. Exhibits were designed in the context of the Middle Rio Grande Administrative Area Guidelines published by the State Engineer.

-Pecos River Basin, New Mexico: Evaluation of hydrologic model of Roswell Basin. Inspected the behavior of the model with regard to climatic and groundwater withdrawal effects on Pecos River baseflow gain. Provided technical comments and advice on adaptations to update the model for use in analysis of Pecos River Compact compliance.

-Sandoval County, New Mexico: Evaluation of hydrogeology in area of Placitas. Expanded the Middle Rio Grande Administrative model to include the area of interest and applied the model to a water rights transfer application submitted to the New Mexico Office of the State Engineer. Designed and developed hydrologic exhibits for use at State Hearing. Exhibits were designed in the context of the Middle Rio Grande Administrative Area Guidelines published by the State Engineer.

-Luna County, New Mexico: Evaluation of hydrology in Mimbres Basin. Performed model simulations with the U. S. Geological Survey/State Engineer model of the Mimbres Basin. Designed and developed hydrologic exhibits for use at State Hearing. Exhibits were designed in the context of the Mimbres Basins Administrative Criteria published by the State Engineer.

-Eddy County, New Mexico: Evaluation of Carlsbad Basin administrative model developed by New Mexico Office of the State Engineer. Performed multiple model simulations to inspect depletion impacts to the Pecos River from wells completed in the adjacent Reef aquifer and in the overlying alluvium.

-Santa Fe County, New Mexico: Evaluation of hydrologic response of two models developed by the U. S. Geological Survey in the Santa Fe Embayment area. The analysis compared the depletion effects to local streams from City of Santa Fe wellfield withdrawals.

-Middle Rio Grande Basin, New Mexico: Comparison of methods for calculating consumptive irrigation requirements for selected crops. Provided technical comments on methods and effects of amounts derived from various methods.

-Santa Fe County, New Mexico: Evaluation of Buckman wellfield impacts to Pojoaque River Basin streams. The analysis compared depletion effects to retired water rights on file with the New Mexico Office of the State Engineer

-Santa Fe County, New Mexico: Preparation of a model designed for administering water rights in the Pojoaque Valley River Basin. Modification of an existing U.S. Geological

Survey model for the purpose of simulating the impacts of applied-for changes in water use on existing or declared water rights within the basin.

-Taos County, New Mexico: Evaluation of a hydrologic model used for estimating groundwater yield potential at future pumping centers.

-Doña Ana County, New Mexico: A study of impacts to the Rio Grande from the transfer of water use from one location to another in the Mesilla Valley. The U.S. Geological Survey model (Frenzel, 1992) was used to quantify the impacts. Calculations were consistent with the New Mexico Office of the State Engineer Lower Rio Grande Administrative Guidelines.

-Doña Ana County, New Mexico: Research of well development and water use activities of selected wells in the Mesilla Valley. Quantified impacts to the Rio Grande from wellfield withdrawals.

-Torrance County, New Mexico: Supervised and performed pump tests at numerous wells within the Estancia Basin. Tests in 1999 resulted in characterizing properties of the San Andres/Glorieta aquifer unit.

-Torrance County, New Mexico: Developed the recharge and overland flow components to a detailed hydrologic model of the Estancia Basin. Used the model in a basin-wide study of long-term water sustainability.

-Middle Rio Grande Basin: Adapted the New Mexico Office of the State Engineer Middle Rio Grande administrative model to incorporate hydrologic impacts in the Placitas mountain zone. Impacts were quantified based on the Middle Rio Grande Draft Administrative Guidelines.

-Middle Rio Grande Basin: Adapted the U.S. Geological Survey model of the Middle Rio Grande Basin to quantify impacts to the Jemez River.

-Santa Fe County, New Mexico: Adapted the U.S. Geological Survey Model of the Tesuque aquifer system near Santa Fe to quantify impacts to Cienega Creek and extended the historical period from 1985 to 1998.

-Lower Rio Grande Basin: Adapted the Maddock/Hamilton model of the Mesilla Basin to quantify impacts to the Rio Grande from explicit withdrawal of groundwater. The work provided a basis for estimating the magnitude of depletion to surface water from unmetered groundwater withdrawals.

-Rio San Jose Basin, New Mexico: Developed a model of the geohydrologic system for use in quantifying long-term post mining effects to water levels and groundwater flow. Determined and managed approach for assessment of post mining effects on hydrologic system. The work included a particle tracking analysis to investigate the advective transport potential of groundwater with degraded quality from the mine site to the regional groundwater flow system. The analysis was done for a Closeout Plan of an underground uranium mine. The Closeout Plan was submitted to and accepted by the Mining and Minerals Division of the New Mexico Environment Department.

-Cibola County, New Mexico: Simulated groundwater flow and transport of uranium tailings with the fully three-dimensional, saturated/unsaturated, density-driven model FEMWATER. Simulations included a sensitivity analysis and long-term projections of the fate of tailings water. The analysis involved variably saturated contaminant transport with geochemical retardation. The work was done for a mine Closeout Plan. The Closeout Plan was submitted to and accepted by the Mining and Mineral Division of the New Mexico Environment Department and by the U.S. Nuclear Regulatory Commission.

-Lander County, Nevada: Provided second opinion on mine-dewatering requirements, the overall water operations plan and the hydrologic model used for analyzing mine water operations. The work involved assessing a numerical model of groundwater flow, comparing analytical models for mine dewatering, commenting on factors of concern to mine planning and commenting on required future dewatering rates and environmental impacts.

-Elko County, Nevada: Developed the surface-water flow component for an expanded version of an open pit mine-dewatering model. The model was used to analyze mine dewatering rates and to assess well placement for future dewatering operations. The surface-water system was integrated with the groundwater system in a numerical model of the hydrologic system. Historical mine dewatering operations were calibrated and used to project future dewatering requirements alongside an assessment of changes to the regional hydrologic system resulting from dewatering operations.

-Los Alamos County, New Mexico: Implementation of the U.S. Department of Agriculture model KINEROS to predict sediment yield due to flood events. The interest in sediment transport was related to two watersheds with deposits of depleted uranium in valley sediments and evaluation of potential for elevated uranium levels in downstream drainages.

**EXPERT TESTIMONY:**

State of Kansas, Before the Division of Water Resources, Kansas Department of Agriculture, *In the Matter of Wichita's Phase II Aquifer Storage and Recovery Project in Harvey and Sedgwick Counties, Kansas, Case No. 18 WATER 14014*, March 4 - 5, 2020) - Assessment of hydrologic and water quality effects to area wells and rivers associated with a proposal to lower the level from which groundwater credit associated with aquifer storage and recovery could be diverted from City of Wichita wells.

Superior Court of the State of Arizona, In and For the County of Maricopa (Contested Case Name: *In re San Pedro Riparian National Conservation Area*, March 12 - 14, 2019) - Assessment of augmentation pumping and use of monitor wells in the context of a federal reserved water right for the San Pedro Riparian National Conservation Area.

New Mexico Office of the State Engineer (Administrative Hearing No. 08-091 & 09-003 Consolidated, January 28 - 29, 2014) - Application for permit to drill a supplemental well within Causey Lingo Underground Water Basin in New Mexico.

New Mexico Office of the State Engineer (Administrative Hearing No. 06-059; October 31 - November 1, 2007) – Application to appropriate groundwater for irrigation use from the High Plains aquifer system in northeastern New Mexico.

New Mexico Office of the State Engineer (Administrative Hearing No. 06-023; May 8, 2007) – Application to transfer groundwater use from a point of diversion in the middle Rio Grande Basin to a municipal supply upstream in the Santa Fe area.

New Mexico Office of the State Engineer (Administrative Hearing No. 00-041, 02-038, 02-068, 02-069, 02-070, & 04-019 consolidated; February 14 - 17, 2005) – Application for a groundwater diversion from a wellfield near an intermittent stream in the Rio Hondo Groundwater Basin.

New Mexico Office of the State Engineer (Administrative Hearing No. 04-003; April 19 - 22, 2005) – Application to transfer a surface-water diversion from irrigation purpose of use to offset storage and evaporation in an upstream reservoir.

New Mexico Office of the State Engineer (Administrative Hearing No. 01-121; September 11 - 13, 2002) – Application to transfer a groundwater point of diversion from a mining purpose of use to municipal use at another location.

# EXHIBIT D

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# Big Bend
# Groundwater Management District 5

## Preliminary Update of GMD5 Model through Year 2020

Presented to GMD5 Board, January 12, 2023

BALLEAU GROUNDWATER, INC.

# Discussion Topics



1. Scope of Model Update and Work Performed
2. Review of Model Results
3. Adjustment of Runoff/Recharge Curves
4. Status of Model and Utility
5. Recommendation

DRAFT

# Scope of Model Update and Work Performed



The GMD5 model historic simulation runs from January 1940 through December 2007. GMD5 retained Balleau Groundwater, Inc. (BGW) to update the simulation to include the period January 2008 through December 2020 and to perform a preliminary inspection of model performance.

During the inspection, BGW observed a pattern in model performance. Namely, simulated water levels in certain areas of the model recovered more quickly than observed after the drought of 2011 - 2012.

A deeper review led BGW to a pattern in precipitation that explains the behavior. Furthermore, we updated the precipitation/runoff/recharge curves in the Rattlesnake Creek and Walnut Creek basins to account for the precipitation pattern.

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# Discussion Topics



1. Scope of Model Update and Work Performed
2. Review of Model Results
3. Adjustment of Runoff/Recharge Curves
4. Status of Model and Utility
5. Recommendation

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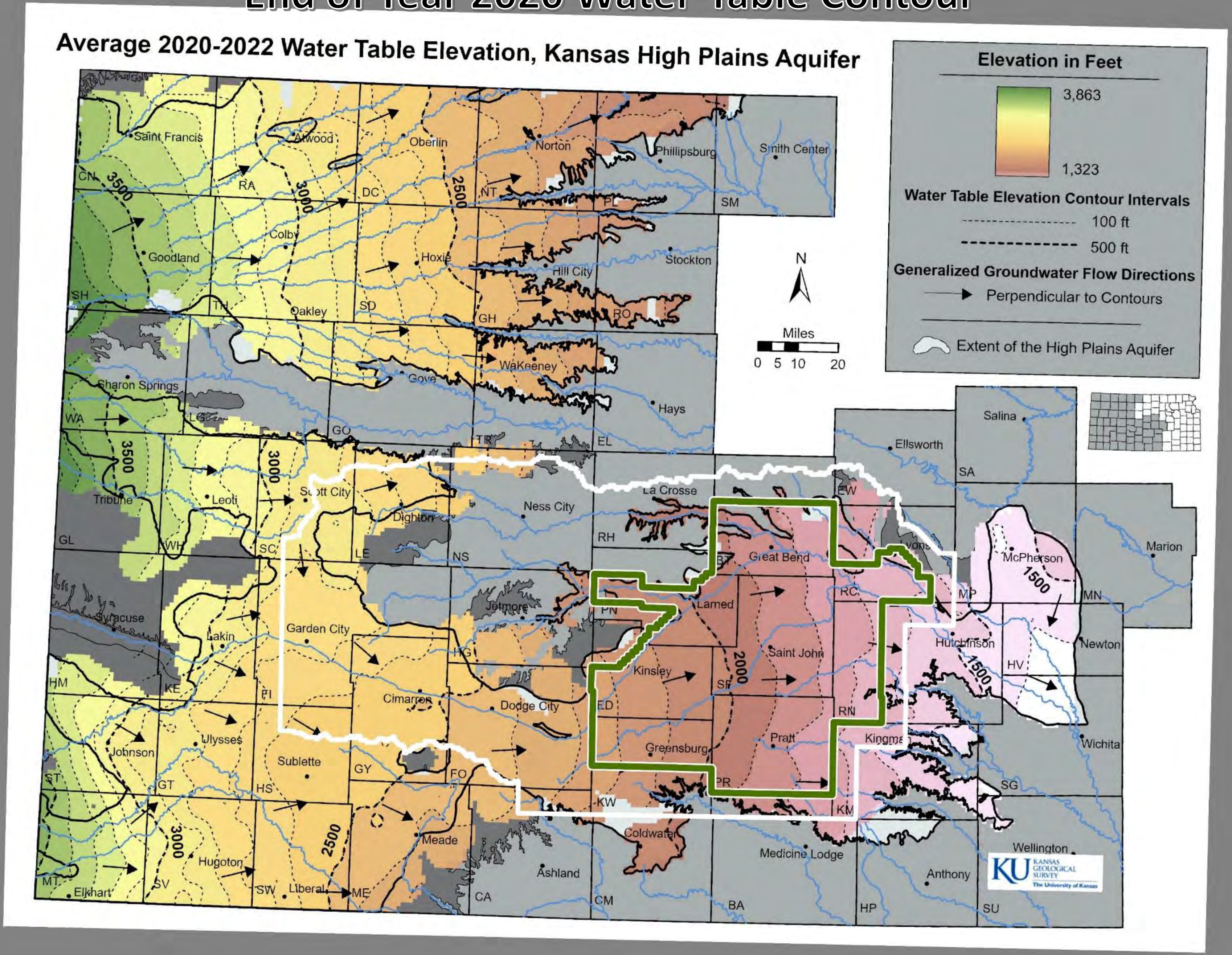
# End of Year 2020 Water-Table Contour






**Water Level: Observed**

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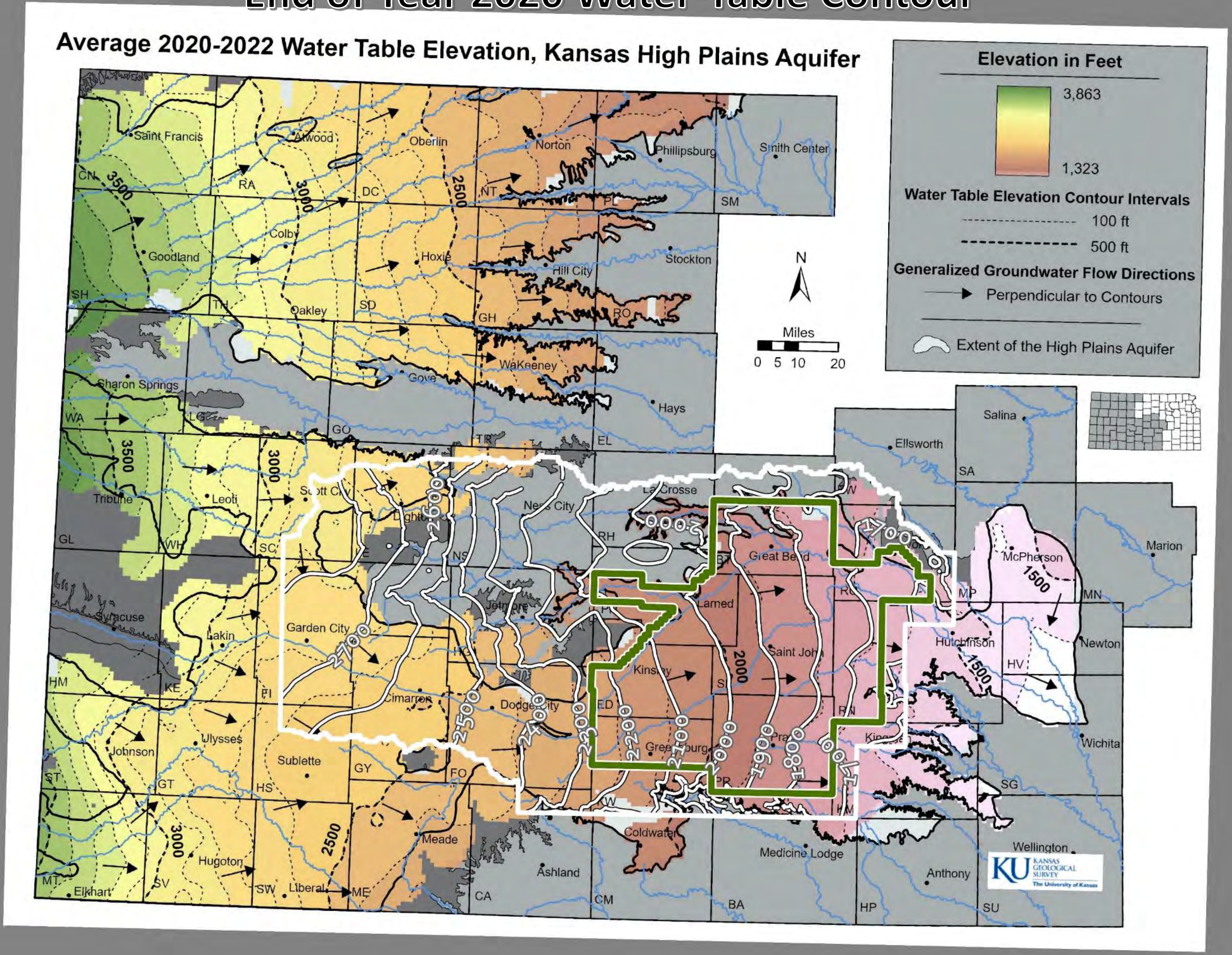
# End of Year 2020 Water-Table Contour






**Water Level: Observed and Simulated**

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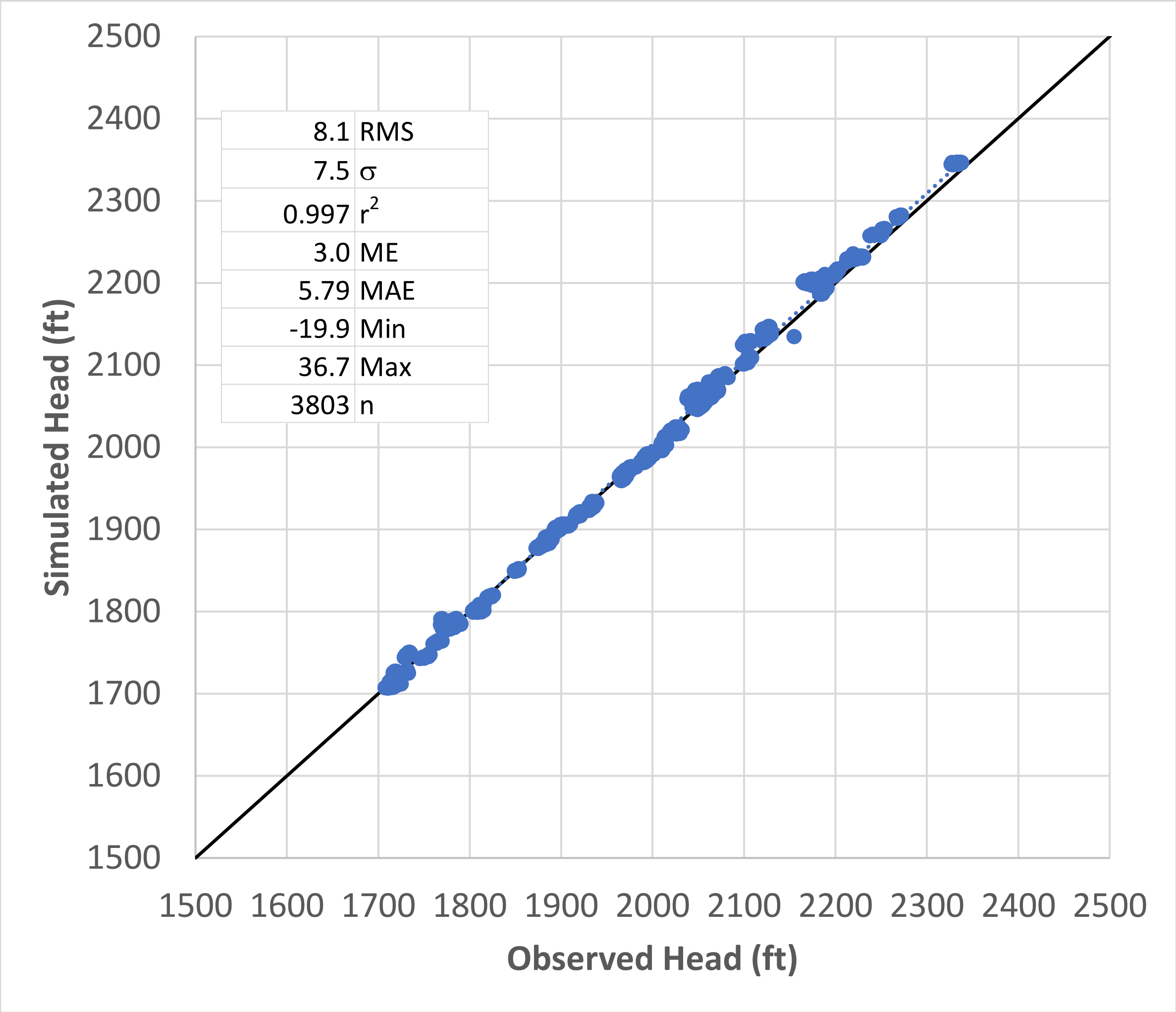
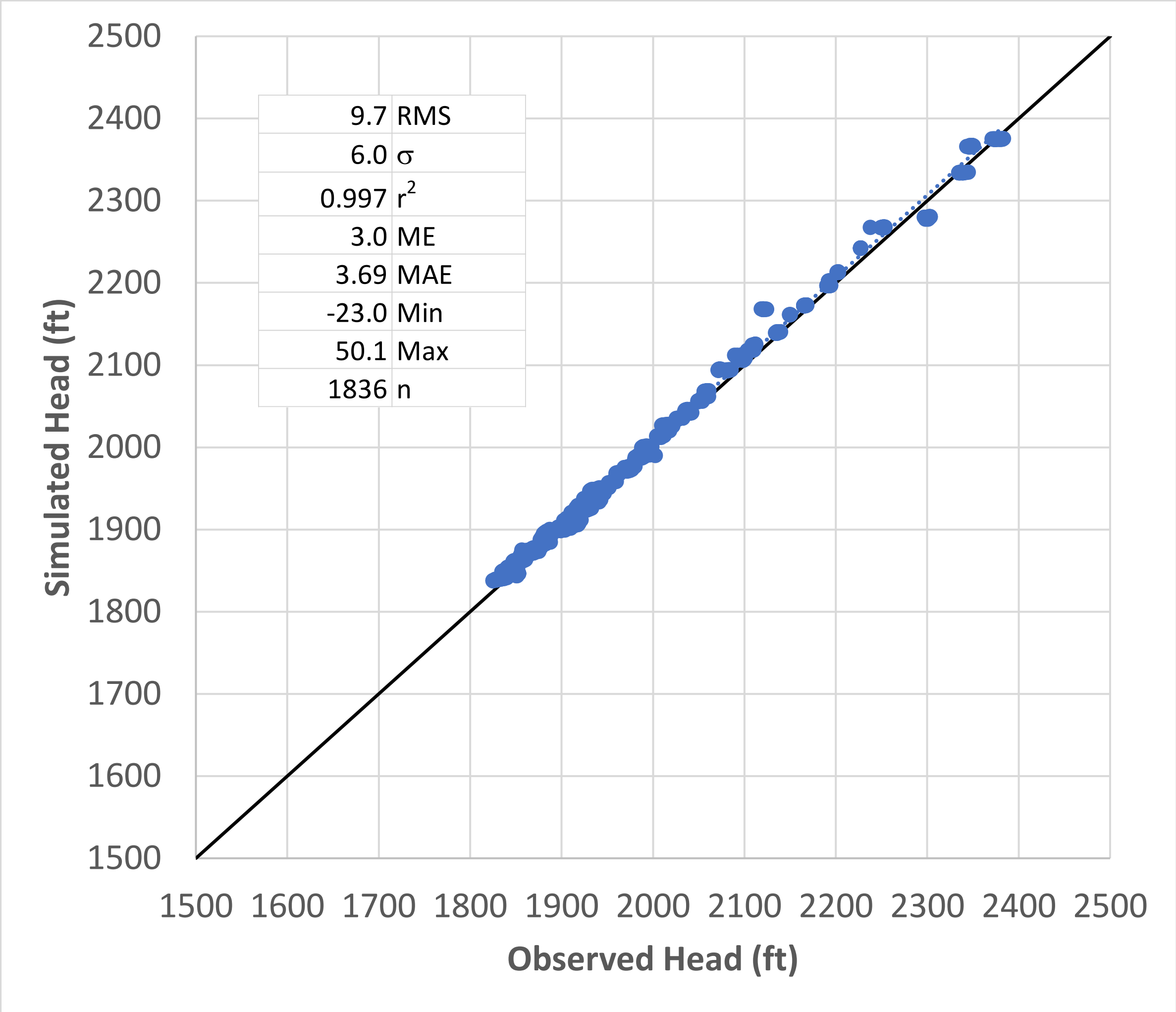
# Water-Level Cross Plots




## Rattlesnake Creek Basin




## Walnut IGUCA

**Model Update Period: 2008 through 2020**

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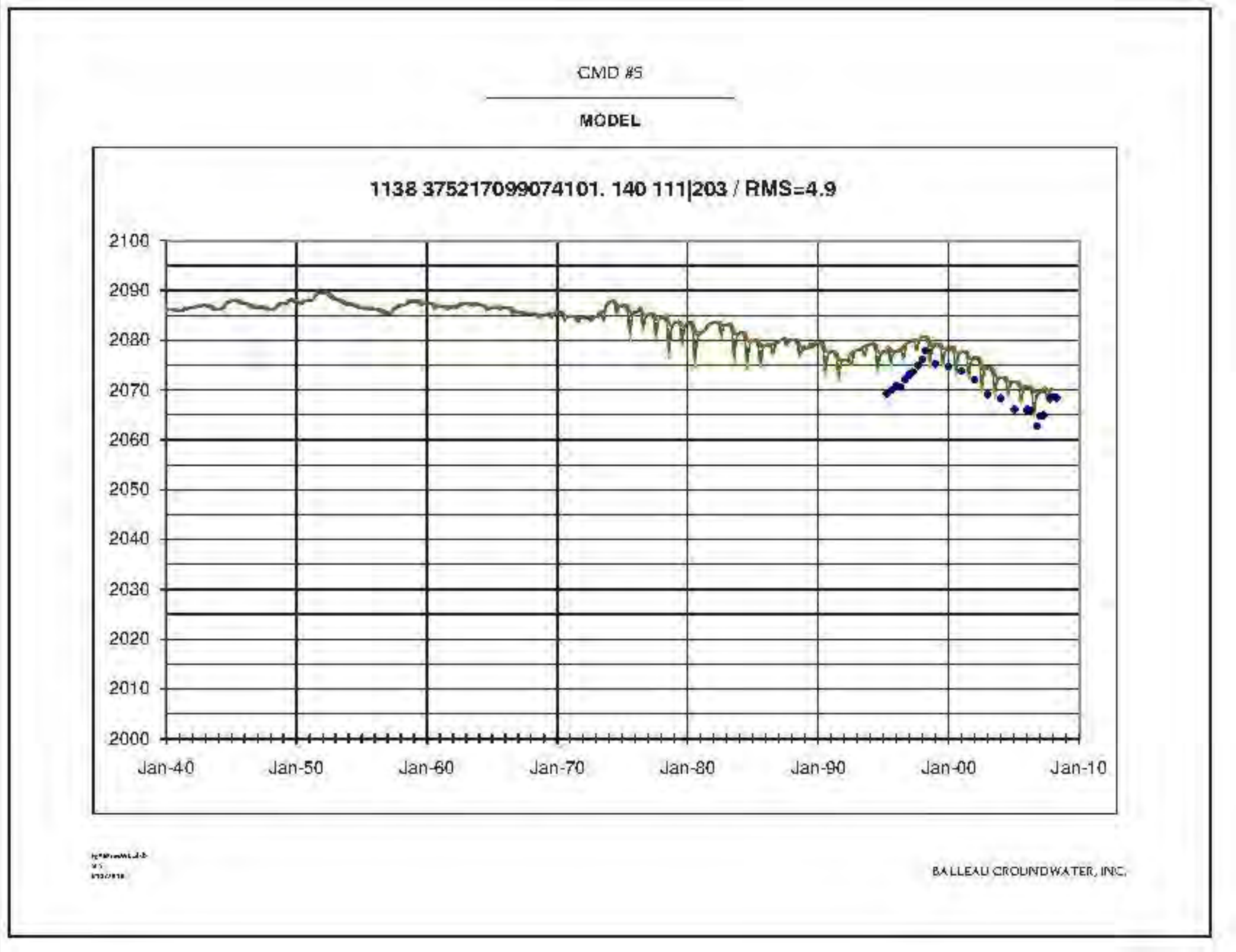
# GW Hydrograph for Edward County Well from Year 2010 Report



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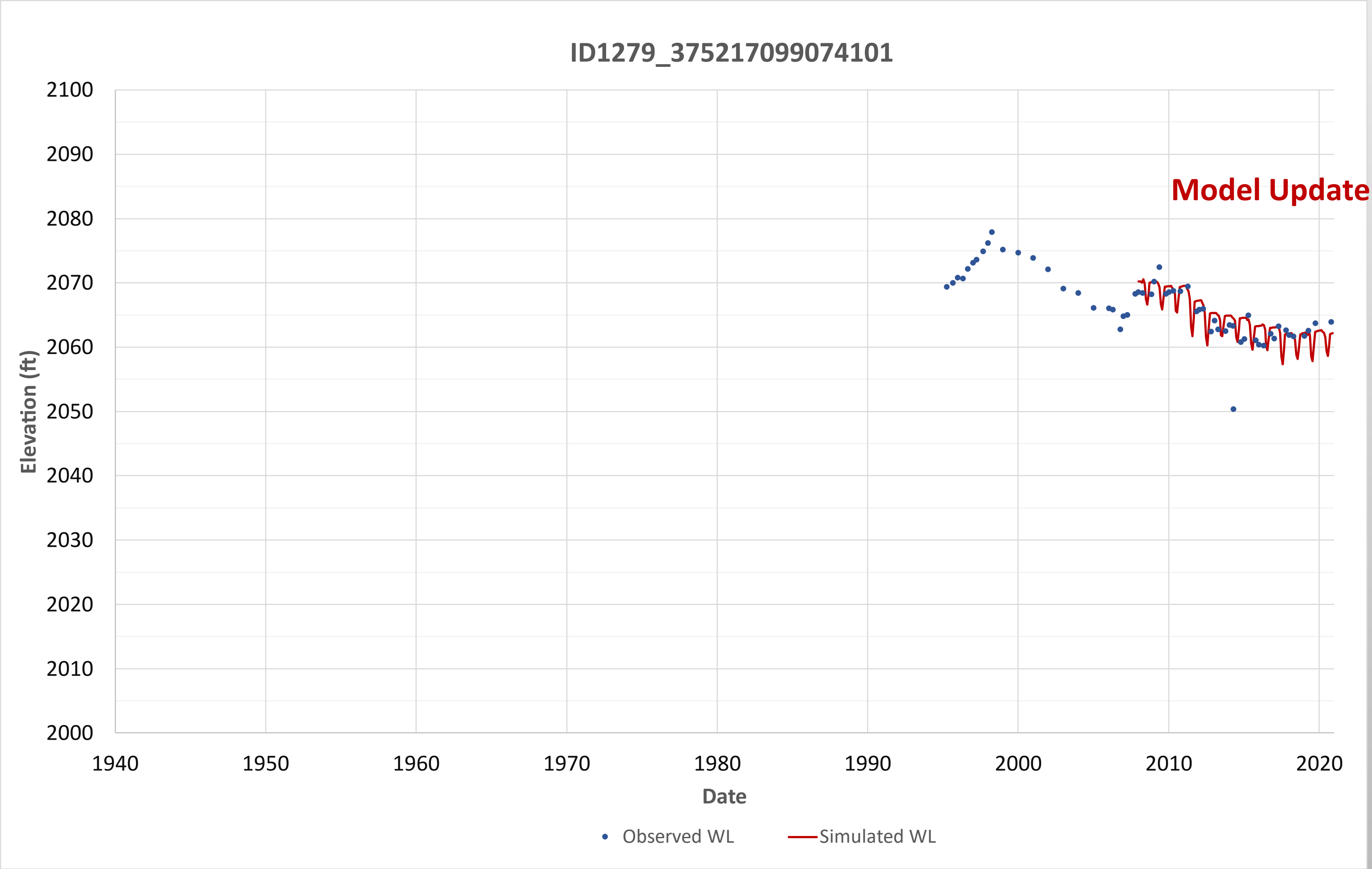
# GW Hydrograph for Edward County Well from Updated Model






Model Update Period: 2008 through 2020

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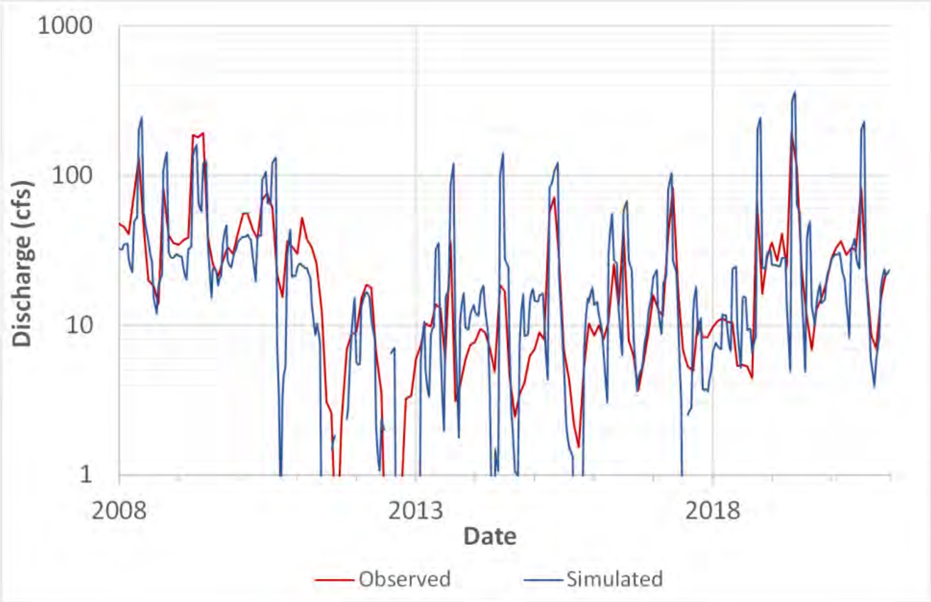
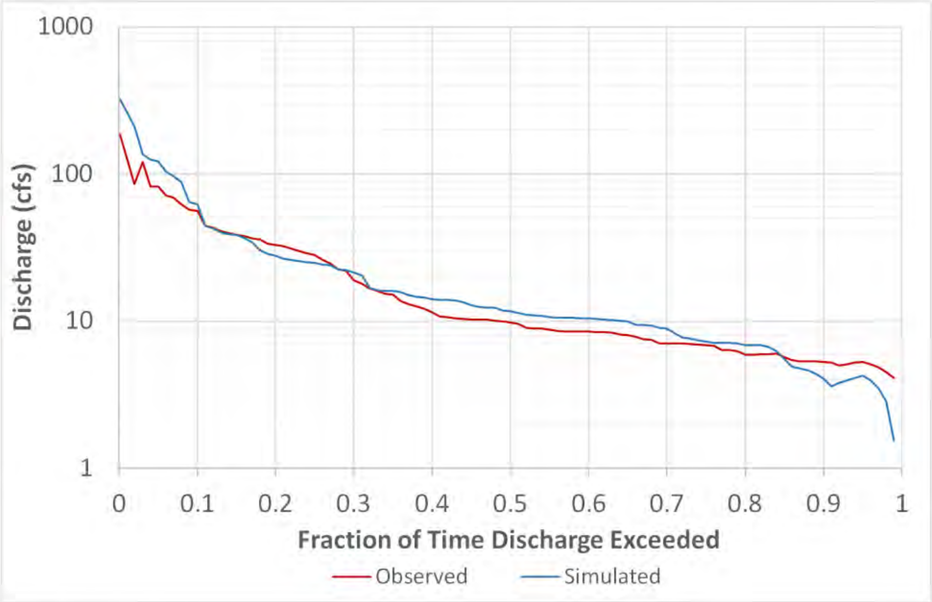
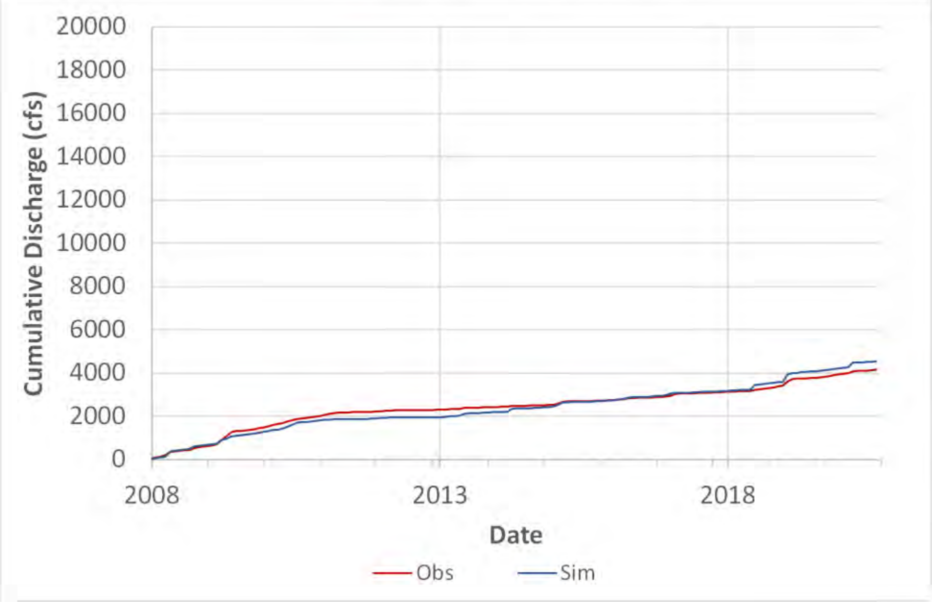
# Zenith Gage from Updated Model




**Model Update Period: 2008 through 2020**



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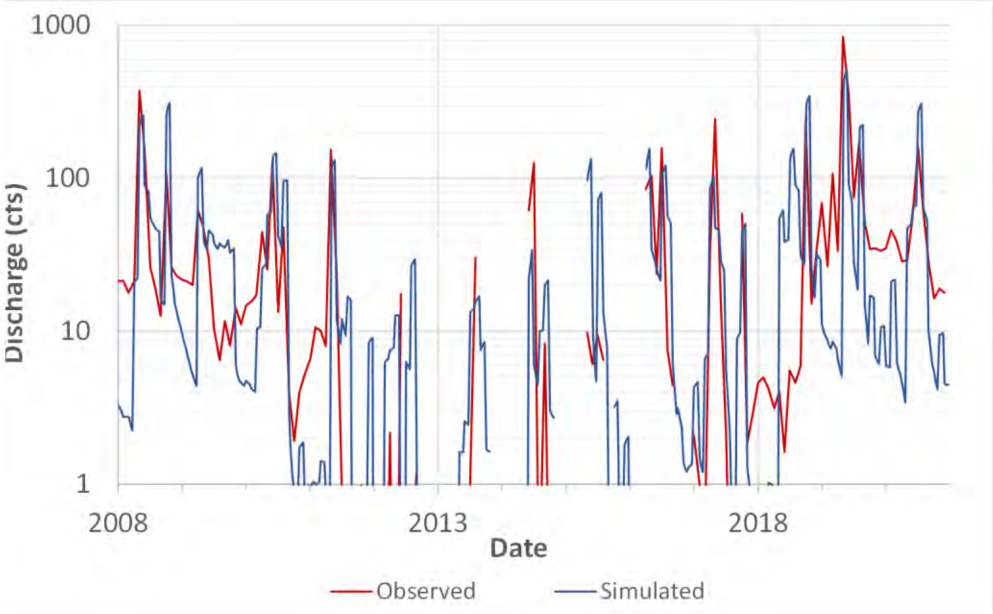
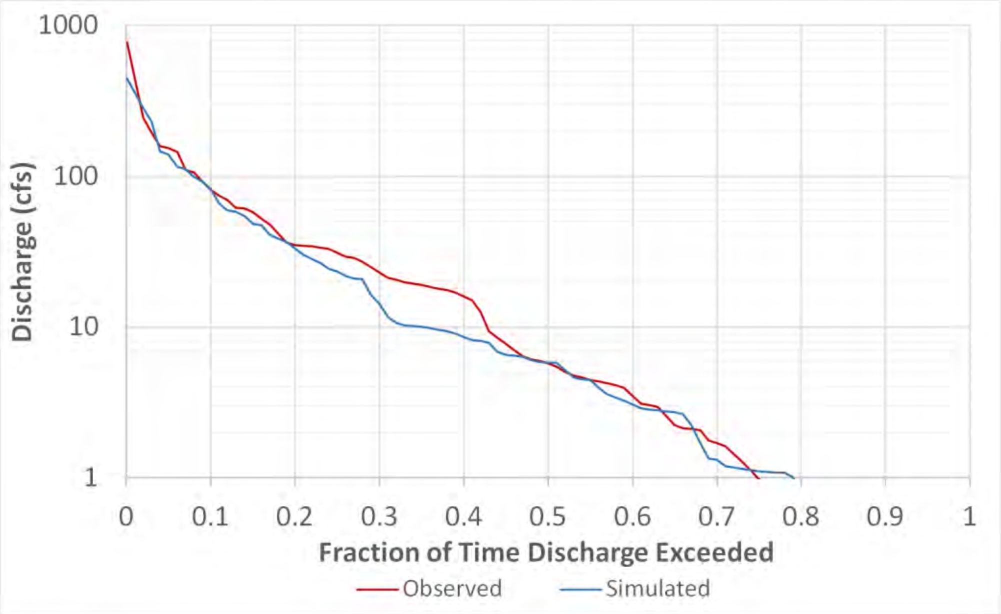
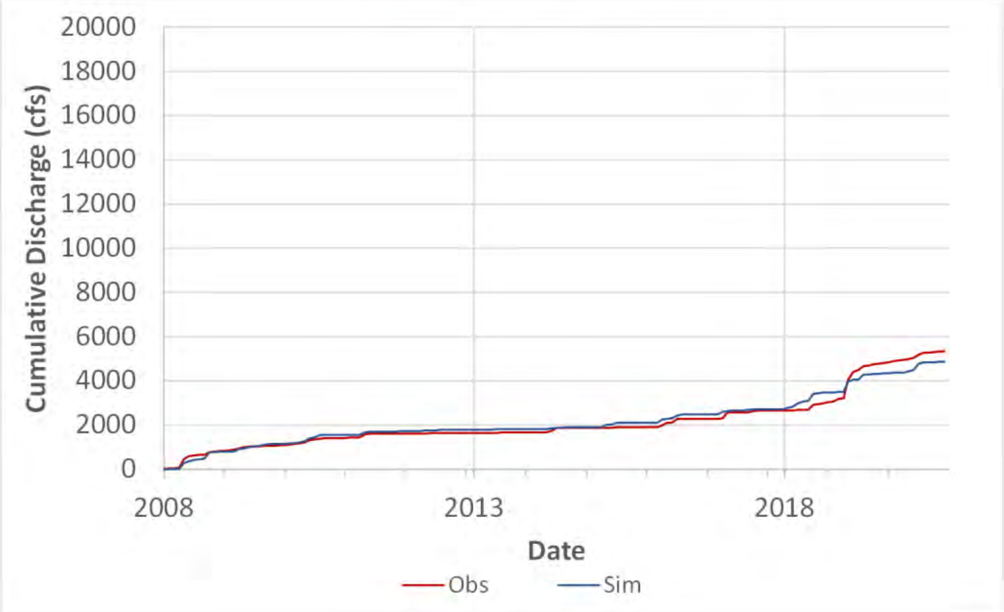
# Albert Gage from Updated Model




**Model Update Period: 2008 through 2020**



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# Discussion Topics

1. Scope of Model Update and Work Performed
2. Review of Model Results
3. Adjustment of Runoff/Recharge Curves
4. Status of Model and Utility
5. Recommendation

# Adjustment of Runoff/Recharge Curves



The model has precip/runoff/recharge relationships that characterize storm events and land use changes that occurred historically (1940 through 2007).

**Observation:**
After the drought of 2011 and 2012, a series of intense precipitation events occurred, practically on an annual basis. A pattern that is distinct from the modeled historical period (1940 through 2007).

**Adjustment:**
We refined the precip/runoff/recharge relationships to account for this wetter pattern that had not previously occurred in the modeled historical period.

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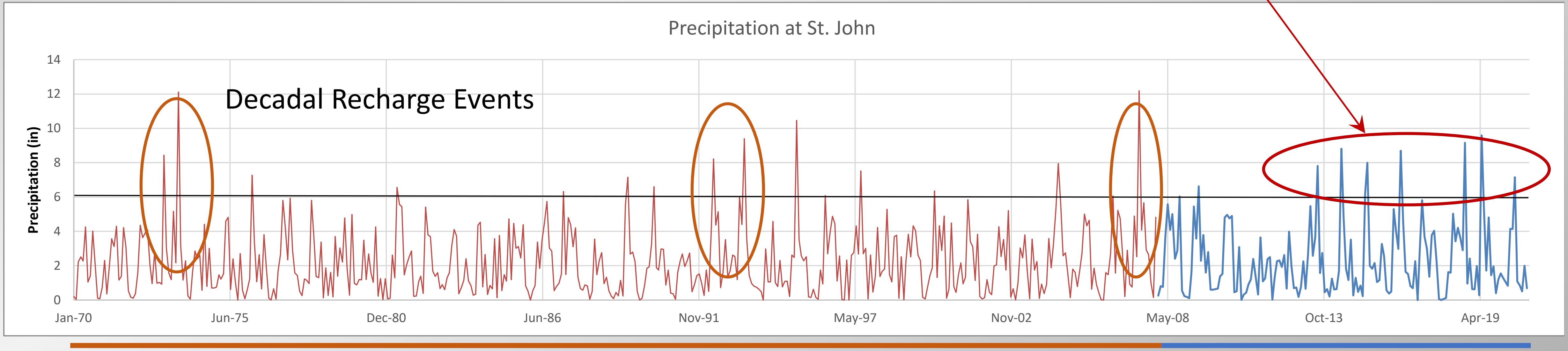
# Historical Precipitation at St. John

Frequency of intense precipitation events (> 6 inches) has increased in the last decade.

Yearly events cause model to overshoot on recharge-driven river flow




Original GMD5 Model Historical Simulation

Update Period
(2008 through 2020)

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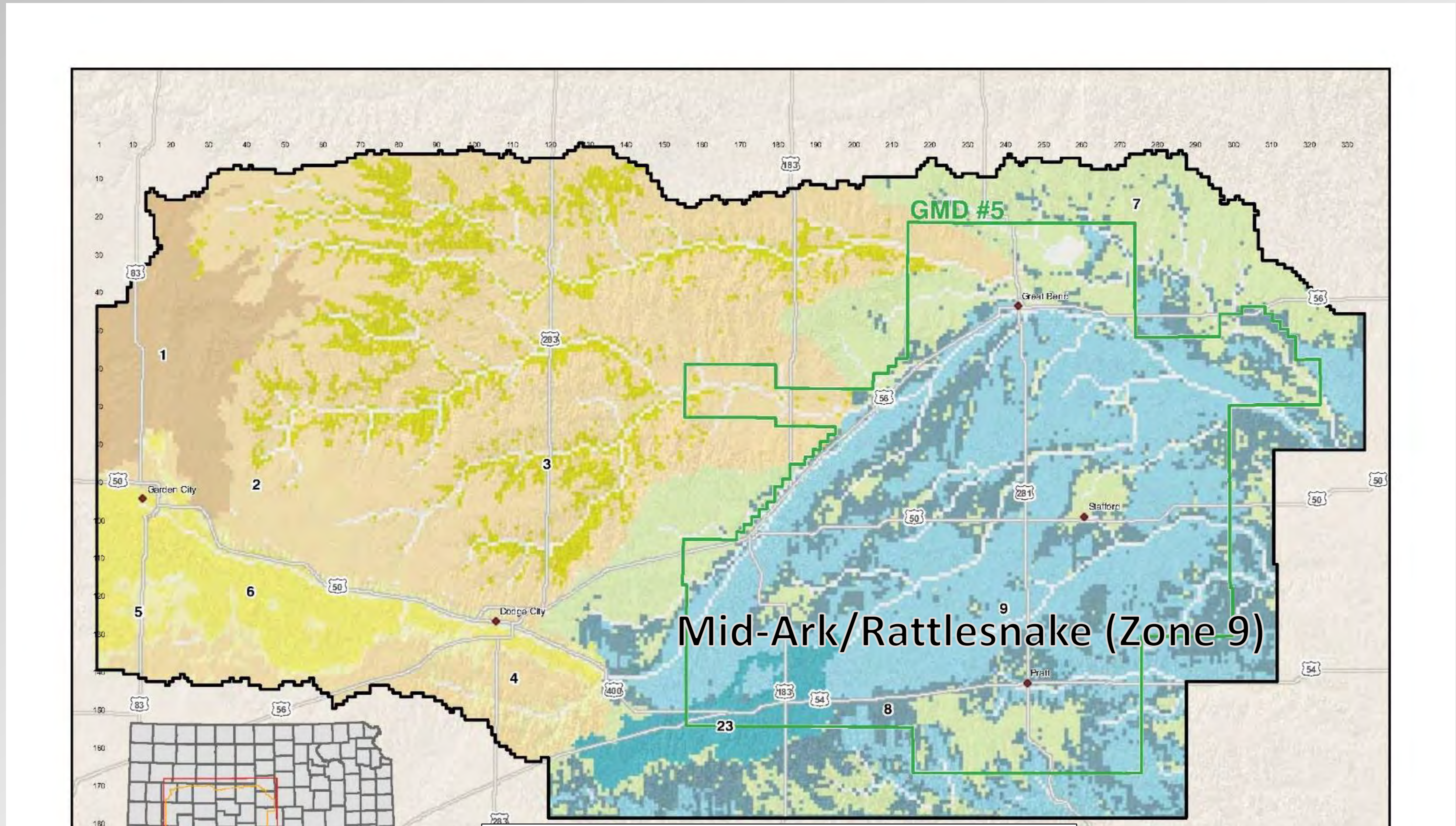
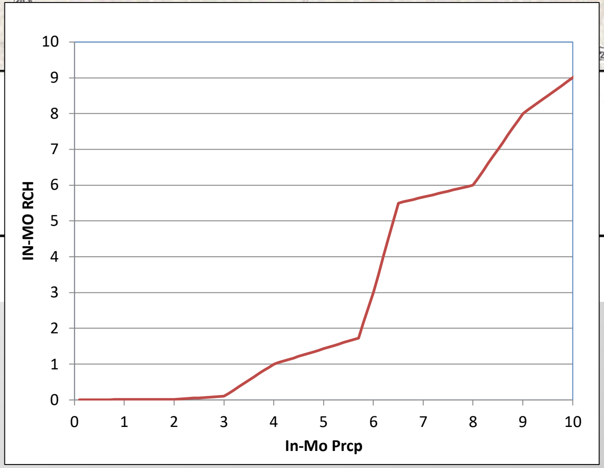
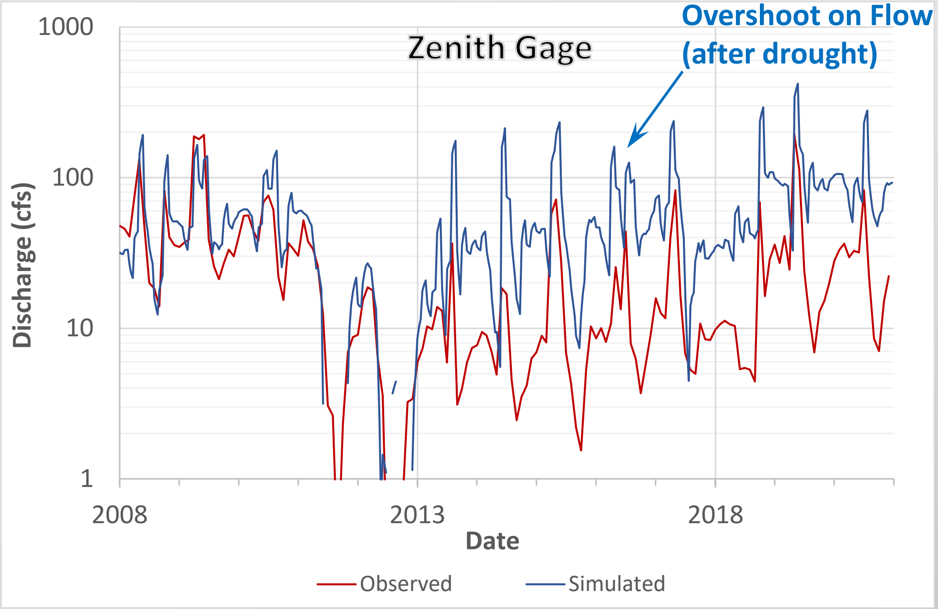
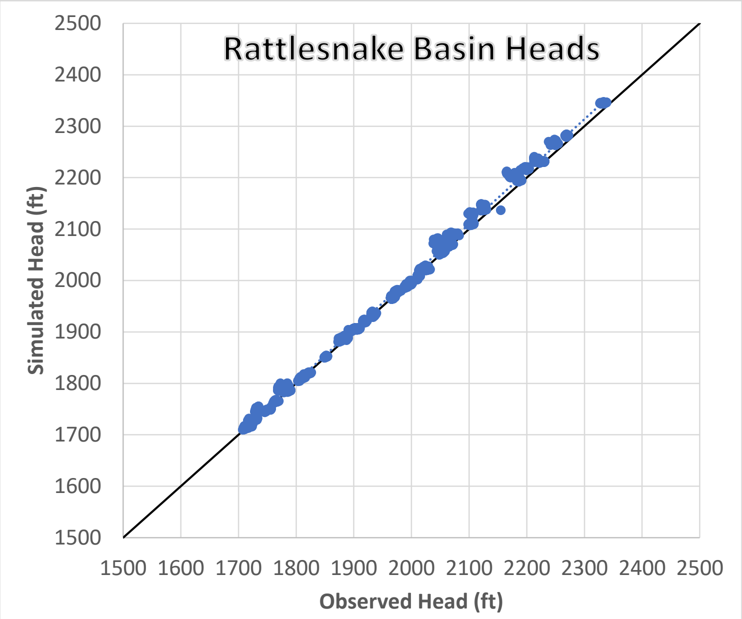
# Unmodified Recharge/Precipitation Relationships




Initial Prcp/Rch Relationship, Mid-Ark/Rattlesnake (Zone 9)




Initial Model Performance: at Zenith Gage and Rattlesnake Heads

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# Updated Recharge/Precipitation Relationships

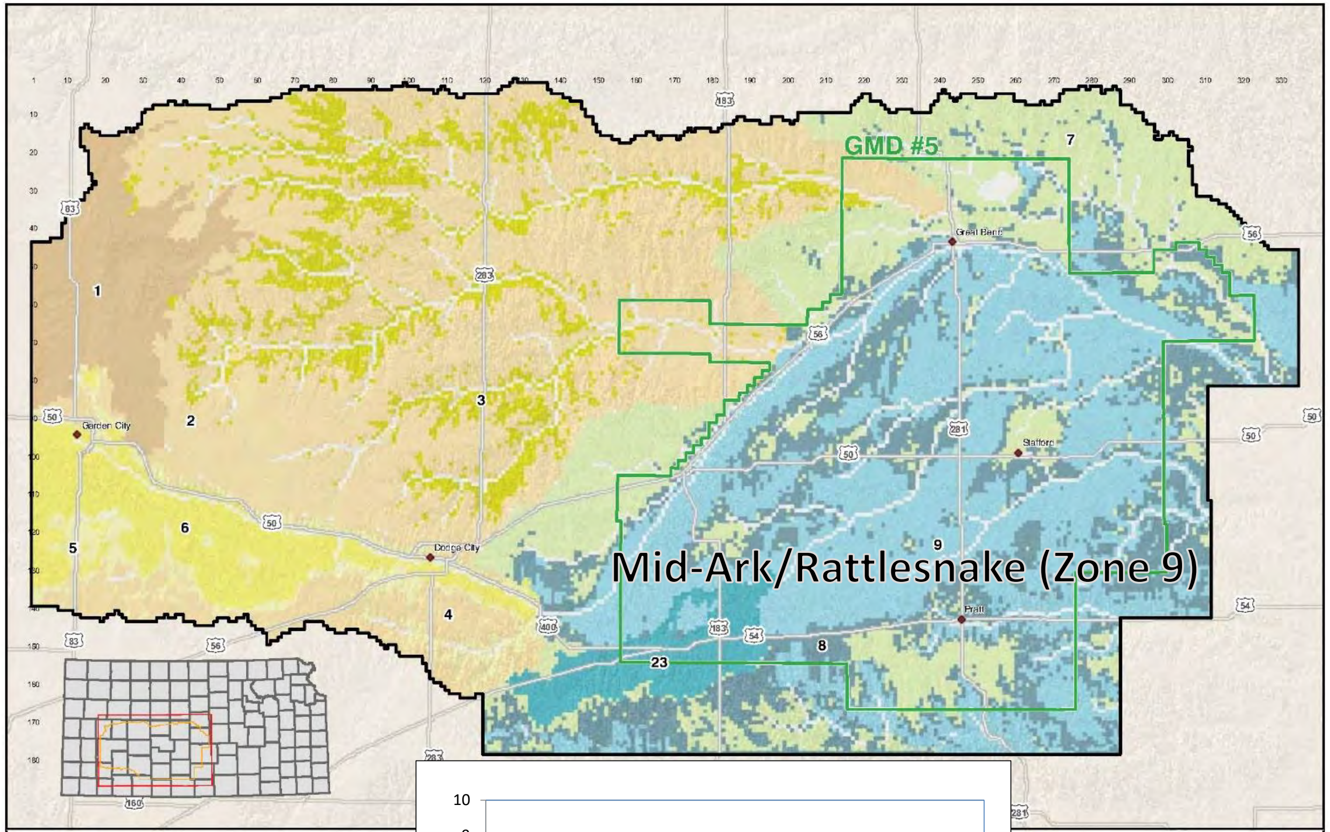
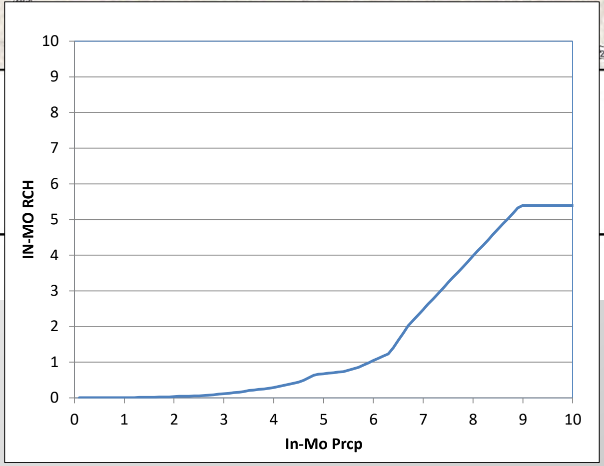


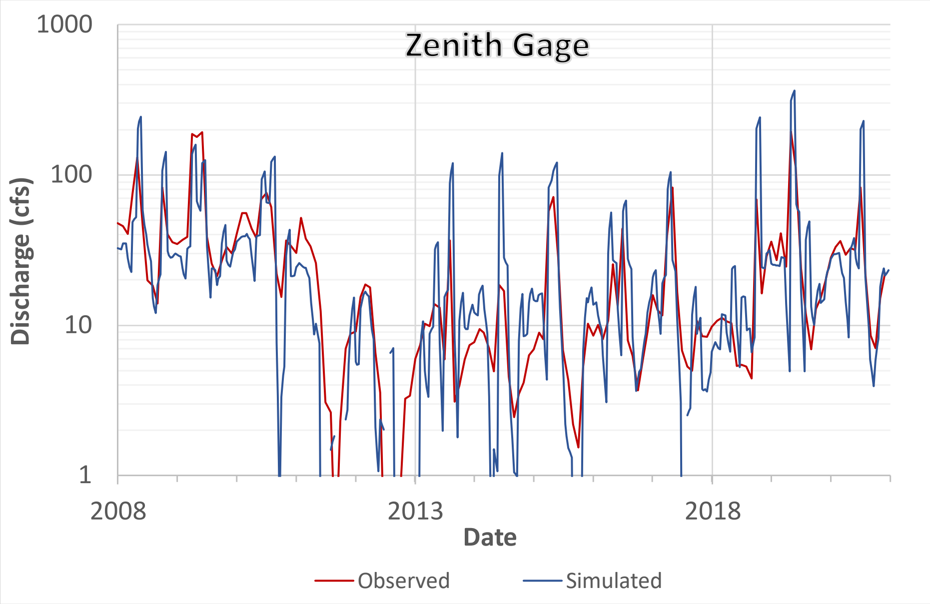

**FIGURE 33.** Modeled Recharge Zones

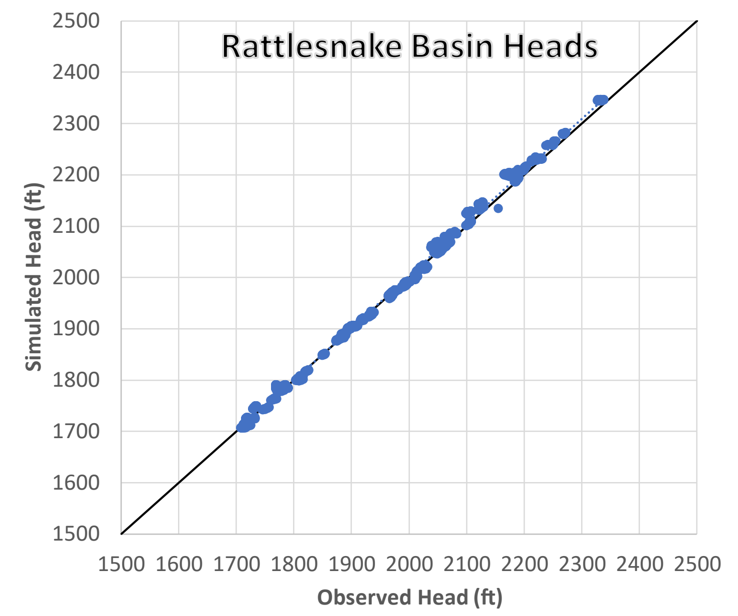
GMD #5 / MODEL

BALLEAU GROUNDWATER, INC.




**Updated Prcp/Rch Relationship, Mid-Ark/Rattlesnake (Zone 9)**

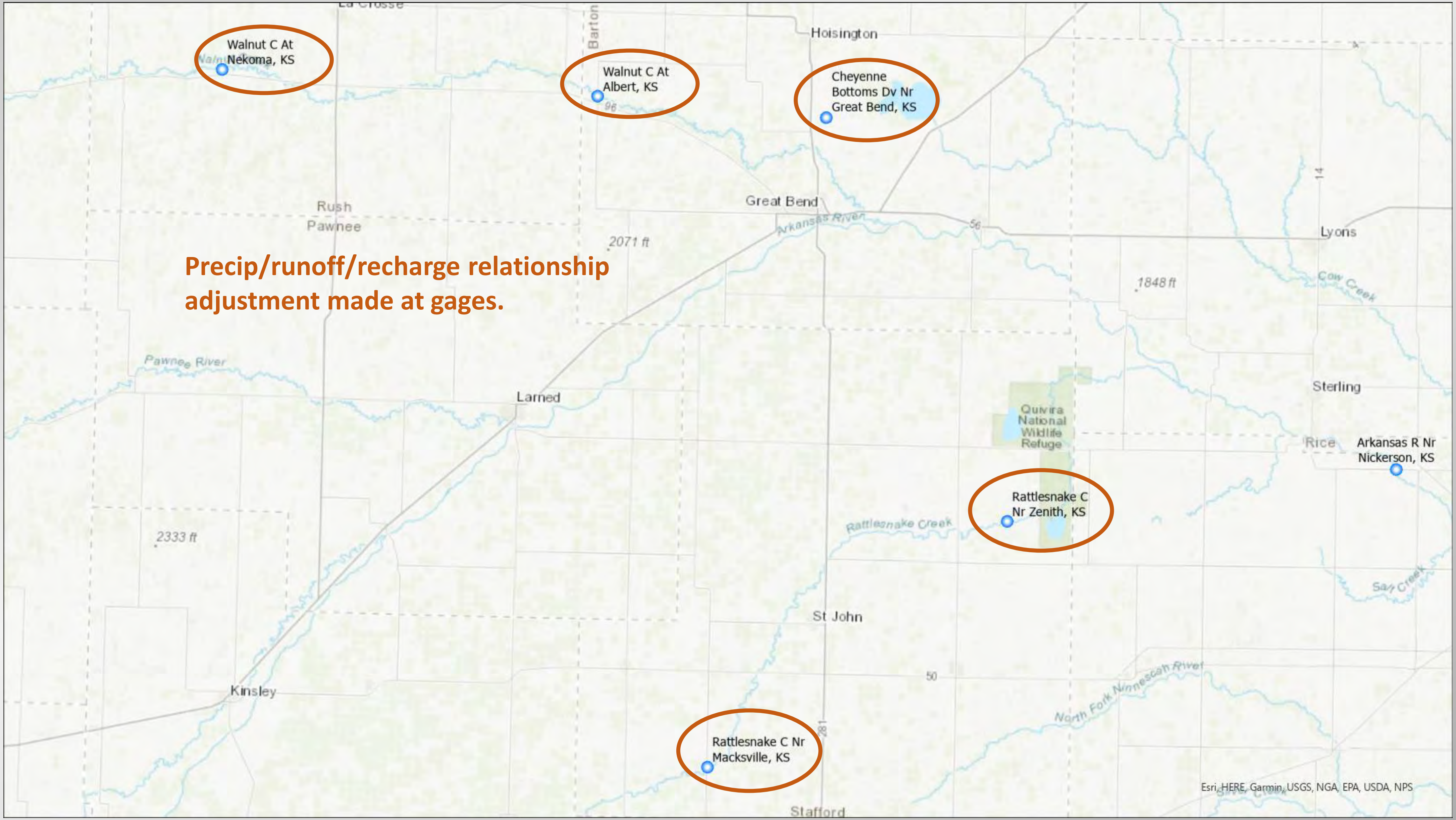



**Updated Model Performance: at Zenith Gage and Rattlesnake Heads**

DRAFT

# Surface-Water Hydrograph Locations




**Precip/runoff/recharge relationship adjustment made at gages.**

DRAFT

# Discussion Topics



1. Scope of Model Update and Work Performed
2. Review of Model Results
3. Adjustment of Runoff/Recharge Curves
4. Status of Model and Utility
5. Recommendation

# Status of Model and Utility



After adjusting the precip/runoff/recharge relationships, the model performance is at a level like that of the original model (calibrated from 1940 through 2007) in the Walnut and Rattlesnake Creek basins. *We note that adjustments could be completed in other basins.*

For analyses in the Walnut Creek IGUCA, we consider the model serviceable. That is, we do not anticipate significant changes to analysis results in the Walnut Creek Basin if the adjustments are made in other basins.

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# Discussion Topics



1. Scope of Model Update and Work Performed
2. Review of Model Results
3. Adjustment of Runoff/Recharge Curves
4. Status of Model and Utility
5. Recommendation

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# Recommendation

In the process of adjusting the precip/runoff/recharge relationships shown today, we learned an improved approach for the adjustment. Currently, it is based on an adjustment to modeled recharge.

The improved approach involves implementing a limit on precipitation that effectively provides recharge. We recommend considering an update to the relationships with the improved approach. It would be applied to at all of the gages shown on Slide 18.

DRAFT

Discussion/Questions?

# EXHIBIT E

No. 126, Original

In The

# Supreme Court of the United States

STATE OF KANSAS,

*Plaintiff,*

v.

STATE OF NEBRASKA

and

STATE OF COLORADO,

*Defendants.*

**FINAL REPORT OF THE SPECIAL MASTER WITH CERTIFICATE OF ADOPTION OF RRCA GROUNDWATER MODEL**

VINCENT L. MCKUSICK
Special Master
One Monument Square
Portland, Maine 04101
(207) 791-1100

September 17, 2003

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## FINAL REPORT OF THE SPECIAL MASTER

By its decree dated May 19, 2003 ("Decree"), this Court approved the Final Settlement Stipulation ("FSS") that all of the parties to this original action, namely, the States of Kansas, Nebraska, and Colorado, had executed and filed with me on December 16, 2002. The FSS laid out the parameters for the RRCA Groundwater Model which would, for use in the accounting formulas for administering the Republican River Compact, determine both stream flow depletions caused by groundwater pumping and streamflow accretions resulting from recharge by imported water. The FSS further prescribed procedures for the timely completion and adoption of the Model by the States. In accordance with Section IV.C of the FSS, the Modeling Committee that was provided for therein completed the RRCA Groundwater Model and submitted it to the States in final form. All three States then approved and adopted the RRCA Groundwater Model prior to July 1, 2003. Accordingly, I present herewith my Certificate of Adoption by the party States of the RRCA Groundwater Model along with documentation of the Model as adopted by the States.

By the Decree the Court also dismissed with prejudice all claims, counterclaims, and cross-claims for which leave to file was or could have been sought in this case arising prior to December 15, 2002, and it made that dismissal effective upon the filing by the Special Master of a final report certifying adoption of the RRCA Groundwater Model by the party States. When the Court hereafter by its customary practice directs that this present report is received and ordered filed, the Court will thereby establish the effective date of the dismissal with prejudice of all claims as ordered by the Decree. By the terms of the

Decree nothing more will remain to be done to bring this action to a conclusion.

Respectfully submitted,

VINCENT L. MCKUSICK
Special Master
One Monument Square
Portland, Maine 04101
(207) 791-1100

September 17, 2003

**SPECIAL MASTER'S CERTIFICATE OF ADOPTION OF RRCA GROUNDWATER MODEL**

I, Vincent L. McKusick, Special Master in this action, hereby certify that the party States of Kansas, Nebraska and Colorado have now completed and adopted the RRCA Groundwater Model in accordance with the terms and conditions of the Final Settlement Stipulation approved by the Court in its Decree dated May 19, 2003. Documentation of the RRCA Groundwater Model as adopted by the States is filed herewith.

Dated: September 17, 2003

VINCENT L. MCKUSICK
Special Master

**STATE ADOPTION OF RRCA GROUNDWATER MODEL, *KANSAS v. NEBRASKA AND COLORADO*, NO. 126, ORIGINAL, UNITED STATES SUPREME COURT**

Pursuant to the terms of the Final Settlement Stipulation herein, the undersigned chief water administration officials and counsels of record hereby adopt the RRCA Groundwater Model, as described and set forth in the attachment hereto.

/s/ Hal D. Simpson
HAL D. SIMPSON
State Engineer
Colorado Division of Water Resources

KEN SALAZAR
Attorney General of Colorado

/s/ Carol D. Angel
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## REPUBLICAN RIVER COMPACT ADMINISTRATION GROUNDWATER 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 Groundwater Modeling Committee developed a comprehensive groundwater model to represent the groundwater flow system in the Republican River Basin. The primary purpose of the Republican River Compact Administration Groundwater 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 groundwater 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 groundwater 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.

## I. 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 1943 in order to equitably divide the waters of the Republican River Basin. Groundwater 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.

The Final Settlement Stipulation (FSS) in *Kansas v. Nebraska and Colorado*, No. 126 Original, which resolved that interstate dispute, provided for development of a comprehensive groundwater model to represent the groundwater flow system in the Republican River Basin. This document describes the content, construction, and calibration of the Republican River Compact Administration Groundwater 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).

### A. 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 groundwater 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.

### B. 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, groundwater 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 Groundwater 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.

### C. Model Findings and Summary

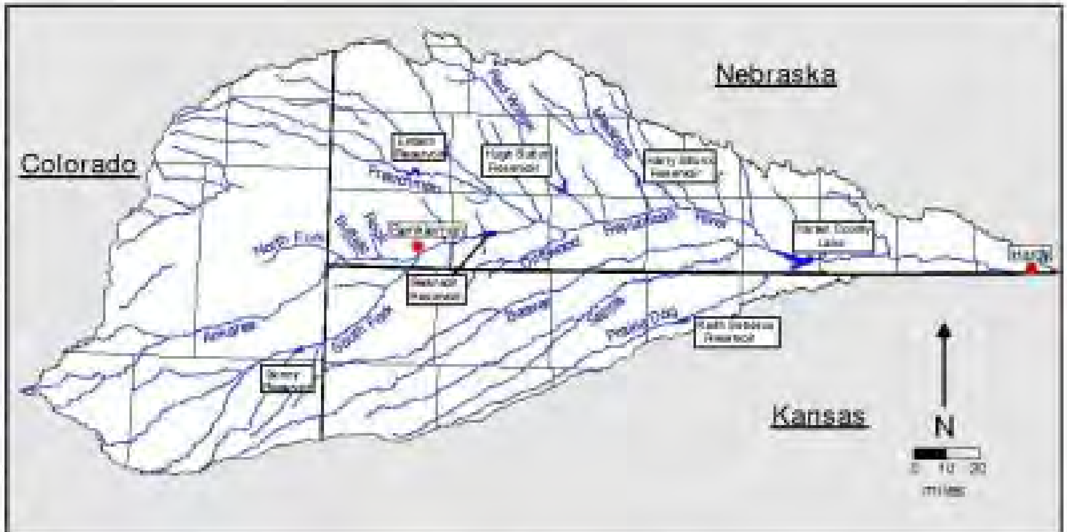
The RRCA Model is fully operational and calibrated to represent the physical and hydrogeological characteristics of the Republican River Basin to a reasonable degree. The RRCA Model reasonably matches the trend and magnitude of groundwater levels and stream baseflow targets distributed throughout the Republican River Basin, without significant bias in any region or hydrologic characteristic. The RRCA Model is calibrated to a sufficient degree that depletions from groundwater 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.

## II. Conceptual Model of Groundwater Flow System

### A. 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 groundwater 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.


Nebraska
Colorado
Kansas
N
miles

### B. Hydrogeology Framework

The predominant source of groundwater supply within the Republican River Basin is the shallow alluvium and deeper bedrock formations that collectively form the High Plains Aquifer. The High Plains Aquifer underlies portions of eight western States, including Colorado, Kansas, and Nebraska, and the topography is characterized by flat to gently rolling terrain that is bisected by mostly eastward-flowing rivers and streams, such as the Republican River. The predominant geologic unit of the High Plains Aquifer is the Miocene-aged Ogallala Formation of the Tertiary period. The Ogallala Formation principally consists of unconsolidated to semi-consolidated sands, gravels, clays, and silts. The High Plains Aquifer is also composed of the shallower river alluvium and eolian deposits of the later Quaternary period. Water-table or unconfined conditions are predominant throughout the Aquifer. However, in some areas the hydraulic interconnection between the stream systems and geologic units may have been broken and in other localized areas cemented “mortar” (caliche) beds are common and create artesian or confined aquifer conditions.

The depositional history of the High Plains Aquifer is complex because it contains both fluvial (stream-deposited) and eolian (wind-deposited) sediments. Braided streams systems that flowed eastward across the alluvial fans adjacent to the Rocky Mountains served as the primary source of deposition of coarse-grained and fine-grained sediments to the Ogallala Formation during the Tertiary time period. However, in the Quaternary period, as the climate in the area turned drier and colder due to mountain uplift, the major form of sediment deposition changed to eolian. The winds transported the fine materials caused by braided stream erosion in dust storms that carried very fine to medium sands to the east before settling into dune deposits, the largest and most prominent being located in west-central Nebraska. The Quaternary age alluvial, valley-fill, dune sand, and loess deposits are also considered to be part of the High Plains Aquifer where they are hydraulically connected to the underlying Ogallala Formation.

The saturated thickness of the High Plains Aquifer ranges from zero in the western edge of the aquifer in Colorado where the aquifer outcrops, to approximately 1,000 feet in west-central Nebraska. Groundwater flow in the High Plains Aquifer is generally from west to east in response to the predominant slope of the water table.

### C. Water Budget

The water budget for the Republican River Basin changed dramatically over the simulation period of 1918-2000. As anticipated, during the pre-development period the natural precipitation recharge, evapotranspiration and stream gains were the only significant stresses on the system. Beginning in the 1940's, accretions from surface water canals in the Platte River Basin began to migrate into the Republican River Basin groundwater system and introduce a significant new recharge into the system. Well pumping increased from approximately 1950 to 1980, then essentially leveled off but continued its impact as a major stress on the system. Coincident with well pumping increases, return flows from groundwater irrigation became a significant source of recharge. For illustrative and comparative purposes, the selected water budget components are tabulated below and a graphical representation is provided in Appendix C.

| **RRCA Model Global Water Budget**<br>Annual Average Amount in acre-feet | | | | | | |
|---|---|---|---|---|---|---|
| Years | **Inflows** | | | | | |
| | Precipitation Recharge | Groundwater Recharge | Surface Water Recharge | Canal Leakage | Stream Losses | Decrease in Storage |
| 1921-1930 | 1,440,697 | 0 | 0 | 0 | 222,780 | 424,581 |
| 1931-1940 | 601,512 | 1,264 | 421 | 15,996 | 229,750 | 632,529 |
| 1941-1950 | 1,916,460 | 15,262 | 47,777 | 632,988 | 208,071 | 467,162 |
| 1951-1960 | 1,283,039 | 69,083 | 99,152 | 652,719 | 207,269 | 812,763 |
| 1961-1970 | 1,479,667 | 237,718 | 102,332 | 598,784 | 230,134 | 1,217,401 |
| 1971-1980 | 1,452,260 | 595,112 | 111,638 | 665,139 | 236,637 | 2,511,248 |
| 1981-1990 | 1,740,645 | 572,102 | 101,767 | 623,134 | 233,679 | 2,309,917 |
| 1991-2000 | 1,998,741 | 498,803 | 86,742 | 607,402 | 234,982 | 2,221,763 |

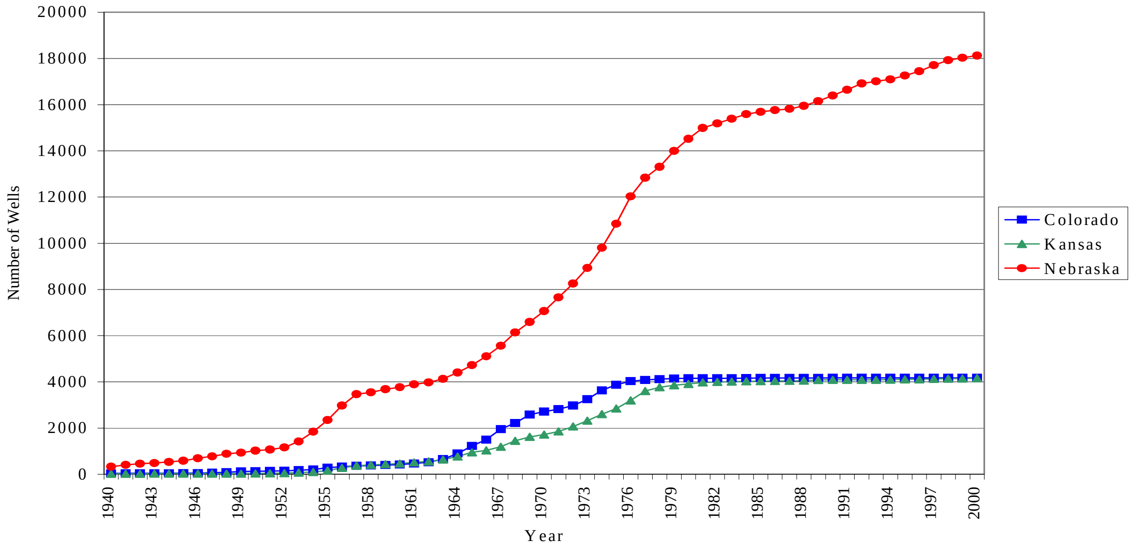
| RRCA Model Global Water Budget<br>Annual Average Amount in acre-feet | | | | | | |
|---|---|---|---|---|---|---|
| Years | Outflows | | | | | |
| | Phreatophyte ET | Springs | Well Pumping | Constant Head Boundaries | Stream Gains | Increase in Storage |
| 1921-1930 | 477,250 | 65,435 | 6,227 | 167,033 | 448,280 | 923,836 |
| 1931-1940 | 460,743 | 65,368 | 10,059 | 165,869 | 439,771 | 339,611 |
| 1941-1950 | 466,106 | 76,599 | 52,441 | 434,574 | 511,874 | 1,746,297 |
| 1951-1960 | 502,402 | 86,981 | 227,993 | 581,770 | 489,936 | 1,234,618 |
| 1961-1970 | 542,580 | 86,624 | 898,512 | 553,367 | 509,096 | 1,276,170 |
| 1971-1980 | 493,572 | 85,542 | 2,553,584 | 557,971 | 466,483 | 1,414,830 |
| 1981-1990 | 487,373 | 83,919 | 2,595,959 | 575,350 | 426,078 | 1,412,304 |
| 1991-2000 | 470,615 | 87,937 | 2,537,878 | 554,059 | 411,616 | 1,586,317 |

### D. Groundwater Pumping

#### 1. Irrigation Pumping

Groundwater pumping for irrigation of croplands in the Republican River Basin was limited prior to World War II but progressed rapidly in the 1960's and 1970's. The cumulative number of irrigation wells within the Republican River model domain over time is illustrated in the graph below. The States agreed to accept the method each one developed to estimate gross irrigation pumping within their respective boundaries for the period 1940-2000. The methods used by each State for estimating historical groundwater pumping and tabulations of the annual pumping estimates are provided in Appendix D.

Cumulative Number of Active Wells in the Republican River Model Domain



### 2. Pumping for Municipal and Industrial Uses

The pumping for municipal and industrial purposes for Colorado and Nebraska was obtained from the USGS and subsequently verified and refined by each state. Kansas developed its estimates from its wateruse database. Municipal and industrial pumping estimates include those quantities equal to or greater than 50 acre-feet/year.

## E. Recharge

Recharge into the groundwater aquifers is from two primary sources of water: recharge from precipitation and recharge from human-induced activities such as irrigation of cropland and seepage from ditches/canals. Recharge from irrigation is further segmented into two principal components based upon the source of water – surface water or groundwater. The following narrative describes how these components were estimated for the period 1940-2000.

### 1. Recharge from Precipitation

Precipitation recharge is a significant variable in the overall water budget because it affects the entire model domain of over 19 million acres. Average precipitation between 1918 and 2000 varies from approximately 16 inches per year in the western part of the study area to approximately 27 inches per year in the eastern part of the Basin. Recharge from precipitation generally increases from west to east across the domain. Recharge from precipitation is also influenced by soil type. More recharge is generated on coarse textured soils than fine textured soils for the same amount of precipitation. Therefore, STATSGO soil maps were initially used to locate sandy soils in the domain. These areas are commonly referred to as the *sand hills* of Colorado and western Nebraska. In a similar manner, medium and fine textured soils were identified. For simplicity, the three soil classifications used in the RRCA Model are described as coarse, medium, and fine. The final distribution of soils across the model domain is illustrated in Appendix E.

Recognizing the amount of precipitation that recharges the groundwater aquifer increases in proportion with the amount of precipitation, a set of two curves was developed for each soil classification. One curve is for irrigated lands and the other for non-irrigated lands. The Y-axis for each curve represents the number of inches of recharge from precipitation and the X-axis depicts the total amount of precipitation each year. In addition to the curves developed for the three predominant soil classifications, a two-curve precipitation recharge set was similarly developed for tributary alluviums and another for the main stem of the Republican River alluvium to represent their unique recharge and soil characteristics. The curves were developed from historical climate information and analysis of output from theoretical soil-water balance computer models and refined as part of the calibration process. The extent of the increase in precipitation recharge for irrigation conditions relative to non-irrigated conditions was the subject of extensive discussion and the resulting recharge curves represent a compromise agreement that shall not be considered a precedent toward application of precipitation recharge to surface water accounting. The Precipitation Recharge Curves are provided in Appendix F and the amount of recharge from precipitation is tabulated in Appendix G.

### 2. Recharge from Groundwater Irrigation

Recharge from groundwater irrigation for all three States is calculated as the product of estimated pumping multiplied by an appropriate efficiency factor. The following methods are applied to calculate recharge from groundwater irrigation in each State for 1940-2000 and the amount of groundwater recharge is tabulated in Appendix H.

Colorado – Recharge from groundwater pumping in Colorado is calculated for each year and for each county. Groundwater recharge from sprinkler irrigation is calculated by multiplying the gross pumping for sprinkler irrigation by the percentage that returns as deep percolation. In a similar manner, the amount of groundwater recharge from flood irrigation is calculated by multiplying the gross pumping for flood irrigation by the percentage that returns to the aquifer as deep percolation. The total amount of recharge from groundwater per county and year is the sum of the returns to deep percolation from sprinkler and flood irrigation.

Kansas – Recharge from groundwater irrigation was calculated by subtracting the net pumping from the gross pumping, and deducting spray loss for sprinkler irrigation or surface water runoff on lands that are flood irrigated. The average percentage of pumping lost to spray loss was 6% until 1986 and declined to 3% in more recent years. The net surface water runoff from flood irrigation is 5%. Once the county monthly pumping and return flow values were calculated, they were distributed to the sections within the county using the annual well count and irrigated acreage. A section's percentage of the county's total irrigated acreage was calculated and multiplied by the county pumping and return flows to obtain values for the section.

Nebraska – Based on professional judgment, Nebraska assumed recharge rates that are generally inverse to assumed farm efficiency. Nebraska applies a groundwater irrigation efficiency of 70% from 1940 to 1960 and a linear increase from 70% in 1960 to 80% in 2000. These percentages were checked for reasonableness using information available on the number of wells and number of center-pivot irrigation systems for each year.

### 3. Recharge from Canals and Laterals

A number of canal systems supply surface water for irrigation within the domain that influences flow in the Republican River and its tributaries. Seepage from these canals and their corresponding laterals is specified in the model as a recharge term. The calculation of canal and lateral seepage recharge specified in the model is dependent on the type of canal system as summarized in the table below. Recharge estimates from canals and laterals are tabulated in Appendix I.

| Canal System Type | Method for Calculating Canal and Lateral Seepage Recharge |
|---|---|
| Small Non-Federal Ditches and Canals | Recharge from canal seepage and from surface water irrigation is combined into one term. The total amount of recharge for both the canal seepage and surface water irrigation is calculated to be 40 percent of tabulated diversions. |

| | |
|---|---|
| Federal Canals (Maintained by the US Bureau of Reclamation) | Recharge from canal seepage calculation based on methodology specified in Section IV.A.2.c in the RRCA Accounting Procedures. |
| Platte River Canals | Where available canal seepage was determined from measured farm headgate deliveries and diversions at the headgate with estimated evaporation from the canal surface subtracted out. Where these data were not available canal loss rates were estimated using the rates from like canal systems with available data. |

#### 4. Recharge from Surface Water Irrigation

Surface water irrigation recharge was specified based on a percentage of the water delivered to farm headgates by canal systems and small pumping plants that extracted water directly from surface water bodies. The methods used to calculate surface water irrigation recharge are provided in the table below. Recharge estimates from surface water are tabulated in Appendix J.

| Canal System Type | Method for Calculating Surface Water Irrigation Recharge |
|---|---|
| Small Non-Federal Ditches and Canals | Recharge from canal seepage and from surface water irrigation is combined into one term. The total amount of recharge for both the canal seepage and surface water irrigation is calculated to be 40 percent of tabulated diversions. |

| | |
|---|---|
| Federal Canals (Maintained by the US Bureau of Reclamation) | Recharge from surface water irrigation calculation based on methodology specified in Section IV.A.2.c in the RRCA Accounting Procedures. |
| Platte River Canals | Recharge from surface water irrigation was specified to be 40 percent of farm headgate deliveries for 1940 to 1960 linearly decreasing to 30 percent in 2000. |
| Small Surface Water Pumping Plants | Recharge was specified to be 25 percent of the water diverted. |

### F. Irrigated Acreage

The States agreed to methods for estimating irrigated acreage for the period 1940-2000, which are documented in Appendix K. The summary of the total estimated irrigated acreage at the beginning of each decade is provided below and the estimates by county and year for each State are tabulated in Appendix K.

| **Total Estimated Irrigated Acreage in Republican River Basin** | | | |
|---|---|---|---|
| Year | Colorado | Kansas | Nebraska |
| 1940 | 5,409 | 2,952 | 22,427 |
| 1950 | 15,900 | 6,080 | 188,031 |
| 1960 | 62,736 | 50,882 | 451,385 |
| 1970 | 428,009 | 196,831 | 638,969 |
| 1980 | 664,161 | 357,710 | 1,428,685 |
| 1990 | 667,351 | 402,132 | 1,498,400 |
| 2000 | 667,891 | 434,767 | 1,654,452 |

### G. Crop Irrigation Requirements

Colorado – The potential irrigation requirement for each crop for each county and year was estimated using the Hargreaves equation calibrated to the Penman-Monteith equation and is tabulated in Appendix L. The crop mix was obtained from County Assessor data. Effective rainfall was estimated using the procedure outlined in Irrigation Water Requirements, Technical Release No. 21, United States Department of Agriculture, April 1967 (Revised September 1970). The gain in soil moisture from winter and spring precipitation was an average of 2.0 inches (source: Republican River Basin Water Management Study, Steven J. Vandas, United States Bureau of Reclamation, March 1983). The net crop irrigation requirement was calculated as the potential consumptive use minus effective precipitation minus the gain in soil moisture from winter and spring precipitation.

Kansas – Using the Hargreaves equation calibrated to the Penman-Monteith calculations and effective rainfall from TR-21, the composite crop-weighted unit CIR was obtained for each year. At climate stations for which the requisite data to calculate the CIR for 1940-1949 were not available, data from a nearby station were substituted. The unit CIR for 1940-2000 was multiplied by the irrigated acreage described above to obtain volume of irrigation demand for each county. To account for winter soil moisture, a preliminary soil moisture factor was applied to each county in April and, if necessary, May, and was used to offset the CIR at the beginning of the irrigation season. The remaining CIR was then used as an initial estimate of net pumping.

Nebraska – Crop irrigation requirements are not estimated in the Nebraska procedure.

### H. Streams and Reservoirs

The RRCA Model considers only the impact of groundwater pumping and surface water imports to the baseflow for the major streams in the Republican River Basin. It is not a surface water model and total streamflows are not incorporated in its design or calculations. The stream network was adopted from the USGS Republican River Study and a schematic diagram is shown in Appendix M. The seven major federal reservoirs were simulated in the RRCA Model using historical elevations or reservoir stages.

### I. Phreatophytes

The potential evapotranspiration rate for the various classifications of phreatophyte vegetation (forest, woody, and marsh) was collapsed into a single ET rate that was calculated by the Hargreaves method using appropriate equivalent crop coefficients. Results were obtained for the Akron, McCook, and Red Cloud climate stations on a monthly time step. For selected Sub-basins, the change or encroachment of phreatophytes over time was adjusted in accordance with the curvilinear time-relationship developed from aerial photographic data provided by Michaela Johnson in a published Master's Thesis (Johnson, 2001) with refinements based on observed streamflows during calibration. The methods used by each State to calculate and assign phreatophyte distribution are provided in Appendix N. The phreatophyte potential evapotranspiration rates used in the RRCA Model are tabulated in

Appendix N in addition to the Sub-basin phreatophyte potential evapotranspiration factors that reflect the expansion of phreatophytes over time.

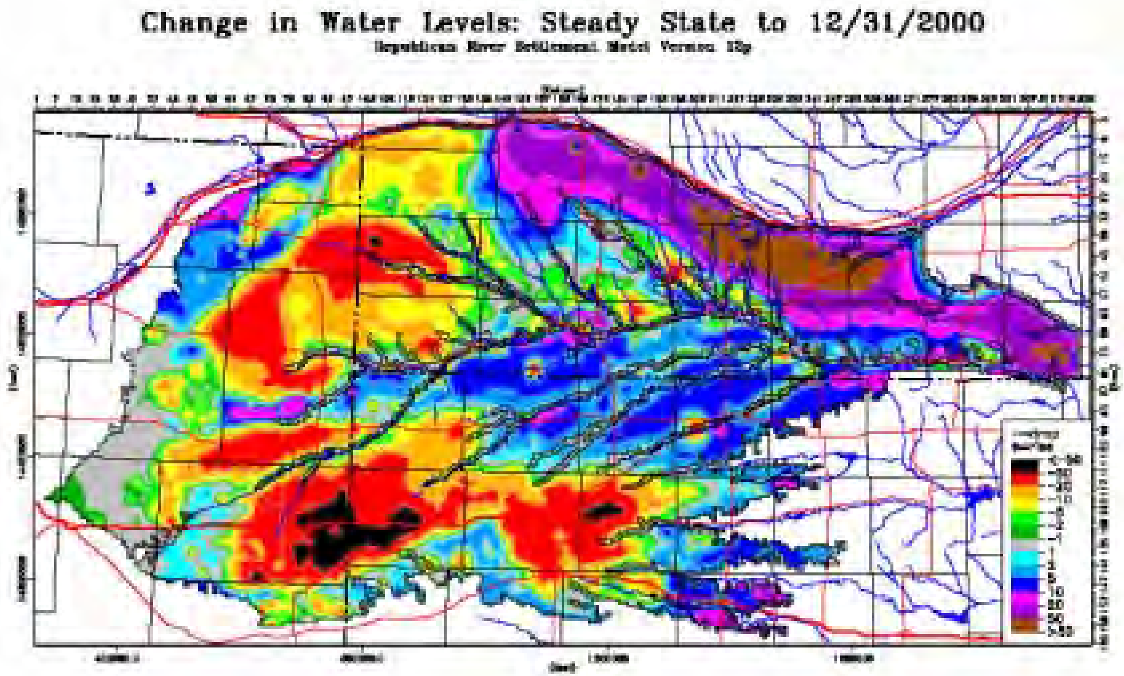
### J. Discussion of Flow Pattern

The general direction of water flow in the Republican River Basin is west to east with tributaries intersecting from both the southern and northern boundaries to the mainstem in the center of this gourd-shaped watershed. In the extreme north-central portion of the basin in Nebraska, there is a small amount of groundwater flow from the Republican River Basin north toward the Platte River Basin. Further east, groundwater migrates south from the Platte River Basin into the Republican River Basin in the northeastern portion area of the watershed referred to as the "mound area" that is approximately centered on the 99th Meridian. Headwaters of the Republican River are born on the high plains of eastern Colorado and combine with tributaries from southwestern Nebraska and northwestern Kansas to form the mainstem of the Republican River at the confluence of the North Fork of the Republican River and Arikaree River near Haigler, Nebraska. The Republican River flows eastward and generally parallel to the Nebraska-Kansas stateline before turning in a southeastern direction to cross the border near Hardy, Nebraska. The Republican River meets the Smoky Hill River at Junction City, Kansas to form the Kansas River, a major tributary to the Missouri River.

Streamflows are captured and retained in seven federal reservoirs that are within the Republican River Basin upstream of the Nebraska-Kansas stateline near Hardy, Nebraska. The reservoirs and associated tributary streams are as follows, progressing from the headwaters downstream:

| | |
|---|---|
| Bonny Reservoir | South Fork of the Republican River, Colorado |
| Swanson Lake | Mainstem of the Republican River, Nebraska |
| Enders Reservoir | Frenchman Creek, Nebraska |
| Hugh Butler Lake | Red Willow Creek, Nebraska |
| Harry Strunk Lake | Medicine Creek, Nebraska |
| Keith Sebelius Lake | Prairie Dog Creek, Kansas |
| Harlan County Lake | Mainstem of the Republican River, Nebraska |

The RRCA Model predicted change in water levels vary dramatically across the Republican River Basin from the pre-development period through 2000. The maximum rise in water level is approximately 179 feet in the mound area in Nebraska and the greatest decline is approximately 86 feet near Burlington, Colorado. For illustrative purposes, the predicted change in water levels in the RRCA Model domain is shown below.


Change in Water Levels: Steady State to 12/31/2000
Republican River Settlement Model Version 12p

## III. Mathematical Representation of Groundwater Flow Model

### A. Model Program

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

### B. 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 groundwater flow system was simulated as if there were a constant transmissivity in order to preserve numerical stability.

### 1. Simulation Period

The RRCA Model represents the long-term steady-state conditions prior to 1918 and transient conditions from 1918 to 2000. Transient conditions are discretized into monthly stress periods. The RRCA Model will be updated annually by the RRCA to reflect data from 2001 to the current accounting year.

### 2. Discretization

The RRCA Model is spatially discretized into one-square mile grid cells and temporally discretized into one-month stress periods, with two time-steps per stress period.

### 3. Boundary Conditions

Constant head boundary conditions for the model were assigned along the Platte River, the eastern boundary of Kearney, Clay, Nuckolls, and Adams Counties, Nebraska; and in Cheyenne County, Colorado where the Ogallala Aquifer continues south of the Republican River Basin. All other boundaries are no-flow boundaries or drains. See Appendix B, RRCA Model Domain for boundary and drain locations.

### 4. Initial Conditions

The steady state recharge, or initial condition, was established on the premise of no groundwater irrigation prior to 1940. The historical recharge for the period of 1918-1940, assuming no irrigation, was used in conjunction with the developed recharge curve(s) to obtain the recharge for each year. The recharge obtained for each year in the 1918-1940 period was averaged and assigned as the initial recharge condition in 1918, also known as the steady state condition. A global multiplier called the steady state multiplier was used to adjust the steady state recharge. During model calibration, the value of the steady state multiplier was established at 0.75, in part to replicate the long-term upward trend in the hydrographs observed in the western part of the domain.

### 5. Aquifer Parameters

The RRCA Model considers two aquifer parameters:

- The specific yield values were obtained from previous USGS investigations and reports and are portrayed in the Distribution of Specific Yields in Appendix O.
- Hydraulic conductivities were quantified through the calibration process and are portrayed in the Distribution of Hydraulic Conductivities in Appendix P.

### 6. Stresses

Calculation of the model stresses is fairly complex due to the variance in the three States' data and methods used to calculate well pumping for groundwater irrigation, surface water irrigation and the associated recharge. To provide resolution and a common platform, a set of programs was developed to transform the data from raw well and irrigation files to a common cell-by-cell format. This common format consists of a set of files named ***yyyy.mm.xxx***, where the letters designate the year, month, and type of information respectively. The type of information is "pmp" for pumping, "rcs" for surface water recharge, "rcg" for groundwater recharge and "rcc" for canal recharge. In addition, the file named **yyyy.xxx** is used to represent annual quantities and type of information respectively. For the annual quantities, "mi" is used to represent municipal and industrial pumping, "asw" is the surface water irrigated area, "agw" is the groundwater irrigated area, and "aco" is the commingled irrigated area. Volumes are always specified in acre-feet, and areas are always specified in acres.

Colorado – The Colorado groundwater input data consist of two databases. The well database specifies the location, county, appropriated acreage, and priority date for each well. The pumping database specifies the county totals for well pumping and the county-by-county groundwater irrigated efficiency. The **mkgw** program is then used to calculate cell-by-cell pumping, groundwater irrigation recharge, and irrigated areas. The program distributes pumping from the county to the model cells by assigning pumping proportional to the appropriated acreage of the active wells for that year. Pumping is distributed from the annual value to monthly values using a fixed proportioning. Irrigation recharge from groundwater is assigned to the same cells where the pumping occurs. The groundwater recharge is equal to the pumped amount multiplied by the return flow fraction, defined as one minus the irrigation efficiency. The appropriated acreage is used to calculate cell-by-cell groundwater irrigated acreage.

The Colorado surface water input data are also contained within two databases. The ditch database consists of the acreage per cell for each ditch system. The diversion database consists of monthly diversions for each ditch. Surface water irrigation returns are calculated as the fixed percentage of the diverted amount as specified in the settlement agreement. The surface water return flow amount is distributed over the ditch acreage proportional to the acreage in each cell. The **mksw** program is used to perform this calculation. The surface water irrigated acreage is the sum of the ditch acreages for each cell. There are no commingled surface and groundwater irrigation applications modeled in Colorado.

Kansas – The Kansas groundwater input data consists of two databases. The well database specifies the location, county and irrigated acreage by year for each well. The pumping database specifies the total pumping for each county by year, the irrigation efficiency by county by year, and the annual to monthly distribution factors by county by year. The **mkgw** program is used to calculate monthly cell-by-cell pumping by distributing annual county totals to months using the monthly factors, and then to cells in proportion to the irrigated acreage for each year. For years that records indicate the well is not pumping, an irrigated acreage of zero switches off pumping in that well. The groundwater recharge from groundwater pumping is assigned in the same cell as where the pumping occurs. The groundwater recharge amount is computed as a percentage of the pumped amount, equal to one minus the irrigation efficiency multiplied by pumping, adjusted down for runoff and spray loss.

The Kansas surface water return flow calculation is performed exactly like the surface water return flow calculation in Colorado except for those lands in Kansas served by the Almena Canal that are surface and groundwater irrigated commingled land.

Nebraska – The Nebraska raw data consists of seven databases. They include the lands served exclusively by groundwater irrigation database, the commingled lands groundwater irrigated database, the lands served exclusively by surface water irrigation database, the commingled surface water database, the river pumpers database, the private canals database, and canal leakage database. Each of the first four databases specifies the annual volume of applied water and area over which it is applied on a cell-by-cell basis. The river pumpers database and private canals database supply only the annual volume by cell and the canal leakage database supplies the monthly volume by cell. The program **mknedat** is used to create the required monthly groundwater pumping files by distributing the annual cell-by-cell pumping to a monthly timestep using a fixed set of factors. The groundwater recharge is calculated as a factor of the pumped amount. This factor is a constant over the State of Nebraska, and is 30% until 1960 and then reduces linearly to 20% in 2000. The pumping and groundwater irrigation recharge are calculated in the same manner for commingled and exclusively groundwater irrigated lands. The total of both commingled and exclusively groundwater pumping is written to a single pumping file. The exclusively groundwater pumping acreage is stored to the groundwater irrigation acreage files. The commingled groundwater acreage is not used in this application since it is the identical acreage that is designated as surface water commingled acreage.

Surface water farm deliveries are specified on a land-by-land basis. For each land, the cell and appropriate canal system is specified. The return flows from each land are calculated as the delivered amount multiplied by a system specific fraction. This fraction is specified in the FSS, and for most systems it is a constant with time, but for some systems the return flow fraction varies with time. The annual volume is accumulated for each cell and distributed to a monthly timestep using the same set of factors used to distribute the pumping. The irrigated acreage served exclusively by surface water is saved to the surface water irrigated area file and the commingled surface water area is saved to the commingled area file for the year.

River pumpers and private canals are specified as annual totals by cell. The return flow from these irrigation methods is calculated as a fixed fraction of the applied amounts and added to the cell-by-cell surface water return flows. The irrigated acreage is not considered.

The canal leakage database specifies canal losses on a cell-by-cell basis for every month and is simply copied to change the file format.

### 7. Stress Calculation

The Republican River Pre-Processor (**rrpp**) program is used to construct MODFLOW recharge and well pumping input files from these cell-by-cell files. The input files for each State are kept in a separate directory. The **rrpp** program reads the cell-by-cell monthly and annual files for all three States, calculates recharge from precipitation and outputs the resulting recharge and well pumping data sets as input to the MODFLOW program. A steady state step is used to establish the model initial condition at the beginning of the 1918 to 2000 transient simulation. There is no well pumping, irrigation recharge or canal leakage in this initial steady state. Therefore, the recharge consists only of precipitation recharge. The rrpp program calculates the precipitation recharge for each year from 1918 to 1940 and then averages the recharge. Each cell is assumed to be only non-irrigated during this period.

The **rrpp** program is used to generate MODFLOW input files for both the historical or base run and the impact runs – "no State pumping" for each of the States and "no Nebraska import." The program reads a set of instructions from a parameter file. The NOPUMP instruction is used to switch off irrigation well pumping and return flows for a particular State as well as the M&I pumping. The MOUND instruction is used to switch off all surface water returns and canal leakage within the area in Nebraska designated as the mound area. A map of the mound area in Nebraska is provided in Appendix A.

Pumping is calculated on a month-by-month basis by accumulating the cell-by-cell pumping specified in the individual State files. If pumping is switched off for a State, pumping for that State is simply omitted. The total pumping for each month is then written to the MODFLOW well file.

Recharge from irrigation is calculated on a month-by-month basis by accumulating the cell-by-cell return flows from precipitation, surface water and groundwater irrigation recharge, and canal leakage. Surface water return flows are accumulated on a cell-by-cell basis for each State, except when the MOUND instruction is used, in which case the surface water return flows inside the designated mound area are omitted. In a similar manner, canal leakage is accumulated on a cell-by-cell basis for each State, except again the mound area is omitted when so instructed. Groundwater recharge is also accumulated on a cell-by-cell basis for each State, except when the NOPUMP instruction is used, in which case the groundwater recharge for that State is omitted.

In order to calculate precipitation recharge, the irrigated area within each cell is accumulated as the sum of the groundwater, surface water and commingled area in the cell. When the MOUND instruction is used, the exclusive surface water acreage is not added within the mound area. Similarly when the NOPUMP instruction is used, exclusive groundwater acreage within the cell is not counted. Commingled acreage is always counted. If the total irrigated acreage within a cell equals or exceeds the number of acres in a cell, the entire cell is treated as irrigated. Otherwise the remaining acreage within a cell is treated as non-irrigated.

The annual precipitation for each cell is calculated by kriging the annual precipitation at a number of stations in the basin to the cell. For both the non-irrigated and irrigated fraction of the cell, the amount of recharge that corresponds to this precipitation amount is then calculated from precipitation recharge curves that correspond to non-irrigated and irrigated lands for the type of soil associated with this cell. The soil type and curves are specified in the parameter file read by the **rrpp** program. The resulting total recharge for the cell is then calculated as the product of the fraction of non-irrigated and irrigated lands multiplied by the respective recharge amounts. The total recharge from precipitation is then adjusted using a spatial multiplier to adjust the recharge amount for spatial variations in terrain. The resulting annual recharge amounts are then distributed to months using a fixed set of monthly factors.

The resultant total recharge is the sum of the precipitation recharge, surface and groundwater irrigation recharge, and canal leakage, appropriately adjusted to honor the NOPUMP or MOUND instructions. These values are written to the MODFLOW recharge file.

### 8. Phreatophyte Evapotranspiration

The MODFLOW evapotranspiration input file is generated by the **mket** program. This program calculates the monthly maximum evapotranspiration rate required by MODFLOW from four input files. The monthly phreatophyte evapotranspiration rate at the Akron, McCook and Red Willow climate stations is read from the first database. This rate is then multiplied by the phreatophyte area. The phreatophyte area is calculated from the present day cell-by-cell areas multiplied by a set of Sub-basin factors. The Sub-basin factors vary by year and hydrologic Sub-basin. Within each Sub-basin, the area is adjusted by the Sub-basin factor for that year. Basin factors were generated for the period 1938-1993. After 1993 the basin factors were assumed to remain at the 1993 levels. From 1935 to 1938, the basin factors were assumed to remain at the 1938 level. Although the basin factors were initially taken from the USGS, they were ultimately determined as calibration factors. However, no information prior to the catastrophic 1935 flood in the Republican River Basin is available. Since the flood regime of the basin changed with the construction of federal reservoirs in the 1950's and beyond, the present day phreatophyte growth is not representative of pre-development growth. Therefore the year 1950 was selected as a surrogate to represent predevelopment phreatophyte evapotranspiration.

The evapotranspiration surface is set equal to the NED ground surface, and the extinction depth is set to a constant ten feet. The NED ground surface is adjusted in the stream package setup to provide for streams always flowing down gradient. In those cells, the evapotranspiration surface is set at five feet above the stream channel elevation. This offset is intended to represent the elevation of the stream banks relative to the incised stream channel and is a constant across the basin.

### 9. Streams and Reservoirs

The stream network previously generated by the USGS was adopted for this study. The streambed conductance, thickness and area were adopted verbatim. The **mkstr** program was used to adjust the streambed elevation to represent the more accurate NED data that became available after the original USGS work and to introduce reservoirs to the stream network.

The streambed elevation for a cell was calculated as the average of the minimum NED elevation for a cell and the upstream cells within the stream network. For headwater cells, the elevation was set equal to the average NED elevation in the cell. The stream network was then traversed in a series of operations designed to ensure that the stream network runs down gradient. Where the NED reflects present day reservoir stages, a linear interpolation from the cell above and below the reservoir was used to represent pre-reservoir stream elevations.

In order to model reservoirs as part of the stream network, each reservoir was associated with one or more stream segments and a set of model cells. At the particular month that a reservoir came into operation, that stream segment was replaced by a set of reservoir cells with a conductance equal to one square mile in area, a hydraulic conductivity of one foot per day, and a thickness of ten feet. The reservoir segment of the stream network is isolated from the rest of the stream network by altering the tributaries array and an inflow into that segment is set to one million cubic feet per second. The stream elevation for each month is set equal to the middle of month stage for the reservoir. This arbitrarily large inflow ensures reservoir losses are not constrained within the reservoir segment. Since outflow from the reservoir segment is not transferred to downstream segments, the assignment of this inflow does not affect downstream computations. Note: the stream network must be specified for every stress period during which reservoirs are active because the reservoir stage changes from month to month. The specific yield was set to zero for those cells containing reservoirs because the reservoir storage change calculations are explicitly incorporated within the RRCA Accounting Procedures.

The HYDMOD package was used to extract stream flows and reservoir leakage at selected locations. A limitation of this package is that the number of reaches within a stream segment cannot change in order for the HYDMOD package to extract the flow at the correct location. Therefore, the **mkstr** program pads the reservoir segments of the stream network with "dummy reaches" to ensure that each segment contains the same number of reaches before and after the reservoir goes in. The dummy reaches can be identified as having a conductance of zero, which precludes any surface-groundwater interaction but ensures proper routing of flow and proper operation of the HYDMOD package.

## IV. Calibration of Groundwater Flow Model

### A. Purpose of Calibration

The purpose of calibrating the RRCA Model is to achieve an acceptable level of correspondence between model inputs, results and historical physical observations of the groundwater flow system in the Republican River Basin. The process of calibrating the RRCA Model also included the mathematical representation of the hydrogeologic framework, boundary conditions and hydraulic properties to reflect the physical characteristics of the Republican River Basin.

### B. Calibration Targets

#### 1. Water Levels

Groundwater levels have been measured throughout the Basin since the early 1900's, but the number of sites increased dramatically post-World War II. The source of groundwater level information used in the RRCA Model is the Groundwater Site Inventory (GWSI) maintained by the United States Geological Survey (USGS) in cooperation with all three States. The tenure of static groundwater level data ranges from a single-year measurement at a discrete location to a continuum of annual measurements that began in the early 1950's and continues to date at the same well. Groundwater levels are typically measured once each year, usually in the non-irrigation season when effects from irrigation pumping are minimized. The RRCA Model is calibrated to a groundwater level dataset that contains a total of 350,233 water level records at 10,835 different sites. The GWSI dataset was converted from latitude/longitude to an X-Y coordinate system. The entire dataset, including one-measurement water levels, was used in model calibration except for wells that were determined by the representative State to be clearly erroneous. The dataset and well hydrographs depicting observations and predictions are provided in electronic format in Appendix A.

### 2. Baseflow

Hydrograph separation is a technique that partitions the amount of surface water and groundwater that is measured as total streamflow at a river gaging station. Determining the component of total streamflow that is contributed by groundwater (also called baseflow) requires professional expertise and judgment. The hydrograph separation analysis used in this application is referred to as the Pilot Point method. This procedure was adopted for application in this groundwater model since it combines the benefits of graphical baseflow analysis with the computational efficiency afforded by electronic spreadsheets. Daily streamflow information for one, or multiple years, is easily tabulated in a Microsoft Excel© electronic spreadsheet. Daily hydrographs are subsequently plotted using the graphics package. The analyst performing the baseflow separation uses the tools available in the electronic graphics package to select pilot or turning points that signify the baseflow component in the total amount of streamflow measured at a river gaging station. A significant contribution of the graphics and computational package afforded by Microsoft Excel© is the flexibility to easily change the assignment of each pilot or turning point upon comparative review with other nearby streamflow hydrographs or in collaboration with another analyst. The analyst may change one or multiple pilot points using the click-and-drag tool to another turning point and instantly recalculate the amount of baseflow for a defined period of time – from a month up to decades.

For the RRCA Model, sixty-five (65) independent baseflow analyses were performed and adopted as calibration targets. Annual and monthly baseflow estimates for each analysis are provided in electronic medium in Appendix A.

**C. Comparison of Model Calculations to Targets**

The RRCA Model calculations match the representative baseflow and water-level targets to a reasonable and acceptable degree. For the baseflow evaluation, the RRCA Model results were evaluated in juxtaposition on a graphical format with the accepted baseflow quantifications for 65 different stream reaches. Based upon professional judgment, the model results reasonably match the trend and magnitude of the actual baseflow condition at the various locations.

Hydrographs showing the physical observations and model predictions were generated for all groundwater wells with measurements. Professional judgment was again used to evaluate the accuracy of the measurements and the comparison to model predictions, with greater weight being given to wells with a consistent measurement set and longer periods of record. In consideration of the magnitude and complexity of the model domain, the RRCA Model generally matched the observed water-level targets. The comparative evaluation of model calculations to physical targets based upon professional judgment, as opposed to a statistical assignment, is an acceptable method for a mathematical model with the magnitude and complexity inherent within the Republican River Basin.

### D. Calibrated Parameters

Calibration parameters are physical, climatic, and/or aquifer properties that can be adjusted to so that the mathematical representation of a groundwater model better represents actual conditions. Selection of final values for calibration parameters requires consideration of the match between model outputs and calibration targets, and whether such values are reasonable considering geologic, climatic, and other conditions in the Republican River Basin. Calibration parameters may vary in a spatial context to reflect different physical and/or geographic conditions. The two principal calibration parameters used in application to the RRCA Model are hydraulic conductivity and precipitation recharge.

#### 1. Hydraulic Conductivity

Hydraulic conductivity may be defined as the measure of the ease in which water can be transmitted through a porous material, i.e. flow through an aquifer. The hydraulic conductivity values applied in the model are based upon professional expertise and vary across the model domain. Hydraulic conductivity parameters were refined and statistically distributed throughout the model domain during the calibration process. Hydraulic conductivity values were specified at a set of user-supplied points, approximately one per county. These point values were distributed to every cell in the domain using logarithmic kriging. The point values were varied during calibration using a combination of professional judgment and automated calibration using a parameter estimation program.

### 2. Precipitation Recharge

The amount of precipitation that percolates into the groundwater aquifer is dependent upon different soil characteristics and the amount of precipitation. Three general soil classifications were identified and distributed throughout the Republican River Basin: coarse, medium, and fine. As part of the model calibration, the STATSGO Soil Type 832 that was originally classified as "fine" was reclassified as "medium" to better differentiate precipitation recharge in the mound area in Nebraska from the rest of the model domain. In addition, the alluvial valleys were treated as distinct soil groups, with one group for the tributary alluviums and one for the alluvium along the mainstem. Recognizing the amount of precipitation that recharges the groundwater aquifer increases in proportion with precipitation, a set of two curves was developed for each of the three soil classifications. One curve is for irrigated lands and the other for non-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 groundwater model include:

### 3. 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.

#### 4. 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.

#### 5. 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.

#### 6. 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.

### 7. 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.

## E. 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 groundwater 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 groundwater 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 groundwater depletions from well pumping as the difference in streamflows using two simulation runs of the model. The "base" run is the simulation with all groundwater pumping, groundwater 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 groundwater pumping and pumping recharge for that particular State is turned "off." The amount of recharge from precipitation is recalculated by converting all groundwater-only irrigated land to non-irrigated land. 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 Nebraska 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 land 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 groundwater 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 groundwater 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 groundwater computed beneficial consumptive use due to State groundwater 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 groundwater well pumping and imported water supply accretions by stream reach are provided in Appendix U for the period 1981-2000.

## V. Conclusions

The RRCA Model fulfills the requirements of the FSS to develop a groundwater 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 groundwater well 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 groundwater 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.

## APPENDIX A

RRCA Model DVD

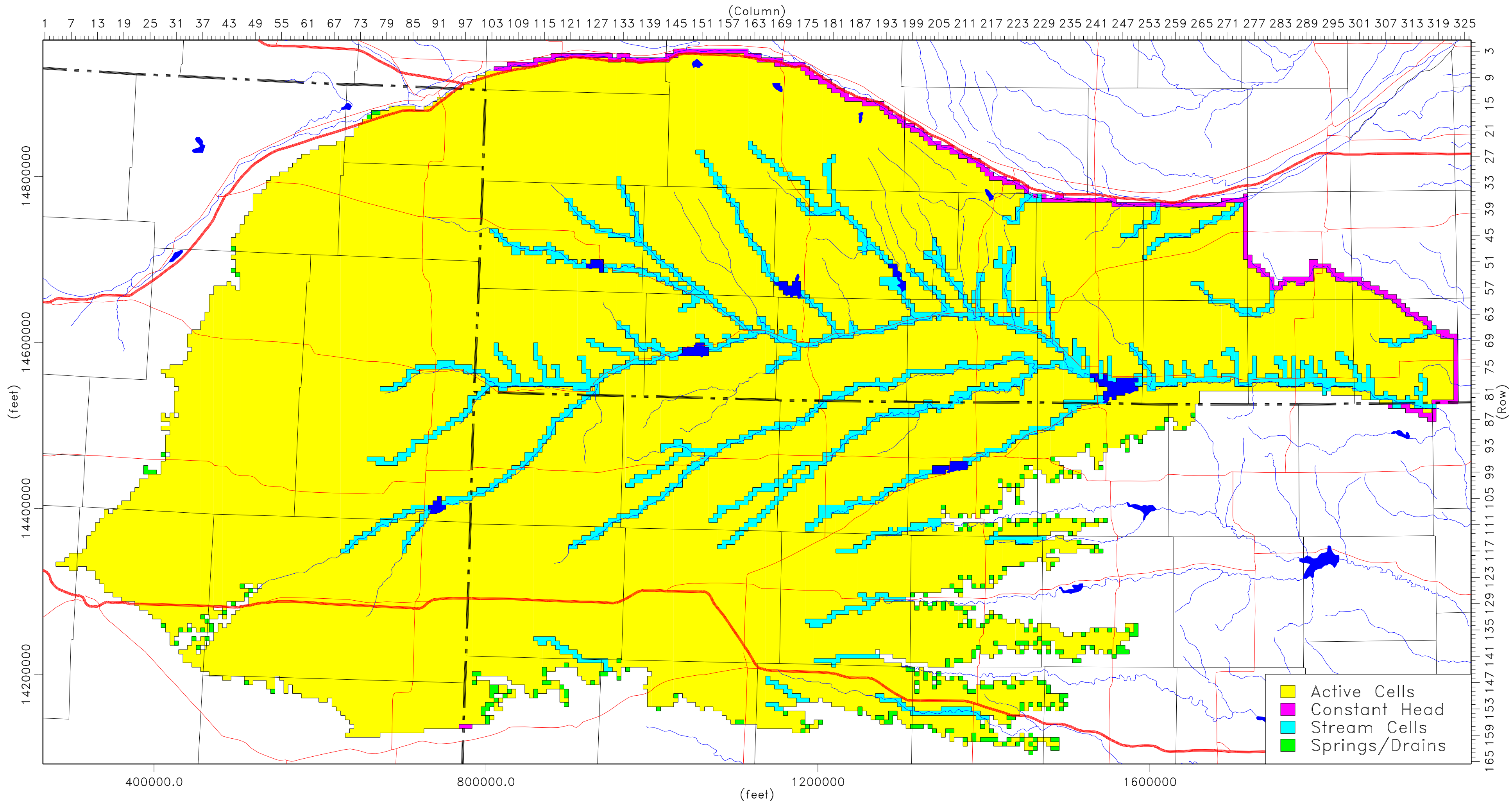
A1

(See inside back cover)

**APPENDIX B**

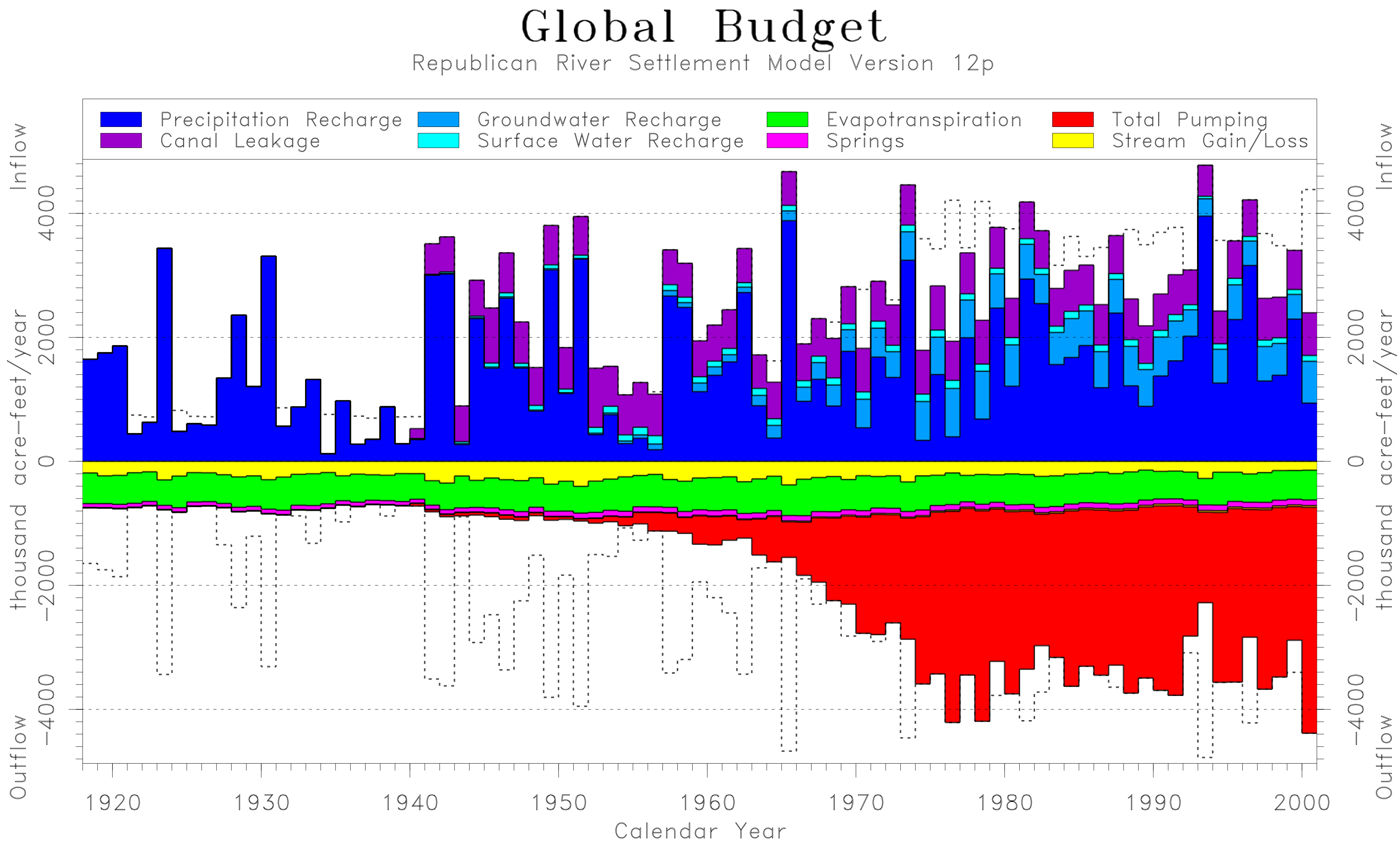
MAP OF RRCA GROUNDWATER MODEL DOMAIN

# RRCA Ground Water Model Domain



## APPENDIX C

GLOBAL WATER BUDGET


Global Budget
Republican River Settlement Model Version 12p
Precipitation Recharge
Canal Leakage
Groundwater Recharge
Surface Water Recharge
Evapotranspiration
Springs
Total Pumping
Stream Gain/Loss
Outflow thousand acre-feet/year Inflow
4000
2000
0
-2000
-4000
1920
1930
1940
1950
1960
1970
1980
1990
2000
Calendar Year

## APPENDIX D

PUMPING ESTIMATES FOR EACH STATE

# Appendix D
## Pumping Estimates for each State

Pumping for Irrigation in Colorado – The State of Colorado employed an eight-step procedure to estimate groundwater pumping:

1. Total acres irrigated by surface and groundwater is estimated for each county based upon data from the respective County Assessor's Office for the area contained in the RRCA Model boundaries. This data was supplemented with irrigated acreage reported by the National Agricultural Statistics Service (NASS).

2. The acreage irrigated by surface water is identified from the County Assessor's Records.

3. The acreage irrigated by groundwater is calculated as the difference between the total acreage and the acreage irrigated by surface water.

4. The maximum farm efficiency for center-pivot sprinkler irrigation and flood irrigation is estimated for each year.

5. The percent of acreage irrigated by center-pivot sprinkler is estimated for each county for each year.

6. The crop water requirement is estimated for each county using the Hargreaves empirical formula calibrated to the Penman-Monteith method for reference crop evapotranspiration. The crop mix for each county is determined from NASS county-level crop statistics. The effective precipitation is estimated using the procedure outlined in Irrigation Water Requirements, Technical Release No. 21, United States Department of Agriculture, April 1967 (Revised September 1970). The crop

irrigation requirement is calculated as the total or potential crop water requirement minus the effective precipitation.

7. The calculated crop irrigation requirement was reduced by two (2) inches per year to account for the gain in antecedent soil moisture from winter and spring precipitation.

8. Pumping for each county is estimated as the product of Irrigated Groundwater Acreage multiplied by the Net Crop Irrigation Requirement multiplied by Fraction of Crop Irrigation Requirement satisfied. The Fraction of Crop Irrigation Requirement satisfied was estimated from available pumping records. The pumping for each county is then divided by the maximum farm efficiency. The maximum farm efficiency is a weighted average based on the amount of sprinkler and flood irrigation. County pumping estimates are distributed to groundwater model cells using the well capacity for irrigation wells.

Pumping for Irrigation in Kansas – The State of Kansas developed estimates of pumping within the model domain using a combination of water use report data and estimates based on irrigated acreage and crop demand for years prior to the availability of reliable water use reports. The amount and location of pumping was taken from the water use report data for the period of 1989-2000. The estimated crop demand was compared to the water use reports for this period and a relationship developed, by county, to estimate pumping prior to 1989. Pumping estimates for 1940-1988 were made on a countywide basis.

The following procedure was used by the State of Kansas to estimate irrigation pumping for the period of 1989-2000: Kansas state officials have received water use reports from water right holders since 1957. In 1989, the Kansas Division of Water Resources (KDWR) was given additional enforcement authority and resources to require, obtain, and review water user reports of all water right holders. As a result, for the period 1989-2000, Kansas relied on the water use reports as its basis for estimating irrigation pumping. The water use report includes the total metered quantity or hours of operation, pumping rate, irrigated acreage, and crop type. Water users with meters are expected to report metered quantity; while those without meters report hours of pumping and diversion rate. Each water use report received by KDWR is reviewed for accuracy and completeness. All wells in the alluvium of the Republican River and its tributaries have been metered since 1998.

The State of Kansas completed a comparison of pumping reported for metered groundwater wells against non-metered users. For the period 1989-2000, the KDWR and the Kansas Water Office published a series of annual reports entitled *Kansas Irrigation Water Use Tables.* The series summarizes Kansas' water use data in a number of ways, including the contrast of metered and un-metered reported use. The data is tabulated by region, including each of the five Groundwater Management Districts (GMDs) and areas outside the GMDs within western, central and eastern Kansas. The statistics contrasting metered and un-metered water use were tabulated for the Northwestern Kansas GMD No. 4. In addition, statistics for Western Kansas GMD No. 1 and Southwest Kansas GMD No. 3 were tabulated for comparative purposes.

For GMD No. 4, for the period 1989-2000, reports of un-metered pumping averaged 21.6% greater than metered pumping on an acre-foot/acre basis. For 1994-2000, the period when the percent metered within the GMD was greater than 10%, the average reported pumping for un-metered points of diversions is 17% greater than for metered. In 1992 and 1993, the un-metered reports were 38% and 39% higher than metered reports, respectively. For GMD No.1 and GMD No. 3, similar differences between metered and un-metered reporting are evident in the early years of the record. However, with increasing metering in each of these GMD's, metered and un-metered reporting merge toward near-identity by the end of the 1989-2000 period. The conclusion of this analysis is that non-metered reported use for 1989-2000 was higher than metered reported use. Based on the results of this analysis, the pumping from the non-metered reports was adjusted downward by 10%.

Net groundwater pumping was determined by multiplying the total pumping by an estimated irrigation efficiency (which includes evaporative spray loss and runoff loss). Recognizing that the type of irrigation method has changed over time, Kansas assumed that all irrigation was flood irrigation until 1959, with an efficiency of 65%. Center pivots (85% efficiency) and other sprinklers (75% efficiency) were in use starting in 1960, and Low-Energy Precision Application systems (LEPA, 90% efficiency) use began in 1990. For 1960 to 1993, the proportion of center pivot and other sprinklers was interpolated from zero in 1959 to the value reported in the Kansas Water Rights Information System in 1993. The same procedure was applied to LEPA for the period 1990-1993. Flood irrigation was assumed to comprise the remainder for each year to bring the sum percentage of groundwater irrigation methods to 100%.

The following procedure was used to estimate irrigation pumping for the period 1940-1988:

1. Determine the potential evapotranspiration (PET) for the irrigated area and crops determined for the study area:

    a. Compute reference ET with the Penman-Monteith method for years when detailed climate data are available.

    b. Develop calibration coefficients for the Hargreaves method to use prior to availability of detailed weather data.

    c. Compute crop PET for study period.

    d. Compute effective precipitation during the growing season, using the procedure outlined in Irrigation Water Requirements, Technical Release No. 21, United States Department of Agriculture, April 1967, (Revised September, 1970). Over-winter soil moisture accumulation was separately computed, using values proposed by the State of Nebraska, and deducted from the CIR to obtain the seasonal irrigation requirement.

    e. Determine crop distribution from county level crop statistics.

    f. Compute crop irrigation requirement (CIR) on a unit basis (inches per acre).

2. Compile a history of well development, including location, date and source. The main data source is the Kansas water use database.

3. Compile irrigated area estimates, based on county crop statistics, previous studies and water use reports.

4. Compute the volume of crop demand for irrigation (CIR) on a county-wide basis, and use this as an initial estimate of the net irrigation pumping.

5. Compare the estimated net irrigation pumping to the water use reports for 1989-2000.
6. Use the comparison of estimated to reported pumping to develop a factor to multiply by the crop demand to estimate the actual net pumping for 1940-1988.

Water use reports collected prior to 1989 were reviewed to evaluate the levels of pumping indicated by these records. Although these records do not provide comprehensive pumping figures for the study area, there is a sufficiently large population of data to assess relative levels of pumping. The data showed that pumping rates (in gallons per minute – gpm) have steadily declined since 1970 to current levels. The data also indicate higher pumping amounts per well in the 1970s. The steady decline in pumping rates and amounts was corroborated by discussions with Kansas water officials. Probable reasons for the declines include reductions in well pumping capacities and changes in irrigation practices. Based on this evaluation, it was concluded that the 1989-2000 level of pumping used to establish the relationship between CIR and pumping was constrained by available pumping capacity and current irrigation practice to a greater degree than pre-1989 pumping. The reported pumping rate (gpm) was used as an indicator of this trend over time. The average pumping rate for a county in a given year (1970-1988), was compared to the 1989-2000 average to obtain an annual ratio. The 3-year running average was used to smooth these values to provide annual adjustment factors to apply to the pumping computed from the fraction of crop demand indicated by the 1989-2000 data. The 1970 factor was used for 1940-1969.

Pumping for Irrigation in Nebraska – The State of Nebraska computes the volume of pumping based on electrical energy use, pumping power requirements, and estimated well discharge based on a correlation to the flow rate recorded at the time of well registration. The method uses a uniform time of operation for wells supplied by a Public Power District. The total volume of water pumped is distributed on a county-level basis for the number of wells and acres irrigated by each respective county within the Republican River Basin. Groundwater is distributed at a uniform irrigation depth within each county for sole-source groundwater irrigated lands and a different uniform depth for commingled lands that receive surface water and groundwater as supply sources.

The total volume of groundwater pumped per county (Vp) is the sum of volume pumped for sole-source groundwater irrigation (Vg) and the volume pumped for commingled lands (Vc). The volume of groundwater pumped for sole-source lands (Vg) is the product of the number of acres of irrigated lands served exclusively by groundwater (Ag) and the depth of groundwater applied to sole-source lands (Dg) in units of acre-inches/acre divided by conversion factor of 12 inches/foot. In a similar manner, the volume of groundwater pumped for commingled lands (Vc) is the number of commingled acres (Ac) multiplied by the depth of groundwater applied to commingled lands (Dc) divided by 12. Since commingled lands received both groundwater and surface water, the average depth of groundwater applied to commingled land is a fraction ($f_g$) of that applied to lands served exclusively by groundwater (i.e., $Dc = f_g \times Dg$). The ratio of the depth of groundwater applied to commingled land to the depth applied to sole-source groundwater irrigated lands was 0.5 for most counties.

Appendix D Pumping Estimates Colorado

| Year | Cheyenne | KitCarson | Lincoln | Logan | Phillips | Sedgwick | Washington | Yuma |
|---|---|---|---|---|---|---|---|---|
| 1918 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1919 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1921 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1922 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1924 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1925 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1926 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1927 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1928 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1929 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1930 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1931 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1932 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1933 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1934 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1935 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1936 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1937 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1938 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1939 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1940 | 126 | 0 | 0 | 194 | 782 | 0 | 244 | 0 |
| 1941 | 94 | 0 | 6 | 112 | 446 | 0 | 614 | 130 |
| 1942 | 102 | 0 | 7 | 135 | 897 | 0 | 594 | 165 |
| 1943 | 142 | 0 | 8 | 223 | 1511 | 0 | 679 | 256 |
| 1944 | 152 | 0 | 7 | 201 | 1359 | 0 | 953 | 229 |
| 1945 | 322 | 0 | 5 | 103 | 657 | 0 | 1068 | 147 |
| 1946 | 478 | 0 | 7 | 176 | 1170 | 0 | 1449 | 336 |
| 1947 | 429 | 433 | 7 | 170 | 1172 | 0 | 2560 | 884 |
| 1948 | 301 | 1600 | 408 | 215 | 1523 | 0 | 3350 | 958 |
| 1949 | 322 | 2982 | 452 | 151 | 1540 | 196 | 2428 | 2747 |
| 1950 | 623 | 4209 | 502 | 178 | 2041 | 236 | 3243.4 | 2954.6 |
| 1951 | 657 | 3530 | 413 | 119 | 1499 | 393 | 3193 | 3578 |
| 1952 | 812 | 6085 | 671 | 246 | 4011 | 786 | 4924.4 | 8122.6 |
| 1953 | 1011 | 6487.6 | 611 | 195 | 3447 | 601 | 5028.9 | 8961.5 |
| 1954 | 1051 | 13328.4 | 784 | 202 | 4059 | 634 | 6391.1 | 12029.5 |
| 1955 | 1333 | 26766.5 | 658 | 192 | 4150 | 626 | 4970.8 | 14303 |
| 1956 | 1666 | 43798.2 | 780 | 229 | 5465 | 1033 | 6699.4 | 21906.1 |
| 1957 | 995 | 28941.3 | 458 | 448 | 5428 | 1314 | 5726.6 | 20337.5 |
| 1958 | 710 | 31050.3 | 462 | 348 | 4549 | 900 | 6319.3 | 19786.2 |
| 1959 | 971 | 54319.2 | 818 | 453 | 5822 | 1306 | 7105.2 | 26628.5 |
| 1960 | 1128 | 49657.4 | 645 | 463 | 6379 | 1315 | 7370.6 | 23129.1 |
| 1961 | 915 | 51574.4 | 607 | 385 | 5887 | 1063 | 6151.9 | 20922 |
| 1962 | 1238 | 53378.2 | 590 | 350 | 5553 | 1018 | 6978.4 | 17525 |
| 1963 | 1739 | 90614.1 | 760 | 669 | 8531 | 1516 | 8111 | 30809.4 |
| 1964 | 2327 | 128033.6 | 918 | 756 | 17763 | 1840 | 9919 | 52281.1 |
| 1965 | 2347.4 | 79503.3 | 465 | 445 | 15726 | 1084 | 9788.2 | 45574.3 |
| 1966 | 3015.3 | 160724.9 | 883 | 506 | 22790.5 | 1156 | 14022.6 | 71347.7 |
| 1967 | 3091.8 | 161996 | 714 | 450 | 34561 | 1633 | 18214.3 | 140716.6 |
| 1968 | 4265.3 | 200982.2 | 879 | 1618 | 55547.7 | 4144 | 24471.8 | 171711 |
| 1969 | 3551.8 | 217455.3 | 987 | 1650 | 60858.9 | 6036 | 25907 | 214575.8 |
| 1970 | 4721.9 | 238606.5 | 1153 | 1958 | 78191.2 | 6927.9 | 27766.8 | 242006.7 |
| 1971 | 6636 | 252694 | 1218 | 1496 | 65397.9 | 6273 | 32982.9 | 263157.1 |
| 1972 | 7018.4 | 216619.6 | 1090 | 1712 | 67124.1 | 6635.1 | 29560.8 | 242300.8 |
| 1973 | 8706.4 | 250188.5 | 1179 | 2719 | 77225.9 | 11055.3 | 33788.4 | 224427.7 |
| 1974 | 14386.9 | 319352.9 | 1741 | 7209 | 121147 | 31226.2 | 51141.8 | 381441.8 |
| 1975 | 14892.1 | 280397.1 | 2149 | 7653 | 112570.3 | 33631.3 | 47420.5 | 381339.2 |
| 1976 | 16465.2 | 328229.9 | 2447 | 9008 | 136485.9 | 41176.8 | 57132.7 | 415334 |
| 1977 | 17711.3 | 277924.3 | 2086 | 7944 | 116934.6 | 36198.1 | 67097.1 | 392632.3 |
| 1978 | 17735.9 | 269977.4 | 2335 | 10002 | 148311.6 | 46002.7 | 56078.7 | 481776.2 |
| 1979 | 16236.2 | 221499.2 | 1645 | 7197 | 110527.5 | 34158.4 | 46228.8 | 395826.8 |
| 1980 | 16113.4 | 243355.6 | 2098 | 8771 | 126998.6 | 41046 | 56423.9 | 360083.4 |
| 1981 | 15230.8 | 268250.9 | 2121 | 7307 | 109630.5 | 34386.5 | 52432.2 | 384906.5 |
| 1982 | 14079 | 198123.2 | 1577 | 5482 | 83114.9 | 26168.3 | 42561.7 | 290366.7 |
| 1983 | 14768.2 | 167691.3 | 1662 | 6365 | 94099.9 | 28966.3 | 42004.8 | 298094.3 |
| 1984 | 14796.6 | 224138.1 | 2133 | 7762 | 107713.3 | 34070.3 | 41045.8 | 385797 |
| 1985 | 14102.7 | 184164.5 | 1573 | 7597 | 105838.4 | 30977.7 | 41537.7 | 298091.8 |
| 1986 | 13412.8 | 216180.1 | 1981 | 7336 | 99597.1 | 30288.8 | 47159.4 | 304889.6 |
| 1987 | 13885.9 | 200054.7 | 1817 | 7063 | 100054.9 | 31026.2 | 42131.3 | 359662.9 |
| 1988 | 13276.5 | 230650.9 | 2078 | 7714 | 107816.6 | 33893.4 | 51889.1 | 399880.5 |
| 1989 | 11386.1 | 222116.5 | 2087 | 6328 | 86083.6 | 27902.1 | 47808.9 | 307374.9 |
| 1990 | 12378.4 | 220857 | 1955 | 7480 | 103701.3 | 33411.6 | 41257.7 | 322515.6 |
| 1991 | 13092.7 | 201308.3 | 1925 | 6880 | 102771.6 | 32135.4 | 54418.9 | 258002.8 |
| 1992 | 14074.6 | 210283.4 | 2104 | 6517 | 90525.1 | 28969.1 | 48548.7 | 294598.5 |
| 1993 | 16368 | 208258.2 | 1955 | 5198 | 70179.1 | 23074.1 | 47035.3 | 281548.8 |
| 1994 | 15444.6 | 224581 | 2099 | 9029 | 129309.7 | 39602 | 69147.1 | 337776.8 |
| 1995 | 14302.2 | 192651.7 | 1773 | 6759 | 97521.5 | 30412 | 42925.2 | 293804.1 |
| 1996 | 14046.3 | 210626.2 | 1913 | 3588 | 50343.2 | 16812.2 | 41129.6 | 255751.5 |
| 1997 | 13807 | 210598.9 | 1988 | 7107 | 104258.9 | 33008.6 | 49645.1 | 301518.6 |
| 1998 | 14515.4 | 197073.9 | 1782 | 6806 | 89641 | 29937.8 | 57600.3 | 347092.4 |
| 1999 | 14441.8 | 186178.8 | 1779 | 5789 | 79476.2 | 25239.4 | 37115.6 | 293224.3 |
| 2000 | 18094.4 | 267000.4 | 2548 | 10000 | 128365.4 | 41726.6 | 62570.8 | 371558.8 |

Appendix D Pumping Estimates Kansas

| Year | Cheyenne | Decatur | Gove | Graham | Jewell | Logan | Norton | Phillips | Rawlins | Sheridan | Sherman | Thomas | Trego | Wallace |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1919 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1921 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1922 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1924 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1925 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1926 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1927 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1928 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1929 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1930 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1931 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1932 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1933 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1934 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1935 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1936 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1937 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1938 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1939 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1940 | 1136.1 | 752.3 | 0 | 0 | 0 | 0 | 135 | 171 | 176 | 504.7 | 278 | 252 | 0 | 0 |
| 1941 | 1234 | 383.8 | 0 | 0 | 0 | 0 | 91 | 129 | 117 | 310 | 278 | 243 | 0 | 0 |
| 1942 | 2175 | 621 | 0 | 0 | 0 | 0 | 89 | 134 | 144 | 410.2 | 304 | 272 | 0 | 0 |
| 1943 | 3230 | 703.9 | 0 | 0 | 0 | 0 | 125 | 163 | 159 | 480 | 321 | 286 | 0 | 0 |
| 1944 | 3122.7 | 391.8 | 0 | 0 | 0 | 0 | 69 | 119 | 117 | 287 | 242 | 224 | 0 | 0 |
| 1945 | 3340.7 | 582.5 | 0 | 0 | 0 | 0 | 120 | 152 | 119 | 418 | 214 | 252 | 0 | 0 |
| 1946 | 4249 | 624.6 | 0 | 0 | 0 | 0 | 130 | 168 | 161 | 459.3 | 251 | 289 | 0 | 0 |
| 1947 | 3764 | 642.9 | 0 | 0 | 0 | 0 | 97 | 137 | 142 | 446.3 | 443 | 240 | 0 | 0 |
| 1948 | 3261 | 555.1 | 0 | 0 | 0 | 0 | 101 | 152 | 125 | 366 | 452 | 532.9 | 0 | 0 |
| 1949 | 3124 | 493.8 | 0 | 0 | 0 | 0 | 80 | 114 | 119 | 358 | 786 | 499 | 0 | 0 |
| 1950 | 3705 | 610.4 | 0 | 0 | 0 | 0 | 147 | 283 | 583 | 564.5 | 1260 | 505.9 | 0 | 0 |
| 1951 | 2328.8 | 363.4 | 0 | 0 | 0 | 0 | 69 | 192 | 309 | 321.3 | 796.9 | 585 | 0 | 0 |
| 1952 | 4661 | 852.1 | 0 | 0 | 0 | 0 | 270 | 398 | 711.9 | 791.5 | 4142 | 1336.9 | 0 | 0 |
| 1953 | 4094.4 | 761.9 | 0 | 0 | 0 | 178 | 173 | 748 | 1192 | 1122.5 | 4657.5 | 1287 | 0 | 0 |
| 1954 | 7361.5 | 1122.8 | 0 | 393 | 0 | 226 | 1064 | 1816.2 | 1443.6 | 1476.5 | 6171 | 1351.9 | 211 | 189 |
| 1955 | 8731.4 | 1948.5 | 312 | 563 | 0 | 246 | 1369.1 | 3879.6 | 2256.6 | 3845.3 | 10569.9 | 3112 | 187 | 197 |
| 1956 | 12202 | 3059.3 | 916 | 833 | 699.1 | 268 | 1747.8 | 5311 | 3405.6 | 9037.3 | 18601.1 | 9708 | 631.9 | 457 |
| 1957 | 12224.2 | 3026.1 | 589 | 466 | 323 | 267 | 1321.2 | 3870.4 | 2926.5 | 8461.9 | 17242.6 | 6804.5 | 342 | 324 |
| 1958 | 13742.2 | 2992.2 | 713.9 | 526.1 | 315 | 352 | 1383.2 | 4255.6 | 2984.5 | 9676.8 | 20513.2 | 7963.2 | 563 | 330 |
| 1959 | 16918.2 | 4238.7 | 1111.1 | 794.1 | 415 | 452 | 2080.6 | 6048 | 4109.9 | 14357.6 | 22260.8 | 11898.4 | 713 | 340.7 |
| 1960 | 22414.3 | 4985.3 | 1079 | 854.9 | 313 | 403 | 2047.1 | 4963.5 | 4688.4 | 14532.2 | 26401.2 | 11135.9 | 760 | 394.7 |
| 1961 | 17560.6 | 5327.6 | 654 | 700.1 | 427 | 567.9 | 2206.8 | 5442 | 3703.6 | 11145.2 | 20570.8 | 10736.6 | 162 | 278 |
| 1962 | 13444.1 | 3333.5 | 1075 | 880.1 | 447 | 417 | 1725.1 | 3567 | 2491.7 | 11420.7 | 25456.3 | 8842.2 | 669 | 289.4 |
| 1963 | 28337.1 | 6384.7 | 1748 | 1155 | 452 | 926.7 | 2122.8 | 5987 | 4896.2 | 16223.9 | 40631.3 | 13277.5 | 1068 | 360.7 |
| 1964 | 37992.4 | 5867.9 | 2583.7 | 1434.9 | 409 | 2620.3 | 3085.8 | 7457.7 | 5618.2 | 29080.9 | 62527.7 | 23795.9 | 1410.9 | 596.9 |
| 1965 | 30187.5 | 4035.2 | 1446 | 1290 | 409 | 1672.5 | 2152.5 | 3773 | 4633.8 | 15290.3 | 58785.1 | 16037.4 | 581 | 570.5 |
| 1966 | 41655.6 | 6121.4 | 4517.5 | 2405 | 556 | 2487.2 | 2695.2 | 6123.6 | 6678.8 | 28420.9 | 73431.3 | 28942.8 | 1150.9 | 1099 |
| 1967 | 45827.7 | 6996.9 | 6179 | 2009 | 453 | 3874 | 1912.5 | 3302.6 | 8068.1 | 33208.9 | 79619.7 | 38896.8 | 925 | 1002 |
| 1968 | 51311.2 | 6178.4 | 6408 | 2680.3 | 295 | 6507.2 | 1338.6 | 2693.8 | 8865 | 37803.1 | 101926.6 | 35433.7 | 975 | 1654.5 |
| 1969 | 54604 | 9721 | 8964.1 | 2449 | 343 | 8580.9 | 2184.8 | 3437.4 | 9176.6 | 50262.1 | 108264.6 | 43199.2 | 1307 | 1528.2 |
| 1970 | 61117.1 | 10679.8 | 10690.9 | 2830 | 474 | 10665.8 | 2924.2 | 5351.4 | 10681 | 66069 | 135239 | 50233.6 | 1550 | 2148 |
| 1971 | 64611.3 | 10385.8 | 15231.5 | 3836 | 520 | 12603.6 | 5966.8 | 7667.1 | 13160 | 81263.8 | 143600 | 62210.8 | 2159.2 | 2263.2 |
| 1972 | 53213.4 | 8416.4 | 15840.7 | 4206.1 | 417 | 10456 | 7647.7 | 7739.5 | 9209.8 | 73735.1 | 105014.7 | 61402.9 | 1384.9 | 2303.8 |
| 1973 | 66006.1 | 16810.9 | 17696.9 | 5590.1 | 372 | 12528.2 | 12961.9 | 7354.9 | 19074.1 | 93374.1 | 133113.3 | 65046.2 | 1657.2 | 3089.1 |
| 1974 | 68595.3 | 14724.6 | 26064.8 | 6548.1 | 639 | 11340.5 | 12239.1 | 14219.6 | 15493.2 | 120448.4 | 160254.2 | 91339.7 | 3018.7 | 5019.8 |
| 1975 | 66737 | 12110.7 | 17665.9 | 4612.1 | 321 | 10747.6 | 5654.6 | 4810.8 | 15976.5 | 84786.7 | 161579.5 | 71924.2 | 2016 | 4952.3 |
| 1976 | 84360.6 | 18953.7 | 33164.1 | 10328.1 | 411.8 | 16059.6 | 11926 | 12139 | 18785 | 161922.2 | 224080.4 | 175689 | 2474.8 | 7280 |
| 1977 | 65040.8 | 10806.4 | 16502.8 | 8667 | 961.9 | 9914.2 | 9072.4 | 7439.4 | 11992.1 | 106922.3 | 169534.7 | 96796.2 | 1921.2 | 5778.1 |
| 1978 | 76345.9 | 16035.1 | 21401.6 | 12968.6 | 1430.9 | 14112.2 | 11053 | 6858.9 | 18015.5 | 133007.9 | 202349.7 | 152435.2 | 1804 | 5742.2 |
| 1979 | 52008.2 | 7578.8 | 13274.8 | 8026.4 | 1767.5 | 8503.1 | 7352.2 | 4837.5 | 14154.2 | 91340.8 | 131651.8 | 96237.1 | 1703.2 | 4144.9 |
| 1980 | 45784.9 | 15863.9 | 16126.5 | 8064.7 | 1560.9 | 11179.3 | 16126.5 | 11752 | 11989.1 | 134149.9 | 126614.5 | 130619.4 | 1542.8 | 3714.8 |
| 1981 | 54106.7 | 15731.9 | 17914.6 | 8127.4 | 942.2 | 11992.6 | 6278.4 | 5362.3 | 11265 | 106812.9 | 180218.5 | 135468.9 | 2040.2 | 6007.3 |
| 1982 | 45155.4 | 13946.1 | 19479.6 | 9032.5 | 728.1 | 8809.7 | 8827.3 | 6030.5 | 14213.2 | 95967.9 | 108590.1 | 85137.8 | 2204 | 3036.5 |
| 1983 | 50151.2 | 16676.3 | 19348.8 | 8343.8 | 857.2 | 12893.1 | 7863.2 | 5896.7 | 15270.4 | 93884.3 | 135666 | 95271.7 | 2338 | 2929.5 |
| 1984 | 43793.3 | 17328.7 | 20831.2 | 10249.2 | 1295.2 | 10675.9 | 15743.4 | 7615.4 | 15011.6 | 128928.3 | 127522.9 | 115572.6 | 2285.2 | 3342.9 |
| 1985 | 42304.2 | 16089.4 | 19087.4 | 13451.1 | 942.8 | 8879.1 | 12803.6 | 7716.6 | 12821.1 | 109074.6 | 113327.5 | 112783.5 | 2110.2 | 3364.8 |
| 1986 | 53941.5 | 14350.2 | 21726.9 | 11420 | 1136.7 | 10158.2 | 11345.7 | 7667.3 | 15442.3 | 107093.1 | 138024 | 155222.6 | 1516.8 | 3719.7 |
| 1987 | 51404.8 | 9333.6 | 17028.7 | 7433.7 | 1035.9 | 5593.2 | 9257.4 | 7049.2 | 15688.4 | 85246.5 | 108467.3 | 109724.2 | 1599.8 | 3131.6 |
| 1988 | 53192.7 | 7994.1 | 17314.6 | 7455.6 | 1267.7 | 9362 | 10285 | 5412.4 | 18006.1 | 103421.9 | 112039 | 114440.7 | 2151 | 2925.1 |
| 1989 | 56642.5 | 14964.7 | 17511.2 | 8306.3 | 945.4 | 9473.6 | 11909.5 | 8192.5 | 18259.9 | 111863.6 | 134230.8 | 134713.6 | 2279 | 3710.1 |
| 1990 | 56449.1 | 13238.7 | 15437.5 | 9224.5 | 1069.4 | 9904.7 | 10699.9 | 7439.8 | 19325.9 | 95161.1 | 139954.5 | 129307.2 | 2332 | 3416.2 |
| 1991 | 50870.4 | 13063.8 | 16778.7 | 10264.1 | 1339.7 | 9213.1 | 10995.3 | 6349.1 | 17189.2 | 97371.5 | 121332.6 | 118946.3 | 1942.2 | 3018.1 |
| 1992 | 35857 | 4308.7 | 6750.9 | 4573.3 | 289.1 | 5997.7 | 4409.7 | 3779.1 | 8309.5 | 48089.5 | 81805.4 | 56967.1 | 656 | 2651.8 |
| 1993 | 39774.8 | 3800.4 | 5323 | 2143.6 | 116.1 | 4976.3 | 3926.5 | 2733.2 | 9770.5 | 34981.6 | 80321.3 | 64788.4 | 433 | 2627.2 |
| 1994 | 49688.9 | 7671.4 | 13003.8 | 6694.5 | 1029.5 | 6595.6 | 7045.7 | 5089.8 | 14183.9 | 76119 | 103625.9 | 97124.7 | 1632.8 | 3456.7 |
| 1995 | 36851.5 | 11570.6 | 12662.7 | 7714.7 | 1238.2 | 6338.3 | 8433.3 | 5535.9 | 14957.3 | 79004 | 89074.2 | 89993.2 | 1209 | 2704.5 |
| 1996 | 44605.2 | 8173.1 | 9849.6 | 6843.6 | 1196.3 | 6075.7 | 5094.6 | 3023.9 | 12297.3 | 67184 | 106803.4 | 89922.1 | 1077 | 3124 |
| 1997 | 54443.6 | 11631 | 10245.1 | 7819.9 | 1085.9 | 7181.2 | 7973.7 | 5347.8 | 17515.2 | 67269.3 | 120769.6 | 100178.1 | 1458.9 | 2545.2 |
| 1998 | 46618.5 | 11786.9 | 10706.2 | 8100 | 909.9 | 6082 | 7462.8 | 4462.9 | 15409.3 | 66273.1 | 111048 | 90677.7 | 1496 | 2740.5 |
| 1999 | 45990.5 | 8148.2 | 9352.3 | 6622 | 1077 | 5866.3 | 6296.4 | 4831.8 | 12061.1 | 57860.7 | 96174.9 | 75958.9 | 1514 | 2711.9 |
| 2000 | 60728.6 | 16301.7 | 13709.4 | 10268 | 1403.5 | 7578.1 | 7867.9 | 3999.6 | 21993.1 | 91260.2 | 131865.1 | 123856.7 | 2094.4 | 4023.6 |

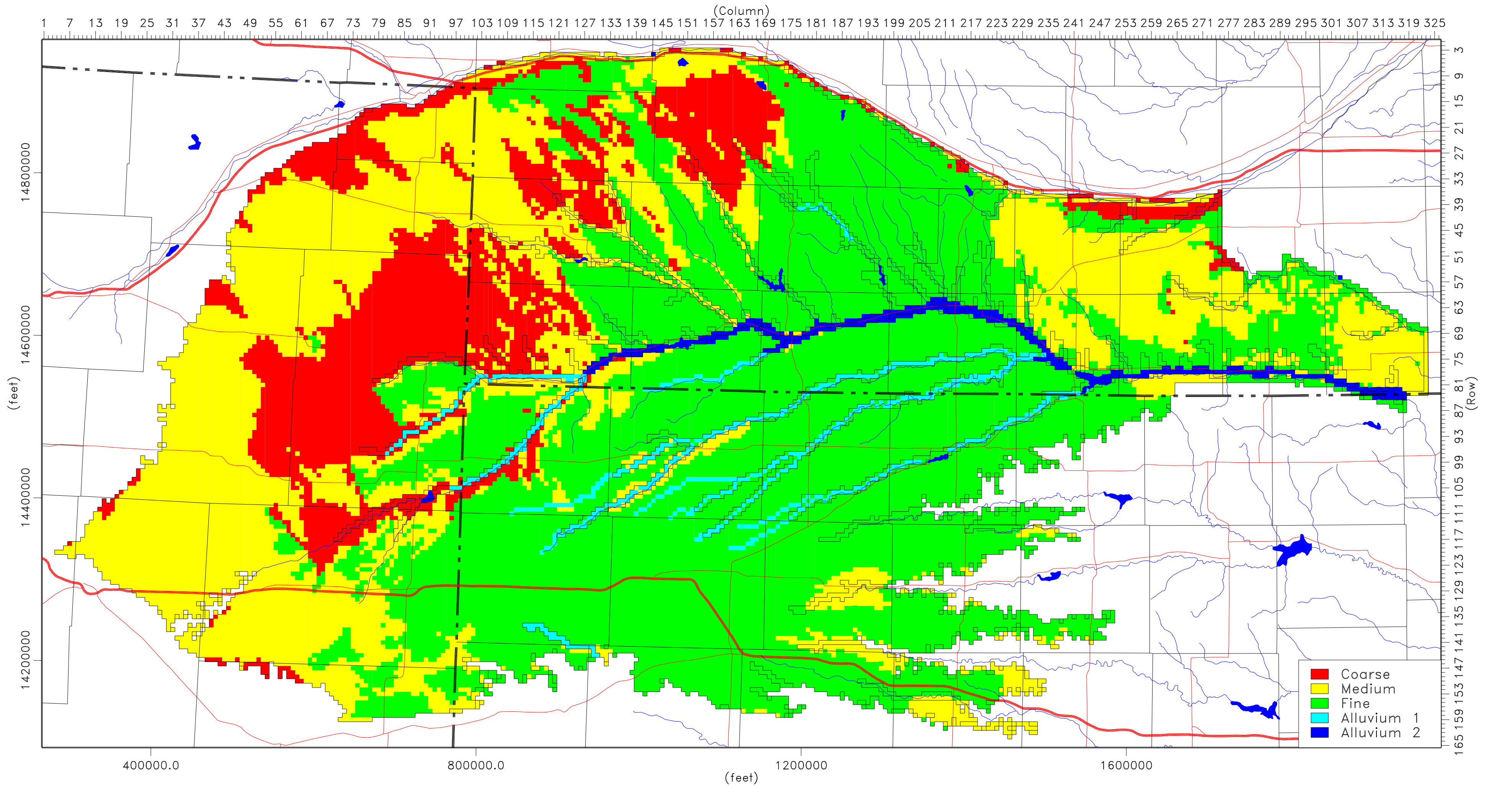
| Year | Adams | Buffalo | Chase | Clay | Dawson | Deuel | Dundy | Franklin | Frontier | Furnas | Gosper | Harlan | Hayes | Hitchcock | Kearney | Keith | Lincoln | Nuckolls | Perkins | Phelps | RedWillow | Webster |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1919 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1921 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1922 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1924 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1925 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1926 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1927 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1928 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1929 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1930 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1931 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1932 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1933 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1934 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1935 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1936 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1937 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1938 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1939 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1940 | 133.6 | 521 | 1154.3 | 0 | 5435 | 1345.3 | 608.6 | 745.9 | 279 | 835.1 | 1505.8 | 401.1 | 437.1 | 2286.7 | 5100.9 | 3230.4 | 5686.3 | 108.1 | 313.8 | 5835.5 | 1030.9 | 416.8 |
| 1941 | 82.3 | 318.3 | 1135.8 | 66 | 4649.3 | 1076 | 491.5 | 449 | 195.8 | 618.4 | 1322.9 | 448.1 | 289.6 | 1711.5 | 3895.5 | 2700.5 | 5440.4 | 113.9 | 253.4 | 4397.1 | 965.4 | 219.5 |
| 1942 | 67.7 | 262.9 | 939.3 | 54.3 | 4862.6 | 852.1 | 433.9 | 484.5 | 214.8 | 420.1 | 1307.1 | 442.3 | 353.2 | 2346.6 | 3521.3 | 3890.7 | 6169 | 82 | 268.5 | 4051.8 | 1067.9 | 158 |
| 1943 | 89.5 | 347.4 | 1766.8 | 71.8 | 6693.4 | 1367.2 | 870.6 | 575.2 | 249.7 | 747.9 | 1871.8 | 545.1 | 399.6 | 2945.2 | 4876.6 | 4234.3 | 7864.8 | 118.5 | 448.9 | 5759.1 | 1511 | 228.5 |
| 1944 | 88.6 | 440.8 | 1903.3 | 71.1 | 4535.3 | 1090.8 | 806.8 | 675.4 | 138.1 | 512 | 1845.8 | 675.1 | 295.4 | 1787 | 5759.1 | 3870.3 | 4478.2 | 109.8 | 356.6 | 5863.2 | 1081.6 | 211.7 |
| 1945 | 88.6 | 621.1 | 2393.5 | 71.1 | 8772.9 | 2378.9 | 1436.1 | 780.3 | 196.8 | 922.9 | 1929.5 | 815.3 | 406.2 | 2509.6 | 6811.7 | 6371 | 6866.4 | 91.6 | 445.4 | 5938.4 | 2018.3 | 176.6 |
| 1946 | 75 | 561.6 | 1675.7 | 60.1 | 8962.8 | 1849 | 1122 | 774.3 | 269.5 | 1139.1 | 1633.3 | 1087.9 | 534.1 | 2576.7 | 7859.7 | 9660.5 | 7035.6 | 100.3 | 290.1 | 5413.3 | 1986.1 | 225.3 |
| 1947 | 454.8 | 3.1 | 2391.1 | 0.3 | 89 | 2737.4 | 1560.9 | 1157.9 | 326.3 | 1388 | 48.1 | 2222.1 | 580.5 | 6195.8 | 166.3 | 9769.3 | 10447.6 | 583.6 | 401.1 | 161.7 | 2815 | 606.9 |
| 1948 | 461.3 | 2.1 | 2652.4 | 0.4 | 67.3 | 2774.1 | 1691 | 1017.2 | 418.3 | 1408 | 38.7 | 2009.5 | 398.2 | 5032.6 | 117.3 | 10977.6 | 656.4 | 479.1 | 811.3 | 136.1 | 2482.6 | 534.6 |
| 1949 | 857.4 | 5.2 | 3006.1 | 1.2 | 93.8 | 2597.7 | 1898.4 | 1349.3 | 605.1 | 1616.2 | 54 | 2021 | 908.2 | 7308.8 | 255.3 | 11816.8 | 1573.2 | 1067 | 881.1 | 143 | 2421.1 | 604 |
| 1950 | 834 | 7.9 | 2412.5 | 2.2 | 63.2 | 1005.6 | 94.2 | 209.2 | 571.7 | 113.6 | 27.6 | 308.4 | 283.9 | 1082.8 | 255.2 | 10213.5 | 2179.2 | 70.3 | 367.7 | 47.2 | 493.6 | 155.6 |
| 1951 | 355.7 | 3.5 | 2417.2 | 1 | 79.1 | 825.2 | 132.8 | 167.4 | 90.8 | 50.9 | 12.2 | 150.2 | 133.3 | 363 | 117.4 | 8303.3 | 2353.4 | 30.1 | 340.7 | 23.9 | 314.2 | 128.9 |
| 1952 | 1248.1 | 14.3 | 4718 | 3.9 | 232.2 | 2168.8 | 465.7 | 519.8 | 106.5 | 167.9 | 48.2 | 324.7 | 569.1 | 1294.6 | 544.3 | 14839.6 | 6509.5 | 132.1 | 1703.5 | 60.3 | 1030 | 451.1 |
| 1953 | 1929.1 | 65.1 | 5110.5 | 19 | 252.6 | 1925.9 | 701 | 858.8 | 134.3 | 236.9 | 66.8 | 678.5 | 823.7 | 1927.6 | 2558.3 | 12364.1 | 10612.7 | 192 | 2288 | 753.8 | 1730.5 | 961.3 |
| 1954 | 2631.6 | 107.6 | 7562.7 | 39.4 | 764.8 | 2469.4 | 2049 | 1272.6 | 935.2 | 831.8 | 482.3 | 1337.5 | 1433 | 3923.9 | 3649.8 | 16721.3 | 23624.8 | 194.9 | 3718.9 | 1240.4 | 3475.8 | 830.4 |
| 1955 | 2270.9 | 124 | 21345.8 | 690.8 | 2842.6 | 2683.1 | 7237.3 | 469.1 | 1919.1 | 2674.9 | 2206.9 | 5482.4 | 1558.8 | 7869.6 | 1058 | 7542.2 | 3995.5 | 3779.6 | 1472 | 3186.1 | 1516.1 | 10740.9 |
| 1956 | 3751.4 | 125.4 | 24873.8 | 483.4 | 3721.3 | 2687.2 | 9126.5 | 5990.8 | 3114.9 | 4123.3 | 3115.1 | 7853.5 | 2134.2 | 9612.4 | 11375.9 | 9097.1 | 6206.2 | 3422.9 | 2219.9 | 24118 | 2318.3 | 10172.7 |
| 1957 | 3692.4 | 534.2 | 14375.9 | 709.9 | 9179.3 | 1700.3 | 8435.6 | 7983.9 | 3120.6 | 7666.5 | 4663.5 | 9489.6 | 1924.8 | 7491.2 | 24079.9 | 10692.2 | 10121.8 | 4789.3 | 2505.3 | 24046.7 | 3820.6 | 6273.5 |
| 1958 | 2392 | 393 | 12281.2 | 403.4 | 5438.5 | 2181.5 | 6961.1 | 5323.5 | 3365.2 | 5400.8 | 3094.3 | 6164.7 | 1838.2 | 7476.2 | 17045.6 | 11885 | 6684.9 | 1838.4 | 1988.6 | 15788.4 | 3817.8 | 2778.4 |
| 1959 | 7765.6 | 1128.4 | 23394.3 | 1357 | 12842.2 | 4495 | 14651.9 | 10677.4 | 7608.9 | 13738 | 6418.5 | 14874.4 | 3635.2 | 15480.7 | 34616.9 | 24841.8 | 16618.8 | 5738.9 | 4277.9 | 32320.5 | 9501.1 | 9185 |
| 1960 | 7446.4 | 1231.2 | 24854.5 | 1340.8 | 14232.2 | 4889.8 | 15360 | 10436.4 | 6978.7 | 9942.2 | 6642.1 | 10932.2 | 3997.7 | 14734.9 | 33428.4 | 28167.1 | 18602 | 5321.2 | 5202.3 | 27714 | 7997.7 | 8758.8 |
| 1961 | 9586.6 | 985.4 | 9675.5 | 1765.2 | 11637.9 | 2394.9 | 13146.5 | 10656.4 | 4452.7 | 8982.9 | 5490.6 | 10278.6 | 3632.6 | 10435.6 | 34510.5 | 14753.2 | 13576.6 | 7118.1 | 2607.2 | 29332.3 | 5470.5 | 11643.2 |
| 1962 | 4896.2 | 477.9 | 8376.6 | 864.5 | 5547.5 | 1729.6 | 7333.4 | 7189.2 | 2438.9 | 4395.9 | 2592.8 | 5193.7 | 2552 | 6097.7 | 23295.8 | 10753 | 7294.8 | 3871.3 | 1884.7 | 19797.4 | 3032.5 | 5719 |
| 1963 | 9725.4 | 1666.9 | 16423.1 | 1657.8 | 19534.8 | 3226.1 | 17088.9 | 14841.1 | 6896.1 | 12018.3 | 8970.8 | 14329.5 | 7245 | 15378.6 | 48970.2 | 20737.4 | 22179.2 | 7507.8 | 3803.6 | 43140.3 | 7768.7 | 11496.9 |
| 1964 | 13830.6 | 1377.4 | 22099.3 | 2398 | 16148.5 | 3398.8 | 17350 | 13269.6 | 9506.6 | 13339.4 | 7704.8 | 14816.6 | 8241.8 | 19322.6 | 44063.3 | 21790.8 | 19850.8 | 11693 | 3847.6 | 39527.1 | 10227 | 17688.5 |
| 1965 | 10524.7 | 920.2 | 15835.9 | 1901.2 | 10608.5 | 2595.3 | 14652.8 | 13390.6 | 9593.1 | 8814.3 | 5477.7 | 10041.8 | 7005.5 | 17467.2 | 44335.5 | 17107.2 | 13926.3 | 8371.2 | 3435.7 | 39515.7 | 9167 | 12812.3 |
| 1966 | 16459.8 | 1437.6 | 22410.8 | 2620.9 | 17105.4 | 2879.1 | 14539.9 | 20111.8 | 11922.9 | 9391.6 | 8512.1 | 11138.5 | 6916.3 | 18576.3 | 67935.1 | 18940.9 | 20420.5 | 13395.3 | 4445.2 | 59505.1 | 10980.4 | 18687.8 |
| 1967 | 19525.5 | 1217.6 | 30071.5 | 2977.3 | 14701.9 | 5691.9 | 18191 | 18984.9 | 17081.4 | 14339.3 | 8939.7 | 18048.6 | 7711.8 | 23763.5 | 62883.6 | 35881.9 | 21353.5 | 15123.2 | 11042.9 | 59656 | 15016.6 | 21477 |
| 1968 | 19058 | 1293.3 | 61817.8 | 3326.6 | 16805.1 | 9788.9 | 32427 | 17655.6 | 27270 | 24501.1 | 12304.1 | 33719.4 | 13174.8 | 32819.5 | 58114.7 | 64019.3 | 28876.4 | 14537.2 | 24855.6 | 63182.1 | 22421.4 | 22600.4 |
| 1969 | 14026.1 | 1332.4 | 76208.5 | 2556 | 17893.5 | 7263.7 | 46082.3 | 17489 | 25797.4 | 19826.5 | 12636.6 | 27695.4 | 19405.3 | 31974.6 | 56708.8 | 50185.1 | 27578 | 9370.1 | 23764.3 | 59614.5 | 20355 | 16326 |
| 1970 | 24981.7 | 1911.1 | 101395.4 | 4612.9 | 25869.2 | 10107.5 | 57775.4 | 32893.9 | 41696.5 | 31179 | 19955.9 | 45007.9 | 25168.7 | 40888.7 | 103909.7 | 71242.8 | 39524.8 | 15719.1 | 35618.4 | 111465 | 32894.3 | 28644.1 |
| 1971 | 28085.4 | 2013 | 94420.1 | 5327.5 | 28023.2 | 5965.4 | 56820.6 | 35302 | 42925.6 | 31731.4 | 23607.1 | 47347.7 | 27821.7 | 37886.3 | 110517 | 43456.1 | 39474.9 | 17693.6 | 25131 | 111141.5 | 34101.8 | 32932.7 |
| 1972 | 19689.9 | 1847.2 | 88817.8 | 3417 | 26925.1 | 5493.7 | 40253.6 | 31104.7 | 52176.6 | 31810.3 | 27284.7 | 49689.4 | 22685.1 | 35177.6 | 95833.8 | 41477 | 41579.6 | 10442.2 | 25579.8 | 100630.7 | 39515.2 | 19771.4 |
| 1973 | 23372.7 | 1768.7 | 100777.7 | 4059.2 | 24803.6 | 6196.2 | 38084.3 | 36481.3 | 50410.9 | 30645.6 | 27658.2 | 52495.8 | 23158.9 | 32082.3 | 113387 | 46238.7 | 46631.3 | 11717 | 35060.4 | 122206 | 37223.7 | 23772.9 |
| 1974 | 32296.7 | 2686.5 | 148495 | 5677.6 | 39529.7 | 7537.7 | 57173.3 | 44852.9 | 72865.9 | 38907.8 | 41905.8 | 69161.4 | 28983.6 | 40090.4 | 136044.8 | 60424 | 74452.5 | 16445.1 | 59705.5 | 154514.6 | 53248.9 | 34993.9 |
| 1975 | 29254.6 | 2363.7 | 163245.3 | 4857.1 | 35665.5 | 6977.6 | 76762.3 | 46982.8 | 78076.9 | 39404.9 | 43052.9 | 69230.9 | 32618.2 | 42526.5 | 130812.1 | 61387.7 | 78570.9 | 14212 | 66055.5 | 152113.8 | 56316.8 | 32437.7 |
| 1976 | 39680.4 | 2922.7 | 216623.9 | 5966.5 | 42964 | 7199.1 | 103930.6 | 64303.3 | 87489.5 | 54419 | 58085.1 | 95081.5 | 41580.6 | 49183.5 | 170192.6 | 69179.9 | 100536.4 | 19355 | 80335.7 | 202895.9 | 62384.9 | 46005.1 |
| 1977 | 21350.5 | 2217 | 185047.7 | 2646.6 | 32181.9 | 5255.9 | 99806.9 | 47064.3 | 65872.7 | 44137.5 | 44148.4 | 72805.6 | 36444 | 39950.3 | 119485.6 | 53196.3 | 80222.6 | 8716.1 | 65743.8 | 144613.3 | 51700.5 | 23204.6 |
| 1978 | 30175.6 | 2517.3 | 260376.4 | 3724 | 38499 | 8794.5 | 124661.4 | 64024.2 | 90210.7 | 49138.2 | 51772.8 | 81398.1 | 46075.3 | 52262.8 | 159689.4 | 90100.7 | 117434 | 13549.3 | 113696.7 | 186500.2 | 70428.8 | 33345.5 |
| 1979 | 22579.4 | 1888.2 | 191437.7 | 3018.8 | 29147.7 | 6231.2 | 97877.3 | 43523.5 | 47040.4 | 30274.6 | 35429.8 | 48846.7 | 36910.9 | 38896.3 | 103388.7 | 67852.9 | 89391.8 | 11369.6 | 90723.8 | 119496.4 | 38940.3 | 26853 |
| 1980 | 31523.4 | 3071.1 | 204188.2 | 3876.4 | 48483.2 | 6475.4 | 97931.3 | 67045 | 78289.1 | 50040.2 | 58291.5 | 78846.9 | 37194 | 47549.8 | 158156.6 | 69312.1 | 122035.8 | 14413.9 | 95772.3 | 178612.5 | 61580.1 | 35581.6 |
| 1981 | 21253.5 | 1829.7 | 178689.9 | 2434 | 27240.9 | 5094.5 | 78526.7 | 50316.7 | 45980.5 | 27112.4 | 32696.9 | 43617.2 | 29803.7 | 34422.5 | 115050.8 | 57004.2 | 86252.1 | 8991.9 | 79605.4 | 125888.3 | 36593.3 | 22741.6 |
| 1982 | 19061.9 | 2163.9 | 139080.2 | 2361 | 33543.6 | 4280.5 | 67910.2 | 42281.7 | 54555.1 | 32569 | 39830.8 | 52516.9 | 26310.4 | 32537.3 | 95110.2 | 48567.1 | 88605.7 | 8496.4 | 68576.8 | 114068.3 | 42123.2 | 21269.7 |
| 1983 | 26254.4 | 1871.3 | 165185.4 | 3373.9 | 29200.4 | 5409.7 | 90043.9 | 52284.1 | 54483.2 | 31393.5 | 36336.7 | 50226.6 | 32353.2 | 38135.9 | 120485.1 | 61933.9 | 96212.7 | 12076.2 | 87299 | 134004.9 | 44342.1 | 30577.6 |
| 1984 | 29070.4 | 2528.7 | 217827.9 | 3500.6 | 38176.2 | 6428.8 | 111366 | 62816.7 | 67033.6 | 43785.6 | 48940 | 69524 | 39648.3 | 44632 | 143301.5 | 74416.8 | 119998.8 | 12554.5 | 106448.9 | 163134.3 | 53189 | 32260.1 |
| 1985 | 24568.3 | 2042.1 | 221161.6 | 3059.5 | 31704.9 | 6650.9 | 113411.3 | 49028.9 | 66257 | 32950.4 | 39228.1 | 52555.4 | 41533.3 | 46930.9 | 111726 | 77577.1 | 116502.1 | 11081.7 | 110816.9 | 126591.3 | 53373.9 | 28390.3 |
| 1986 | 23982.3 | 2519.9 | 183425.6 | 2674.8 | 39436.9 | 6234.9 | 107156.3 | 54916.3 | 69471.6 | 40691.2 | 48228 | 65977.3 | 39426.2 | 45342.9 | 125578.6 | 74466.9 | 121371 | 9287 | 105964.5 | 144253.4 | 54897 | 24864.9 |
| 1987 | 26035.2 | 2199.7 | 169902.2 | 2797.5 | 34041.8 | 5966.9 | 98462.3 | 59678.5 | 60301.3 | 28851.2 | 38478.6 | 47045 | 36390.2 | 40756.2 | 140292.5 | 67870.2 | 107885.6 | 9715.7 | 97104.7 | 153516.1 | 47472 | 25841.2 |
| 1988 | 42445.1 | 2914.3 | 200346.9 | 4979.1 | 44555.7 | 6485.2 | 107211.7 | 86038.7 | 63567.7 | 40104.7 | 51066 | 64458 | 39290.9 | 42355 | 202941.1 | 74192.5 | 123829.7 | 17431.5 | 105682.7 | 222033.6 | 49831.1 | 46185.5 |
| 1989 | 30074 | 2746.5 | 202602.4 | 3430.8 | 38495.8 | 6138.8 | 102387.4 | 67565.2 | 75794.2 | 47738.6 | 50434.2 | 76408.1 | 37555.3 | 43568.3 | 157228.2 | 71631 | 116950.6 | 11776.8 | 101306.5 | 178688.3 | 59546.9 | 31168.5 |
| 1990 | 27865.9 | 3365 | 236069.8 | 2898.8 | 49631.4 | 8103.1 | 135778.4 | 70870.6 | 77609.1 | 46205.8 | 57093 | 75421.3 | 49332.7 | 51687.3 | 165692.7 | 95203.4 | 147689.2 | 9993.2 | 134020.5 | 184897.2 | 61670.7 | 26707.1 |
| 1991 | 42162.9 | 3816.6 | 214761.8 | 4913 | 54757.4 | 8257.1 | 112315.9 | 96672.4 | 83911.2 | 54262.5 | 64094 | 87616.2 | 41611.7 | 46476.4 | 220279.2 | 97528.9 | 155272.6 | 17913.8 | 136737.5 | 251218.6 | 67407.2 | 44305.6 |
| 1992 | 18483.9 | 2253.7 | 174805.6 | 1879.2 | 34106 | 5129.4 | 74285.3 | 50135.3 | 42841.2 | 30206.1 | 37736.9 | 50012.2 | 26487.5 | 27657.4 | 112799.5 | 60478.6 | 93645.5 | 7119.2 | 86660.6 | 132588.7 | 35612.4 | 17911.2 |
| 1993 | 6523.3 | 657.1 | 143610.9 | 629.2 | 9901.7 | 3578.8 | 52838.8 | 18356 | 4515.1 | 6716.7 | 9962.9 | 11468.6 | 17704.1 | 13955 | 41408.7 | 42251.1 | 43590.2 | 2409.4 | 61003.9 | 45663.1 | 6279.7 | 6063.6 |
| 1994 | 24599.4 | 2327 | 244291.3 | 2756.6 | 33742.3 | 7873.4 | 117644.2 | 57664.8 | 71595.6 | 35192.6 | 40387.5 | 59188.5 | 42147.2 | 46002.8 | 130165.6 | 94731.5 | 126078.5 | 10821.7 | 133907 | 147586.5 | 62801.1 | 26495.7 |
| 1995 | 38543.4 | 3386.9 | 202246.4 | 4256.4 | 48633.5 | 7446.2 | 111603.9 | 90486.3 | 75981.7 | 44464.6 | 55209.7 | 75439.6 | 40162.9 | 44351.4 | 203718.4 | 91087.9 | 139789.7 | 16953.3 | 126302.3 | 223282.2 | 65334.9 | 41636.6 |
| 1996 | 23268.8 | 2199.7 | 165144.2 | 2567.7 | 32406 | 4671.2 | 83802 | 53914.2 | 42213.5 | 17875.3 | 31189.3 | 30694.7 | 29383 | 30477.1 | 121360.5 | 57976.4 | 90480.5 | 10782.9 | 80203.7 | 126377.5 | 37404.5 | 25559.1 |
| 1997 | 33686.8 | 3599.6 | 235756.6 | 3438.4 | 51988.7 | 6814.1 | 135981.3 | 86758.4 | 69947.6 | 44158.9 | 58175.4 | 76659.1 | 51008.2 | 48619.9 | 188432.5 | 85598.9 | 141660.5 | 14780.4 | 118603.9 | 202909 | 62511.7 | 35282.7 |
| 1998 | 24682.8 | 2874.2 | 236303.1 | 2445.6 | 42481 | 7129 | 146150.3 | 64780.9 | 70843.9 | 39490.7 | 49791.5 | 68175.3 | 56837.2 | 52047.9 | 140094.1 | 88420.2 | 135572.3 | 10639.1 | 121880.7 | 151042.6 | 65390.8 | 26216.3 |
| 1999 | 26203 | 2410.4 | 181923.5 | 2911.3 | 32969.6 | 5682.8 | 100441.7 | 58095.4 | 14303.3 | 24960.4 | 35643.1 | 44032.3 | 38700.2 | 26866.8 | 125274.7 | 72592.9 | 95953.6 | 13203.7 | 98645.1 | 129077.4 | 16236.7 | 31537 |
| 2000 | 41878.5 | 4597.4 | 298110.9 | 4304.6 | 64086.1 | 10651 | 181823.6 | 106837.9 | 83964 | 42474.3 | 67011.6 | 75268.8 | 75587.6 | 63833.8 | 226836 | 138003.2 | 202150.6 | 19437.2 | 184537.6 | 227509.8 | 77184.7 | 46619.7 |

## APPENDIX E

DISTRIBUTION OF SOIL CLASSIFICATIONS

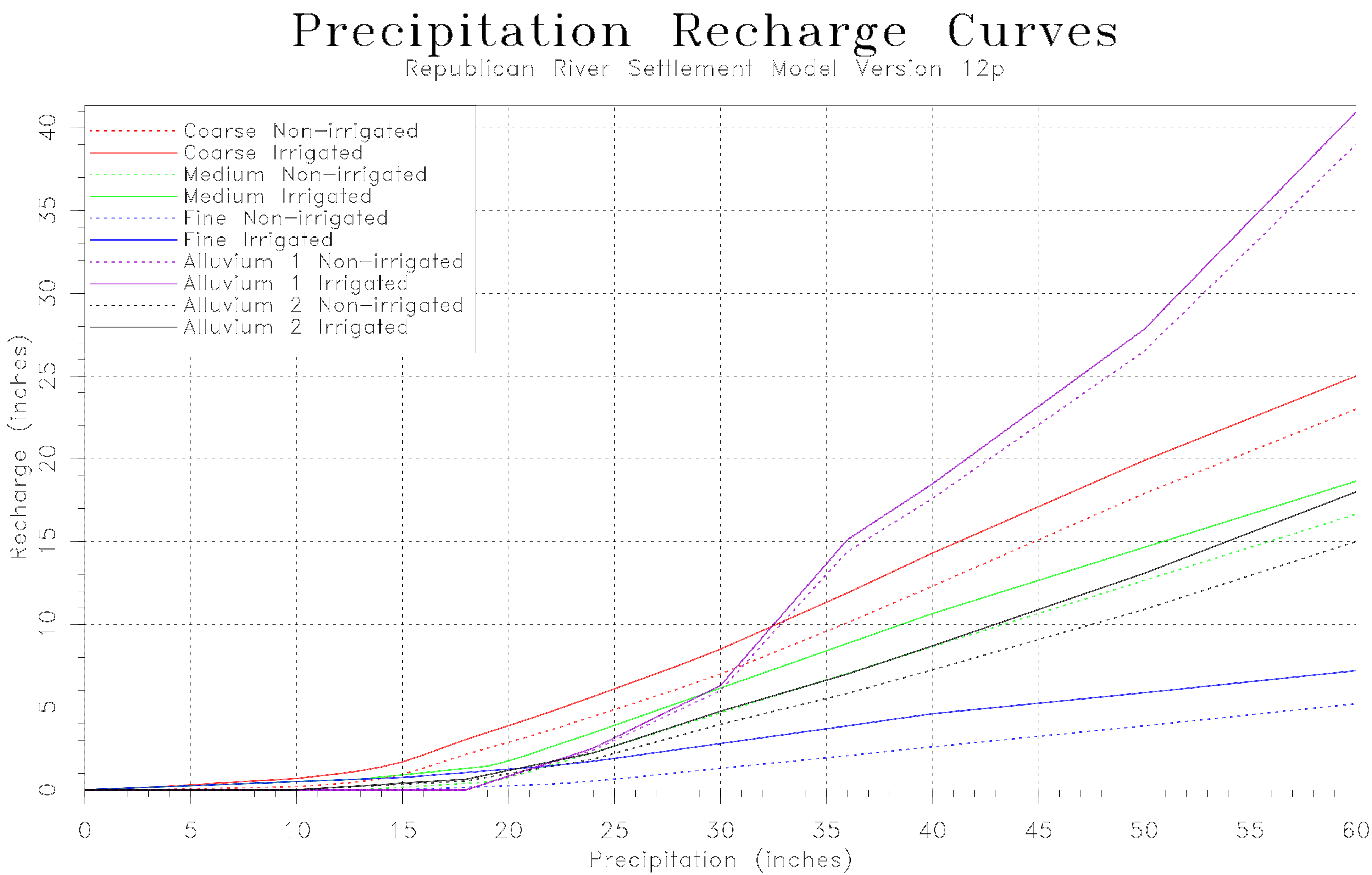
# Distribution of Soil Classifications

Republican River Settlement Model Version 12p



**APPENDIX F**

PRECIPITATION RECHARGE CURVES


Precipitation Recharge Curves
Republican River Settlement Model Version 12p
Coarse Non–irrigated
Coarse Irrigated
Medium Non–irrigated
Medium Irrigated
Fine Non–irrigated
Fine Irrigated
Alluvium 1 Non–irrigated
Alluvium 1 Irrigated
Alluvium 2 Non–irrigated
Alluvium 2 Irrigated
Recharge (inches)
0
5
10
15
20
25
30
35
40
0
5
10
15
20
25
30
35
40
45
50
55
60
Precipitation (inches)

**APPENDIX G**

RECHARGE FROM PRECIPITATION

Appendix G Recharge from Precipitation (acre-feet per year)

| Year | Colorado | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cheyenne | KitCarson | Lincoln | Logan | Phillips | Sedgwick | Washington | Yuma |
| 1918 | 22655.0 | 75803.9 | 28546.8 | 25385.8 | 35658.2 | 34597.5 | 87688.5 | 187601.7 |
| 1919 | 4979.8 | 22715.0 | 3386.4 | 1942.8 | 2806.1 | 8649.7 | 15190.6 | 21993.6 |
| 1920 | 18374.7 | 103662.5 | 29291.0 | 44130.9 | 86452.1 | 37108.4 | 141475.6 | 354719.5 |
| 1921 | 10027.6 | 39228.5 | 7104.1 | 2148.8 | 2876.0 | 3310.9 | 13022.7 | 38421.9 |
| 1922 | 7065.7 | 40064.3 | 10341.8 | 11542.1 | 16423.1 | 13268.2 | 46792.1 | 107421.6 |
| 1923 | 38300.1 | 189987.4 | 66738.9 | 33368.5 | 24669.9 | 68364.6 | 163601.5 | 172571.2 |
| 1924 | 458.5 | 7722.3 | 115.2 | 3938.0 | 9331.2 | 16580.5 | 5362.3 | 38572.0 |
| 1925 | 453.0 | 6297.1 | 92.0 | 3142.2 | 5448.3 | 15009.1 | 3642.0 | 25088.2 |
| 1926 | 1852.8 | 27262.0 | 10588.2 | 15657.1 | 12712.2 | 14980.8 | 65762.5 | 92093.5 |
| 1927 | 4199.4 | 31060.9 | 10599.2 | 19299.6 | 28395.7 | 22470.6 | 68644.5 | 151706.9 |
| 1928 | 15917.5 | 107212.9 | 11398.2 | 18827.6 | 55509.5 | 34467.6 | 53285.5 | 265210.5 |
| 1929 | 5518.8 | 60780.5 | 19748.8 | 27869.0 | 36782.5 | 19716.8 | 145347.6 | 238555.2 |
| 1930 | 30365.3 | 182012.0 | 23622.5 | 26751.9 | 49843.9 | 61301.1 | 85620.5 | 243877.2 |
| 1931 | 271.7 | 3350.9 | 80.0 | 808.3 | 1405.2 | 1228.9 | 2901.3 | 13640.0 |
| 1932 | 426.0 | 9730.4 | 212.0 | 18551.2 | 50422.3 | 21959.1 | 31402.5 | 204760.5 |
| 1933 | 8172.2 | 57382.0 | 14493.9 | 24133.9 | 31893.7 | 27833.3 | 77270.8 | 186730.0 |
| 1934 | 275.5 | 2094.1 | 168.3 | 2098.0 | 3220.6 | 2243.2 | 6143.2 | 24611.8 |
| 1935 | 375.8 | 12856.9 | 558.6 | 8065.0 | 8198.4 | 6363.2 | 41986.3 | 73389.0 |
| 1936 | 255.2 | 4467.7 | 41.0 | 1995.2 | 21856.1 | 4054.6 | 2961.1 | 94936.3 |
| 1937 | 295.1 | 4122.4 | 81.5 | 1305.0 | 3388.0 | 2537.4 | 3325.9 | 26569.2 |
| 1938 | 3389.8 | 39003.1 | 182.8 | 8705.2 | 31735.1 | 16628.8 | 13950.9 | 157937.0 |
| 1939 | 1198.0 | 8669.0 | 96.9 | 2377.9 | 6584.3 | 7595.6 | 3961.3 | 36597.1 |
| 1940 | 1822.7 | 9801.8 | 795.6 | 3288.6 | 7179.2 | 6603.6 | 13049.0 | 45201.7 |
| 1941 | 16721.4 | 105970.5 | 7591.7 | 37251.9 | 107065.9 | 54358.5 | 67795.7 | 393461.9 |
| 1942 | 12793.7 | 86910.5 | 14694.3 | 30124.8 | 102022.9 | 36307.1 | 104442.0 | 390054.4 |
| 1943 | 4140.0 | 20663.1 | 694.7 | 1461.3 | 3037.3 | 2071.4 | 7150.4 | 31956.1 |
| 1944 | 9730.7 | 57038.8 | 1164.2 | 8256.7 | 26528.1 | 19077.0 | 19170.9 | 143411.9 |
| 1945 | 14737.4 | 110853.3 | 19749.6 | 34129.7 | 49081.4 | 40214.0 | 103937.5 | 255268.3 |
| 1946 | 903.9 | 22251.8 | 111.4 | 9431.0 | 26182.4 | 23771.9 | 11950.1 | 121232.9 |
| 1947 | 12473.4 | 82962.3 | 7165.6 | 11803.5 | 61090.9 | 9620.0 | 46915.5 | 297171.7 |
| 1948 | 5446.2 | 22716.0 | 125.9 | 1453.9 | 6569.6 | 6596.9 | 4778.4 | 89546.2 |
| 1949 | 10715.2 | 116291.1 | 26571.2 | 57335.7 | 94800.6 | 39186.3 | 220800.8 | 443738.6 |
| 1950 | 866.7 | 10278.9 | 328.4 | 7237.6 | 11086.6 | 9108.4 | 21766.4 | 81354.6 |
| 1951 | 5832.9 | 56059.8 | 1916.3 | 32587.4 | 94333.5 | 74799.3 | 50352.4 | 241584.8 |
| 1952 | 1746.8 | 11825.8 | 1538.3 | 8458.0 | 8125.8 | 17453.5 | 17170.3 | 49730.9 |
| 1953 | 504.2 | 3164.5 | 256.3 | 14470.8 | 23940.8 | 24067.4 | 12064.6 | 49407.3 |
| 1954 | 230.8 | 1678.7 | 108.0 | 3664.5 | 18554.1 | 4755.7 | 3174.5 | 28915.7 |
| 1955 | 463.8 | 5204.4 | 312.1 | 13810.2 | 21810.2 | 19832.5 | 15692.6 | 44548.1 |
| 1956 | 231.6 | 2942.8 | 137.1 | 4411.4 | 7729.8 | 13534.0 | 3746.5 | 19623.3 |
| 1957 | 32504.2 | 162262.5 | 18475.4 | 15786.4 | 28148.5 | 26080.2 | 69547.0 | 223626.6 |
| 1958 | 44803.0 | 214889.2 | 26925.3 | 33816.5 | 91675.0 | 60333.1 | 83593.7 | 349895.9 |
| 1959 | 4305.4 | 10307.5 | 282.0 | 10335.0 | 36306.5 | 14101.4 | 11891.2 | 82035.9 |
| 1960 | 9275.6 | 54375.9 | 1067.4 | 3629.8 | 13996.7 | 9369.1 | 12383.1 | 106895.3 |
| 1961 | 11928.8 | 58433.5 | 10730.1 | 17719.0 | 31115.4 | 24160.2 | 53501.2 | 193743.1 |
| 1962 | 5100.1 | 49999.6 | 550.6 | 13561.4 | 61671.6 | 21725.5 | 38045.7 | 337693.0 |
| 1963 | 555.5 | 10891.6 | 249.5 | 5592.4 | 14004.1 | 10123.0 | 13712.8 | 68803.5 |
| 1964 | 370.1 | 5492.7 | 178.7 | 2920.6 | 4989.7 | 3980.7 | 6144.0 | 28356.8 |
| 1965 | 19657.9 | 143588.5 | 8058.5 | 23237.4 | 55094.5 | 59469.0 | 48099.8 | 256421.1 |
| 1966 | 6314.3 | 37764.6 | 5955.5 | 25250.3 | 65714.3 | 37259.8 | 38569.8 | 230376.5 |
| 1967 | 2229.0 | 27384.7 | 1953.5 | 17019.6 | 46953.6 | 19327.6 | 36658.6 | 141245.9 |
| 1968 | 404.5 | 11067.8 | 167.0 | 2472.8 | 5166.2 | 3675.7 | 7534.3 | 51977.0 |
| 1969 | 7906.3 | 20215.9 | 643.9 | 5472.5 | 20120.3 | 16305.3 | 8232.4 | 82275.1 |
| 1970 | 3313.0 | 13425.3 | 343.7 | 3862.3 | 12354.6 | 6255.7 | 8809.2 | 62794.6 |
| 1971 | 2991.4 | 23130.5 | 250.0 | 13412.5 | 58703.1 | 33112.9 | 11760.3 | 122649.2 |
| 1972 | 2509.0 | 19660.0 | 249.0 | 7331.3 | 31801.7 | 15168.0 | 10018.1 | 100607.0 |
| 1973 | 6038.9 | 58379.9 | 8446.0 | 38125.3 | 87020.9 | 38608.6 | 112304.7 | 354507.7 |
| 1974 | 569.1 | 10893.1 | 222.3 | 1888.3 | 8140.9 | 2565.8 | 7642.0 | 55220.1 |
| 1975 | 1340.3 | 20018.0 | 461.3 | 18327.1 | 28132.9 | 31853.4 | 31733.8 | 111419.2 |
| 1976 | 828.3 | 8732.6 | 263.7 | 1955.1 | 7189.3 | 2983.5 | 6429.0 | 35648.4 |
| 1977 | 1217.5 | 15707.6 | 246.1 | 20138.8 | 61859.5 | 40494.6 | 14584.4 | 153201.0 |
| 1978 | 2826.0 | 19871.6 | 641.9 | 2157.2 | 6055.1 | 3351.9 | 14069.2 | 47588.6 |
| 1979 | 9079.5 | 75300.5 | 12320.9 | 24076.3 | 40195.2 | 27725.8 | 78005.2 | 182606.3 |
| 1980 | 8227.1 | 70945.6 | 8224.9 | 14041.7 | 46077.5 | 13986.0 | 53384.8 | 267715.1 |
| 1981 | 10036.9 | 72246.6 | 8574.1 | 36010.5 | 97770.9 | 48362.2 | 77271.9 | 307862.3 |
| 1982 | 8199.2 | 66978.8 | 4879.3 | 27342.9 | 102058.5 | 35999.5 | 66886.5 | 361073.2 |
| 1983 | 6002.9 | 54518.6 | 7963.3 | 18823.8 | 31518.2 | 18277.1 | 55250.4 | 156155.6 |
| 1984 | 1291.2 | 18665.0 | 1695.1 | 13096.7 | 23023.5 | 9621.8 | 43286.9 | 93967.9 |
| 1985 | 9029.9 | 69301.1 | 11638.8 | 17845.9 | 28090.8 | 15410.0 | 65170.7 | 176645.5 |
| 1986 | 1614.5 | 15777.9 | 378.8 | 6095.6 | 16797.4 | 10319.7 | 12806.1 | 77502.8 |
| 1987 | 9532.7 | 66801.3 | 11684.0 | 30802.0 | 51122.3 | 51397.2 | 73005.0 | 165609.7 |
| 1988 | 5172.6 | 34885.6 | 8230.3 | 24822.5 | 43844.5 | 33523.5 | 50652.9 | 143692.2 |
| 1989 | 10577.0 | 34359.0 | 6173.3 | 6374.3 | 22340.5 | 9223.6 | 19963.4 | 91371.0 |
| 1990 | 4862.1 | 43936.4 | 9687.1 | 15031.5 | 25218.9 | 20520.6 | 68008.0 | 196032.5 |
| 1991 | 7646.9 | 63876.4 | 3962.3 | 15757.2 | 46359.7 | 26099.7 | 44466.4 | 291485.5 |
| 1992 | 11489.0 | 72329.8 | 6402.9 | 22703.2 | 37696.4 | 46653.1 | 51415.5 | 207924.4 |
| 1993 | 3104.5 | 31444.4 | 273.9 | 8560.1 | 45769.2 | 22536.9 | 19962.7 | 172425.9 |
| 1994 | 7626.1 | 48796.8 | 2421.5 | 3089.1 | 13480.4 | 6661.4 | 23322.4 | 143324.1 |
| 1995 | 30482.1 | 201935.5 | 63788.1 | 28008.1 | 45359.2 | 20945.8 | 204851.9 | 327633.9 |
| 1996 | 8336.4 | 63482.2 | 9837.5 | 62530.3 | 147649.5 | 82639.6 | 88245.3 | 293240.8 |
| 1997 | 5048.8 | 28642.7 | 618.0 | 4570.4 | 13277.7 | 18280.2 | 15224.3 | 88038.4 |
| 1998 | 16036.1 | 103493.5 | 6424.5 | 10506.9 | 31944.9 | 21457.4 | 27250.8 | 126009.4 |
| 1999 | 27690.2 | 200054.1 | 43688.2 | 35715.8 | 72346.0 | 38339.3 | 144165.5 | 305669.0 |
| 2000 | 1519.2 | 26130.0 | 423.6 | 2617.6 | 7505.5 | 5297.4 | 13689.7 | 74082.4 |

Appendix G Recharge from Precipitation (acre-feet per year)

| Year | Kansas | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cheyenne | Decatur | Gove | Graham | Jewell | Logan | Norton | Phillips | Rawlins | Sheridan | Sherman | Thomas | Trego | Wallace |
| 1918 | 33974.7 | 24513.5 | 11031.1 | 22246.2 | 1773.9 | 5527.1 | 30599.1 | 15184.2 | 25265.6 | 27556.7 | 14864.7 | 16567.7 | 22826.4 | 6134.5 |
| 1919 | 18675.1 | 26016.0 | 12692.4 | 45342.0 | 2540.5 | 3555.9 | 66272.6 | 36742.6 | 11244.4 | 29671.5 | 9326.4 | 11251.2 | 41226.9 | 2524.5 |
| 1920 | 65519.7 | 15916.6 | 13061.5 | 10155.5 | 1526.0 | 13077.9 | 13013.1 | 8790.2 | 52231.2 | 34591.9 | 33063.6 | 48869.1 | 8901.4 | 9695.4 |
| 1921 | 17737.3 | 9942.0 | 8401.6 | 7954.6 | 254.1 | 5134.6 | 5630.9 | 4189.2 | 9822.2 | 14821.3 | 13089.2 | 14414.6 | 13094.0 | 4459.5 |
| 1922 | 21947.3 | 13455.7 | 4962.0 | 6372.0 | 466.3 | 3306.7 | 7909.3 | 4280.0 | 13076.0 | 14050.1 | 9430.8 | 12134.4 | 4747.0 | 2562.1 |
| 1923 | 142692.3 | 122640.9 | 44149.4 | 57633.1 | 1673.5 | 21648.3 | 70029.0 | 22938.6 | 144981.2 | 121793.2 | 68669.7 | 75465.1 | 60083.0 | 18856.1 |
| 1924 | 16166.4 | 7234.7 | 1760.9 | 1258.1 | 274.5 | 800.3 | 3559.8 | 3051.7 | 11194.5 | 8260.7 | 3519.1 | 5525.5 | 1236.6 | 274.2 |
| 1925 | 7895.6 | 3705.3 | 1759.7 | 5356.6 | 1161.3 | 52.6 | 3518.5 | 5941.1 | 6752.4 | 4326.5 | 272.2 | 242.1 | 5441.1 | 175.2 |
| 1926 | 12573.9 | 82.3 | 478.6 | 161.3 | 692.1 | 0.2 | 193.9 | 3652.7 | 1350.1 | 4522.9 | 498.2 | 0.0 | 431.8 | 80.4 |
| 1927 | 21769.0 | 15237.7 | 8508.5 | 11953.0 | 1062.0 | 3425.2 | 14617.8 | 8612.7 | 20179.6 | 14267.0 | 6137.9 | 10951.7 | 25060.6 | 1615.3 |
| 1928 | 93873.8 | 35965.5 | 29877.9 | 49564.7 | 1270.6 | 9907.1 | 49521.6 | 30066.1 | 69762.1 | 67027.2 | 32574.8 | 27073.3 | 59741.2 | 9196.7 |
| 1929 | 46776.9 | 12119.2 | 8076.4 | 13481.1 | 725.9 | 4166.7 | 23038.3 | 7062.7 | 21197.0 | 28362.8 | 13931.1 | 15484.0 | 7423.7 | 2457.9 |
| 1930 | 86470.7 | 87930.1 | 25382.1 | 34793.3 | 929.0 | 13409.0 | 52960.6 | 20067.7 | 95075.1 | 66837.4 | 48928.3 | 47983.9 | 41955.1 | 14930.1 |
| 1931 | 7943.4 | 5981.6 | 5629.8 | 13956.1 | 931.6 | 1122.7 | 10738.6 | 13491.6 | 3572.9 | 9416.5 | 913.1 | 3256.0 | 22386.8 | 71.6 |
| 1932 | 26534.3 | 791.0 | 8553.8 | 11510.4 | 334.5 | 1649.3 | 2682.8 | 5586.8 | 5541.1 | 15493.8 | 1773.8 | 3111.4 | 27726.4 | 63.8 |
| 1933 | 60308.1 | 18457.7 | 7499.2 | 8009.7 | 318.3 | 3444.1 | 9485.6 | 3454.6 | 41741.7 | 31240.4 | 14909.9 | 14270.7 | 4637.9 | 2929.1 |
| 1934 | 1409.3 | 0.0 | 0.0 | 60.1 | 35.2 | 0.0 | 0.0 | 186.6 | 0.0 | 0.0 | 0.0 | 0.0 | 290.8 | 0.0 |
| 1935 | 21745.2 | 3326.4 | 6762.9 | 10841.2 | 1477.1 | 302.6 | 6167.9 | 6285.2 | 7612.9 | 14646.1 | 1764.3 | 772.7 | 19958.2 | 22.4 |
| 1936 | 7734.1 | 0.0 | 304.9 | 155.3 | 156.7 | 0.0 | 0.0 | 6.8 | 421.5 | 1527.2 | 0.0 | 0.0 | 1137.1 | 0.0 |
| 1937 | 9732.1 | 4670.4 | 212.7 | 100.3 | 609.6 | 41.6 | 1674.5 | 1520.6 | 5727.7 | 3874.4 | 312.0 | 924.1 | 399.1 | 26.6 |
| 1938 | 19135.0 | 4256.4 | 6636.7 | 7330.6 | 1382.9 | 3098.4 | 4023.6 | 4022.7 | 10183.7 | 10182.2 | 9836.1 | 9267.6 | 16636.5 | 2449.3 |
| 1939 | 8193.2 | 0.0 | 2272.1 | 1137.6 | 528.0 | 912.9 | 67.3 | 178.7 | 1104.4 | 3447.3 | 2026.1 | 1435.8 | 3486.5 | 694.0 |
| 1940 | 4468.9 | 7.4 | 3710.1 | 4576.1 | 554.5 | 1267.0 | 1262.3 | 2333.4 | 535.5 | 3207.1 | 251.1 | 1263.4 | 12811.1 | 477.8 |
| 1941 | 121148.7 | 96681.6 | 34420.3 | 46259.9 | 2905.5 | 20862.5 | 51785.5 | 27493.1 | 128792.6 | 91849.7 | 59835.8 | 81658.6 | 49463.7 | 14547.6 |
| 1942 | 83467.5 | 33808.1 | 16742.5 | 26513.1 | 2781.1 | 7304.9 | 44137.0 | 22144.5 | 43350.0 | 53479.5 | 23737.2 | 23133.5 | 25330.6 | 6221.0 |
| 1943 | 2175.1 | 1124.3 | 16.1 | 309.1 | 472.8 | 65.7 | 1882.9 | 3522.2 | 338.4 | 87.2 | 374.4 | 6.4 | 570.1 | 816.7 |
| 1944 | 63108.3 | 73746.2 | 24356.8 | 39121.3 | 2963.2 | 14662.1 | 55666.8 | 24899.1 | 101707.4 | 52277.1 | 36280.4 | 58729.4 | 51592.8 | 9604.3 |
| 1945 | 28666.9 | 9436.5 | 7506.0 | 7368.5 | 1774.3 | 4925.3 | 4885.2 | 5875.1 | 15135.0 | 15961.5 | 17756.9 | 14977.8 | 10499.8 | 5753.0 |
| 1946 | 79490.9 | 70190.8 | 27222.5 | 35485.8 | 1610.1 | 12075.3 | 37742.5 | 25223.5 | 103901.3 | 65101.2 | 29650.7 | 56883.6 | 51498.0 | 4193.4 |
| 1947 | 38687.8 | 14434.9 | 5265.0 | 11626.1 | 568.5 | 2684.2 | 20223.0 | 10850.7 | 20344.4 | 16630.5 | 13606.0 | 7978.2 | 7503.1 | 4256.8 |
| 1948 | 38304.8 | 16134.2 | 14996.9 | 14880.7 | 705.4 | 6310.1 | 7415.6 | 2094.9 | 24725.3 | 30534.4 | 15736.5 | 18113.2 | 30236.1 | 4170.4 |
| 1949 | 126411.1 | 43210.3 | 27096.8 | 35386.0 | 2305.9 | 14730.2 | 47736.6 | 24772.7 | 74682.6 | 88114.5 | 47250.3 | 58221.9 | 25130.7 | 8497.1 |
| 1950 | 4727.7 | 1877.9 | 1521.1 | 8224.7 | 1646.5 | 138.2 | 12683.1 | 12779.2 | 3131.8 | 2251.3 | 92.0 | 844.9 | 10743.8 | 209.4 |
| 1951 | 65214.5 | 43783.0 | 31687.3 | 63058.1 | 3729.2 | 9657.9 | 61690.8 | 47663.9 | 56662.7 | 59243.7 | 23257.8 | 28276.5 | 85205.3 | 5458.1 |
| 1952 | 2109.5 | 613.0 | 197.9 | 845.4 | 632.8 | 19.2 | 4303.1 | 5200.4 | 503.9 | 187.2 | 68.3 | 30.8 | 2067.6 | 161.8 |
| 1953 | 3241.8 | 20778.2 | 2561.3 | 13208.8 | 1451.9 | 1265.0 | 34936.0 | 8745.1 | 10455.2 | 5033.4 | 570.1 | 7431.6 | 12723.7 | 69.0 |
| 1954 | 852.5 | 19.9 | 78.6 | 1785.2 | 702.5 | 5.9 | 2083.8 | 3101.3 | 8.8 | 43.1 | 59.5 | 33.1 | 3090.3 | 0.0 |
| 1955 | 1419.0 | 33.7 | 542.2 | 2790.5 | 381.4 | 6.2 | 1096.1 | 2091.5 | 33.5 | 361.5 | 152.3 | 66.3 | 6409.3 | 0.0 |
| 1956 | 1555.4 | 28.7 | 21.5 | 27.2 | 291.9 | 4.7 | 14.1 | 24.1 | 20.3 | 200.3 | 228.2 | 149.7 | 35.3 | 5.7 |
| 1957 | 46373.7 | 27568.5 | 31636.7 | 42274.3 | 1357.4 | 19059.9 | 41016.4 | 32751.5 | 53751.8 | 42180.8 | 45677.5 | 54615.8 | 69983.0 | 17448.5 |
| 1958 | 81157.8 | 21522.3 | 26218.6 | 25348.1 | 2231.0 | 14156.3 | 20971.6 | 10725.9 | 38352.1 | 57884.6 | 47635.3 | 32847.4 | 40400.1 | 18195.0 |
| 1959 | 7672.5 | 10517.7 | 4615.9 | 10861.6 | 1692.4 | 1817.2 | 14491.1 | 8108.0 | 10715.2 | 6626.2 | 1900.6 | 4952.2 | 19300.0 | 1271.6 |
| 1960 | 18627.2 | 16475.9 | 9647.7 | 19138.4 | 1705.2 | 5442.1 | 29062.9 | 18627.8 | 25275.2 | 13481.9 | 15915.4 | 17635.4 | 29664.0 | 5357.0 |
| 1961 | 16329.9 | 14699.7 | 21194.4 | 36248.1 | 2012.1 | 5318.0 | 26510.0 | 22560.3 | 10071.2 | 21694.4 | 10205.4 | 10828.2 | 72104.3 | 4348.7 |
| 1962 | 63892.5 | 35757.3 | 7603.5 | 14276.2 | 1697.5 | 6064.0 | 30838.4 | 20776.6 | 78572.6 | 23007.5 | 19832.0 | 31529.5 | 11199.1 | 4006.2 |
| 1963 | 16592.1 | 13347.0 | 2944.8 | 8518.1 | 1332.6 | 1280.9 | 17153.0 | 13564.6 | 13006.0 | 10737.8 | 4088.4 | 7698.7 | 5361.6 | 253.0 |
| 1964 | 2988.5 | 2616.2 | 196.1 | 404.3 | 639.1 | 60.9 | 2255.6 | 2212.6 | 2080.6 | 1106.0 | 1063.6 | 488.6 | 2167.3 | 12.8 |
| 1965 | 84941.2 | 116243.8 | 30840.1 | 59265.4 | 1681.1 | 14332.3 | 99126.6 | 49704.5 | 115357.9 | 74745.8 | 51138.6 | 58206.6 | 64485.9 | 13384.7 |
| 1966 | 17649.6 | 6408.9 | 1279.3 | 3507.9 | 314.5 | 284.3 | 11444.2 | 3440.4 | 6850.0 | 7413.4 | 3270.2 | 1441.4 | 1581.0 | 999.3 |
| 1967 | 7250.2 | 11183.5 | 2067.0 | 11010.1 | 1456.0 | 161.5 | 24952.9 | 12426.4 | 6664.1 | 4939.7 | 2223.1 | 867.6 | 14438.9 | 223.6 |
| 1968 | 7746.0 | 16762.8 | 2636.9 | 9176.2 | 1522.5 | 1195.4 | 16509.4 | 17447.9 | 14812.6 | 8158.5 | 3911.4 | 9501.4 | 7389.0 | 121.2 |
| 1969 | 22873.9 | 17781.7 | 9171.7 | 20547.1 | 1805.0 | 3441.7 | 33361.2 | 32305.8 | 23898.5 | 17433.1 | 8115.4 | 9851.5 | 27691.2 | 2383.4 |
| 1970 | 4551.7 | 3954.3 | 5015.3 | 8055.6 | 827.4 | 2001.0 | 6121.9 | 4982.4 | 6807.3 | 4533.6 | 3573.5 | 5361.2 | 22489.3 | 751.5 |
| 1971 | 23434.0 | 24575.2 | 4673.8 | 10885.3 | 1090.1 | 2185.0 | 26961.1 | 11576.7 | 38909.2 | 11987.6 | 8430.8 | 10251.7 | 14054.2 | 1428.6 |
| 1972 | 25014.1 | 15392.8 | 10578.0 | 16919.1 | 1898.5 | 3643.0 | 20671.5 | 9478.6 | 22971.0 | 20349.4 | 10055.0 | 12583.8 | 28078.2 | 1633.8 |
| 1973 | 69407.8 | 59998.2 | 24314.7 | 35951.2 | 4810.4 | 10673.0 | 46524.9 | 32386.1 | 88129.3 | 50165.7 | 25402.3 | 42296.8 | 56442.9 | 4434.2 |
| 1974 | 8527.0 | 4868.2 | 1235.1 | 1196.6 | 219.6 | 488.0 | 2978.5 | 213.3 | 8127.4 | 6402.4 | 3962.8 | 6800.3 | 757.3 | 96.0 |
| 1975 | 20491.1 | 36299.8 | 12745.9 | 19142.2 | 1192.6 | 6300.4 | 29083.3 | 9970.9 | 31793.1 | 24949.5 | 15400.7 | 29748.9 | 31432.0 | 1747.1 |
| 1976 | 2403.5 | 2390.7 | 1435.4 | 2716.4 | 240.9 | 406.4 | 3529.9 | 5713.6 | 756.6 | 3296.4 | 3961.2 | 3957.8 | 5773.6 | 112.7 |
| 1977 | 14581.7 | 30604.9 | 4546.0 | 8528.4 | 2317.5 | 3457.5 | 21268.0 | 8644.2 | 34239.6 | 13550.3 | 11061.9 | 23090.2 | 8009.7 | 923.3 |
| 1978 | 4422.1 | 1484.8 | 2040.1 | 3399.1 | 1315.1 | 778.5 | 3197.4 | 4493.0 | 1376.1 | 4996.7 | 5986.0 | 5554.4 | 4919.6 | 535.6 |
| 1979 | 62605.9 | 66369.4 | 19321.1 | 27214.9 | 1600.0 | 10659.2 | 40077.4 | 21400.5 | 71699.5 | 61724.6 | 37354.5 | 51852.9 | 26647.2 | 6229.6 |
| 1980 | 44434.0 | 13561.1 | 8765.0 | 7528.6 | 911.7 | 3166.9 | 8143.9 | 4015.3 | 12538.7 | 29939.8 | 19481.6 | 12709.7 | 7359.3 | 2801.7 |
| 1981 | 94743.2 | 43740.0 | 16570.3 | 18083.3 | 1678.8 | 10275.4 | 39186.8 | 16358.0 | 76924.1 | 63657.3 | 39341.3 | 48912.0 | 11789.5 | 6459.4 |
| 1982 | 51957.1 | 39765.2 | 11821.7 | 12376.4 | 1434.4 | 9028.5 | 19810.4 | 11283.8 | 66329.3 | 30839.7 | 29829.1 | 46201.9 | 15167.2 | 5187.1 |
| 1983 | 15530.2 | 36059.5 | 2310.1 | 8727.0 | 2024.9 | 645.1 | 23256.9 | 16103.1 | 20303.6 | 13438.2 | 10626.5 | 8213.0 | 4391.7 | 1192.3 |
| 1984 | 23923.4 | 42683.4 | 12171.5 | 19545.2 | 1601.8 | 4008.0 | 24140.8 | 9257.0 | 47776.0 | 25509.8 | 12768.4 | 24571.5 | 36955.2 | 761.1 |
| 1985 | 16509.2 | 37131.8 | 5139.1 | 9930.8 | 1758.6 | 4066.4 | 27273.3 | 8911.1 | 30715.4 | 15903.9 | 19000.8 | 25581.8 | 8195.2 | 3376.6 |
| 1986 | 9438.8 | 14071.4 | 6268.2 | 13763.2 | 2589.2 | 1707.0 | 15298.3 | 9041.5 | 8658.1 | 12992.3 | 6669.2 | 12692.3 | 21078.0 | 464.2 |
| 1987 | 22628.2 | 32631.9 | 9197.0 | 19063.3 | 2900.2 | 3873.9 | 32327.7 | 22471.2 | 30286.8 | 21035.6 | 16855.6 | 21032.8 | 25916.4 | 3304.3 |
| 1988 | 22424.0 | 15362.0 | 3363.1 | 3182.5 | 310.5 | 1805.0 | 6996.5 | 3420.2 | 24706.4 | 14075.0 | 9993.0 | 13247.5 | 2305.0 | 1162.1 |
| 1989 | 7708.8 | 3432.4 | 3795.9 | 3875.4 | 556.7 | 2911.6 | 3354.4 | 2986.9 | 8479.5 | 7345.0 | 9606.5 | 13533.2 | 5518.1 | 2562.4 |
| 1990 | 37571.1 | 15723.3 | 13578.6 | 15960.6 | 1016.2 | 4571.5 | 11888.1 | 13711.8 | 13846.3 | 35018.7 | 16190.1 | 19552.3 | 26503.6 | 1917.7 |
| 1991 | 61818.3 | 33758.5 | 8898.4 | 10053.0 | 773.5 | 4299.2 | 14018.4 | 6866.9 | 41433.9 | 38609.0 | 23201.4 | 23913.8 | 5533.8 | 3198.9 |
| 1992 | 29915.9 | 32899.5 | 15021.7 | 30198.4 | 2908.4 | 10036.1 | 45145.6 | 17023.1 | 45868.3 | 28953.0 | 29834.2 | 43071.9 | 38762.1 | 7146.6 |
| 1993 | 55459.2 | 87059.9 | 31895.7 | 53257.2 | 3804.4 | 16744.4 | 77237.7 | 55678.6 | 106778.9 | 55947.2 | 36257.1 | 75754.6 | 81040.2 | 5900.1 |
| 1994 | 11461.5 | 30149.0 | 4050.1 | 5666.8 | 603.6 | 5260.7 | 23070.2 | 249.8 | 29567.4 | 12036.4 | 18489.8 | 30014.3 | 4170.1 | 3693.0 |
| 1995 | 40166.2 | 16380.6 | 25063.5 | 20970.5 | 965.9 | 11012.2 | 21822.3 | 321.5 | 20455.7 | 41985.4 | 35044.2 | 31472.3 | 43635.0 | 10913.4 |
| 1996 | 29925.8 | 46199.1 | 17414.9 | 23839.9 | 2590.4 | 9417.8 | 53605.5 | 2968.5 | 55456.9 | 27873.6 | 25889.3 | 41910.8 | 50581.0 | 4985.9 |
| 1997 | 11136.6 | 11368.0 | 13871.5 | 16931.1 | 2437.3 | 5195.2 | 17653.1 | 230.8 | 11009.0 | 16434.7 | 13756.1 | 19528.4 | 45454.1 | 2577.8 |
| 1998 | 22937.9 | 9426.8 | 19338.7 | 15475.7 | 1427.9 | 9815.4 | 11161.2 | 166.9 | 12403.9 | 26430.4 | 33025.9 | 29356.9 | 44624.8 | 9454.6 |
| 1999 | 20952.8 | 25930.9 | 9878.8 | 10644.1 | 725.3 | 5352.3 | 16704.6 | 212.8 | 21910.0 | 17264.3 | 26577.6 | 20285.9 | 26873.5 | 8089.5 |
| 2000 | 7735.8 | 5945.9 | 5946.7 | 7264.7 | 298.4 | 1778.2 | 10433.5 | 201.0 | 4136.7 | 9841.6 | 8634.8 | 9404.1 | 18190.0 | 578.4 |

Appendix G Recharge from Precipitation (acre-feet per year)

| Year | Nebraska | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Adams | Buffalo | Chase | Clay | Dawson | Deuel | Dundy | Franklin | Frontier | Furnas | Gosper | Harlan | Hayes | Hitchcock | Kearney | Keith | Lincoln | Nuckolls | Perkins | Phelps | RedWillow | Webster |
| 1918 | 10153.2 | 63.7 | 83359.8 | 1671.1 | 4737.0 | 1296.9 | 78328.5 | 49363.2 | 20596.7 | 23438.2 | 9480.7 | 30779.5 | 38064.1 | 16344.9 | 53766.7 | 25113.7 | 174668.2 | 80276.6 | 87893.4 | 26882.1 | 14272.1 | 44238.9 |
| 1919 | 24384.0 | 352.5 | 108214.5 | 3325.6 | 4472.5 | 885.4 | 33495.2 | 122131.7 | 14260.7 | 34607.2 | 15418.4 | 81695.5 | 25563.2 | 5920.6 | 182162.7 | 31340.8 | 186311.2 | 127515.4 | 113891.3 | 105295.8 | 10702.2 | 89186.6 |
| 1920 | 7279.6 | 90.5 | 92304.8 | 1045.8 | 5591.4 | 779.4 | 123739.7 | 26657.6 | 20887.3 | 26257.4 | 17733.7 | 14252.9 | 21626.1 | 20585.0 | 61837.6 | 9151.2 | 90269.0 | 59299.3 | 52602.3 | 19559.7 | 12498.2 | 24998.2 |
| 1921 | 1204.6 | 31.7 | 12371.3 | 161.2 | 2984.7 | 138.7 | 15574.7 | 8017.5 | 10125.4 | 13600.0 | 13387.5 | 12083.3 | 2711.9 | 1272.4 | 20460.8 | 1618.2 | 27817.5 | 7434.6 | 8122.7 | 23565.0 | 6900.3 | 5264.4 |
| 1922 | 2033.7 | 32.7 | 32041.7 | 250.6 | 1089.5 | 443.7 | 38688.1 | 11225.5 | 616.1 | 5753.1 | 1269.7 | 10221.0 | 5412.5 | 3193.9 | 26363.2 | 5863.2 | 44160.9 | 11305.5 | 30136.8 | 16706.6 | 2665.3 | 5874.8 |
| 1923 | 15294.1 | 279.3 | 129637.8 | 1952.2 | 11915.6 | 2797.1 | 132420.6 | 84138.9 | 65882.2 | 74255.6 | 41504.5 | 74869.3 | 86470.2 | 68614.2 | 136816.9 | 38429.9 | 235796.8 | 78769.3 | 164984.0 | 119217.1 | 69756.7 | 47003.5 |
| 1924 | 2002.4 | 59.9 | 47939.2 | 226.8 | 1786.2 | 710.4 | 42276.8 | 11527.1 | 5408.2 | 15075.0 | 7184.7 | 18237.6 | 9513.3 | 9230.4 | 34467.9 | 5414.2 | 33516.1 | 8469.8 | 35791.9 | 36887.4 | 5530.0 | 4597.3 |
| 1925 | 7572.0 | 88.2 | 32557.0 | 1267.6 | 3878.8 | 728.4 | 29119.9 | 34424.5 | 15646.5 | 6218.3 | 11600.1 | 20013.1 | 17205.2 | 11743.6 | 51375.8 | 7216.0 | 75324.3 | 56898.6 | 32512.4 | 46268.1 | 10628.8 | 25563.4 |
| 1926 | 3470.7 | 29.9 | 29969.1 | 584.7 | 2268.8 | 525.7 | 26817.0 | 16158.9 | 9270.3 | 6466.5 | 6379.4 | 11376.1 | 9588.0 | 5417.9 | 23307.5 | 6325.2 | 59169.4 | 27554.1 | 27685.0 | 19907.4 | 5736.4 | 18357.5 |
| 1927 | 9266.9 | 68.1 | 79254.2 | 1057.6 | 4117.2 | 764.3 | 75279.1 | 60793.7 | 20852.9 | 30122.5 | 14113.2 | 46077.8 | 37852.6 | 19961.0 | 62094.6 | 12979.0 | 125776.2 | 46956.1 | 64802.8 | 67154.4 | 20703.5 | 32503.4 |
| 1928 | 9182.3 | 73.1 | 146230.5 | 844.1 | 3768.7 | 999.4 | 183208.9 | 80266.1 | 29176.1 | 37737.7 | 9581.8 | 58866.9 | 81433.3 | 61124.5 | 75950.8 | 15958.6 | 163197.5 | 46507.5 | 85951.5 | 40559.8 | 30148.1 | 39106.6 |
| 1929 | 929.2 | 8.5 | 86900.5 | 227.8 | 2573.7 | 471.2 | 96830.5 | 5505.6 | 12798.8 | 21461.6 | 4755.8 | 10730.7 | 14513.5 | 11510.0 | 6983.0 | 6176.1 | 73066.0 | 19712.1 | 39683.4 | 7608.4 | 13434.1 | 5523.1 |
| 1930 | 12053.0 | 436.3 | 187670.3 | 1458.4 | 20526.6 | 2138.0 | 148805.4 | 72166.4 | 100509.3 | 88195.5 | 50845.4 | 95805.0 | 104085.7 | 58916.4 | 165934.3 | 28797.8 | 288144.6 | 49570.0 | 155730.7 | 191446.4 | 99904.5 | 28747.5 |
| 1931 | 6659.1 | 79.1 | 16630.2 | 1068.9 | 2388.4 | 62.9 | 10851.3 | 46216.0 | 8590.2 | 7846.0 | 9557.8 | 38551.9 | 8068.4 | 2358.2 | 48938.8 | 2255.2 | 53109.9 | 48314.6 | 15847.8 | 66007.3 | 8258.4 | 26830.3 |
| 1932 | 1635.1 | 48.3 | 52078.8 | 219.1 | 2591.5 | 587.2 | 78196.8 | 11831.0 | 6969.6 | 5335.7 | 10453.2 | 14711.4 | 8765.9 | 5011.1 | 28010.1 | 10944.8 | 74299.0 | 9712.5 | 47603.7 | 38587.6 | 2954.0 | 3813.1 |
| 1933 | 3360.4 | 136.2 | 69187.0 | 396.9 | 4527.5 | 940.5 | 110735.6 | 16839.7 | 20601.5 | 17976.2 | 20779.9 | 20799.1 | 24492.3 | 29082.7 | 58695.1 | 14824.5 | 112729.1 | 11886.2 | 48366.8 | 60890.6 | 16216.3 | 7292.0 |
| 1934 | 141.6 | 0.0 | 15068.6 | 0.0 | 125.4 | 63.0 | 13094.7 | 2722.7 | 782.8 | 952.0 | 0.0 | 1916.8 | 7728.0 | 2060.1 | 4410.1 | 622.3 | 17789.5 | 114.0 | 6764.8 | 2100.1 | 1912.5 | 318.7 |
| 1935 | 9279.6 | 96.8 | 47077.0 | 1872.7 | 7232.3 | 335.5 | 49043.7 | 31420.4 | 24996.0 | 15905.7 | 11301.6 | 21671.0 | 30239.0 | 14582.4 | 49896.1 | 14607.2 | 176110.6 | 77770.1 | 51763.2 | 35458.3 | 11746.2 | 32119.5 |
| 1936 | 86.8 | 0.0 | 31310.5 | 7.5 | 218.2 | 81.4 | 51758.5 | 572.4 | 16.4 | 964.6 | 0.0 | 649.8 | 4899.4 | 1516.4 | 2834.1 | 1047.3 | 21068.1 | 2146.7 | 13641.2 | 1098.4 | 793.4 | 425.5 |
| 1937 | 1905.9 | 26.7 | 20441.5 | 320.0 | 2543.5 | 130.1 | 22784.2 | 8759.4 | 6878.3 | 11961.4 | 3512.9 | 9919.6 | 10307.5 | 3582.3 | 19842.9 | 5011.9 | 75868.8 | 19448.8 | 33788.6 | 16120.5 | 4936.9 | 6239.6 |
| 1938 | 4847.4 | 33.9 | 49177.2 | 900.6 | 1355.5 | 525.2 | 61950.8 | 24049.6 | 9412.9 | 11060.7 | 5864.4 | 18542.1 | 14870.1 | 12597.5 | 30165.4 | 10807.6 | 84529.1 | 55645.6 | 39400.7 | 29128.9 | 8509.6 | 21016.1 |
| 1939 | 2287.7 | 34.7 | 15941.8 | 392.7 | 382.1 | 346.0 | 21107.9 | 8601.2 | 61.4 | 3124.3 | 2524.1 | 6954.4 | 2217.0 | 1133.3 | 25806.1 | 4928.0 | 27270.4 | 18069.9 | 21179.9 | 19448.5 | 1108.9 | 7794.9 |
| 1940 | 1728.1 | 7.2 | 30796.0 | 278.7 | 737.7 | 345.1 | 19857.8 | 8334.5 | 2332.3 | 3649.8 | 247.5 | 5216.4 | 7777.9 | 1283.9 | 10058.8 | 5738.0 | 50977.7 | 15947.7 | 39501.5 | 4604.7 | 2739.6 | 8713.3 |
| 1941 | 21920.7 | 199.0 | 90203.6 | 3390.6 | 9249.6 | 1300.1 | 159636.4 | 102701.2 | 50405.3 | 48766.6 | 30578.6 | 59167.4 | 36135.6 | 44575.0 | 124640.9 | 14772.4 | 135089.0 | 142071.9 | 68848.4 | 67613.7 | 61551.3 | 83378.1 |
| 1942 | 19863.2 | 320.5 | 206100.1 | 2725.9 | 12473.1 | 991.2 | 177098.8 | 108844.4 | 43322.4 | 64512.3 | 49088.4 | 96960.7 | 56087.8 | 25671.1 | 151436.4 | 22370.4 | 185850.8 | 122669.3 | 164797.9 | 183546.7 | 34903.2 | 69199.4 |
| 1943 | 2092.7 | 13.8 | 7574.5 | 215.3 | 2233.9 | 132.9 | 9222.5 | 19531.6 | 6376.6 | 9771.6 | 16202.5 | 12408.3 | 754.6 | 421.4 | 16730.3 | 2614.8 | 22735.3 | 10833.2 | 8916.3 | 21579.6 | 2301.6 | 6695.3 |
| 1944 | 23350.9 | 405.7 | 74328.0 | 3332.6 | 4933.3 | 825.6 | 104709.9 | 107042.7 | 20064.0 | 57495.5 | 18235.9 | 81754.3 | 31447.6 | 41672.4 | 198509.5 | 16104.2 | 133629.9 | 138307.1 | 67630.5 | 132312.1 | 44893.6 | 70555.6 |
| 1945 | 12166.7 | 133.1 | 49814.2 | 1857.3 | 3732.3 | 1444.0 | 59542.8 | 50524.2 | 10767.2 | 6888.4 | 4737.5 | 23835.8 | 15827.7 | 8347.7 | 81499.6 | 19430.7 | 118888.3 | 81356.8 | 64325.5 | 43626.0 | 9501.3 | 39697.1 |
| 1946 | 23104.5 | 554.3 | 107600.8 | 2785.9 | 11607.0 | 1120.6 | 127993.4 | 129821.1 | 50646.6 | 66640.8 | 43981.5 | 124312.4 | 72705.0 | 51692.7 | 239964.8 | 14652.0 | 166364.8 | 90107.5 | 84677.7 | 237974.2 | 54373.5 | 75799.2 |
| 1947 | 6512.2 | 164.4 | 73700.5 | 925.0 | 8113.7 | 253.7 | 110374.5 | 33860.6 | 22487.7 | 21996.7 | 12142.8 | 36772.9 | 31932.6 | 22431.2 | 70095.2 | 6087.2 | 129648.7 | 30092.6 | 53766.8 | 69626.6 | 19267.1 | 21304.4 |
| 1948 | 4390.0 | 59.7 | 36192.7 | 748.6 | 4322.9 | 515.1 | 59140.8 | 14209.7 | 13022.4 | 3814.3 | 6494.0 | 8805.7 | 17872.2 | 12668.2 | 36380.2 | 5411.5 | 73782.5 | 31847.4 | 40252.9 | 32461.0 | 13091.0 | 14574.7 |
| 1949 | 17913.8 | 265.2 | 138173.4 | 2963.1 | 8877.8 | 1084.7 | 172531.4 | 80404.9 | 31751.0 | 48455.0 | 22238.5 | 72555.6 | 67431.5 | 30031.1 | 123655.4 | 15414.4 | 166578.3 | 119347.8 | 100674.2 | 111103.9 | 30889.2 | 64147.9 |
| 1950 | 13239.5 | 399.8 | 28292.4 | 2066.0 | 5464.0 | 615.0 | 32884.5 | 56825.8 | 14983.2 | 18691.0 | 13647.7 | 57743.4 | 11960.3 | 6671.2 | 155892.1 | 14665.8 | 126631.7 | 81119.2 | 35958.2 | 131155.5 | 12883.9 | 44304.9 |
| 1951 | 29090.9 | 440.1 | 169611.4 | 4274.2 | 12917.5 | 2653.9 | 147489.9 | 143029.0 | 47173.5 | 45653.9 | 25445.7 | 99652.9 | 96191.8 | 44711.1 | 214307.4 | 42958.2 | 283037.9 | 174148.4 | 190901.6 | 134299.5 | 35128.2 | 111975.4 |
| 1952 | 3636.6 | 34.4 | 21778.9 | 729.3 | 846.4 | 917.5 | 18283.2 | 15477.1 | 2792.8 | 14509.6 | 2246.3 | 22063.5 | 6353.1 | 2951.4 | 27929.9 | 6918.2 | 30216.0 | 31048.5 | 24639.2 | 28412.9 | 6816.9 | 18846.3 |
| 1953 | 6521.8 | 74.3 | 35680.5 | 1318.1 | 1878.4 | 980.4 | 25766.4 | 22569.6 | 8501.8 | 29058.6 | 6678.9 | 35376.8 | 9814.9 | 7138.3 | 46836.9 | 8232.3 | 44274.5 | 66901.8 | 33108.5 | 51959.7 | 16743.6 | 23401.1 |
| 1954 | 3686.8 | 57.2 | 14850.7 | 544.7 | 1966.9 | 218.1 | 10545.4 | 16799.6 | 328.5 | 1810.9 | 2692.6 | 10087.1 | 890.9 | 751.9 | 38796.0 | 1553.5 | 15473.1 | 26988.9 | 7432.9 | 26728.4 | 560.2 | 16354.1 |
| 1955 | 4539.2 | 33.6 | 20977.8 | 495.6 | 1298.0 | 792.8 | 12739.9 | 18859.7 | 351.8 | 1547.9 | 2586.4 | 9453.8 | 3050.6 | 1168.4 | 32455.5 | 5804.5 | 22751.6 | 14376.7 | 23038.1 | 25291.8 | 1363.5 | 17510.8 |
| 1956 | 1451.0 | 12.0 | 25273.5 | 189.4 | 1439.1 | 746.6 | 13260.5 | 3037.8 | 426.1 | 665.2 | 511.3 | 832.3 | 2087.5 | 707.1 | 13231.3 | 4602.2 | 20353.3 | 8693.1 | 18229.0 | 5484.3 | 594.7 | 4679.2 |
| 1957 | 21055.8 | 423.1 | 82840.8 | 2599.1 | 12708.4 | 1360.8 | 88717.6 | 119182.1 | 38419.0 | 58433.7 | 37114.7 | 112567.1 | 40719.8 | 25178.3 | 188001.8 | 22518.7 | 188059.1 | 80827.0 | 85895.2 | 196587.1 | 36406.9 | 77846.6 |
| 1958 | 18860.9 | 172.2 | 112510.6 | 2981.5 | 5028.9 | 2090.0 | 121502.1 | 53194.4 | 16991.0 | 23560.8 | 6557.4 | 33502.6 | 35828.3 | 17899.3 | 107521.1 | 30297.6 | 166695.6 | 114194.7 | 126710.1 | 43533.1 | 16855.6 | 50574.6 |
| 1959 | 17335.8 | 330.6 | 51618.6 | 2696.2 | 7337.1 | 515.0 | 46917.4 | 42281.1 | 18330.8 | 15297.9 | 11399.4 | 33812.4 | 22315.8 | 16731.6 | 144870.5 | 6146.3 | 99873.7 | 93375.5 | 43636.3 | 91392.7 | 18495.8 | 39630.7 |
| 1960 | 19386.2 | 400.4 | 47671.7 | 3018.4 | 5780.7 | 545.4 | 66695.9 | 55460.1 | 12652.9 | 34164.6 | 16397.4 | 64812.0 | 19003.7 | 17067.4 | 172232.5 | 4731.4 | 67561.4 | 99811.7 | 27298.3 | 123704.0 | 12669.1 | 51077.1 |
| 1961 | 18309.1 | 237.7 | 45111.2 | 2847.9 | 4932.0 | 1019.8 | 60972.4 | 74460.7 | 12445.4 | 32661.1 | 9716.1 | 73119.5 | 14535.5 | 8928.7 | 127030.5 | 10155.6 | 80600.7 | 106302.8 | 41487.6 | 100403.0 | 12903.6 | 49391.2 |
| 1962 | 22326.3 | 335.9 | 178874.8 | 2922.8 | 15955.2 | 1011.1 | 210173.0 | 98723.5 | 55685.8 | 45603.9 | 34177.5 | 82813.3 | 86351.1 | 59541.2 | 165756.3 | 25158.6 | 263907.9 | 96467.9 | 130902.2 | 145508.1 | 36073.9 | 58454.5 |
| 1963 | 12618.0 | 32.9 | 45285.8 | 2017.7 | 5896.6 | 694.8 | 45864.0 | 46995.6 | 12246.0 | 23403.3 | 16048.5 | 36494.9 | 10727.3 | 7316.2 | 40582.3 | 10701.2 | 87298.6 | 77057.1 | 56619.9 | 48993.1 | 10730.5 | 38847.0 |
| 1964 | 5474.5 | 51.1 | 12171.6 | 1005.7 | 4644.7 | 362.0 | 14907.8 | 10477.0 | 8770.8 | 9748.3 | 4338.0 | 10772.8 | 5669.4 | 4781.2 | 35564.9 | 4322.0 | 70570.7 | 35484.2 | 12211.1 | 23543.1 | 5822.4 | 10982.0 |
| 1965 | 34382.4 | 654.6 | 149610.3 | 4329.5 | 20207.2 | 2514.9 | 153967.9 | 155251.9 | 72160.3 | 131979.3 | 69307.7 | 163429.6 | 69481.2 | 58144.9 | 286562.9 | 36598.8 | 256439.9 | 119524.5 | 136036.9 | 279853.4 | 73167.8 | 107756.4 |
| 1966 | 2866.5 | 29.0 | 57881.3 | 351.3 | 4116.1 | 1168.8 | 80516.9 | 8530.1 | 11366.6 | 20413.5 | 8542.5 | 14801.1 | 18219.5 | 12768.4 | 25638.8 | 9297.5 | 71859.3 | 11550.9 | 39616.7 | 28216.5 | 8186.8 | 5521.6 |
| 1967 | 13078.7 | 322.0 | 76449.1 | 1817.3 | 7043.1 | 664.0 | 70778.4 | 40152.1 | 21156.7 | 41094.7 | 25954.4 | 58114.9 | 20537.9 | 17410.2 | 137003.0 | 7104.7 | 88522.4 | 68358.4 | 35723.0 | 126194.3 | 18575.1 | 28866.0 |
| 1968 | 18888.6 | 251.2 | 8718.5 | 2811.9 | 4134.6 | 364.1 | 17682.3 | 69918.1 | 7068.3 | 17673.6 | 11549.8 | 59714.9 | 5566.5 | 9805.2 | 128974.6 | 2727.7 | 33424.4 | 92839.2 | 11547.0 | 107767.6 | 10094.2 | 49259.7 |
| 1969 | 24397.4 | 305.9 | 53411.0 | 3271.4 | 10760.4 | 904.0 | 74095.2 | 122978.2 | 39260.4 | 60156.3 | 51671.3 | 118299.8 | 35045.5 | 29212.7 | 163434.4 | 9147.3 | 102513.3 | 106940.9 | 45125.3 | 194304.3 | 24526.2 | 75772.9 |
| 1970 | 10553.0 | 45.4 | 16948.8 | 1616.1 | 1725.3 | 402.1 | 30853.6 | 29490.9 | 1377.5 | 5714.6 | 2512.7 | 20352.7 | 3103.5 | 6081.2 | 51375.0 | 2907.4 | 23755.2 | 52808.3 | 9063.4 | 34696.4 | 1062.0 | 28872.5 |
| 1971 | 14359.9 | 178.5 | 133922.8 | 2179.8 | 8953.2 | 1409.6 | 115962.1 | 48415.7 | 27730.6 | 48313.4 | 21207.9 | 61803.3 | 38305.4 | 38856.7 | 88887.8 | 21632.9 | 157707.2 | 69540.4 | 119279.0 | 113243.6 | 27310.7 | 43661.2 |
| 1972 | 21418.4 | 235.5 | 67611.2 | 3068.2 | 4240.3 | 737.0 | 80257.0 | 72287.2 | 12150.9 | 22072.1 | 9383.9 | 54170.6 | 20469.4 | 19878.1 | 137840.1 | 9288.2 | 82500.4 | 104711.1 | 45272.5 | 101602.1 | 12682.8 | 61697.9 |
| 1973 | 35911.9 | 426.1 | 137261.9 | 5972.6 | 9768.3 | 1222.2 | 174322.0 | 126993.0 | 42544.0 | 66551.7 | 23869.6 | 118050.5 | 71944.5 | 58877.2 | 213998.5 | 13015.8 | 149785.5 | 234427.5 | 86898.5 | 190027.5 | 57434.8 | 121529.1 |
| 1974 | 1966.6 | 6.2 | 23514.0 | 225.0 | 1968.2 | 229.8 | 32904.6 | 5293.2 | 4713.0 | 2125.0 | 2413.6 | 5910.1 | 10576.4 | 8296.5 | 14498.7 | 2327.9 | 34297.8 | 6689.6 | 11907.7 | 17903.2 | 6571.4 | 3309.2 |
| 1975 | 14096.7 | 180.4 | 53984.9 | 2315.6 | 8303.3 | 1483.9 | 47651.2 | 35902.7 | 33162.1 | 46698.2 | 30652.9 | 45516.0 | 27424.7 | 15700.4 | 93746.0 | 14142.5 | 104745.7 | 75085.7 | 50082.7 | 95116.2 | 32929.7 | 34772.7 |
| 1976 | 4900.0 | 21.9 | 13301.2 | 523.6 | 5673.6 | 252.8 | 10463.9 | 21857.5 | 13395.0 | 11663.8 | 9290.0 | 17667.7 | 6900.1 | 3671.1 | 32423.4 | 2965.7 | 53981.7 | 10875.3 | 13699.3 | 30126.1 | 7106.0 | 11363.3 |
| 1977 | 31805.7 | 337.3 | 81416.4 | 4619.7 | 14311.5 | 1560.9 | 73902.1 | 90771.2 | 52479.0 | 40091.6 | 28610.1 | 52941.5 | 60488.9 | 32930.8 | 184212.1 | 23435.6 | 217802.6 | 142262.0 | 87093.2 | 121617.1 | 44435.7 | 93780.3 |
| 1978 | 15237.8 | 84.3 | 29903.2 | 2281.8 | 7342.3 | 294.0 | 21907.5 | 42503.7 | 15257.8 | 7753.0 | 12851.5 | 24563.4 | 12512.5 | 3562.7 | 71876.7 | 2656.3 | 56001.0 | 77578.1 | 13636.5 | 60093.3 | 5093.0 | 43112.9 |
| 1979 | 30914.0 | 396.5 | 58502.1 | 3672.2 | 11824.1 | 1111.1 | 69087.8 | 131779.2 | 42941.7 | 50922.2 | 49734.6 | 97596.4 | 40732.2 | 28251.3 | 222738.9 | 14327.5 | 120872.5 | 102923.4 | 68300.1 | 203630.9 | 45978.1 | 89801.4 |
| 1980 | 8760.4 | 76.8 | 61771.5 | 1232.8 | 3655.6 | 421.7 | 89118.9 | 22118.2 | 11579.3 | 21401.0 | 11761.4 | 26707.6 | 9556.8 | 8816.4 | 68760.1 | 3776.1 | 23882.7 | 47313.7 | 30144.5 | 57590.9 | 15265.8 | 16294.6 |
| 1981 | 28709.0 | 418.0 | 148975.7 | 3632.0 | 16664.6 | 1492.6 | 164771.0 | 100308.2 | 57200.4 | 66615.0 | 34343.2 | 84383.3 | 68721.4 | 50030.7 | 220384.0 | 19799.4 | 205526.9 | 103925.5 | 100421.8 | 166341.4 | 50665.5 | 75948.5 |
| 1982 | 25771.1 | 307.2 | 170657.7 | 3268.5 | 9368.8 | 1095.6 | 163528.2 | 87321.5 | 33708.6 | 37366.7 | 31347.6 | 57390.8 | 74675.4 | 45443.9 | 182289.5 | 15156.5 | 138691.7 | 92239.8 | 115438.9 | 123699.2 | 25939.5 | 64618.6 |
| 1983 | 26542.2 | 293.3 | 45741.6 | 3962.5 | 5957.7 | 755.9 | 51279.4 | 93912.5 | 14380.0 | 39735.8 | 18485.6 | 76517.8 | 11642.4 | 11917.3 | 164350.5 | 10089.7 | 78247.7 | 127493.4 | 35209.4 | 129282.6 | 16499.5 | 69456.9 |
| 1984 | 17962.8 | 271.9 | 57089.9 | 2911.3 | 14216.3 | 506.4 | 64450.7 | 51403.9 | 42609.1 | 47780.8 | 32192.2 | 61521.5 | 45878.7 | 35125.5 | 134394.6 | 11798.3 | 165175.1 | 97487.8 | 56729.8 | 146156.5 | 38498.9 | 35891.0 |
| 1985 | 28420.9 | 386.6 | 43685.3 | 4121.8 | 13272.2 | 662.5 | 51582.6 | 81119.9 | 37915.6 | 57505.1 | 46937.9 | 70553.6 | 21704.6 | 17233.9 | 191927.8 | 10157.8 | 108647.8 | 121505.7 | 35304.5 | 182039.8 | 40167.8 | 76818.7 |
| 1986 | 21697.5 | 322.1 | 54194.0 | 4031.2 | 7361.5 | 637.6 | 45175.1 | 35106.4 | 20100.3 | 18392.0 | 16145.4 | 36093.8 | 18021.0 | 8558.4 | 148392.2 | 9303.1 | 87412.4 | 145696.2 | 43833.9 | 101636.4 | 18272.2 | 50218.4 |
| 1987 | 31105.8 | 390.1 | 94929.7 | 4291.5 | 14084.7 | 2039.7 | 70699.1 | 132431.1 | 35426.3 | 44646.9 | 40846.9 | 108554.5 | 41121.8 | 22103.2 | 213429.3 | 25676.9 | 169051.9 | 150730.2 | 110439.2 | 216214.7 | 25674.5 | 81947.0 |
| 1988 | 6366.4 | 83.2 | 65144.4 | 661.7 | 9675.1 | 1314.9 | 74784.5 | 23523.3 | 27558.7 | 18630.3 | 13144.5 | 26626.8 | 43768.1 | 28571.9 | 61282.4 | 16392.0 | 153476.4 | 14082.2 | 61328.8 | 64795.4 | 17521.2 | 10986.5 |
| 1989 | 11627.0 | 173.9 | 44160.7 | 1516.4 | 6370.2 | 491.3 | 40972.4 | 25632.4 | 15416.0 | 6122.1 | 14924.2 | 19865.2 | 18654.9 | 13305.6 | 95467.2 | 7673.4 | 78734.4 | 37850.1 | 40358.5 | 83545.3 | 8132.8 | 26627.3 |
| 1990 | 15959.6 | 31.8 | 89961.8 | 2290.3 | 5957.1 | 1038.1 | 80739.7 | 55452.5 | 15919.0 | 19382.9 | 16998.8 | 35936.0 | 15451.5 | 6573.2 | 55531.9 | 11252.7 | 65257.8 | 70597.1 | 61792.1 | 50549.2 | 13269.9 | 54618.2 |
| 1991 | 9009.0 | 35.3 | 102786.6 | 1290.6 | 7819.1 | 1124.9 | 131498.4 | 28743.6 | 24966.2 | 20247.5 | 12763.0 | 27728.9 | 33716.4 | 24460.1 | 49976.3 | 14754.1 | 120531.9 | 43541.2 | 81310.3 | 51271.6 | 25188.8 | 19410.1 |
| 1992 | 22288.0 | 212.4 | 60076.3 | 3781.7 | 8284.5 | 1952.4 | 73962.4 | 66207.6 | 25488.4 | 29745.3 | 24340.1 | 64179.0 | 44057.6 | 30291.5 | 123358.0 | 18154.9 | 123399.8 | 145576.0 | 65501.0 | 140707.6 | 25875.0 | 56683.5 |
| 1993 | 42664.5 | 772.1 | 186041.6 | 5909.5 | 23898.8 | 1241.4 | 150840.3 | 193178.2 | 82559.9 | 131512.2 | 76632.9 | 209538.3 | 87555.6 | 55149.8 | 363431.7 | 32556.4 | 288751.0 | 199266.7 | 146755.4 | 377060.8 | 69329.6 | 120537.0 |
| 1994 | 14597.1 | 284.7 | 66576.0 | 1798.5 | 9691.5 | 534.7 | 58755.7 | 22778.8 | 27119.0 | 24122.4 | 20992.0 | 17848.3 | 26001.1 | 16419.1 | 140127.6 | 9615.8 | 109566.1 | 41428.5 | 61922.7 | 106258.3 | 23478.4 | 23423.7 |
| 1995 | 18963.7 | 201.6 | 90767.7 | 2505.5 | 8619.8 | 933.0 | 74656.0 | 33891.6 | 30038.0 | 32035.3 | 24720.6 | 24749.1 | 32879.3 | 14765.3 | 116577.7 | 18523.6 | 135609.1 | 68344.8 | 112266.0 | 110548.6 | 26316.5 | 49897.3 |
| 1996 | 25304.3 | 454.9 | 165654.7 | 3305.8 | 14192.5 | 2329.6 | 126428.1 | 96940.1 | 46264.9 | 101725.0 | 53383.9 | 111208.6 | 68051.2 | 45082.0 | 217634.9 | 29856.9 | 197208.0 | 123171.8 | 131997.2 | 300788.9 | 45194.1 | 74592.2 |
| 1997 | 18643.3 | 213.8 | 59849.7 | 2735.3 | 7125.7 | 1334.6 | 40456.9 | 35193.0 | 17955.4 | 19526.3 | 17183.8 | 17258.8 | 16838.6 | 10545.0 | 122442.6 | 22668.5 | 121188.1 | 109464.5 | 103031.3 | 99513.7 | 20770.1 | 51542.6 |
| 1998 | 11028.0 | 232.3 | 48868.9 | 1607.1 | 5852.8 | 1117.5 | 33825.7 | 20454.2 | 10364.1 | 16699.6 | 16399.2 | 23393.9 | 14983.4 | 3976.6 | 108196.9 | 26271.7 | 136191.1 | 63213.0 | 78694.1 | 123223.0 | 6944.3 | 30189.5 |
| 1999 | 12438.3 | 281.4 | 112815.6 | 1376.8 | 12254.2 | 1485.5 | 85359.5 | 26980.6 | 40022.2 | 34309.0 | 38156.1 | 28808.1 | 47210.0 | 18466.6 | 129618.2 | 31291.9 | 200842.0 | 37524.3 | 125500.1 | 149938.9 | 34020.4 | 28912.6 |
| 2000 | 17343.1 | 203.7 | 41424.7 | 1464.9 | 6904.7 | 507.2 | 32617.5 | 51549.3 | 21090.5 | 22136.4 | 14228.8 | 20255.6 | 14915.7 | 7160.3 | 144438.1 | 9926.2 | 96410.4 | 22092.7 | 38310.4 | 81687.5 | 20334.2 | 39230.6 |

# APPENDIX H

RECHARGE FROM GROUNDWATER IRRIGATION

Appendix H Recharge from Ground Water Irrigation Colorado

| Year | Cheyenne | KitCarson | Lincoln | Logan | Phillips | Sedgwick | Washington | Yuma |
|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 37.8 | 0.0 | 0.0 | 58.2 | 234.6 | 0.0 | 73.2 | 0.0 |
| 1941 | 28.2 | 0.0 | 1.8 | 33.6 | 133.8 | 0.0 | 184.2 | 39.0 |
| 1942 | 30.6 | 0.0 | 2.1 | 40.5 | 269.1 | 0.0 | 178.2 | 49.5 |
| 1943 | 42.6 | 0.0 | 2.4 | 66.9 | 453.3 | 0.0 | 203.7 | 76.8 |
| 1944 | 45.6 | 0.0 | 2.1 | 60.3 | 407.7 | 0.0 | 285.9 | 68.7 |
| 1945 | 96.6 | 0.0 | 1.5 | 30.9 | 197.1 | 0.0 | 320.4 | 44.1 |
| 1946 | 143.4 | 0.0 | 2.1 | 52.8 | 351.0 | 0.0 | 434.7 | 100.8 |
| 1947 | 128.7 | 129.9 | 2.1 | 51.0 | 351.6 | 0.0 | 768.0 | 265.2 |
| 1948 | 90.3 | 480.0 | 122.4 | 64.5 | 456.9 | 0.0 | 1005.0 | 287.4 |
| 1949 | 96.6 | 894.6 | 135.6 | 45.3 | 462.0 | 58.8 | 728.4 | 824.1 |
| 1950 | 186.9 | 1262.7 | 150.6 | 53.4 | 612.3 | 70.8 | 973.0 | 886.4 |
| 1951 | 197.1 | 1059.0 | 123.9 | 35.7 | 449.7 | 117.9 | 957.9 | 1073.4 |
| 1952 | 243.6 | 1825.5 | 201.3 | 73.8 | 1203.3 | 235.8 | 1477.3 | 2436.8 |
| 1953 | 303.3 | 1946.3 | 183.3 | 58.5 | 1034.1 | 180.3 | 1508.7 | 2688.4 |
| 1954 | 315.3 | 3998.5 | 235.2 | 60.6 | 1217.7 | 190.2 | 1917.3 | 3608.8 |
| 1955 | 399.9 | 8029.9 | 197.4 | 57.6 | 1245.0 | 187.8 | 1491.2 | 4290.9 |
| 1956 | 499.8 | 13139.5 | 234.0 | 68.7 | 1639.5 | 309.9 | 2009.8 | 6571.8 |
| 1957 | 298.5 | 8682.4 | 137.4 | 134.4 | 1628.4 | 394.2 | 1718.0 | 6101.3 |
| 1958 | 213.0 | 9315.1 | 138.6 | 104.4 | 1364.7 | 270.0 | 1895.8 | 5935.8 |
| 1959 | 291.3 | 16295.8 | 245.4 | 135.9 | 1746.6 | 391.8 | 2131.6 | 7988.5 |
| 1960 | 338.4 | 14897.2 | 193.5 | 138.9 | 1913.7 | 394.5 | 2211.2 | 6938.7 |
| 1961 | 265.4 | 15007.5 | 177.2 | 111.3 | 1719.0 | 307.2 | 1789.9 | 6046.9 |
| 1962 | 346.6 | 15051.6 | 167.6 | 97.3 | 1577.1 | 283.0 | 1960.6 | 4872.6 |
| 1963 | 469.5 | 24735.1 | 209.8 | 179.3 | 2354.6 | 406.3 | 2205.2 | 8227.3 |
| 1964 | 605.0 | 33669.5 | 246.0 | 194.3 | 4760.5 | 472.9 | 2607.0 | 13389.4 |
| 1965 | 584.5 | 20188.8 | 120.9 | 109.5 | 4088.8 | 266.7 | 2475.4 | 11171.2 |
| 1966 | 720.7 | 39370.7 | 222.5 | 118.9 | 5745.5 | 271.7 | 3420.1 | 16704.9 |
| 1967 | 708.0 | 38221.5 | 174.9 | 101.2 | 8470.5 | 367.4 | 4278.2 | 31395.8 |
| 1968 | 934.1 | 45610.4 | 208.3 | 346.3 | 13176.5 | 886.8 | 5503.8 | 36426.6 |
| 1969 | 742.3 | 47391.8 | 226.0 | 335.0 | 13949.9 | 1225.3 | 5588.7 | 43168.4 |
| 1970 | 939.7 | 49846.9 | 254.8 | 375.9 | 17303.7 | 1330.2 | 5738.9 | 46051.5 |
| 1971 | 1320.6 | 52789.3 | 269.2 | 287.2 | 14471.6 | 1204.4 | 6818.1 | 50064.2 |
| 1972 | 1396.7 | 45253.1 | 240.9 | 328.7 | 14853.4 | 1273.9 | 6111.1 | 46096.9 |
| 1973 | 1734.3 | 52268.7 | 260.6 | 522.0 | 17083.6 | 2122.6 | 6987.5 | 42714.0 |
| 1974 | 2865.1 | 66709.1 | 384.8 | 1384.1 | 26786.5 | 6021.1 | 10576.0 | 72568.9 |
| 1975 | 2965.3 | 58568.7 | 474.9 | 1469.4 | 24863.4 | 6479.7 | 9806.4 | 72557.3 |
| 1976 | 3278.7 | 68565.0 | 540.8 | 1729.5 | 30105.6 | 7932.0 | 11816.7 | 79041.5 |
| 1977 | 3528.6 | 58052.3 | 461.0 | 1525.2 | 25790.2 | 6972.0 | 13880.0 | 74717.5 |
| 1978 | 3533.4 | 56386.8 | 516.0 | 1920.4 | 32711.8 | 8860.3 | 11597.2 | 91656.0 |
| 1979 | 3234.2 | 46261.0 | 363.5 | 1381.8 | 24372.1 | 6579.2 | 9560.3 | 75299.5 |
| 1980 | 3210.1 | 50831.0 | 463.7 | 1684.0 | 28005.0 | 7904.7 | 11671.6 | 68518.9 |
| 1981 | 3034.9 | 56033.4 | 468.7 | 1402.9 | 24168.7 | 6622.6 | 10844.7 | 73225.3 |
| 1982 | 2804.6 | 41382.9 | 348.5 | 1052.5 | 18321.8 | 5039.5 | 8803.7 | 55242.7 |
| 1983 | 2941.3 | 35021.8 | 367.3 | 1222.1 | 20747.6 | 5578.7 | 8688.2 | 56715.7 |
| 1984 | 2947.8 | 46814.3 | 471.4 | 1490.3 | 23742.6 | 6562.1 | 8487.7 | 73389.0 |
| 1985 | 2809.1 | 38465.2 | 347.6 | 1458.6 | 23338.1 | 5967.9 | 8591.6 | 56721.3 |
| 1986 | 2672.3 | 45156.3 | 437.8 | 1408.5 | 21955.2 | 5833.6 | 9755.1 | 58015.2 |
| 1987 | 2766.2 | 41782.8 | 401.6 | 1356.1 | 22047.9 | 5975.3 | 8713.0 | 68421.0 |
| 1988 | 2525.9 | 46098.2 | 444.7 | 1403.9 | 22998.1 | 6190.3 | 10264.5 | 72089.0 |
| 1989 | 2166.6 | 44398.0 | 446.6 | 1151.7 | 18362.6 | 5095.7 | 9458.8 | 55427.3 |
| 1990 | 2232.0 | 42374.7 | 402.7 | 1294.0 | 21296.5 | 5802.0 | 7830.4 | 54952.9 |
| 1991 | 2360.2 | 38624.9 | 396.6 | 1190.2 | 21109.4 | 5581.1 | 10332.8 | 43979.2 |
| 1992 | 2537.1 | 40345.2 | 433.4 | 1127.4 | 18583.8 | 5030.7 | 9216.4 | 50181.5 |
| 1993 | 2982.0 | 39957.4 | 402.7 | 899.3 | 14400.3 | 4006.5 | 8929.2 | 47943.2 |
| 1994 | 2814.2 | 43087.8 | 445.0 | 1562.0 | 26175.2 | 6876.1 | 13129.0 | 57536.6 |
| 1995 | 2605.8 | 36961.4 | 375.9 | 1169.3 | 19546.1 | 5279.0 | 8148.0 | 50025.6 |
| 1996 | 2559.5 | 40415.2 | 401.7 | 620.7 | 9791.4 | 2915.7 | 7807.8 | 43537.1 |
| 1997 | 2515.9 | 40409.6 | 417.5 | 1229.5 | 20087.1 | 5723.8 | 9425.8 | 52213.6 |
| 1998 | 2644.4 | 37612.9 | 374.2 | 1177.4 | 16744.1 | 5187.5 | 10935.3 | 59408.7 |
| 1999 | 2630.8 | 35534.6 | 373.6 | 1001.5 | 14612.7 | 4372.2 | 6971.1 | 50170.5 |
| 2000 | 3292.0 | 47795.5 | 542.7 | 1730.0 | 23479.7 | 7227.4 | 11755.9 | 64308.8 |

Appendix H Recharge from Ground Water Irrigation Kansas

| Year | Cheyenne | Decatur | Gove | Graham | Jewell | Logan | Norton | Phillips | Rawlins | Sheridan | Sherman | Thomas | Trego | Wallace |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 340.8 | 225.7 | 0.0 | 0.0 | 0.0 | 0.0 | 40.5 | 51.3 | 52.8 | 151.4 | 83.4 | 75.6 | 0.0 | 0.0 |
| 1941 | 370.2 | 115.1 | 0.0 | 0.0 | 0.0 | 0.0 | 27.3 | 38.7 | 35.1 | 93.0 | 83.4 | 72.9 | 0.0 | 0.0 |
| 1942 | 652.5 | 186.3 | 0.0 | 0.0 | 0.0 | 0.0 | 26.7 | 40.2 | 43.2 | 123.1 | 91.2 | 81.6 | 0.0 | 0.0 |
| 1943 | 969.0 | 211.2 | 0.0 | 0.0 | 0.0 | 0.0 | 37.5 | 48.9 | 47.7 | 144.0 | 96.3 | 85.8 | 0.0 | 0.0 |
| 1944 | 936.8 | 117.5 | 0.0 | 0.0 | 0.0 | 0.0 | 20.7 | 35.7 | 35.1 | 86.1 | 72.6 | 67.2 | 0.0 | 0.0 |
| 1945 | 1002.2 | 174.8 | 0.0 | 0.0 | 0.0 | 0.0 | 36.0 | 45.6 | 35.7 | 125.4 | 64.2 | 75.6 | 0.0 | 0.0 |
| 1946 | 1274.7 | 187.4 | 0.0 | 0.0 | 0.0 | 0.0 | 39.0 | 50.4 | 48.3 | 137.8 | 75.3 | 86.7 | 0.0 | 0.0 |
| 1947 | 1129.2 | 192.9 | 0.0 | 0.0 | 0.0 | 0.0 | 29.1 | 41.1 | 42.6 | 133.9 | 132.9 | 72.0 | 0.0 | 0.0 |
| 1948 | 978.3 | 166.5 | 0.0 | 0.0 | 0.0 | 0.0 | 30.3 | 45.6 | 37.5 | 109.8 | 135.6 | 159.9 | 0.0 | 0.0 |
| 1949 | 937.2 | 148.1 | 0.0 | 0.0 | 0.0 | 0.0 | 24.0 | 34.2 | 35.7 | 107.4 | 235.8 | 149.7 | 0.0 | 0.0 |
| 1950 | 1111.5 | 183.1 | 0.0 | 0.0 | 0.0 | 0.0 | 44.1 | 84.9 | 174.9 | 169.4 | 378.0 | 151.8 | 0.0 | 0.0 |
| 1951 | 698.6 | 109.0 | 0.0 | 0.0 | 0.0 | 0.0 | 20.7 | 57.6 | 92.7 | 96.4 | 239.1 | 175.5 | 0.0 | 0.0 |
| 1952 | 1398.3 | 255.6 | 0.0 | 0.0 | 0.0 | 0.0 | 81.0 | 119.4 | 213.6 | 237.5 | 1242.6 | 401.1 | 0.0 | 0.0 |
| 1953 | 1228.3 | 228.6 | 0.0 | 0.0 | 0.0 | 53.4 | 51.9 | 224.4 | 357.6 | 336.8 | 1397.2 | 386.1 | 0.0 | 0.0 |
| 1954 | 2208.4 | 336.9 | 0.0 | 117.9 | 0.0 | 67.8 | 319.2 | 544.9 | 433.1 | 443.0 | 1851.3 | 405.6 | 63.3 | 56.7 |
| 1955 | 2619.4 | 584.6 | 93.6 | 168.9 | 0.0 | 73.8 | 410.7 | 1163.9 | 677.0 | 1153.6 | 3171.0 | 933.6 | 56.1 | 59.1 |
| 1956 | 3660.6 | 917.8 | 274.8 | 249.9 | 209.7 | 80.4 | 524.3 | 1593.3 | 1021.7 | 2711.2 | 5580.3 | 2912.4 | 189.6 | 137.1 |
| 1957 | 3667.3 | 907.8 | 176.7 | 139.8 | 96.9 | 80.1 | 396.3 | 1161.1 | 877.9 | 2538.6 | 5172.8 | 2041.3 | 102.6 | 97.2 |
| 1958 | 4122.7 | 897.7 | 214.2 | 157.8 | 94.5 | 105.6 | 414.9 | 1276.7 | 895.4 | 2903.0 | 6154.0 | 2389.0 | 168.9 | 99.0 |
| 1959 | 5075.5 | 1271.6 | 333.3 | 238.2 | 124.5 | 135.6 | 624.2 | 1814.4 | 1233.0 | 4307.3 | 6678.3 | 3569.5 | 213.9 | 102.2 |
| 1960 | 6502.1 | 1495.6 | 312.9 | 247.9 | 93.9 | 120.9 | 614.1 | 1489.1 | 1359.6 | 4218.1 | 7658.3 | 3229.4 | 220.4 | 118.4 |
| 1961 | 5092.4 | 1545.8 | 189.7 | 196.0 | 123.8 | 164.7 | 640.0 | 1578.2 | 1074.0 | 3228.3 | 5965.5 | 3006.2 | 47.0 | 80.6 |
| 1962 | 3764.1 | 967.0 | 301.0 | 237.6 | 129.6 | 120.9 | 500.3 | 1034.4 | 697.7 | 3199.7 | 7129.2 | 2475.8 | 187.3 | 83.9 |
| 1963 | 7650.4 | 1789.1 | 489.4 | 288.8 | 126.6 | 259.5 | 614.7 | 1736.2 | 1322.0 | 4384.2 | 10972.3 | 3586.8 | 288.4 | 101.0 |
| 1964 | 10254.6 | 1644.5 | 697.6 | 344.4 | 114.5 | 733.7 | 864.0 | 2088.2 | 1516.9 | 7849.4 | 16884.5 | 6192.2 | 380.9 | 167.1 |
| 1965 | 7846.8 | 1092.5 | 390.4 | 296.7 | 114.5 | 468.3 | 601.8 | 1056.4 | 1204.8 | 3975.1 | 15286.3 | 4012.9 | 151.1 | 159.7 |
| 1966 | 10414.3 | 1655.6 | 1174.5 | 529.1 | 150.1 | 671.5 | 753.3 | 1714.6 | 1736.5 | 7384.1 | 18360.4 | 6951.2 | 287.7 | 296.7 |
| 1967 | 11452.1 | 1826.0 | 1544.7 | 421.9 | 122.3 | 1046.0 | 532.5 | 891.7 | 2017.0 | 8300.9 | 19905.5 | 9339.9 | 231.3 | 270.5 |
| 1968 | 12309.5 | 1614.7 | 1602.0 | 536.1 | 76.7 | 1691.9 | 360.3 | 727.3 | 2127.6 | 9076.3 | 24462.7 | 8155.2 | 234.0 | 430.2 |
| 1969 | 12556.0 | 2534.5 | 2151.4 | 440.8 | 89.2 | 2231.0 | 588.3 | 928.1 | 2202.4 | 12065.6 | 24902.7 | 9511.6 | 300.6 | 397.3 |
| 1970 | 14049.0 | 2682.4 | 2565.8 | 481.1 | 123.3 | 2773.1 | 786.4 | 1391.4 | 2456.6 | 15198.0 | 29760.7 | 10562.7 | 356.5 | 537.7 |
| 1971 | 14208.2 | 2606.0 | 3503.3 | 613.8 | 130.0 | 3150.9 | 1550.6 | 1993.4 | 2895.2 | 17883.2 | 31590.1 | 12457.2 | 475.0 | 544.2 |
| 1972 | 11173.0 | 2034.0 | 3641.1 | 646.6 | 104.2 | 2614.0 | 1989.2 | 2012.3 | 2026.2 | 16221.3 | 22058.7 | 12292.7 | 290.8 | 557.1 |
| 1973 | 13856.0 | 4046.4 | 3891.0 | 799.1 | 89.3 | 3006.8 | 3367.6 | 1838.7 | 4005.6 | 19616.4 | 26641.0 | 12375.1 | 331.4 | 724.5 |
| 1974 | 13719.2 | 3406.8 | 5470.9 | 870.1 | 153.4 | 2721.7 | 3061.1 | 3554.9 | 3253.6 | 24092.0 | 32061.2 | 16467.7 | 603.7 | 1167.9 |
| 1975 | 12682.4 | 2795.7 | 3708.1 | 567.1 | 77.0 | 2579.4 | 1414.9 | 1202.7 | 3197.5 | 16954.6 | 30715.1 | 12254.6 | 383.0 | 1145.0 |
| 1976 | 16030.8 | 4365.2 | 6961.5 | 1263.1 | 98.9 | 3854.3 | 2981.3 | 3034.8 | 3758.0 | 32369.6 | 42593.0 | 29906.2 | 470.2 | 1700.3 |
| 1977 | 12359.1 | 2490.0 | 3463.8 | 1054.6 | 230.9 | 2379.4 | 2268.5 | 1859.8 | 2398.5 | 21372.3 | 32225.7 | 16478.5 | 365.0 | 1343.1 |
| 1978 | 14508.4 | 3693.8 | 4492.2 | 1573.4 | 343.4 | 3386.9 | 2762.0 | 1714.7 | 3605.9 | 26570.1 | 38458.8 | 25948.5 | 342.8 | 1332.8 |
| 1979 | 9883.6 | 1744.5 | 2786.2 | 974.8 | 424.4 | 2040.7 | 1837.2 | 1209.4 | 2831.8 | 18247.1 | 25022.9 | 16384.5 | 323.6 | 956.4 |
| 1980 | 8700.8 | 3650.4 | 3384.5 | 984.4 | 374.9 | 2683.0 | 4028.8 | 2938.0 | 2401.2 | 26811.0 | 24064.2 | 22232.0 | 293.1 | 853.9 |
| 1981 | 10281.8 | 3617.4 | 3760.4 | 988.4 | 226.3 | 2878.2 | 1566.3 | 1340.6 | 2258.3 | 21342.5 | 34255.0 | 23057.8 | 387.6 | 1403.3 |
| 1982 | 8581.4 | 3207.2 | 4089.2 | 1095.8 | 174.9 | 2114.3 | 2203.4 | 1507.6 | 2847.3 | 19185.2 | 20638.5 | 14495.6 | 418.8 | 696.4 |
| 1983 | 9530.8 | 3835.1 | 4061.8 | 1012.6 | 206.1 | 3094.4 | 1961.4 | 1474.2 | 3059.8 | 18769.1 | 25781.8 | 16225.9 | 444.2 | 667.8 |
| 1984 | 8322.7 | 3983.9 | 4372.6 | 1245.8 | 311.2 | 2562.2 | 3930.1 | 1903.9 | 3008.3 | 25772.9 | 24236.0 | 19674.1 | 434.2 | 767.6 |
| 1985 | 8039.5 | 3698.1 | 4006.7 | 1627.4 | 226.6 | 2131.0 | 3195.5 | 1929.2 | 2569.8 | 21801.4 | 21538.4 | 19195.8 | 400.9 | 774.9 |
| 1986 | 10250.9 | 3297.8 | 4561.0 | 1383.4 | 273.1 | 2438.0 | 2830.2 | 1916.8 | 3093.0 | 21390.8 | 26231.0 | 26414.1 | 288.2 | 860.0 |
| 1987 | 10276.7 | 2143.7 | 3574.7 | 902.3 | 249.0 | 1342.4 | 2309.7 | 1762.3 | 3141.3 | 17039.2 | 21696.7 | 19765.5 | 320.0 | 720.9 |
| 1988 | 10629.1 | 1834.0 | 3634.5 | 907.0 | 304.9 | 2246.9 | 2565.1 | 1353.1 | 3604.3 | 20672.2 | 22409.1 | 20620.1 | 430.2 | 667.0 |
| 1989 | 11323.7 | 3581.6 | 3850.8 | 1093.2 | 227.3 | 2273.7 | 2969.5 | 2048.1 | 3839.2 | 23470.4 | 26848.5 | 24273.0 | 455.8 | 858.8 |
| 1990 | 11273.6 | 3038.8 | 3240.5 | 1209.1 | 257.0 | 2179.0 | 2665.7 | 1860.0 | 3870.2 | 19010.9 | 26597.0 | 22006.0 | 466.4 | 751.5 |
| 1991 | 9659.4 | 2870.7 | 3354.3 | 1444.2 | 334.6 | 1842.6 | 2842.2 | 1650.8 | 3270.9 | 18481.8 | 23052.3 | 19052.4 | 407.9 | 636.2 |
| 1992 | 6802.0 | 904.8 | 1282.0 | 643.1 | 72.2 | 1079.6 | 1137.6 | 982.6 | 1498.0 | 8645.1 | 14729.8 | 8556.0 | 137.8 | 535.0 |
| 1993 | 6760.4 | 758.7 | 957.1 | 301.1 | 29.0 | 696.7 | 940.2 | 683.3 | 1566.0 | 5579.1 | 13655.2 | 7788.2 | 90.9 | 473.5 |
| 1994 | 7954.2 | 1606.0 | 2595.1 | 938.4 | 248.3 | 923.4 | 1548.4 | 1218.0 | 2274.2 | 11407.0 | 16583.7 | 11672.5 | 310.2 | 621.2 |
| 1995 | 5534.6 | 2313.5 | 2401.2 | 1005.2 | 299.0 | 887.4 | 1851.5 | 1377.8 | 2250.9 | 11845.9 | 13366.3 | 10812.8 | 217.6 | 465.5 |
| 1996 | 6691.4 | 1631.0 | 1768.9 | 890.7 | 288.1 | 789.8 | 1069.2 | 722.0 | 1728.7 | 9398.2 | 14963.2 | 9904.1 | 193.9 | 511.4 |
| 1997 | 7088.6 | 2094.0 | 1635.3 | 861.2 | 253.1 | 861.7 | 1671.0 | 1277.7 | 2284.2 | 8077.6 | 14507.5 | 10032.8 | 233.4 | 379.8 |
| 1998 | 5613.1 | 1896.8 | 1602.0 | 730.9 | 203.4 | 669.0 | 1489.6 | 1064.0 | 2006.7 | 7293.5 | 12231.0 | 8176.9 | 224.4 | 387.9 |
| 1999 | 5534.6 | 1302.1 | 1399.5 | 597.7 | 240.4 | 645.3 | 1256.8 | 1153.6 | 1570.1 | 6365.0 | 10594.6 | 6849.4 | 227.1 | 384.4 |
| 2000 | 7308.7 | 2617.3 | 2051.1 | 926.8 | 314.6 | 833.6 | 1568.2 | 952.7 | 2864.0 | 10043.8 | 14524.0 | 11168.6 | 314.2 | 562.6 |

Appendix H Recharge from Ground Water Irrigation Nebraska

| Year | Adams | Buffalo | Chase | Clay | Dawson | Deuel | Dundy | Franklin | Frontier | Furnas | Gosper | Harlan | Hayes | Hitchcock | Kearney | Keith | Lincoln | Nuckolls | Perkins | Phelps | RedWillow | Webster |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 40.1 | 156.3 | 346.3 | 0.0 | 1630.5 | 403.6 | 182.6 | 223.8 | 83.7 | 250.5 | 451.7 | 120.3 | 131.1 | 686.0 | 1530.3 | 969.1 | 1705.9 | 32.4 | 94.1 | 1750.7 | 309.3 | 125.0 |
| 1941 | 24.7 | 95.5 | 340.7 | 19.8 | 1394.8 | 322.8 | 147.5 | 134.7 | 58.7 | 185.5 | 396.9 | 134.4 | 86.9 | 513.5 | 1168.7 | 810.2 | 1632.1 | 34.2 | 76.0 | 1319.1 | 289.6 | 65.9 |
| 1942 | 20.3 | 78.9 | 281.8 | 16.3 | 1458.8 | 255.6 | 130.2 | 145.3 | 64.4 | 126.0 | 392.1 | 132.7 | 106.0 | 704.0 | 1060.6 | 1167.2 | 1850.7 | 24.6 | 80.5 | 1223.2 | 320.4 | 47.4 |
| 1943 | 26.8 | 104.2 | 530.0 | 21.5 | 2008.0 | 410.2 | 261.2 | 172.6 | 74.9 | 224.4 | 561.5 | 163.5 | 119.9 | 883.6 | 1468.5 | 1270.3 | 2359.4 | 35.6 | 134.7 | 1741.6 | 453.3 | 68.5 |
| 1944 | 26.6 | 132.2 | 571.0 | 21.3 | 1360.6 | 327.2 | 242.1 | 202.6 | 41.4 | 153.6 | 553.8 | 202.5 | 88.6 | 536.1 | 1733.3 | 1161.1 | 1343.5 | 33.0 | 107.0 | 1772.7 | 324.5 | 63.5 |
| 1945 | 26.6 | 186.3 | 718.0 | 21.3 | 2852.5 | 801.0 | 430.8 | 234.1 | 59.0 | 276.9 | 578.9 | 244.6 | 121.9 | 752.9 | 2049.0 | 2216.3 | 2072.0 | 27.5 | 133.6 | 1795.2 | 605.5 | 53.0 |
| 1946 | 22.5 | 168.5 | 502.7 | 18.0 | 2909.3 | 613.0 | 336.6 | 232.3 | 80.8 | 341.7 | 490.0 | 326.4 | 160.2 | 773.0 | 2364.1 | 3322.5 | 2123.6 | 30.1 | 87.0 | 1635.6 | 595.8 | 67.6 |
| 1947 | 136.4 | 0.9 | 717.3 | 0.1 | 30.0 | 900.4 | 468.3 | 347.4 | 97.9 | 416.4 | 14.4 | 666.6 | 174.2 | 1858.7 | 49.9 | 3342.0 | 3151.6 | 175.1 | 120.3 | 48.6 | 844.5 | 182.1 |
| 1948 | 138.4 | 0.6 | 795.7 | 0.1 | 21.9 | 912.5 | 507.3 | 305.2 | 125.5 | 422.4 | 11.6 | 602.8 | 119.4 | 1509.8 | 35.2 | 3731.7 | 197.8 | 143.7 | 243.4 | 40.9 | 744.8 | 160.4 |
| 1949 | 257.2 | 1.6 | 901.8 | 0.4 | 30.5 | 854.3 | 569.5 | 404.8 | 181.5 | 484.9 | 16.2 | 606.3 | 272.5 | 2192.6 | 76.8 | 4011.6 | 474.1 | 320.1 | 264.3 | 43.0 | 726.3 | 181.2 |
| 1950 | 250.2 | 2.4 | 723.7 | 0.6 | 20.6 | 330.3 | 28.3 | 62.8 | 171.5 | 34.1 | 8.3 | 92.5 | 85.2 | 324.8 | 77.0 | 3452.1 | 655.6 | 21.1 | 110.3 | 14.2 | 148.1 | 46.7 |
| 1951 | 106.7 | 1.1 | 725.2 | 0.3 | 25.8 | 271.1 | 39.9 | 50.2 | 27.2 | 15.2 | 3.7 | 44.5 | 40.0 | 108.9 | 35.4 | 2799.7 | 708.1 | 9.0 | 102.2 | 7.2 | 94.3 | 38.7 |
| 1952 | 374.4 | 4.3 | 1415.4 | 1.2 | 75.8 | 708.0 | 139.7 | 155.9 | 32.0 | 49.8 | 14.4 | 96.0 | 170.7 | 383.7 | 164.1 | 4984.0 | 1959.0 | 38.9 | 511.1 | 18.2 | 293.5 | 135.3 |
| 1953 | 578.7 | 19.5 | 1533.2 | 5.7 | 82.8 | 627.5 | 210.3 | 257.1 | 40.3 | 70.3 | 20.1 | 201.2 | 247.1 | 572.6 | 771.9 | 4115.2 | 3193.2 | 56.7 | 686.4 | 232.2 | 519.0 | 288.4 |
| 1954 | 789.5 | 32.3 | 2268.8 | 11.8 | 248.9 | 801.4 | 614.7 | 380.7 | 280.6 | 238.9 | 145.4 | 396.7 | 429.9 | 1164.3 | 1104.1 | 5518.5 | 7104.6 | 57.6 | 1115.7 | 380.9 | 1039.2 | 249.1 |
| 1955 | 681.3 | 37.2 | 6403.7 | 207.2 | 909.6 | 867.8 | 2171.2 | 140.5 | 575.7 | 776.3 | 664.2 | 1632.3 | 467.6 | 2337.4 | 319.7 | 2474.6 | 1201.3 | 1124.6 | 441.6 | 978.6 | 453.7 | 3144.9 |
| 1956 | 1125.4 | 37.6 | 7462.1 | 145.0 | 1195.3 | 867.6 | 2752.0 | 1794.9 | 934.5 | 1205.9 | 947.7 | 2342.0 | 640.2 | 2852.9 | 3443.3 | 2987.0 | 1866.5 | 1021.1 | 666.0 | 7436.3 | 694.1 | 3014.1 |
| 1957 | 1107.7 | 160.3 | 4312.8 | 213.0 | 2982.1 | 547.2 | 2548.1 | 2392.6 | 936.2 | 2248.5 | 1419.9 | 2832.0 | 577.5 | 2228.0 | 7292.6 | 3586.3 | 3044.3 | 1430.2 | 751.6 | 7534.1 | 1144.2 | 1867.8 |
| 1958 | 717.6 | 117.9 | 3684.4 | 121.0 | 1801.9 | 701.8 | 2109.3 | 1593.5 | 1009.5 | 1574.9 | 952.0 | 1829.9 | 551.5 | 2219.4 | 5164.0 | 4264.4 | 2031.7 | 545.7 | 596.6 | 5260.3 | 1068.2 | 825.4 |
| 1959 | 2329.7 | 338.5 | 7018.3 | 407.1 | 4203.1 | 1442.9 | 4442.1 | 3197.2 | 2282.7 | 4012.8 | 1959.4 | 4418.7 | 1090.6 | 4586.3 | 10479.7 | 8731.4 | 5045.0 | 1707.6 | 1283.4 | 10350.6 | 2705.0 | 2724.3 |
| 1960 | 2233.9 | 369.4 | 7456.4 | 402.2 | 4540.1 | 1569.2 | 4632.4 | 3126.1 | 2093.6 | 2922.6 | 2015.5 | 3252.6 | 1199.3 | 4378.7 | 10113.7 | 9426.5 | 5639.4 | 1587.0 | 1560.7 | 8737.4 | 2319.9 | 2605.1 |
| 1961 | 2852.0 | 293.1 | 2878.5 | 525.1 | 3766.7 | 763.8 | 3939.3 | 3165.6 | 1324.7 | 2619.8 | 1662.7 | 3033.0 | 1080.7 | 3075.7 | 10396.6 | 4897.3 | 4089.0 | 2101.3 | 775.6 | 9255.9 | 1576.0 | 3430.1 |
| 1962 | 1444.4 | 141.0 | 2471.1 | 255.0 | 1889.9 | 544.2 | 2181.4 | 2118.0 | 719.5 | 1266.7 | 782.3 | 1518.3 | 752.8 | 1784.7 | 6960.0 | 3554.4 | 2178.4 | 1134.5 | 556.0 | 6234.1 | 871.0 | 1662.7 |
| 1963 | 2844.7 | 487.6 | 4803.8 | 484.9 | 6328.9 | 1007.2 | 5025.9 | 4337.5 | 2017.1 | 3454.1 | 2665.2 | 4166.4 | 2119.2 | 4349.4 | 14488.1 | 6795.8 | 6573.4 | 2184.8 | 1112.6 | 13337.6 | 2055.4 | 3333.4 |
| 1964 | 4010.9 | 399.4 | 6408.8 | 695.4 | 5256.3 | 1052.6 | 5056.4 | 3846.0 | 2756.9 | 3763.3 | 2278.0 | 4268.1 | 2390.1 | 5517.4 | 12965.4 | 7252.4 | 5841.9 | 3367.8 | 1115.8 | 12231.8 | 2709.5 | 5056.2 |
| 1965 | 3025.9 | 264.6 | 4543.9 | 546.6 | 3455.5 | 798.2 | 4229.2 | 3849.3 | 2758.0 | 2467.3 | 1625.2 | 2869.1 | 2014.1 | 4953.3 | 12932.5 | 5733.3 | 4067.7 | 2393.0 | 987.8 | 12184.2 | 2483.8 | 3639.9 |
| 1966 | 4691.0 | 409.7 | 6368.5 | 747.0 | 5448.5 | 878.8 | 4161.0 | 5733.3 | 3398.0 | 2612.4 | 2484.3 | 3159.5 | 1971.2 | 5068.3 | 19616.5 | 6167.1 | 5912.1 | 3800.5 | 1266.9 | 17835.4 | 2955.1 | 5283.8 |
| 1967 | 5516.0 | 344.0 | 8467.3 | 841.1 | 4655.0 | 1721.6 | 5159.3 | 5365.8 | 4825.5 | 3988.0 | 2578.0 | 5079.7 | 2178.6 | 6642.5 | 17983.0 | 11465.5 | 6108.6 | 4255.6 | 3119.6 | 17825.4 | 4089.2 | 6031.3 |
| 1968 | 5336.2 | 362.1 | 17276.4 | 931.5 | 5338.4 | 3007.7 | 9105.7 | 4948.5 | 7635.6 | 6775.9 | 3508.1 | 9413.2 | 3688.9 | 9090.2 | 16477.0 | 19973.4 | 8201.6 | 4015.5 | 6959.6 | 18716.2 | 6045.7 | 6294.9 |
| 1969 | 3892.2 | 369.7 | 21097.2 | 709.3 | 5628.7 | 2171.3 | 12824.0 | 4860.5 | 7158.8 | 5422.6 | 3560.6 | 7664.0 | 5385.0 | 8778.3 | 15949.0 | 16067.3 | 7764.0 | 2562.6 | 6594.6 | 17274.3 | 5464.9 | 4508.1 |
| 1970 | 6870.0 | 525.6 | 27823.1 | 1268.6 | 8105.9 | 3061.6 | 15924.0 | 9061.2 | 11466.5 | 8479.4 | 5578.1 | 12349.3 | 6921.4 | 11148.9 | 28919.7 | 21879.9 | 11022.4 | 4274.7 | 9795.1 | 32298.3 | 8830.3 | 7847.4 |
| 1971 | 7653.3 | 548.5 | 25650.2 | 1451.8 | 8601.1 | 1754.3 | 15510.7 | 9639.4 | 11697.2 | 8574.0 | 6539.2 | 12876.8 | 7581.4 | 10247.6 | 30505.3 | 13187.7 | 10889.5 | 4767.6 | 6848.2 | 31542.2 | 9125.6 | 8945.1 |
| 1972 | 5316.3 | 498.7 | 23915.0 | 922.6 | 8143.5 | 1601.9 | 10886.8 | 8423.7 | 14087.7 | 8519.6 | 7481.5 | 13392.7 | 6125.0 | 9426.2 | 26225.5 | 12339.1 | 11380.2 | 2784.6 | 6906.5 | 28416.7 | 10463.6 | 5319.0 |
| 1973 | 6252.2 | 473.1 | 26904.4 | 1085.8 | 7318.8 | 1789.2 | 10204.0 | 9788.2 | 13484.9 | 8140.4 | 7515.1 | 14018.0 | 6195.0 | 8536.8 | 30698.3 | 13559.1 | 12629.0 | 3100.7 | 9378.7 | 34113.2 | 9754.5 | 6336.6 |
| 1974 | 8558.6 | 711.9 | 39271.3 | 1504.6 | 11420.1 | 2158.1 | 15175.6 | 11927.4 | 19309.5 | 10244.9 | 11269.4 | 18294.9 | 7680.7 | 10587.0 | 36476.8 | 17433.8 | 19929.2 | 4316.6 | 15822.0 | 42662.2 | 13855.2 | 9243.3 |
| 1975 | 7679.3 | 620.5 | 42780.0 | 1275.0 | 10225.0 | 1982.8 | 20177.8 | 12370.9 | 20495.2 | 10294.0 | 11455.7 | 18152.0 | 8562.3 | 11142.5 | 34748.4 | 17311.0 | 20837.7 | 3700.4 | 17339.6 | 41537.1 | 14592.4 | 8495.7 |
| 1976 | 10316.9 | 759.9 | 56251.7 | 1551.3 | 12187.1 | 2030.6 | 27071.9 | 16767.3 | 22747.3 | 14100.9 | 15323.6 | 24695.1 | 10810.5 | 12639.9 | 44749.4 | 19403.0 | 26380.3 | 4996.3 | 20887.3 | 54793.4 | 16034.0 | 11940.8 |
| 1977 | 5497.7 | 570.9 | 47586.3 | 681.5 | 9067.8 | 1471.2 | 25737.7 | 12158.2 | 16962.2 | 11330.5 | 11491.4 | 18734.1 | 9384.0 | 10198.9 | 31084.3 | 14675.3 | 20818.2 | 2227.9 | 16929.0 | 38404.5 | 13188.7 | 5967.5 |
| 1978 | 7694.8 | 641.9 | 66321.6 | 949.6 | 10737.2 | 2440.0 | 31857.2 | 16386.7 | 23003.7 | 12495.1 | 13371.9 | 20748.6 | 11749.0 | 13237.7 | 41158.9 | 24600.1 | 30168.0 | 3435.6 | 28992.7 | 49417.7 | 17824.9 | 8493.9 |
| 1979 | 5701.3 | 476.8 | 48279.8 | 762.2 | 7980.8 | 1711.0 | 24765.0 | 11036.5 | 11877.7 | 7628.2 | 9062.8 | 12332.1 | 9319.9 | 9788.9 | 26368.1 | 18203.3 | 22733.8 | 2856.8 | 22907.8 | 31252.9 | 9778.9 | 6773.8 |
| 1980 | 7880.9 | 767.8 | 50996.5 | 969.1 | 13104.8 | 1766.5 | 24542.7 | 16831.7 | 19572.3 | 12494.2 | 14741.0 | 19713.8 | 9298.4 | 11883.6 | 39928.1 | 18391.6 | 30706.5 | 3590.1 | 23943.1 | 46190.7 | 15344.2 | 8888.3 |
| 1981 | 5260.2 | 452.9 | 44173.9 | 602.4 | 7294.3 | 1379.0 | 19479.8 | 12516.1 | 11380.2 | 6706.9 | 8211.4 | 10800.0 | 7376.4 | 8543.1 | 28767.4 | 14989.2 | 21474.6 | 2218.0 | 19702.3 | 32246.4 | 9046.1 | 5624.5 |
| 1982 | 4670.2 | 530.2 | 34037.3 | 578.4 | 8934.6 | 1149.5 | 16679.6 | 10405.9 | 13366.0 | 7983.2 | 9901.6 | 12876.0 | 6446.0 | 8017.9 | 23554.0 | 12630.6 | 21859.6 | 2074.6 | 16801.3 | 28886.1 | 10329.5 | 5206.2 |
| 1983 | 6366.7 | 453.8 | 40020.9 | 818.2 | 8139.0 | 1441.6 | 21909.6 | 12779.0 | 13212.2 | 7626.6 | 9055.4 | 12196.4 | 7845.7 | 9372.6 | 29760.5 | 16106.8 | 23553.9 | 2918.1 | 21170.0 | 34564.8 | 10837.6 | 7407.9 |
| 1984 | 6976.9 | 606.9 | 52233.6 | 840.1 | 9927.4 | 1698.8 | 26783.6 | 15160.2 | 16088.1 | 10533.2 | 11922.4 | 16706.4 | 9515.7 | 10835.6 | 34774.7 | 18856.8 | 28987.9 | 3009.5 | 25547.7 | 40541.2 | 12861.3 | 7738.1 |
| 1985 | 5835.0 | 485.0 | 52492.9 | 726.6 | 8113.3 | 1743.3 | 26998.2 | 11709.8 | 15736.0 | 7851.8 | 9457.4 | 12503.8 | 9864.2 | 11292.9 | 26836.8 | 19440.8 | 27849.8 | 2630.3 | 26319.0 | 31101.4 | 12771.6 | 6739.5 |
| 1986 | 5635.8 | 592.2 | 43073.0 | 628.6 | 10165.2 | 1616.5 | 25245.0 | 12986.2 | 16325.8 | 9603.7 | 11545.7 | 15533.7 | 9265.3 | 10880.1 | 29861.0 | 18548.3 | 28739.7 | 2182.2 | 24901.7 | 35267.8 | 13079.3 | 5840.9 |
| 1987 | 6053.2 | 511.4 | 39466.6 | 650.4 | 8802.8 | 1539.4 | 22957.5 | 13978.3 | 14020.0 | 6747.1 | 9126.6 | 10966.6 | 8460.9 | 9733.2 | 33051.3 | 16981.1 | 25312.4 | 2260.4 | 22576.9 | 37212.3 | 11198.8 | 6005.9 |
| 1988 | 9762.4 | 670.3 | 46033.1 | 1145.2 | 11311.1 | 1659.4 | 24732.1 | 19931.5 | 14620.6 | 9289.2 | 11962.1 | 14861.1 | 9037.2 | 10033.2 | 47275.1 | 18423.2 | 28736.8 | 4016.1 | 24307.0 | 53168.9 | 11651.4 | 10621.1 |
| 1989 | 6841.8 | 624.8 | 46058.0 | 780.5 | 9624.3 | 1557.7 | 23356.5 | 15477.6 | 17243.2 | 10923.8 | 11653.5 | 17429.7 | 8544.2 | 10259.0 | 36165.4 | 17541.9 | 26816.4 | 2686.3 | 23047.2 | 42069.0 | 13785.5 | 7094.7 |
| 1990 | 6269.8 | 757.1 | 53074.4 | 652.2 | 12312.6 | 2038.6 | 30638.1 | 16063.1 | 17462.0 | 10469.5 | 13045.7 | 17018.8 | 11100.3 | 12041.6 | 37700.5 | 22939.7 | 33503.7 | 2257.5 | 30154.6 | 43057.6 | 14132.7 | 6012.8 |
| 1991 | 9381.2 | 849.2 | 47753.1 | 1093.1 | 13438.0 | 2059.8 | 25058.9 | 21679.8 | 18670.2 | 12172.8 | 14494.5 | 19557.1 | 9259.0 | 10726.2 | 49570.8 | 23282.8 | 34823.9 | 4012.9 | 30424.1 | 57830.5 | 15327.3 | 9878.0 |
| 1992 | 4066.4 | 495.8 | 38422.9 | 413.4 | 8368.2 | 1268.9 | 16392.0 | 11135.3 | 9425.1 | 6710.1 | 8444.9 | 11042.4 | 5827.5 | 6373.7 | 25096.7 | 14384.8 | 20770.2 | 1578.6 | 19065.3 | 30274.4 | 8014.2 | 3955.4 |
| 1993 | 1418.8 | 142.9 | 31204.2 | 136.8 | 2406.7 | 877.8 | 11522.9 | 4037.5 | 982.0 | 1479.9 | 2207.6 | 2509.2 | 3850.9 | 3221.6 | 9121.5 | 9988.7 | 9566.7 | 529.4 | 13268.3 | 10339.9 | 1405.7 | 1324.5 |
| 1994 | 5288.9 | 500.3 | 52487.3 | 592.7 | 8078.2 | 1914.4 | 25373.5 | 12537.1 | 15393.1 | 7654.6 | 8831.9 | 12773.5 | 9062.2 | 10494.9 | 28316.1 | 22079.9 | 27333.9 | 2352.0 | 28790.0 | 32848.0 | 13903.1 | 5721.4 |
| 1995 | 8190.5 | 719.7 | 42948.3 | 904.5 | 11558.6 | 1791.6 | 23791.6 | 19464.9 | 16146.1 | 9585.8 | 11942.8 | 16101.7 | 8535.2 | 10146.4 | 43813.6 | 21033.9 | 29953.8 | 3650.5 | 26839.2 | 49235.5 | 14407.5 | 8891.5 |
| 1996 | 4886.4 | 461.9 | 34656.5 | 539.2 | 7626.3 | 1115.9 | 17655.4 | 11467.2 | 8864.8 | 3809.7 | 6669.7 | 6475.2 | 6170.9 | 6841.3 | 25788.9 | 13171.9 | 19146.6 | 2294.8 | 16842.8 | 27523.9 | 8166.4 | 5394.5 |
| 1997 | 6990.0 | 746.9 | 48895.3 | 713.5 | 12110.9 | 1613.3 | 28316.2 | 18212.4 | 14514.1 | 9303.5 | 12288.7 | 15970.4 | 10585.0 | 10778.6 | 39577.0 | 19200.7 | 29632.0 | 3117.1 | 24610.3 | 43665.0 | 13487.7 | 7363.4 |
| 1998 | 5060.0 | 589.2 | 48414.6 | 501.4 | 9735.4 | 1672.6 | 30073.6 | 13447.3 | 14523.0 | 8246.7 | 10360.2 | 14036.6 | 11652.5 | 11483.1 | 29080.5 | 19597.3 | 27867.5 | 2215.0 | 24985.5 | 32176.6 | 14012.3 | 5400.9 |
| 1999 | 5306.1 | 488.1 | 36818.0 | 589.5 | 7440.9 | 1324.0 | 20424.0 | 11915.5 | 2896.4 | 5163.9 | 7336.8 | 8965.7 | 7837.4 | 5891.8 | 25689.5 | 15940.4 | 19486.9 | 2713.8 | 19975.6 | 27139.5 | 3455.4 | 6418.6 |
| 2000 | 8375.7 | 919.5 | 59598.8 | 860.9 | 14248.9 | 2560.8 | 36507.8 | 21649.7 | 16792.8 | 8645.5 | 13612.3 | 15126.8 | 15118.7 | 13790.2 | 45937.5 | 30035.9 | 40542.3 | 3958.3 | 36907.5 | 47210.3 | 16220.5 | 9374.3 |

## APPENDIX I

RECHARGE FROM CANALS AND LATERALS

Appendix I Recharge from Canals and Laterals Colorado

| Year | Cheyenne | KitCarson | Lincoln | Logan | Phillips | Sedgwick | Washington | Yuma |
|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1941 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1942 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1943 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1944 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1945 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1946 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1947 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1948 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1949 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1950 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1951 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1952 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1953 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1954 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1955 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1956 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1957 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1958 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1959 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1960 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1961 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1962 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1963 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1964 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1965 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1966 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1967 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1968 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1969 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1970 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1971 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1972 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1973 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1974 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1975 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1976 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1977 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1978 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1979 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1981 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1982 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1983 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1984 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1985 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1986 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1987 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1988 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1989 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1990 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1991 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1992 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1993 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1994 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1995 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1996 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1998 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Appendix I Recharge from Canals and Laterals Kansas

| Year | Cheyenne | Decatur | Gove | Graham | Jewell | Logan | Norton | Phillips | Rawlins | Sheridan | Sherman | Thomas | Trego | Wallace |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1941 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1942 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1943 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1944 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1945 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1946 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1947 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1948 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1949 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1950 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1951 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1952 | 0.0 | 0.0 | 0.0 | 0.0 | 183.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1953 | 0.0 | 0.0 | 0.0 | 0.0 | 268.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1954 | 0.0 | 0.0 | 0.0 | 0.0 | 1047.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1955 | 0.0 | 0.0 | 0.0 | 0.0 | 2500.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1956 | 0.0 | 0.0 | 0.0 | 0.0 | 3332.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1957 | 0.0 | 0.0 | 0.0 | 0.0 | 2083.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1958 | 0.0 | 0.0 | 0.0 | 0.0 | 2393.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1959 | 0.0 | 0.0 | 0.0 | 0.0 | 2524.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1960 | 0.0 | 0.0 | 0.0 | 0.0 | 2274.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1961 | 0.0 | 0.0 | 0.0 | 0.0 | 2416.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1962 | 0.0 | 0.0 | 0.0 | 0.0 | 2555.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1963 | 0.0 | 0.0 | 0.0 | 0.0 | 3386.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1964 | 0.0 | 0.0 | 0.0 | 0.0 | 1999.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1965 | 0.0 | 0.0 | 0.0 | 0.0 | 2842.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1966 | 0.0 | 0.0 | 0.0 | 0.0 | 3273.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1967 | 0.0 | 0.0 | 0.0 | 0.0 | 2739.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1968 | 0.0 | 0.0 | 0.0 | 0.0 | 2851.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1969 | 0.0 | 0.0 | 0.0 | 0.0 | 3218.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1970 | 0.0 | 0.0 | 0.0 | 0.0 | 2690.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1971 | 0.0 | 0.0 | 0.0 | 0.0 | 2618.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1972 | 0.0 | 0.0 | 0.0 | 0.0 | 2197.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1973 | 0.0 | 0.0 | 0.0 | 0.0 | 2524.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1974 | 0.0 | 0.0 | 0.0 | 0.0 | 2395.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1975 | 0.0 | 0.0 | 0.0 | 0.0 | 2668.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1976 | 0.0 | 0.0 | 0.0 | 0.0 | 3254.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1977 | 0.0 | 0.0 | 0.0 | 0.0 | 2145.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1978 | 0.0 | 0.0 | 0.0 | 0.0 | 3091.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1979 | 0.0 | 0.0 | 0.0 | 0.0 | 2553.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 0.0 | 0.0 | 0.0 | 0.0 | 2799.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1981 | 0.0 | 0.0 | 0.0 | 0.0 | 2528.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1982 | 0.0 | 0.0 | 0.0 | 0.0 | 3919.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1983 | 0.0 | 0.0 | 0.0 | 0.0 | 2711.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1984 | 0.0 | 0.0 | 0.0 | 0.0 | 3342.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1985 | 0.0 | 0.0 | 0.0 | 0.0 | 3204.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1986 | 0.0 | 0.0 | 0.0 | 0.0 | 3671.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1987 | 0.0 | 0.0 | 0.0 | 0.0 | 2933.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1988 | 0.0 | 0.0 | 0.0 | 0.0 | 3915.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1989 | 0.0 | 0.0 | 0.0 | 0.0 | 2810.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1990 | 0.0 | 0.0 | 0.0 | 0.0 | 2959.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1991 | 0.0 | 0.0 | 0.0 | 0.0 | 2653.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1992 | 0.0 | 0.0 | 0.0 | 0.0 | 1781.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1993 | 0.0 | 0.0 | 0.0 | 0.0 | 2976.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1994 | 0.0 | 0.0 | 0.0 | 0.0 | 4710.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1995 | 0.0 | 0.0 | 0.0 | 0.0 | 4479.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1996 | 0.0 | 0.0 | 0.0 | 0.0 | 2796.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 0.0 | 0.0 | 0.0 | 0.0 | 3488.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1998 | 0.0 | 0.0 | 0.0 | 0.0 | 3382.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1999 | 0.0 | 0.0 | 0.0 | 0.0 | 3970.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2000 | 0.0 | 0.0 | 0.0 | 0.0 | 3520.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Appendix I Recharge from Canals and Laterals Nebraska

| Year | Adams | Buffalo | Chase | Clay | Dawson | Deuel | Dundy | Franklin | Frontier | Furnas | Gosper | Harlan | Hayes | Hitchcock | Kearney | Keith | Lincoln | Nuckolls | Perkins | Phelps | RedWillow | Webster |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1049.7 | 158913.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1941 | 0.0 | 0.0 | 0.0 | 0.0 | 95167.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 121694.2 | 0.0 | 0.0 | 0.0 | 0.0 | 1083.8 | 259759.9 | 0.0 | 0.0 | 16203.8 | 0.0 | 0.0 |
| 1942 | 0.0 | 0.0 | 0.0 | 0.0 | 94599.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 112564.3 | 0.0 | 0.0 | 0.0 | 31656.8 | 1006.0 | 255654.7 | 0.0 | 0.0 | 69429.0 | 0.0 | 0.0 |
| 1943 | 0.0 | 0.0 | 0.0 | 0.0 | 80078.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 124597.3 | 0.0 | 0.0 | 0.0 | 31796.9 | 1446.9 | 267053.7 | 0.0 | 0.0 | 71701.1 | 0.0 | 0.0 |
| 1944 | 0.0 | 0.0 | 0.0 | 0.0 | 80350.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 116319.3 | 0.0 | 0.0 | 0.0 | 28761.2 | 1757.0 | 284812.6 | 0.0 | 0.0 | 67186.5 | 0.0 | 0.0 |
| 1945 | 0.0 | 0.0 | 0.0 | 0.0 | 80790.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 119514.6 | 0.0 | 0.0 | 0.0 | 24719.4 | 4767.9 | 596620.9 | 0.0 | 0.0 | 62236.4 | 0.0 | 0.0 |
| 1946 | 0.0 | 0.0 | 0.0 | 0.0 | 84357.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 144462.7 | 0.0 | 0.0 | 0.0 | 32545.5 | 2268.4 | 304883.7 | 0.0 | 0.0 | 75841.9 | 0.0 | 0.0 |
| 1947 | 0.0 | 0.0 | 0.0 | 0.0 | 81334.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 137374.7 | 0.0 | 0.0 | 0.0 | 31906.0 | 2442.9 | 338954.1 | 0.0 | 0.0 | 74025.8 | 0.0 | 0.0 |
| 1948 | 0.0 | 0.0 | 0.0 | 0.0 | 84436.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 118404.9 | 0.0 | 0.0 | 0.0 | 40313.8 | 1783.5 | 280415.4 | 0.0 | 0.0 | 86812.2 | 0.0 | 0.0 |
| 1949 | 0.0 | 0.0 | 0.0 | 0.0 | 75908.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 156340.9 | 0.0 | 0.0 | 0.0 | 31169.7 | 2016.7 | 297489.8 | 0.0 | 0.0 | 72829.2 | 0.0 | 0.0 |
| 1950 | 0.0 | 0.0 | 0.0 | 0.0 | 75503.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 119208.6 | 0.0 | 0.0 | 0.0 | 37339.9 | 2437.4 | 350786.7 | 0.0 | 0.0 | 82954.9 | 0.0 | 0.0 |
| 1951 | 0.0 | 0.0 | 0.0 | 0.0 | 73802.1 | 0.0 | 0.0 | 0.0 | 0.0 | 7298.0 | 146817.4 | 0.0 | 0.0 | 0.0 | 36441.6 | 1996.6 | 280399.2 | 0.0 | 0.0 | 78945.2 | 0.0 | 0.0 |
| 1952 | 0.0 | 0.0 | 0.0 | 0.0 | 45475.7 | 0.0 | 0.0 | 0.0 | 0.0 | 5448.0 | 114634.3 | 0.0 | 0.0 | 1271.2 | 36766.8 | 4979.2 | 654856.2 | 4390.1 | 0.0 | 83979.0 | 1747.9 | 1137.4 |
| 1953 | 0.0 | 0.0 | 0.0 | 0.0 | 56109.2 | 0.0 | 0.0 | 1879.0 | 0.0 | 13397.8 | 120911.3 | 0.0 | 0.0 | 706.1 | 39238.3 | 1895.6 | 305614.0 | 6410.8 | 0.0 | 94397.9 | 971.0 | 1660.9 |
| 1954 | 0.0 | 0.0 | 0.0 | 0.0 | 58019.6 | 0.0 | 0.0 | 3689.2 | 0.0 | 11714.2 | 104437.9 | 266.8 | 0.0 | 1155.8 | 41613.3 | 1993.0 | 315926.9 | 4679.2 | 0.0 | 93741.8 | 2074.1 | 3557.0 |
| 1955 | 0.0 | 0.0 | 0.0 | 0.0 | 43446.0 | 0.0 | 0.0 | 5148.3 | 0.0 | 12719.2 | 116377.3 | 639.0 | 0.0 | 1149.9 | 46278.6 | 2623.0 | 375465.6 | 6476.0 | 0.0 | 98610.0 | 3543.8 | 4759.7 |
| 1956 | 0.0 | 0.0 | 0.0 | 0.0 | 44117.7 | 0.0 | 0.0 | 6474.0 | 0.0 | 14455.0 | 100796.8 | 617.0 | 0.0 | 1015.6 | 49896.9 | 2126.4 | 320125.3 | 7363.6 | 0.0 | 106058.0 | 2565.6 | 6556.4 |
| 1957 | 0.0 | 0.0 | 0.0 | 0.0 | 55005.9 | 0.0 | 0.0 | 3265.0 | 0.0 | 15670.7 | 120854.3 | 310.7 | 0.0 | 1702.7 | 41267.2 | 1443.1 | 211698.4 | 5043.8 | 0.0 | 94217.6 | 4354.6 | 3872.3 |
| 1958 | 0.0 | 0.0 | 0.0 | 0.0 | 70620.7 | 0.0 | 0.0 | 5053.7 | 0.0 | 7194.1 | 110352.0 | 441.2 | 657.1 | 19499.9 | 40560.5 | 1161.0 | 170977.2 | 6534.1 | 0.0 | 99445.8 | 5618.9 | 5631.8 |
| 1959 | 0.0 | 0.0 | 0.0 | 0.0 | 60138.4 | 0.0 | 0.0 | 6910.8 | 0.0 | 7292.6 | 101310.9 | 677.0 | 521.4 | 18626.7 | 48223.7 | 1396.0 | 192109.2 | 7855.6 | 0.0 | 113308.7 | 9159.3 | 6771.2 |
| 1960 | 0.0 | 0.0 | 0.0 | 0.0 | 62137.2 | 0.0 | 0.0 | 6786.5 | 0.0 | 7592.9 | 106691.8 | 648.2 | 504.3 | 16805.6 | 40492.0 | 1556.1 | 215737.6 | 6983.6 | 0.0 | 96991.7 | 7515.3 | 6226.9 |
| 1961 | 0.0 | 0.0 | 0.0 | 0.0 | 85239.6 | 0.0 | 0.0 | 8418.7 | 0.0 | 8875.5 | 123268.4 | 866.1 | 653.9 | 21126.1 | 48221.4 | 1222.6 | 186028.3 | 7467.2 | 0.0 | 111541.8 | 9830.4 | 7352.5 |
| 1962 | 0.0 | 0.0 | 0.0 | 0.0 | 81991.3 | 0.0 | 0.0 | 7546.6 | 0.0 | 8758.3 | 110161.1 | 850.8 | 533.8 | 18393.8 | 38163.1 | 1011.0 | 160103.9 | 7343.9 | 0.0 | 93660.3 | 10870.2 | 7018.4 |
| 1963 | 0.0 | 0.0 | 0.0 | 0.0 | 59205.5 | 0.0 | 0.0 | 8113.0 | 0.0 | 9904.5 | 81550.3 | 804.2 | 761.5 | 25797.0 | 50199.8 | 1005.0 | 154014.5 | 9225.3 | 0.0 | 111364.2 | 15420.1 | 8039.8 |
| 1964 | 0.0 | 0.0 | 0.0 | 0.0 | 59116.6 | 0.0 | 0.0 | 8460.7 | 0.0 | 10491.5 | 93259.0 | 876.5 | 498.9 | 19494.5 | 42342.4 | 1239.3 | 215271.9 | 6923.5 | 0.0 | 102618.6 | 17071.2 | 7041.4 |
| 1965 | 0.0 | 0.0 | 0.0 | 0.0 | 66361.2 | 0.0 | 0.0 | 7564.4 | 0.0 | 8900.8 | 90716.7 | 771.9 | 443.9 | 18195.3 | 34946.8 | 1151.6 | 192861.4 | 7299.2 | 0.0 | 88770.2 | 16145.9 | 7009.8 |
| 1966 | 0.0 | 0.0 | 0.0 | 0.0 | 73556.4 | 0.0 | 0.0 | 9429.1 | 0.0 | 11343.5 | 107002.9 | 904.2 | 184.3 | 13158.2 | 43394.7 | 1022.8 | 185766.0 | 8443.2 | 0.0 | 104705.2 | 20049.2 | 8632.0 |
| 1967 | 0.0 | 0.0 | 0.0 | 0.0 | 66268.0 | 0.0 | 0.0 | 7613.8 | 0.0 | 9992.6 | 85947.0 | 765.2 | 523.7 | 20365.5 | 38483.1 | 1371.1 | 248838.4 | 6457.0 | 0.0 | 90941.3 | 17733.0 | 6709.8 |
| 1968 | 0.0 | 0.0 | 0.0 | 0.0 | 65359.4 | 0.0 | 0.0 | 6780.6 | 0.0 | 10735.8 | 105395.6 | 679.8 | 415.2 | 18259.1 | 44030.2 | 1181.0 | 242074.6 | 6614.1 | 0.0 | 104445.5 | 19605.9 | 6499.8 |
| 1969 | 0.0 | 0.0 | 0.0 | 0.0 | 66303.4 | 0.0 | 0.0 | 7139.0 | 0.0 | 9047.4 | 116134.5 | 677.6 | 453.9 | 18518.2 | 37612.3 | 1091.1 | 212312.4 | 7391.5 | 0.0 | 91439.5 | 18094.2 | 7186.4 |
| 1970 | 0.0 | 0.0 | 0.0 | 0.0 | 78060.1 | 0.0 | 0.0 | 9833.2 | 0.0 | 11805.5 | 114296.4 | 965.1 | 426.5 | 19219.4 | 42613.5 | 1644.4 | 280719.4 | 7126.2 | 0.0 | 101586.4 | 21095.6 | 7933.0 |
| 1971 | 0.0 | 0.0 | 0.0 | 0.0 | 79214.9 | 0.0 | 0.0 | 11308.2 | 0.0 | 11689.6 | 121020.2 | 1062.7 | 491.5 | 21071.0 | 43957.5 | 1278.1 | 207454.1 | 7522.4 | 0.0 | 103069.9 | 21071.8 | 8684.4 |
| 1972 | 0.0 | 0.0 | 0.0 | 0.0 | 73473.4 | 0.0 | 0.0 | 9613.5 | 0.0 | 12147.3 | 100429.7 | 951.5 | 469.3 | 20795.6 | 41855.3 | 1233.8 | 246999.7 | 6880.5 | 0.0 | 102540.4 | 21869.8 | 7848.9 |
| 1973 | 0.0 | 0.0 | 0.0 | 0.0 | 73825.4 | 0.0 | 0.0 | 10158.5 | 0.0 | 10012.7 | 108138.1 | 967.6 | 483.4 | 19189.7 | 39655.4 | 1143.0 | 250188.1 | 7519.3 | 0.0 | 96607.0 | 17911.2 | 8403.4 |
| 1974 | 0.0 | 0.0 | 0.0 | 0.0 | 68368.9 | 0.0 | 0.0 | 8893.8 | 0.0 | 11308.5 | 91210.0 | 898.2 | 339.3 | 15958.3 | 40540.9 | 1833.0 | 335601.8 | 6222.2 | 0.0 | 95684.1 | 18188.7 | 7256.1 |
| 1975 | 0.0 | 0.0 | 0.0 | 0.0 | 64181.1 | 0.0 | 0.0 | 10073.7 | 0.0 | 9236.6 | 87394.7 | 920.6 | 408.9 | 17184.3 | 37175.6 | 1790.2 | 357213.6 | 7186.3 | 0.0 | 90359.8 | 17563.3 | 7946.8 |
| 1976 | 0.0 | 0.0 | 0.0 | 0.0 | 82974.5 | 0.0 | 0.0 | 9813.5 | 0.0 | 12665.2 | 103237.1 | 1013.1 | 204.4 | 11888.7 | 41123.7 | 910.9 | 235113.3 | 8487.7 | 0.0 | 91971.2 | 17380.7 | 8458.2 |
| 1977 | 0.0 | 0.0 | 0.0 | 0.0 | 82686.8 | 0.0 | 0.0 | 7598.4 | 0.0 | 11149.1 | 129432.9 | 783.4 | 217.2 | 12030.9 | 35643.0 | 1189.3 | 266908.7 | 5588.5 | 0.0 | 80677.1 | 16710.7 | 6102.4 |
| 1978 | 0.0 | 0.0 | 0.0 | 0.0 | 77548.9 | 0.0 | 0.0 | 9512.3 | 0.0 | 11109.9 | 129768.0 | 986.5 | 242.9 | 12413.5 | 37593.9 | 1862.3 | 303579.5 | 8323.5 | 0.0 | 83347.9 | 15595.9 | 8373.1 |
| 1979 | 0.0 | 0.0 | 0.0 | 0.0 | 77189.4 | 0.0 | 0.0 | 6106.0 | 0.0 | 10145.5 | 134774.5 | 641.6 | 191.6 | 10949.4 | 32660.6 | 1277.9 | 277465.7 | 6588.2 | 0.0 | 74903.6 | 15360.5 | 5868.7 |
| 1980 | 0.0 | 0.0 | 0.0 | 0.0 | 86525.2 | 0.0 | 0.0 | 8397.5 | 0.0 | 10128.2 | 146746.8 | 871.0 | 181.0 | 11306.0 | 39740.3 | 942.9 | 206446.2 | 7652.2 | 0.0 | 87263.5 | 15710.8 | 7338.8 |
| 1981 | 0.0 | 0.0 | 0.0 | 0.0 | 73800.1 | 0.0 | 0.0 | 5889.7 | 0.0 | 9788.0 | 135510.4 | 597.8 | 195.0 | 12854.7 | 33395.7 | 916.4 | 206515.5 | 6283.3 | 0.0 | 78686.5 | 18091.3 | 5858.5 |
| 1982 | 0.0 | 0.0 | 0.0 | 0.0 | 68226.5 | 0.0 | 0.0 | 7916.7 | 0.0 | 9759.2 | 132887.7 | 797.0 | 158.6 | 11204.5 | 28477.3 | 939.2 | 238455.1 | 8466.1 | 0.0 | 69124.2 | 17702.5 | 8026.9 |
| 1983 | 0.0 | 0.0 | 0.0 | 0.0 | 70535.6 | 0.0 | 0.0 | 8907.5 | 0.0 | 9621.3 | 133665.5 | 902.6 | 161.5 | 11088.1 | 22844.5 | 1247.9 | 256570.6 | 8060.8 | 0.0 | 57241.3 | 16519.5 | 7826.8 |
| 1984 | 0.0 | 0.0 | 0.0 | 0.0 | 103070.4 | 0.0 | 0.0 | 10572.3 | 0.0 | 7266.0 | 160963.2 | 1039.0 | 186.7 | 11773.2 | 23110.4 | 1174.5 | 247462.4 | 9301.7 | 0.0 | 54867.0 | 16516.0 | 9135.7 |
| 1985 | 0.0 | 0.0 | 0.0 | 0.0 | 74325.8 | 0.0 | 0.0 | 10396.5 | 0.0 | 10236.9 | 124521.0 | 1079.8 | 199.3 | 11581.6 | 25156.4 | 1467.7 | 286600.4 | 9143.7 | 0.0 | 57559.4 | 16055.1 | 9126.7 |
| 1986 | 0.0 | 0.0 | 0.0 | 0.0 | 89116.5 | 0.0 | 0.0 | 11278.7 | 0.0 | 9480.8 | 143058.8 | 1142.1 | 229.7 | 12080.7 | 27882.5 | 1176.1 | 252873.7 | 10130.2 | 0.0 | 63275.6 | 14826.6 | 9683.4 |
| 1987 | 0.0 | 0.0 | 0.0 | 0.0 | 83410.7 | 0.0 | 0.0 | 9542.0 | 0.0 | 10003.0 | 149735.0 | 903.3 | 170.9 | 10102.4 | 22250.4 | 1024.2 | 238041.7 | 8145.8 | 0.0 | 51983.2 | 14708.7 | 8275.0 |
| 1988 | 0.0 | 0.0 | 0.0 | 0.0 | 65897.6 | 0.0 | 0.0 | 10644.1 | 0.0 | 10554.3 | 123891.9 | 985.6 | 205.3 | 10970.5 | 29500.8 | 1258.3 | 294842.3 | 10807.4 | 0.0 | 66927.9 | 14385.8 | 9752.4 |
| 1989 | 0.0 | 0.0 | 0.0 | 0.0 | 60727.3 | 0.0 | 0.0 | 9305.1 | 0.0 | 9163.0 | 116751.0 | 906.6 | 152.5 | 9430.2 | 25711.2 | 1150.4 | 276508.2 | 8607.5 | 0.0 | 61560.8 | 13405.4 | 8294.7 |
| 1990 | 0.0 | 0.0 | 0.0 | 0.0 | 66990.7 | 0.0 | 0.0 | 7758.8 | 0.0 | 8486.9 | 123045.6 | 788.7 | 190.3 | 10104.8 | 31451.9 | 1144.6 | 234172.3 | 7981.5 | 0.0 | 68654.4 | 12414.0 | 7261.1 |
| 1991 | 0.0 | 0.0 | 0.0 | 0.0 | 67303.2 | 0.0 | 0.0 | 7813.1 | 0.0 | 7124.7 | 137709.4 | 737.1 | 199.7 | 9948.1 | 32700.5 | 1144.1 | 277317.2 | 7534.6 | 0.0 | 71407.2 | 11401.6 | 6988.9 |
| 1992 | 0.0 | 0.0 | 0.0 | 0.0 | 62999.0 | 0.0 | 0.0 | 5680.4 | 0.0 | 8156.6 | 111046.3 | 525.4 | 202.7 | 9662.1 | 31163.0 | 1297.5 | 236893.4 | 5409.1 | 0.0 | 67095.7 | 11384.6 | 5140.0 |
| 1993 | 0.0 | 0.0 | 0.0 | 0.0 | 65142.6 | 0.0 | 0.0 | 3835.4 | 0.0 | 8536.2 | 98520.5 | 350.7 | 172.6 | 10660.2 | 16242.9 | 1216.7 | 223599.3 | 8653.1 | 0.0 | 40159.9 | 14180.0 | 5415.1 |
| 1994 | 0.0 | 0.0 | 0.0 | 0.0 | 64729.8 | 0.0 | 0.0 | 12997.6 | 0.0 | 12213.2 | 101131.5 | 1237.0 | 202.9 | 12241.7 | 22878.1 | 976.5 | 194872.8 | 10516.5 | 0.0 | 57461.1 | 16276.1 | 11368.1 |
| 1995 | 0.0 | 0.0 | 0.0 | 0.0 | 74519.4 | 0.0 | 0.0 | 13509.2 | 0.0 | 10728.6 | 116375.3 | 1274.2 | 170.7 | 13380.2 | 29163.9 | 1108.1 | 223631.2 | 11640.2 | 0.0 | 70360.7 | 18326.4 | 11773.6 |
| 1996 | 0.0 | 0.0 | 0.0 | 0.0 | 80920.6 | 0.0 | 0.0 | 11532.4 | 0.0 | 8208.8 | 110649.8 | 1070.9 | 184.8 | 10564.3 | 19595.2 | 1329.0 | 266622.0 | 8695.3 | 0.0 | 43805.8 | 12642.2 | 9803.5 |
| 1997 | 0.0 | 0.0 | 0.0 | 0.0 | 87534.6 | 0.0 | 0.0 | 12346.9 | 0.0 | 8887.0 | 123273.2 | 1238.9 | 161.9 | 10378.9 | 32997.2 | 1296.6 | 280158.7 | 8993.5 | 0.0 | 74984.1 | 14192.3 | 10303.7 |
| 1998 | 0.0 | 0.0 | 0.0 | 0.0 | 85791.2 | 0.0 | 0.0 | 12021.0 | 0.0 | 10043.3 | 118917.0 | 1137.9 | 170.7 | 10205.1 | 28342.9 | 1184.9 | 281738.5 | 8921.5 | 0.0 | 67221.6 | 13888.7 | 10357.0 |
| 1999 | 0.0 | 0.0 | 0.0 | 0.0 | 87233.7 | 0.0 | 0.0 | 12189.0 | 0.0 | 10506.6 | 120618.4 | 1204.8 | 96.0 | 7273.7 | 26678.8 | 1048.7 | 263685.2 | 10061.6 | 0.0 | 59996.7 | 12545.7 | 10859.4 |
| 2000 | 0.0 | 0.0 | 0.0 | 0.0 | 76408.3 | 0.0 | 0.0 | 14548.8 | 0.0 | 10860.5 | 128538.0 | 1445.8 | 154.4 | 8214.8 | 25923.7 | 1613.4 | 318572.6 | 10412.9 | 0.0 | 62290.6 | 11625.3 | 11874.0 |

# APPENDIX J

RECHARGE FROM SURFACE WATER IRRIGATION

Appendix J Recharge from Surface Water Irrigation Colorado

| Year | Cheyenne | KitCarson | Lincoln | Logan | Phillips | Sedgwick | Washington | Yuma |
|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2767.0 |
| 1941 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2654.0 |
| 1942 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2502.0 |
| 1943 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3165.2 |
| 1944 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3225.8 |
| 1945 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3246.4 |
| 1946 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3497.4 |
| 1947 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3064.8 |
| 1948 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1920.8 |
| 1949 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1783.6 |
| 1950 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2336.2 |
| 1951 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2353.6 |
| 1952 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2609.0 |
| 1953 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3266.4 |
| 1954 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4367.6 |
| 1955 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4119.4 |
| 1956 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 4165.4 |
| 1957 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2874.0 |
| 1958 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3021.8 |
| 1959 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3775.6 |
| 1960 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3599.2 |
| 1961 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3161.0 |
| 1962 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2550.8 |
| 1963 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3336.2 |
| 1964 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3320.8 |
| 1965 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2300.0 |
| 1966 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2010.6 |
| 1967 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2548.6 |
| 1968 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3418.4 |
| 1969 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3246.2 |
| 1970 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2007.2 |
| 1971 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2123.2 |
| 1972 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2011.4 |
| 1973 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1278.2 |
| 1974 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2943.8 |
| 1975 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2832.6 |
| 1976 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3144.8 |
| 1977 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2466.6 |
| 1978 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2611.6 |
| 1979 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2506.0 |
| 1980 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1895.8 |
| 1981 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1479.4 |
| 1982 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2429.8 |
| 1983 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2340.0 |
| 1984 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2255.6 |
| 1985 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1283.0 |
| 1986 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2562.6 |
| 1987 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2185.4 |
| 1988 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2576.4 |
| 1989 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2099.0 |
| 1990 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2138.4 |
| 1991 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1937.8 |
| 1992 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2882.2 |
| 1993 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2393.4 |
| 1994 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1318.0 |
| 1995 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1793.0 |
| 1996 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1105.0 |
| 1997 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1909.8 |
| 1998 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2079.4 |
| 1999 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2446.6 |
| 2000 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2020.0 |

Appendix J Recharge from Surface Water Irrigation Kansas

| Year | Cheyenne | Decatur | Gove | Graham | Jewell | Logan | Norton | Phillips | Rawlins | Sheridan | Sherman | Thomas | Trego | Wallace |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1941 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1942 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1943 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1944 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1945 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1946 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1947 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1948 | 0.0 | 0.0 | 0.0 | 0.0 | 5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1949 | 0.0 | 0.0 | 0.0 | 0.0 | 5.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1950 | 0.0 | 0.0 | 0.0 | 0.0 | 4.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1951 | 0.0 | 0.0 | 0.0 | 0.0 | 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1952 | 0.0 | 0.0 | 0.0 | 0.0 | 45.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1953 | 0.0 | 0.0 | 0.0 | 0.0 | 104.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1954 | 0.0 | 0.0 | 0.0 | 0.0 | 98.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1955 | 0.0 | 0.0 | 0.0 | 0.0 | 278.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1956 | 0.0 | 0.0 | 0.0 | 0.0 | 241.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1957 | 0.0 | 0.0 | 0.0 | 0.0 | 208.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1958 | 1.1 | 0.0 | 0.0 | 0.0 | 100.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1959 | 1.5 | 0.0 | 0.0 | 0.0 | 255.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1960 | 1.5 | 0.0 | 0.0 | 0.0 | 178.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1961 | 1.3 | 0.0 | 0.0 | 0.0 | 182.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1962 | 0.8 | 0.0 | 0.0 | 0.0 | 138.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1963 | 0.9 | 0.0 | 0.0 | 0.0 | 187.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1964 | 1.1 | 0.0 | 0.0 | 0.0 | 225.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1965 | 0.9 | 0.0 | 0.0 | 0.0 | 171.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1966 | 0.6 | 0.0 | 0.0 | 0.0 | 204.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1967 | 0.9 | 0.0 | 0.0 | 0.0 | 210.8 | 0.0 | 1088.6 | 1574.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1968 | 0.8 | 0.0 | 0.0 | 0.0 | 244.4 | 0.0 | 1736.2 | 2511.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1969 | 0.9 | 0.0 | 0.0 | 0.0 | 136.5 | 0.0 | 1333.7 | 1929.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1970 | 0.8 | 0.0 | 0.0 | 0.0 | 272.8 | 0.0 | 1400.2 | 2025.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1971 | 0.8 | 0.0 | 0.0 | 0.0 | 250.0 | 0.0 | 1035.3 | 1497.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1972 | 0.9 | 0.0 | 0.0 | 0.0 | 172.9 | 0.0 | 543.9 | 786.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1973 | 0.6 | 0.0 | 0.0 | 0.0 | 159.1 | 0.0 | 1195.3 | 1729.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1974 | 0.8 | 0.0 | 0.0 | 0.0 | 250.8 | 0.0 | 677.7 | 980.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1975 | 0.9 | 0.0 | 0.0 | 0.0 | 215.6 | 0.0 | 1097.2 | 1587.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1976 | 0.9 | 0.0 | 0.0 | 0.0 | 313.9 | 0.0 | 916.2 | 1325.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1977 | 0.9 | 0.0 | 0.0 | 0.0 | 171.5 | 0.0 | 684.2 | 989.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1978 | 0.6 | 0.0 | 0.0 | 0.0 | 174.0 | 0.0 | 777.1 | 1124.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1979 | 0.9 | 0.0 | 0.0 | 0.0 | 104.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1980 | 0.9 | 0.0 | 0.0 | 0.0 | 203.6 | 0.0 | 260.9 | 377.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1981 | 0.8 | 0.0 | 0.0 | 0.0 | 80.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1982 | 0.6 | 0.0 | 0.0 | 0.0 | 136.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1983 | 0.4 | 0.0 | 0.0 | 0.0 | 176.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1984 | 0.6 | 0.0 | 0.0 | 0.0 | 175.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1985 | 0.6 | 0.0 | 0.0 | 0.0 | 123.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1986 | 0.6 | 0.0 | 0.0 | 0.0 | 149.6 | 0.0 | 412.1 | 596.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1987 | 0.6 | 0.0 | 0.0 | 0.0 | 157.1 | 0.0 | 474.8 | 686.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1988 | 0.6 | 0.0 | 0.0 | 0.0 | 213.1 | 0.0 | 398.0 | 575.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1989 | 0.8 | 0.0 | 0.0 | 0.0 | 167.0 | 0.0 | 252.1 | 364.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1990 | 0.6 | 0.0 | 0.0 | 0.0 | 159.6 | 0.0 | 299.3 | 433.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1991 | 0.6 | 0.0 | 0.0 | 0.0 | 134.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1992 | 0.6 | 0.0 | 0.0 | 0.0 | 58.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1993 | 0.6 | 0.0 | 0.0 | 0.0 | 13.0 | 0.0 | 308.7 | 446.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1994 | 0.6 | 0.0 | 0.0 | 0.0 | 130.7 | 0.0 | 543.2 | 785.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1995 | 0.4 | 0.0 | 0.0 | 0.0 | 137.7 | 0.0 | 1069.9 | 1547.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1996 | 0.6 | 0.0 | 0.0 | 0.0 | 117.2 | 0.0 | 988.8 | 1430.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1997 | 0.6 | 0.0 | 0.0 | 0.0 | 95.8 | 0.0 | 1439.6 | 2082.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1998 | 0.8 | 0.0 | 0.0 | 0.0 | 130.4 | 0.0 | 620.3 | 897.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1999 | 0.8 | 0.0 | 0.0 | 0.0 | 135.5 | 0.0 | 567.6 | 821.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2000 | 0.6 | 0.0 | 0.0 | 0.0 | 169.6 | 0.0 | 354.9 | 513.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Appendix J Recharge from Surface Water Irrigation Nebraska

| Year | Adams | Buffalo | Chase | Clay | Dawson | Deuel | Dundy | Franklin | Frontier | Furnas | Gosper | Harlan | Hayes | Hitchcock | Kearney | Keith | Lincoln | Nuckolls | Perkins | Phelps | RedWillow | Webster |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1919 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1920 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1921 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1922 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1923 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1924 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1925 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1926 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1927 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1928 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1929 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1930 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1931 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1932 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1933 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1934 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1935 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1936 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1937 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1938 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1939 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1940 | 0.0 | 0.0 | 145.5 | 0.0 | 0.0 | 0.0 | 106.0 | 536.8 | 145.4 | 281.2 | 0.0 | 435.2 | 288.4 | 396.6 | 0.0 | 0.0 | 0.0 | 450.6 | 0.0 | 80.5 | 224.4 | 202.8 |
| 1941 | 0.0 | 0.0 | 145.5 | 0.0 | 0.0 | 0.0 | 106.0 | 536.8 | 141.5 | 452.4 | 0.0 | 451.8 | 296.6 | 396.6 | 0.0 | 0.0 | 0.0 | 450.6 | 0.0 | 80.5 | 220.0 | 202.8 |
| 1942 | 0.0 | 0.0 | 145.5 | 0.0 | 0.0 | 0.0 | 106.0 | 536.8 | 141.5 | 527.2 | 1961.2 | 443.5 | 296.6 | 396.6 | 6181.2 | 0.0 | 0.0 | 450.6 | 0.0 | 12259.7 | 209.9 | 241.3 |
| 1943 | 0.0 | 0.0 | 145.5 | 0.0 | 0.0 | 0.0 | 3735.6 | 536.8 | 151.3 | 543.9 | 2102.0 | 584.7 | 293.8 | 396.6 | 6680.8 | 0.0 | 0.0 | 450.6 | 0.0 | 13181.7 | 237.3 | 241.3 |
| 1944 | 0.0 | 0.0 | 145.5 | 0.0 | 0.0 | 0.0 | 3836.4 | 536.8 | 150.4 | 546.0 | 1783.6 | 595.4 | 293.8 | 396.6 | 5520.8 | 0.0 | 0.0 | 450.6 | 0.0 | 11066.5 | 236.2 | 241.3 |
| 1945 | 0.0 | 0.0 | 145.5 | 0.0 | 20025.2 | 842.4 | 4317.2 | 536.8 | 150.3 | 561.7 | 2096.0 | 579.8 | 293.8 | 396.6 | 6606.4 | 5836.4 | 1740.8 | 450.6 | 0.0 | 13093.3 | 236.2 | 241.3 |
| 1946 | 0.0 | 0.0 | 145.5 | 0.0 | 20025.2 | 842.4 | 4317.2 | 536.8 | 150.3 | 565.0 | 2096.0 | 576.4 | 293.8 | 396.6 | 6606.4 | 5836.4 | 1740.8 | 450.6 | 0.0 | 13093.3 | 236.2 | 241.3 |
| 1947 | 0.0 | 0.0 | 145.5 | 0.0 | 14897.2 | 1225.2 | 4409.5 | 536.8 | 150.3 | 565.0 | 1783.6 | 618.1 | 293.8 | 396.6 | 5466.8 | 8488.8 | 1418.0 | 450.6 | 0.0 | 11018.5 | 236.2 | 258.8 |
| 1948 | 0.0 | 0.0 | 145.5 | 0.0 | 14022.8 | 1458.0 | 3517.9 | 555.1 | 150.3 | 594.4 | 3083.6 | 813.5 | 293.8 | 396.6 | 10144.8 | 10102.0 | 1378.0 | 457.3 | 0.0 | 19619.7 | 236.2 | 495.8 |
| 1949 | 0.0 | 0.0 | 161.9 | 0.0 | 14400.4 | 1202.4 | 3491.1 | 587.1 | 150.3 | 601.8 | 2038.0 | 896.0 | 293.8 | 396.6 | 7589.6 | 8328.8 | 1264.0 | 606.4 | 0.0 | 13805.7 | 236.2 | 497.9 |
| 1950 | 0.0 | 0.0 | 161.9 | 0.0 | 10193.2 | 1034.8 | 4042.9 | 593.1 | 147.9 | 602.5 | 2192.8 | 836.6 | 293.8 | 530.7 | 6227.2 | 7171.6 | 867.2 | 550.4 | 0.0 | 13064.6 | 234.7 | 688.0 |
| 1951 | 0.0 | 0.0 | 161.9 | 0.0 | 8677.6 | 1382.0 | 2924.1 | 614.8 | 147.9 | 760.5 | 1879.2 | 869.4 | 293.8 | 576.5 | 3982.4 | 9570.8 | 755.6 | 504.7 | 0.0 | 9968.6 | 234.6 | 630.9 |
| 1952 | 0.0 | 0.0 | 161.9 | 0.0 | 18989.2 | 1910.4 | 4086.4 | 554.6 | 132.7 | 984.8 | 3248.4 | 864.0 | 503.7 | 1162.8 | 12294.8 | 13234.8 | 1635.7 | 811.7 | 0.0 | 22113.2 | 1461.2 | 659.3 |
| 1953 | 0.0 | 0.0 | 161.9 | 0.0 | 21957.2 | 1047.6 | 4429.1 | 1047.8 | 121.5 | 1602.0 | 3680.0 | 845.3 | 645.1 | 3763.2 | 15334.4 | 7255.6 | 1922.0 | 1204.4 | 0.0 | 29856.7 | 531.4 | 761.5 |
| 1954 | 0.0 | 0.0 | 268.5 | 0.0 | 16372.4 | 770.4 | 4593.2 | 1374.1 | 123.6 | 2650.1 | 5021.3 | 990.1 | 687.1 | 3381.1 | 12302.8 | 5337.2 | 1448.8 | 1117.2 | 0.0 | 26029.7 | 511.1 | 884.4 |
| 1955 | 0.0 | 0.0 | 298.0 | 0.0 | 19852.8 | 971.2 | 4751.2 | 2432.5 | 107.6 | 5785.3 | 6441.1 | 1410.2 | 655.2 | 2786.9 | 16255.2 | 6727.2 | 1716.2 | 2872.1 | 0.0 | 30514.8 | 829.7 | 1515.5 |
| 1956 | 0.0 | 0.0 | 298.0 | 0.0 | 19438.8 | 690.8 | 5076.9 | 3402.0 | 110.1 | 5573.4 | 7664.1 | 1327.5 | 657.3 | 3572.7 | 20483.6 | 4789.2 | 1703.0 | 2841.8 | 0.0 | 36700.7 | 882.1 | 2364.9 |
| 1957 | 0.0 | 0.0 | 298.0 | 0.0 | 14015.2 | 1463.6 | 4406.8 | 2658.4 | 111.5 | 2328.5 | 5507.7 | 740.4 | 660.7 | 3174.5 | 8554.8 | 10138.4 | 1242.0 | 2973.4 | 0.0 | 18748.9 | 628.1 | 2138.4 |
| 1958 | 0.0 | 0.0 | 298.0 | 0.0 | 11468.4 | 850.8 | 4288.0 | 1387.9 | 111.5 | 4020.9 | 4171.7 | 1413.9 | 660.7 | 1517.4 | 8131.6 | 5893.6 | 1558.8 | 1339.0 | 0.0 | 20036.1 | 2241.4 | 1401.4 |
| 1959 | 0.0 | 0.0 | 253.7 | 0.0 | 14155.6 | 864.8 | 5774.5 | 3809.5 | 114.5 | 6032.1 | 5419.4 | 2405.4 | 595.5 | 1387.5 | 10804.4 | 5988.8 | 2443.9 | 4171.2 | 0.0 | 24617.6 | 3183.5 | 3279.7 |
| 1960 | 0.0 | 0.0 | 237.6 | 0.0 | 11191.2 | 1000.4 | 5373.9 | 2999.9 | 115.2 | 5554.7 | 4726.0 | 2002.7 | 536.8 | 1830.5 | 10090.0 | 6930.8 | 2337.6 | 2922.5 | 0.0 | 21580.8 | 4644.9 | 2665.1 |
| 1961 | 0.0 | 0.0 | 241.6 | 0.0 | 13166.8 | 2143.6 | 4661.2 | 2938.4 | 103.2 | 5055.4 | 4628.0 | 1951.5 | 542.5 | 1840.7 | 9600.4 | 14851.2 | 2366.9 | 3160.6 | 0.0 | 22328.9 | 4565.9 | 2642.5 |
| 1962 | 0.0 | 0.0 | 411.1 | 0.0 | 9493.2 | 1550.8 | 3276.1 | 1656.6 | 41.2 | 3265.1 | 3866.3 | 1237.9 | 769.8 | 1698.1 | 5486.6 | 10741.6 | 1614.3 | 2436.5 | 0.0 | 16183.1 | 3462.8 | 1931.8 |
| 1963 | 0.0 | 0.0 | 1505.9 | 0.0 | 13108.8 | 886.4 | 3721.9 | 3649.9 | 202.3 | 6056.5 | 5387.8 | 2298.7 | 823.9 | 4560.7 | 13107.1 | 6144.8 | 2472.1 | 3707.9 | 0.0 | 26949.4 | 9325.0 | 3006.6 |
| 1964 | 0.0 | 0.0 | 1394.8 | 0.0 | 15393.6 | 530.4 | 4285.5 | 3918.1 | 188.3 | 6023.7 | 6017.7 | 2496.2 | 488.6 | 2871.0 | 10866.2 | 3674.0 | 2530.3 | 4218.7 | 0.0 | 26070.6 | 8160.8 | 3202.2 |
| 1965 | 0.0 | 0.0 | 1562.0 | 0.0 | 12896.8 | 1431.6 | 3430.1 | 2097.9 | 184.4 | 4189.8 | 3848.4 | 1581.1 | 602.8 | 2423.9 | 7599.3 | 9920.4 | 2126.4 | 3583.4 | 0.0 | 17728.0 | 7110.3 | 2042.4 |
| 1966 | 0.0 | 0.0 | 1524.0 | 0.0 | 15864.0 | 852.4 | 2537.6 | 3075.9 | 131.4 | 3833.3 | 5492.8 | 1754.6 | 595.9 | 6836.2 | 10873.6 | 5903.6 | 2592.4 | 3804.4 | 0.0 | 24720.4 | 7817.9 | 2713.1 |
| 1967 | 0.0 | 0.0 | 1331.5 | 0.0 | 15800.0 | 1246.8 | 3848.8 | 2984.0 | 134.3 | 4138.1 | 3858.9 | 1798.4 | 451.8 | 3142.6 | 10137.0 | 8640.4 | 2715.8 | 4086.0 | 0.0 | 20715.4 | 7576.2 | 2705.2 |
| 1968 | 0.0 | 0.0 | 1913.6 | 0.0 | 15261.2 | 1116.0 | 3102.4 | 3237.8 | 284.9 | 5597.2 | 4962.6 | 2112.3 | 805.5 | 3545.3 | 10953.9 | 7734.0 | 2603.5 | 3915.0 | 0.0 | 24254.2 | 9427.1 | 3100.2 |
| 1969 | 0.0 | 0.0 | 1187.0 | 0.0 | 15936.4 | 903.6 | 3237.3 | 2434.1 | 187.6 | 5137.4 | 3880.7 | 2024.9 | 515.8 | 3179.6 | 8271.8 | 6258.0 | 2690.9 | 2306.0 | 0.0 | 17477.8 | 9180.6 | 2144.1 |
| 1970 | 0.0 | 0.0 | 1136.5 | 0.0 | 18086.4 | 1864.4 | 3120.2 | 4375.3 | 260.2 | 6544.1 | 4890.1 | 2644.5 | 480.0 | 3392.1 | 9919.1 | 12918.0 | 2986.0 | 4982.4 | 0.0 | 21383.0 | 9465.3 | 3911.4 |
| 1971 | 0.0 | 0.0 | 1284.7 | 0.0 | 20515.6 | 517.6 | 2793.2 | 4095.1 | 314.9 | 6219.6 | 5111.0 | 2621.4 | 361.4 | 3455.6 | 11824.3 | 3585.6 | 3238.5 | 4337.8 | 0.0 | 23339.4 | 9493.8 | 3623.0 |
| 1972 | 0.0 | 0.0 | 1334.2 | 0.0 | 20514.0 | 677.2 | 3496.2 | 3250.8 | 327.6 | 5910.2 | 5308.4 | 2364.6 | 250.4 | 2862.8 | 8856.3 | 4693.6 | 3256.9 | 2941.6 | 0.0 | 20122.1 | 8563.1 | 2742.7 |
| 1973 | 0.0 | 0.0 | 1155.8 | 0.0 | 21174.0 | 752.8 | 2725.0 | 3593.0 | 371.8 | 5912.8 | 4591.3 | 2367.0 | 228.1 | 3127.9 | 10720.0 | 5213.2 | 3290.8 | 3025.5 | 0.0 | 21099.6 | 9399.4 | 3075.7 |
| 1974 | 0.0 | 0.0 | 1125.3 | 0.0 | 21233.6 | 825.2 | 3234.5 | 4630.4 | 368.8 | 7222.5 | 5493.1 | 3123.4 | 133.3 | 3411.2 | 10998.2 | 5716.0 | 3439.1 | 5105.3 | 0.0 | 22937.8 | 9610.1 | 4365.1 |
| 1975 | 0.0 | 0.0 | 1227.2 | 0.0 | 19226.4 | 1060.8 | 3560.6 | 3916.0 | 354.6 | 6378.4 | 4665.1 | 3034.6 | 146.0 | 3362.4 | 10199.3 | 7347.2 | 3038.4 | 4502.3 | 0.0 | 20387.7 | 9857.2 | 3867.6 |
| 1976 | 0.0 | 0.0 | 1165.9 | 0.0 | 19227.2 | 623.2 | 3950.1 | 5349.4 | 416.6 | 8163.7 | 5930.1 | 3694.7 | 225.5 | 6254.3 | 12611.1 | 4317.6 | 3315.1 | 6630.6 | 0.0 | 25391.4 | 10326.0 | 5190.7 |
| 1977 | 0.0 | 0.0 | 1191.8 | 0.0 | 17521.2 | 590.0 | 3652.9 | 3389.7 | 260.0 | 5277.7 | 4889.2 | 2474.1 | 302.7 | 4874.6 | 9908.3 | 4088.8 | 2797.1 | 3286.8 | 0.0 | 20194.8 | 6790.0 | 2814.5 |
| 1978 | 0.0 | 0.0 | 852.9 | 0.0 | 20553.6 | 567.2 | 2505.4 | 3008.1 | 303.2 | 5753.5 | 6326.9 | 2202.6 | 307.3 | 4726.9 | 12221.1 | 3929.6 | 3336.4 | 3595.2 | 0.0 | 28919.4 | 8228.4 | 2803.3 |
| 1979 | 0.0 | 0.0 | 661.9 | 0.0 | 17974.0 | 1645.6 | 3093.8 | 2031.1 | 147.7 | 2664.4 | 4877.4 | 1194.8 | 127.7 | 3562.9 | 6080.8 | 11400.8 | 2498.7 | 2471.7 | 0.0 | 19907.6 | 4465.1 | 1830.8 |
| 1980 | 0.0 | 0.0 | 583.1 | 0.0 | 23243.6 | 605.6 | 3120.0 | 4366.1 | 338.2 | 4863.1 | 6648.3 | 2290.7 | 153.6 | 3881.5 | 11174.1 | 4194.0 | 3617.2 | 4224.7 | 0.0 | 29186.0 | 6243.8 | 3732.5 |
| 1981 | 0.0 | 0.0 | 1059.5 | 0.0 | 18244.4 | 1116.0 | 2979.0 | 1589.4 | 199.6 | 2494.2 | 5328.2 | 1184.8 | 307.3 | 3781.1 | 7354.1 | 7734.0 | 2225.3 | 1904.8 | 0.0 | 23560.2 | 4753.0 | 1536.9 |
| 1982 | 0.0 | 0.0 | 920.0 | 0.0 | 20142.8 | 924.0 | 2395.7 | 2622.2 | 258.9 | 3929.5 | 4825.4 | 1851.6 | 233.5 | 3620.6 | 7841.6 | 6402.4 | 2670.3 | 2863.1 | 0.0 | 22173.7 | 5502.1 | 2378.7 |
| 1983 | 0.0 | 0.0 | 141.6 | 0.0 | 17546.0 | 1752.4 | 1510.7 | 3408.4 | 436.4 | 4186.9 | 4753.7 | 1789.4 | 123.1 | 3950.2 | 7748.9 | 12141.2 | 2200.8 | 3673.5 | 0.0 | 21242.1 | 6293.4 | 2970.8 |
| 1984 | 0.0 | 0.0 | 233.8 | 0.0 | 18036.0 | 1910.4 | 1885.5 | 3720.2 | 208.1 | 5032.6 | 6010.1 | 2064.5 | 150.8 | 4099.5 | 11255.3 | 13234.8 | 2735.2 | 3808.2 | 0.0 | 28180.4 | 6606.8 | 3287.9 |
| 1985 | 0.0 | 0.0 | 629.0 | 0.0 | 20022.0 | 1818.8 | 2098.5 | 3221.7 | 234.2 | 3289.4 | 4608.5 | 1558.5 | 150.1 | 3639.0 | 6875.0 | 12602.4 | 2695.2 | 2578.7 | 0.0 | 19223.0 | 6080.2 | 2673.8 |
| 1986 | 0.0 | 0.0 | 847.0 | 0.0 | 22502.8 | 996.0 | 2109.3 | 4162.0 | 274.1 | 4419.8 | 5603.1 | 2089.5 | 149.8 | 3930.0 | 7338.4 | 6905.6 | 3232.8 | 3070.1 | 0.0 | 22734.8 | 6345.4 | 3325.4 |
| 1987 | 0.0 | 0.0 | 1063.1 | 0.0 | 19750.4 | 849.6 | 2205.4 | 2891.3 | 233.5 | 3690.9 | 4649.3 | 1742.4 | 156.3 | 3911.1 | 6799.1 | 5886.0 | 2731.5 | 3127.2 | 0.0 | 19540.0 | 6060.2 | 2572.0 |
| 1988 | 0.0 | 0.0 | 801.1 | 0.0 | 19371.6 | 1030.8 | 2223.1 | 4066.4 | 186.5 | 4625.0 | 5320.9 | 2093.9 | 125.5 | 3764.4 | 9112.0 | 7139.6 | 3086.0 | 4579.4 | 0.0 | 24871.5 | 5621.9 | 3222.0 |
| 1989 | 0.0 | 0.0 | 792.2 | 0.0 | 20722.4 | 804.4 | 2517.9 | 2964.0 | 216.9 | 4989.7 | 5056.0 | 2131.7 | 143.4 | 4027.0 | 7602.2 | 5575.6 | 3077.8 | 3595.6 | 0.0 | 22512.7 | 6048.7 | 2403.9 |
| 1990 | 0.0 | 0.0 | 502.6 | 0.0 | 20650.0 | 1107.6 | 2253.7 | 2397.6 | 296.1 | 4740.6 | 5686.2 | 1964.3 | 190.7 | 3794.7 | 10094.5 | 7673.6 | 3335.5 | 3558.7 | 0.0 | 26605.5 | 6712.6 | 2067.9 |
| 1991 | 0.0 | 0.0 | 46.2 | 0.0 | 19155.6 | 1046.8 | 2075.8 | 2467.0 | 231.5 | 4493.7 | 5374.8 | 1956.5 | 143.1 | 3288.4 | 11072.8 | 7252.0 | 3202.1 | 2793.6 | 0.0 | 27246.9 | 5162.9 | 1902.0 |
| 1992 | 0.0 | 0.0 | 62.8 | 0.0 | 17784.8 | 1452.0 | 2465.6 | 1720.2 | 232.9 | 3610.2 | 4132.1 | 1578.9 | 146.9 | 2483.1 | 6502.3 | 10059.2 | 2539.2 | 727.3 | 0.0 | 18106.3 | 3599.3 | 1068.6 |
| 1993 | 0.0 | 0.0 | 23.5 | 0.0 | 10668.8 | 685.6 | 1984.3 | 326.9 | 62.2 | 1164.5 | 1130.7 | 469.2 | 65.6 | 2831.7 | 1166.1 | 4751.2 | 1302.3 | 306.6 | 0.0 | 4768.7 | 3646.6 | 285.4 |
| 1994 | 0.0 | 0.0 | 56.8 | 0.0 | 17644.8 | 632.8 | 2221.7 | 3179.9 | 370.6 | 4334.6 | 5242.3 | 2020.5 | 201.3 | 3645.4 | 6594.9 | 4381.2 | 2921.2 | 2932.5 | 0.0 | 20603.0 | 6264.0 | 2703.1 |
| 1995 | 0.0 | 0.0 | 40.1 | 0.0 | 21688.0 | 881.6 | 1634.2 | 3225.8 | 313.0 | 4870.6 | 5087.1 | 2011.1 | 137.8 | 3524.2 | 9742.8 | 6108.4 | 3155.6 | 3564.5 | 0.0 | 24434.3 | 6326.6 | 2957.6 |
| 1996 | 0.0 | 0.0 | 46.0 | 0.0 | 17258.0 | 985.2 | 2239.5 | 1891.3 | 241.7 | 1905.5 | 3687.5 | 967.2 | 139.4 | 3310.8 | 3648.6 | 6826.8 | 2271.1 | 3131.6 | 0.0 | 12888.8 | 4552.3 | 2048.9 |
| 1997 | 0.0 | 0.0 | 46.0 | 0.0 | 19066.8 | 1402.4 | 2083.1 | 3045.4 | 241.7 | 4797.0 | 5208.7 | 2029.7 | 139.9 | 3882.1 | 8659.3 | 9719.6 | 2835.9 | 2615.3 | 0.0 | 22435.1 | 6309.0 | 2594.2 |
| 1998 | 0.0 | 0.0 | 46.0 | 0.0 | 19524.0 | 1116.4 | 2639.9 | 2651.9 | 241.7 | 4069.5 | 4373.3 | 1787.0 | 139.4 | 3339.8 | 6068.6 | 7736.0 | 1758.3 | 3114.3 | 0.0 | 18976.7 | 5570.0 | 2438.1 |
| 1999 | 0.0 | 0.0 | 46.0 | 0.0 | 14844.4 | 1326.4 | 2627.9 | 2908.7 | 241.7 | 3326.1 | 3428.2 | 1580.0 | 139.9 | 3043.2 | 5180.2 | 9188.0 | 1370.3 | 3399.4 | 0.0 | 14806.4 | 4575.2 | 2650.3 |
| 2000 | 0.0 | 0.0 | 46.0 | 0.0 | 18784.4 | 774.0 | 2418.3 | 3508.3 | 241.7 | 3657.0 | 4943.7 | 1709.8 | 139.4 | 3573.4 | 8261.1 | 5362.8 | 1605.9 | 4301.6 | 0.0 | 22378.8 | 5554.2 | 3233.3 |

## APPENDIX K

IRRIGATED ACREAGE ESTIMATES

## Appendix K – Irrigated Acreage Estimates

*Colorado* – Estimates of the irrigated acreage for 1940 through 2000 in Colorado for the area covered by the RRCA Model include lands in Kit Carson, Yuma, and Phillips Counties and parts of Sedgwick, Logan, Washington, Lincoln, and Cheyenne Counties. A small area of Elbert County is located in the RRCA Model area, but since there are no irrigation wells or ditches in that area, it was excluded.

The estimates are based on the County Assessors' records of irrigated acreage and well permit information contained in the Colorado Groundwater Commission's Northern High Plains Well Database with adjustments for irrigated fields set aside under federal farm programs. The results were compared to irrigated crop statistics compiled and published by the Colorado Department of Agriculture and the National Agricultural Statistics Service (NASS) and irrigated acreage records for farms participating in federally subsidized programs that were provided by local Farm Service Agency offices through the U.S. Department of Agriculture. Descriptions of these sources and procedures follow:

### County Assessor Records

The county assessor is an elected official in county government and their duties are prescribed by Colorado Revised Statutes. Succinctly, the county assessor must discover, list, classify, and value all taxable real and personal property within their respective county. Procedures for classifying and valuing property are set forth in the "Personal Property Valuation Manual", the "Land Valuation Manual", and other references prepared by the

Colorado Division of Taxation. The assessor's appraised property values form the basis for taxing districts to set mill levies and taxes. The county treasurer is responsible for collecting all property taxes.

For agricultural land, the assessor must determine the value of the land based on its production capability by considering soils, irrigation sources and methods, crop yields, crop values and farm sales. The assessor relies on aerial photographs, county clerk records, the county soil survey, agricultural statistics from NASS, climatalogical records, interviews with local farmers, and other locally available information. Since 1989, all property is appraised every other year based on sales of equivalent property during the preceding two years. Provisions are allowed to conduct interim appraisals if necessary to reflect a change in property values assessment such as conversion from irrigated cropland to dry land pasture.

The county assessors must publish an "Abstract of Assessment" by August 25 of each year that summarizes the amount and value of various categories of property as of the previous 1st of January. The abstracts also document the valuation, mill levy, and revenue for each taxing district in the county. Categories of property include irrigated farmland, meadow hay land, dry farmland, grazing land, and other agricultural land. Since 1993, the abstracts tabulate acreage by sprinkler and flood irrigation. The Colorado Department of Local Affairs summarizes the abstracts and submits an annual report to the Colorado General Assembly.

Irrigated land that is taken out of production due to farm programs, such as the Payment in Kind (PIK) and Conservation Reserve Program (CRP), remain classified as irrigated by the county assessor pursuant to requirements in federal authorizing legislation for these programs. They remain classified as irrigated to assure payment to the farm owner by the federal government is commensurate with irrigated land production capability and to maintain the assignment of tax burden. The Farm Service Agency (FSA) of the US Department of Agriculture (USDA) administers the federal crop programs. Each year, program participants must report crop acreage to the local FSA office that compiles records of irrigated and non-irrigated croplands. Federal farm program acreage records for 1990 through 2000 were available and summarized for each county as CRP fields and fallow fields. Those annual values were deducted from the assessors' irrigated acreage. The PIK Program reduced irrigated acreage significantly in the 1980s. Since the USDA does not retain records for more than 10 years, Colorado estimated the PIK acreage using NASS records as described later in this document.

### Colorado Groundwater Commission's Northern High Plains Well Database

The Northern High Plains Well Database covers the entirety of the RRCA Model area in Colorado. The information contained in the well database for the model area includes 3,967 groundwater well records. Each record includes the well location, use of the water, place of use, pumping rate, irrigated acreage, owner, and priority date. The records for each county were sorted by use, priority date, and location. For each county and priority year, the number of irrigation wells is counted and the acreage shown on the well permits is quantified.

The irrigated acreage identified in the well permits exceeds the actual irrigated acreage identified through County Assessor data. Review of well permit acreage information indicates most cite a square quarter-section of land, or 160 acres. Center-pivot sprinkler systems are the prevalent water application method in the model area and a typical circular quarter-section system irrigates only 130 acres. Comparison of permitted irrigated acreage with NASS data also indicates the well permit information exceeds the irrigated crop acreage reported by NASS.

Estimate of Surface Water Irrigated Acreage in Colorado

Surface water irrigation in the Basin in Colorado occurs only in Yuma and Kit Carson Counties. The surface water acreage was obtained from the respective County Assessor's records that documented a total of 2,902 (Yuma) and 1,861 (Kit Carson) acres in 1940. These quantities were carried forth to date and do not reflect the small decrease in surface water irrigation that has occurred since 1940.

Estimate of Irrigated Acreage by County Over Time in Colorado

The assessors' records of irrigated acreage for Kit Carson and Yuma Counties include land irrigated from surface water sources that precede 1940. Irrigation of additional acreage after 1940 can be attributed exclusively to groundwater development. Review of historic county assessor records confirms there has been little change in irrigated acreage since 1979 and the Assessors' records for recent years provide the most accurate quantification of irrigated acreage in each county.

To estimate the irrigated acreage over time, the ratio of the assessors reported acreage in 2000 to the cumulative acreage under all well permits for irrigation is calculated. For Phillips, Sedgwick, Logan, Washington, Lincoln, and Cheyenne Counties, that ratio is multiplied by the annual cumulative well permit acreage to determine the acreage in a specific year. For Kit Carson and Yuma Counties, the ratio was multiplied by the yearly permitted acreage and the resultant was added to the previous year's acreage to account for surface-water irrigated land developed before 1940. For 1990 through 2000, the fallow irrigated fields and fields idled due to farm programs (USDA records) were deducted from the calculated acreage to determine the net irrigated acreage for those years. From 1982 through 1988, significant acreage was taken out of production through the USDA's Payment in Kind (PIK) program. The USDA represents that it does not have records of the county acreage idled by this program during the 1980's because it retains records on individual farms for only 10 years. The NASS records show significant reductions in irrigated acreage, up to 110,000 acres in 1983, in Kit Carson, Yuma, and Phillips Counties. To reflect this program, Colorado combined the NASS acreage for the three counties[1] and calculated the annual reduction percentage from the acreage in 1981.

[1] The NASS records for the other five counties were not used for these calculations because the irrigated acreage in these counties overlaps into other river basins.

| **Year** | **Total Irrigated Acres** | **Reduction as Percent of 1981** |
|---|---|---|
| 1981 | 507,774 | 0.0 |
| 1982 | 480,443 | 5.4 |
| 1983 | 392,562 | 22.7 |
| 1984 | 426,248 | 16.1 |
| 1985 | 431,243 | 15.1 |
| 1986 | 416,416 | 18.0 |
| 1987 | 465,633 | 8.3 |
| 1988 | 468,627 | 7.7 |

The annual reduction percentages were multiplied by the irrigated acreage in each county and the resultant was subtracted to determine net irrigated acreage.

*Kansas* – The irrigated acreage in Kansas was determined from an analysis of available data from the water use reports, NASS, Census of Agriculture, and tabulations of water rights and groundwater wells. For the period 1989-1999, irrigated acres from the Water Use Reports were used. In addition to acreage data, crop information was used to develop countywide crop distributions for computing crop irrigation demand over the entire study period.

The NASS data for agricultural statistics provide countywide data that is the most complete in Kansas after 1972, and was used as the basis for the acreage estimates for the period of 1972-1988. However, some irrigated crops are not tracked individually in these records. The Census of Agriculture data from 1987, 1992 and 1997 were used to distribute some acreage to irrigated crops from the total crop acreage given in the NASS data. The percentage of each county's irrigated acreage included within the model domain was determined from the Water Use Report data and multiplied by the countywide irrigated acreages determined from the NASS data and Census data. For the pre-1972 acreage, the annual well count was multiplied by a ratio of acres per well derived from either the Water Use Reports or the adjusted NASS data for 1972, whichever gave a better fit to the subsequent year's estimates.

Irrigated acreage for each section was calculated by multiplying the annual well count by the irrigated acres per well, with a maximum of 520 irrigated acres per section. All remaining acreage above the 520 acre limit was assigned pro rata to other sections in the county.

*Nebraska* – In cooperation with the Nebraska Department of Agriculture (NDA), NASS prepares an estimate of crop acreage by county. Annually they produce "Nebraska Agricultural Statistics" which is a compilation of information about farms, crops, and livestock. Every five years, NASS produces the Census of Agriculture, which is a detailed counting of farms, crops, and livestock. For the intervening four years, the estimates are prepared using a much smaller sample than the census. Periodically, NASS presents revisions to the annual estimates based on the results of the most recent census.

Reports are prepared annually for Nebraska and the data are collected and summarized statewide and by county. Farmers are surveyed each fall following harvest. Those surveys are supplemented with surveys of grain elevators and mills for volumes of grain received, meat packing plants, and other agribusiness. Crops are added and deleted from the annual report as cropping patterns change. For example, broom corn was deleted from the surveys in the 1960s and sunflowers were added in 1990. Generally, the USDA is most interested in farm program crops such as corn and wheat and the NDA is interested in other crops such as alfalfa, grass hay, fruits, and table vegetables.

The annual reports break out irrigated and non-irrigated acreage for some crops. For other crops, such as alfalfa and corn for silage, NASS reports total acreage harvested every year but reports irrigated acreage periodically. In these cases, estimates of the irrigated acreage for the crop is based on the ratio of reported irrigated acreage and total harvested acreage in other years.

Appendix K Irrigated Acreage Colorado

| Year | Cheyenne | KitCarson | Lincoln | Logan | Phillips | Sedgwick | Washingto | Yuma |
|---|---|---|---|---|---|---|---|---|
| 1918 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1919 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1921 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1922 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1924 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1925 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1926 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1927 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1928 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1929 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1930 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1931 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1932 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1933 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1934 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1935 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1936 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1937 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1938 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1939 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1940 | 115 | 359 | 96 | 156 | 800 | 0 | 202 | 3681 |
| 1941 | 115 | 359 | 109 | 156 | 800 | 0 | 410 | 3929 |
| 1942 | 115 | 359 | 109 | 156 | 1115 | 0 | 410 | 3929 |
| 1943 | 115 | 359 | 109 | 156 | 1115 | 0 | 410 | 3929 |
| 1944 | 115 | 359 | 109 | 156 | 1115 | 0 | 570 | 3929 |
| 1945 | 365 | 359 | 109 | 156 | 1115 | 0 | 780 | 3929 |
| 1946 | 365 | 359 | 109 | 156 | 1115 | 0 | 972 | 4049 |
| 1947 | 365 | 715 | 129 | 156 | 1115 | 0 | 1256 | 4449 |
| 1948 | 365 | 1939 | 874 | 156 | 1235 | 0 | 1908 | 3885 |
| 1949 | 445 | 3284 | 1054 | 156 | 1812 | 160 | 2172 | 5425 |
| 1950 | 540 | 3590 | 1083 | 156 | 1972 | 160 | 2810 | 5590 |
| 1951 | 540 | 4105 | 1083 | 156 | 2092 | 390 | 2810 | 7293 |
| 1952 | 540 | 4425 | 1083 | 156 | 2380 | 390 | 2920 | 7856 |
| 1953 | 780 | 5011 | 1213 | 156 | 2620 | 390 | 3316 | 8590 |
| 1954 | 780 | 7784 | 1213 | 156 | 2950 | 390 | 3436 | 10442 |
| 1955 | 852 | 17556 | 1213 | 188 | 3260 | 390 | 3641 | 13553 |
| 1956 | 852 | 21381 | 1245 | 188 | 3460 | 550 | 3716 | 17189 |
| 1957 | 852 | 23815 | 1245 | 348 | 3616 | 760 | 4138 | 19111 |
| 1958 | 852 | 24931 | 1365 | 348 | 3984 | 760 | 4198 | 20001 |
| 1959 | 852 | 27570 | 1365 | 348 | 4102 | 760 | 4218 | 20366 |
| 1960 | 852 | 29590 | 1365 | 444 | 4428 | 760 | 4330 | 20966 |
| 1961 | 868 | 33346 | 1365 | 444 | 4777 | 760 | 4643 | 22210 |
| 1962 | 1028 | 40350 | 1365 | 444 | 4937 | 760 | 4824 | 24080 |
| 1963 | 1132 | 58033 | 1401 | 604 | 5766 | 1000 | 5534 | 26129 |
| 1964 | 1952 | 79492 | 1686 | 604 | 10294 | 1004 | 5935 | 37546 |
| 1965 | 2668 | 105305 | 1878 | 604 | 14914 | 1004 | 8091 | 57473 |
| 1966 | 2668 | 117845 | 1878 | 604 | 19595 | 1004 | 10020 | 82850 |
| 1967 | 2908 | 131198 | 1878 | 604 | 30143 | 1454 | 14794 | 126366 |
| 1968 | 3348 | 138790 | 1947 | 1244 | 33939 | 2566 | 17758 | 150159 |
| 1969 | 3748 | 147790 | 2147 | 1404 | 41862 | 4126 | 20071 | 187573 |
| 1970 | 4298 | 153155 | 2307 | 1404 | 46823 | 4126 | 20769 | 195127 |
| 1971 | 4850 | 158049 | 2517 | 1404 | 49685 | 4786 | 23309 | 201318 |
| 1972 | 5875 | 161826 | 2677 | 1708 | 51603 | 5396 | 24351 | 216195 |
| 1973 | 6531 | 172870 | 2837 | 2166 | 55760 | 8105 | 28612 | 236897 |
| 1974 | 8722 | 182301 | 3157 | 4536 | 65516 | 17658 | 32344 | 263105 |
| 1975 | 10434 | 185362 | 3672 | 5686 | 69466 | 21963 | 37785 | 282978 |
| 1976 | 11304 | 186572 | 3672 | 5990 | 72877 | 24051 | 39895 | 301678 |
| 1977 | 11844 | 186572 | 3992 | 6310 | 74051 | 24341 | 40595 | 305361 |
| 1978 | 11896 | 187282 | 3992 | 6310 | 74460 | 24573 | 41585 | 308720 |
| 1979 | 11896 | 187512 | 3992 | 6310 | 75673 | 24740 | 41651 | 311525 |
| 1980 | 11896 | 187512 | 3992 | 6310 | 75804 | 24742 | 41781 | 312125 |
| 1981 | 12096 | 187512 | 3992 | 6310 | 75950 | 24740 | 41781 | 312175 |
| 1982 | 12096 | 187512 | 3992 | 6310 | 75966 | 24731 | 41781 | 312467 |
| 1983 | 12096 | 187512 | 3992 | 6310 | 75814 | 24731 | 41781 | 312499 |
| 1984 | 12096 | 187622 | 3992 | 6470 | 76186 | 24760 | 41781 | 313378 |
| 1985 | 12096 | 187622 | 3992 | 6730 | 76324 | 24756 | 41781 | 312632 |
| 1986 | 12096 | 187670 | 3992 | 6810 | 76287 | 24732 | 41781 | 313462 |
| 1987 | 12096 | 187670 | 3992 | 6810 | 76310 | 24733 | 41781 | 313483 |
| 1988 | 12096 | 187670 | 3992 | 6810 | 76332 | 24733 | 41781 | 313450 |
| 1989 | 12096 | 187670 | 4064 | 6810 | 76347 | 24740 | 41781 | 313640 |
| 1990 | 12096 | 187670 | 4148 | 6810 | 76369 | 24738 | 41781 | 313740 |
| 1991 | 12096 | 187770 | 4148 | 6810 | 76382 | 24738 | 41921 | 313766 |
| 1992 | 12096 | 187770 | 4148 | 6810 | 76381 | 24741 | 41921 | 313707 |
| 1993 | 12096 | 187770 | 4148 | 6810 | 76343 | 24740 | 41921 | 313758 |
| 1994 | 12096 | 187770 | 4148 | 7018 | 76367 | 24744 | 41921 | 312950 |
| 1995 | 12096 | 187770 | 4148 | 7018 | 76365 | 24747 | 41921 | 313731 |
| 1996 | 12096 | 187770 | 4148 | 7018 | 76385 | 24746 | 41930 | 313782 |
| 1997 | 12096 | 187770 | 4148 | 7018 | 76389 | 24739 | 41930 | 313793 |
| 1998 | 12096 | 187770 | 4148 | 7018 | 76369 | 24745 | 41930 | 313772 |
| 1999 | 12096 | 187770 | 4148 | 7018 | 76375 | 24745 | 41930 | 313757 |
| 2000 | 12096 | 187770 | 4148 | 7018 | 76381 | 24748 | 41930 | 313800 |

Appendix K Irrigated Acreage Kansas

| Year | Cheyenne | Decatur | Gove | Graham | Jewell | Logan | Norton | Phillips | Rawlins | Sheridan | Sherman | Thomas | Trego | Wallace |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1919 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1921 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1922 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1924 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1925 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1926 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1927 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1928 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1929 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1930 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1931 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1932 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1933 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1934 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1935 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1936 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1937 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1938 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1939 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1940 | 480 | 288 | 0 | 0 | 553 | 0 | 264 | 661 | 254 | 226 | 115 | 110 | 0 | 0 |
| 1941 | 974 | 333 | 0 | 0 | 553 | 0 | 264 | 661 | 388 | 226 | 174 | 110 | 0 | 0 |
| 1942 | 1334 | 335 | 0 | 0 | 553 | 0 | 264 | 661 | 388 | 226 | 174 | 110 | 0 | 0 |
| 1943 | 1694 | 335 | 0 | 0 | 553 | 0 | 264 | 661 | 388 | 226 | 174 | 110 | 0 | 0 |
| 1944 | 2054 | 336 | 0 | 0 | 553 | 0 | 264 | 661 | 388 | 226 | 174 | 110 | 0 | 0 |
| 1945 | 2054 | 337 | 0 | 0 | 553 | 0 | 264 | 661 | 388 | 226 | 174 | 110 | 0 | 0 |
| 1946 | 2054 | 336 | 0 | 0 | 553 | 0 | 264 | 661 | 388 | 226 | 174 | 110 | 0 | 0 |
| 1947 | 2054 | 355 | 0 | 0 | 553 | 0 | 264 | 661 | 388 | 226 | 289 | 110 | 0 | 0 |
| 1948 | 2054 | 355 | 0 | 0 | 553 | 0 | 376 | 661 | 388 | 226 | 289 | 220 | 0 | 0 |
| 1949 | 2054 | 358 | 0 | 0 | 553 | 0 | 376 | 661 | 388 | 226 | 519 | 220 | 0 | 0 |
| 1950 | 2054 | 399 | 0 | 0 | 553 | 0 | 446 | 761 | 658 | 356 | 634 | 220 | 0 | 0 |
| 1951 | 2054 | 499 | 0 | 0 | 553 | 0 | 446 | 761 | 658 | 356 | 634 | 440 | 0 | 0 |
| 1952 | 2054 | 455 | 0 | 0 | 1002 | 0 | 446 | 761 | 658 | 356 | 1669 | 550 | 0 | 0 |
| 1953 | 2054 | 597 | 0 | 0 | 1002 | 120 | 446 | 1061 | 1018 | 746 | 2247 | 660 | 0 | 0 |
| 1954 | 3264 | 627 | 0 | 260 | 1002 | 120 | 866 | 1561 | 1108 | 746 | 2594 | 660 | 200 | 0 |
| 1955 | 3744 | 1065 | 180 | 390 | 1002 | 120 | 1006 | 2661 | 1648 | 1916 | 4200 | 1320 | 200 | 0 |
| 1956 | 5064 | 1581 | 450 | 520 | 1257 | 120 | 1216 | 3461 | 2278 | 4304 | 6959 | 3740 | 600 | 150 |
| 1957 | 7104 | 2018 | 540 | 520 | 1257 | 240 | 1404 | 3561 | 2818 | 6912 | 8571 | 5280 | 600 | 150 |
| 1958 | 7587 | 2097 | 630 | 520 | 1257 | 240 | 1404 | 4158 | 2998 | 7692 | 9645 | 5280 | 1000 | 150 |
| 1959 | 7947 | 2238 | 720 | 650 | 1257 | 240 | 1614 | 4158 | 3268 | 8862 | 10341 | 5720 | 1000 | 150 |
| 1960 | 9387 | 2644 | 720 | 780 | 1257 | 240 | 1754 | 4158 | 3268 | 9122 | 10573 | 5830 | 1000 | 150 |
| 1961 | 10323 | 3217 | 720 | 910 | 1257 | 360 | 1824 | 4367 | 3448 | 9512 | 12311 | 6160 | 1000 | 150 |
| 1962 | 10928 | 3428 | 990 | 910 | 1257 | 360 | 1964 | 4367 | 3628 | 10032 | 14508 | 6710 | 1000 | 150 |
| 1963 | 12860 | 3328 | 1260 | 910 | 1257 | 600 | 1964 | 4468 | 3718 | 10942 | 19135 | 7490 | 1200 | 150 |
| 1964 | 15717 | 3623 | 1350 | 910 | 1257 | 1200 | 2012 | 4568 | 4078 | 13932 | 24885 | 9470 | 1300 | 300 |
| 1965 | 18437 | 4211 | 1890 | 1820 | 1257 | 1680 | 2642 | 4658 | 4528 | 16710 | 31028 | 13430 | 1400 | 450 |
| 1966 | 20028 | 4348 | 2970 | 1820 | 1257 | 1800 | 2712 | 4758 | 4664 | 17880 | 33959 | 14640 | 1400 | 750 |
| 1967 | 21748 | 4573 | 3960 | 2080 | 1257 | 3000 | 6986 | 8857 | 5698 | 21000 | 40228 | 17060 | 1400 | 750 |
| 1968 | 24485 | 4933 | 5490 | 2210 | 1257 | 4320 | 7266 | 8857 | 6508 | 26898 | 49372 | 22530 | 1700 | 1200 |
| 1969 | 26121 | 5391 | 6660 | 2340 | 1257 | 5280 | 7413 | 8896 | 7228 | 31318 | 56441 | 24730 | 1700 | 1200 |
| 1970 | 27220 | 5796 | 7110 | 2470 | 1257 | 5760 | 7578 | 8896 | 7948 | 34828 | 58520 | 26250 | 2000 | 1200 |
| 1971 | 29033 | 6146 | 8280 | 2730 | 1257 | 6240 | 7935 | 9159 | 8308 | 38469 | 61173 | 29220 | 2000 | 1200 |
| 1972 | 31485 | 6298 | 10443 | 4313 | 1293 | 6664 | 8584 | 9229 | 9580 | 46418 | 61158 | 34831 | 1931 | 1480 |
| 1973 | 31553 | 9263 | 12886 | 5208 | 1248 | 8707 | 10021 | 9227 | 14987 | 49892 | 68540 | 40810 | 1946 | 1456 |
| 1974 | 31479 | 8121 | 15033 | 5166 | 1257 | 6887 | 9128 | 9676 | 12673 | 52349 | 70316 | 51167 | 2508 | 1864 |
| 1975 | 34479 | 10459 | 17279 | 5724 | 1242 | 9923 | 8914 | 9099 | 14639 | 59351 | 84256 | 62295 | 2916 | 2205 |
| 1976 | 37682 | 10456 | 18334 | 7182 | 1177 | 8021 | 9084 | 9058 | 13185 | 62477 | 97692 | 80666 | 2246 | 2657 |
| 1977 | 43236 | 10616 | 15695 | 9472 | 1258 | 9512 | 9562 | 9532 | 15008 | 71857 | 106822 | 85616 | 2732 | 2956 |
| 1978 | 39422 | 10903 | 14947 | 10963 | 1288 | 8284 | 9554 | 9499 | 15760 | 65269 | 103137 | 84508 | 2047 | 2501 |
| 1979 | 36413 | 10475 | 14090 | 9106 | 1442 | 7553 | 6909 | 5485 | 15308 | 66896 | 104011 | 90075 | 2459 | 2737 |
| 1980 | 34953 | 9921 | 11502 | 5855 | 1410 | 6188 | 10836 | 9702 | 11852 | 61404 | 111435 | 78255 | 1551 | 2847 |
| 1981 | 39493 | 11747 | 14423 | 8659 | 1521 | 8084 | 5611 | 5510 | 13991 | 68693 | 114550 | 95243 | 2356 | 3275 |
| 1982 | 40652 | 11911 | 21048 | 10882 | 1569 | 9818 | 7152 | 5178 | 17238 | 76383 | 114632 | 93032 | 3138 | 2510 |
| 1983 | 32594 | 11974 | 15027 | 7991 | 1464 | 8870 | 4898 | 3773 | 12429 | 52528 | 101744 | 65719 | 2506 | 1695 |
| 1984 | 31681 | 14063 | 18192 | 9785 | 1582 | 7520 | 8347 | 4657 | 13780 | 73809 | 104223 | 86802 | 2632 | 2174 |
| 1985 | 34174 | 15245 | 17628 | 12849 | 1600 | 6956 | 8615 | 6267 | 15194 | 71823 | 103452 | 98645 | 2230 | 2309 |
| 1986 | 37296 | 14564 | 20019 | 12768 | 1665 | 6270 | 10848 | 10293 | 14745 | 73786 | 95651 | 107830 | 2013 | 2079 |
| 1987 | 41690 | 8651 | 18436 | 7808 | 1562 | 4750 | 9926 | 10175 | 16671 | 66421 | 88350 | 98032 | 1980 | 2036 |
| 1988 | 39343 | 8209 | 14281 | 6113 | 1466 | 6745 | 9690 | 9494 | 17135 | 65075 | 91734 | 80341 | 2170 | 1887 |
| 1989 | 42926 | 10922 | 14295 | 6973 | 1459 | 7584 | 10253 | 9557 | 17443 | 74246 | 105567 | 99335 | 1632 | 2124 |
| 1990 | 44402 | 10630 | 13110 | 7708 | 1475 | 7296 | 10560 | 9611 | 17217 | 72649 | 106665 | 96898 | 1734 | 2177 |
| 1991 | 44347 | 11467 | 14167 | 8184 | 1555 | 7488 | 7740 | 5117 | 16114 | 73286 | 107197 | 96506 | 2006 | 2143 |
| 1992 | 42444 | 8283 | 12573 | 7509 | 1516 | 6912 | 7128 | 6039 | 14507 | 67375 | 103403 | 92546 | 1836 | 2241 |
| 1993 | 44082 | 8735 | 10396 | 5800 | 1237 | 7104 | 9899 | 9368 | 15185 | 67595 | 105561 | 94917 | 1260 | 2022 |
| 1994 | 46051 | 10333 | 14362 | 7896 | 1610 | 7488 | 10019 | 10305 | 17741 | 71513 | 110463 | 98655 | 2065 | 2249 |
| 1995 | 43236 | 11068 | 14164 | 8086 | 1586 | 7275 | 10288 | 10531 | 19088 | 71925 | 103928 | 95308 | 2135 | 1969 |
| 1996 | 47041 | 10326 | 14509 | 8749 | 1575 | 7566 | 10019 | 9714 | 17104 | 73552 | 115264 | 98978 | 2100 | 2238 |
| 1997 | 48606 | 11463 | 14583 | 9127 | 1619 | 7663 | 10614 | 10403 | 17715 | 75133 | 116659 | 99936 | 1944 | 2002 |
| 1998 | 47797 | 10540 | 15416 | 9813 | 1563 | 7857 | 10328 | 9469 | 17970 | 75555 | 116655 | 98451 | 2340 | 2087 |
| 1999 | 47734 | 10302 | 14381 | 10109 | 1570 | 7546 | 10432 | 9895 | 17071 | 75458 | 114338 | 99047 | 2268 | 2254 |
| 2000 | 49519 | 11698 | 14931 | 10408 | 1305 | 7644 | 11013 | 9952 | 18743 | 76728 | 115994 | 102013 | 2394 | 2426 |

Appendix K Irrigated Acreage Nebraska

| Year | Adams | Buffalo | Chase | Clay | Dawson | Deuel | Dundy | Franklin | Frontier | Furnas | Gosper | Harlan | Hayes | Hitchcock | Kearney | Keith | Lincoln | Nuckolls | Perkins | Phelps | RedWillow | Webster |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1919 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1920 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1921 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1922 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1924 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1925 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1926 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1927 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1928 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1929 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1930 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1931 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1932 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1933 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1934 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1935 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1936 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1937 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1938 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1939 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1940 | 91 | 0 | 736.2 | 0 | 2929.9 | 848.8 | 384 | 476 | 190 | 533 | 945.7 | 255.9 | 297 | 1562 | 2988 | 1857 | 3327 | 69 | 198 | 3772 | 702 | 266 |
| 1941 | 91 | 0 | 914.2 | 0 | 3557.1 | 848.4 | 384 | 544 | 190 | 749.3 | 1388.4 | 543 | 297 | 1846 | 3749 | 2175 | 4040 | 138 | 198 | 4699 | 813 | 266 |
| 1942 | 91 | 0 | 1003.2 | 0 | 4163.9 | 908.4 | 480 | 680 | 190 | 789.7 | 7675.4 | 543 | 297 | 2059 | 27208 | 2585 | 4234 | 138 | 297 | 46241 | 1006 | 266 |
| 1943 | 91 | 0 | 1181.2 | 0 | 4354.5 | 908.4 | 3014 | 680 | 190 | 870.7 | 7743.9 | 604.8 | 297 | 2201 | 27375 | 2683 | 4748 | 138 | 297 | 46634 | 1201 | 266 |
| 1944 | 91 | 0 | 1624.6 | 0 | 4480.1 | 908.3 | 3110 | 748 | 190 | 951.7 | 7745.3 | 730.3 | 380 | 2414 | 28292 | 2881 | 4924 | 138 | 297 | 46791 | 1629 | 266 |
| 1945 | 91 | 0 | 1624.6 | 0 | 18490.8 | 2311.4 | 3397.9 | 1019.9 | 190 | 992.4 | 7821 | 920.4 | 380 | 2414 | 29382 | 11355 | 6247 | 138 | 297 | 46875 | 2018 | 266 |
| 1946 | 91 | 0 | 1710.6 | 0 | 18687.9 | 2551 | 3590 | 1291.9 | 285 | 1226.2 | 7816.2 | 1625.8 | 547 | 2769 | 31892 | 11731 | 7055 | 138 | 297 | 47369 | 2136 | 304 |
| 1947 | 546 | 0 | 1799.6 | 0 | 18917.8 | 2730.7 | 3590 | 1426.5 | 330 | 1741.5 | 7964.9 | 2539.9 | 547 | 6150 | 33722 | 12362 | 9781 | 407 | 297 | 47639 | 3133 | 738 |
| 1948 | 1038.1 | 0 | 1977.6 | 0 | 19421.3 | 2730.1 | 3685.9 | 1633.7 | 570 | 1514 | 8156.1 | 2778.2 | 547 | 7100 | 35206 | 12726 | 12098 | 605 | 594 | 48410 | 3243 | 810 |
| 1949 | 1082 | 0 | 2403.2 | 0 | 19770.6 | 2730.3 | 3926.1 | 1778.6 | 690 | 2721 | 8394.7 | 2674 | 922 | 7840 | 36124 | 12809 | 11723 | 1125 | 693 | 48805 | 3390 | 731 |
| 1950 | 1170 | 0 | 2735 | 0 | 19957.4 | 2730.5 | 4500.3 | 2892.9 | 2614.7 | 3731.7 | 8501.5 | 3119.5 | 718 | 8582 | 37272 | 13167 | 20230 | 1040 | 792 | 49592 | 3679 | 1006 |
| 1951 | 1344.6 | 0 | 3470.8 | 0 | 20068.9 | 2730.4 | 4693 | 4203.8 | 1294.6 | 9352.8 | 8456.6 | 4376.5 | 1122 | 9555 | 37814 | 13373 | 19761 | 1423 | 891 | 50207 | 5868 | 1372 |
| 1952 | 1432.5 | 0 | 3743.6 | 0 | 20245 | 2910.2 | 5457.3 | 3876.1 | 1853.4 | 9599 | 8455.1 | 3927.8 | 1269 | 10081 | 38966 | 13589 | 18254 | 4710 | 1188 | 50418 | 13195 | 1540 |
| 1953 | 1729.8 | 0 | 4994.5 | 54.3 | 21210.4 | 2969.5 | 6221.7 | 5002.1 | 2552.3 | 9805.8 | 9252 | 4544.4 | 1547 | 12752 | 46405 | 14092 | 19638 | 5048 | 1782 | 63941 | 6048 | 1597 |
| 1954 | 2511.3 | 0 | 6628.1 | 38.9 | 22203.7 | 3089.3 | 8468.3 | 7829.2 | 4261.4 | 15229.9 | 14956.3 | 6316.6 | 1895 | 13575 | 51310 | 14957 | 25262 | 6139 | 2376 | 67557 | 8245 | 3239 |
| 1955 | 3244.6 | 0 | 9037 | 50.8 | 23897.1 | 3209.1 | 10487.3 | 10891.7 | 5840 | 16555.7 | 17073.9 | 8791.5 | 2736 | 13226 | 55995 | 15576 | 27839 | 7475 | 2685 | 71563 | 10926 | 4184 |
| 1956 | 4888 | 0 | 10241.1 | 134.2 | 26389.7 | 3269.2 | 11734.6 | 13794.4 | 7822.8 | 18239.3 | 18843.1 | 10783 | 2731 | 14284 | 63783 | 16236 | 24289 | 8345 | 3180 | 79108 | 12140 | 5373 |
| 1957 | 7089.7 | 0 | 9304 | 296.9 | 24936 | 3390 | 9378.7 | 17981.7 | 10161.6 | 19111 | 18948.4 | 12138.2 | 3689 | 17125 | 68110 | 14060 | 25565 | 9022 | 3899 | 74999 | 14555 | 6705 |
| 1958 | 7376.5 | 0 | 9741 | 297.4 | 24270.2 | 3431 | 9765.6 | 19215.5 | 9614.7 | 21226.4 | 18850.7 | 12417.3 | 3918 | 16976 | 65844 | 10652 | 23445 | 8024 | 4255 | 71933 | 14542 | 9148 |
| 1959 | 7689.4 | 0 | 11168.4 | 334.2 | 26056.3 | 3505.4 | 9496.6 | 21727 | 10378.4 | 21742 | 20645.8 | 14603.6 | 3492 | 15824 | 72543 | 11400 | 25354 | 8826 | 4802 | 81342 | 16218 | 8361 |
| 1960 | 8212.9 | 0 | 10857.3 | 348.8 | 31887.9 | 3509.6 | 14821.2 | 25102.6 | 12932.8 | 24169.7 | 24544.6 | 16616.8 | 5337 | 20131 | 76102 | 14323 | 28348 | 10211 | 4966 | 89627 | 19744 | 9593 |
| 1961 | 7363.5 | 0 | 12366.8 | 289.7 | 27296.7 | 3509.9 | 12324.6 | 22339.1 | 11284.3 | 25354.8 | 21323.4 | 16237.2 | 4854 | 19742 | 60087 | 14539 | 24773 | 8891 | 4900 | 85498 | 19834 | 8917 |
| 1962 | 7239.7 | 0 | 13036.7 | 299.5 | 21197.6 | 3629.7 | 11436.6 | 20480.2 | 10429.3 | 23915 | 20560 | 14499 | 5337 | 22174 | 59971 | 14494 | 26507 | 9267 | 4935 | 82976 | 21370 | 7341 |
| 1963 | 8181.8 | 0 | 14467.2 | 331.8 | 25509.6 | 3690.5 | 15621.4 | 24979.8 | 13407.3 | 26774.6 | 22546.4 | 18211.4 | 5511 | 23910 | 67958 | 15098 | 25500 | 10005 | 4655 | 88888 | 24974 | 9957 |
| 1964 | 8082.7 | 0 | 15909.3 | 307.3 | 24310.6 | 3748.4 | 17208.5 | 21778.4 | 12596.5 | 21705 | 21540.2 | 15932.2 | 5532 | 18002 | 60775 | 13897 | 23983 | 8639 | 4462 | 84979 | 25246 | 8557 |
| 1965 | 8631.7 | 0 | 19429.2 | 374.6 | 23771.8 | 3747.1 | 21213.4 | 22515.6 | 13166.2 | 21518 | 20333.5 | 16115.6 | 5553 | 18842 | 67871 | 13237 | 23382 | 9115 | 5793 | 85601 | 27355 | 8545 |
| 1966 | 10031.9 | 0 | 23114.1 | 526.8 | 25958.6 | 3809 | 20859.9 | 25878.1 | 14851.2 | 21838.4 | 23225.5 | 19060.8 | 5296 | 19105 | 75855 | 14795 | 24228 | 9630 | 5526 | 101408 | 27362 | 10071 |
| 1967 | 11886.3 | 0 | 32293.3 | 539.1 | 25996.8 | 3932.7 | 22168.5 | 30050.8 | 17256.3 | 25663 | 25733.6 | 22917.7 | 6209 | 20752 | 83202 | 16159 | 30716 | 10014 | 8932 | 99993 | 30542 | 11625 |
| 1968 | 11929.8 | 0 | 38204.9 | 690.5 | 24946.1 | 4054.8 | 23455.8 | 31829.6 | 18739.4 | 28583.8 | 26746.5 | 28043.9 | 7483 | 19483 | 86127 | 18110 | 27641 | 10819 | 10613 | 102099 | 30425 | 11400 |
| 1969 | 11168.6 | 0 | 37911.7 | 864.4 | 25471.7 | 4112.3 | 25383.3 | 29461.6 | 20230.1 | 25655.3 | 28771 | 29521.3 | 8096 | 18433 | 87653 | 17875 | 29219 | 10268 | 11192 | 119376 | 31099 | 12556 |
| 1970 | 12582.9 | 0 | 44502.3 | 968.3 | 25389.5 | 4115.8 | 30456.1 | 32530.9 | 24607.8 | 28357.2 | 34087.3 | 34427.1 | 9775 | 20423 | 99041 | 18891 | 31259 | 11598 | 15542 | 110581 | 35208 | 14625 |
| 1971 | 13613.4 | 0 | 57335.8 | 1000.1 | 27281.5 | 4176.2 | 36279.2 | 34565.2 | 34562.7 | 31601.6 | 34251.8 | 36057 | 10692 | 24533 | 102684 | 19667 | 36748 | 11382 | 20572 | 130116 | 39524 | 16022 |
| 1972 | 12901.6 | 0 | 67191.5 | 908.4 | 28781 | 4239.2 | 36266 | 32622.4 | 37065.3 | 30767.2 | 37484.2 | 36163.6 | 12361 | 22451 | 104897 | 22001 | 34248 | 10808 | 26649 | 127890 | 38531 | 14469 |
| 1973 | 13802.7 | 0 | 76179.5 | 1129.5 | 31705.8 | 4361.7 | 39647.9 | 39967.2 | 39964.5 | 35104.4 | 40134.5 | 39066.5 | 12328 | 24247 | 117760 | 23402 | 39699 | 11983 | 35213 | 136469 | 42103 | 16246 |
| 1974 | 15270.6 | 0 | 87977.5 | 1171.6 | 35296.3 | 4422 | 40497 | 41077.4 | 40088.4 | 34883.7 | 45263.6 | 42411 | 18487 | 28738 | 120533 | 25972 | 50295 | 12534 | 43741 | 146550 | 42884 | 16736 |
| 1975 | 16008 | 0 | 96016.8 | 1345.8 | 35555.6 | 4425.9 | 51479.6 | 50506.8 | 51240.3 | 37813.5 | 48826.3 | 44596.7 | 16915 | 30222 | 126170 | 31127 | 51864 | 13276 | 64354 | 154902 | 50194 | 20960 |
| 1976 | 17502.1 | 0 | 99646.5 | 1404.2 | 36638.3 | 4426.8 | 54029.3 | 58404 | 54199.9 | 43967.7 | 45805.2 | 49550.2 | 19263 | 28607 | 138678 | 30647 | 61266 | 14362 | 69024 | 160448 | 50855 | 23741 |
| 1977 | 20709.5 | 0 | 124469.9 | 1454.5 | 36523.9 | 4431.1 | 67058.7 | 62878.1 | 60121.7 | 43639.1 | 58473.3 | 58187.8 | 22429 | 30589 | 154293 | 34231 | 74504 | 13538 | 79577 | 187689 | 54723 | 28861 |
| 1978 | 21133.4 | 0 | 135361.1 | 1539.6 | 37431.4 | 4491.8 | 77871.7 | 59748.9 | 63159.3 | 43527.1 | 59790.7 | 58796.6 | 32006 | 30573 | 149949 | 35298 | 80242 | 15077 | 87022 | 184863 | 54596 | 31232 |
| 1979 | 22757.3 | 0 | 142602.1 | 1699.5 | 40896.2 | 4618.2 | 82828.4 | 60530.7 | 66136.7 | 46055.8 | 58128.7 | 56432.3 | 34206 | 33604 | 163236 | 40294 | 85872 | 15337 | 101736 | 199042 | 56252 | 32074 |
| 1980 | 24480.8 | 0 | 145618.5 | 1752.5 | 42984.9 | 4559.7 | 74930.3 | 66284.3 | 68027.1 | 50187.5 | 66632.5 | 70857.6 | 34133 | 34204 | 173526 | 41978 | 98215 | 17153 | 108915 | 212227 | 56909 | 35111 |
| 1981 | 24855.6 | 0 | 142880.2 | 1657.6 | 43560.7 | 4559.7 | 78669.5 | 60520 | 69413 | 46480.8 | 62579.9 | 60643.3 | 35428 | 33032 | 175892 | 42503 | 110155 | 16321 | 112600 | 212273 | 59388 | 35710 |
| 1982 | 24097.6 | 0 | 150630.3 | 1686.3 | 42538.4 | 4561.3 | 76601.2 | 71131.8 | 64191.1 | 42427.9 | 60728 | 59474.4 | 33982 | 33518 | 170191 | 44130 | 97264 | 14435 | 103024 | 221394 | 56297 | 25882 |
| 1983 | 16124.1 | 0 | 100676.1 | 1271.1 | 30557.4 | 4553.2 | 62080.2 | 46731.9 | 50412.5 | 37577.5 | 40698.4 | 41901 | 30430 | 24674 | 111195 | 39130 | 72825 | 12120 | 90705 | 141425 | 35398 | 23251 |
| 1984 | 22379.1 | 0 | 143388.9 | 1880.5 | 45460.7 | 4571.8 | 96680.6 | 67054.9 | 71022.6 | 45626.3 | 63399.3 | 64313.1 | 36119 | 34600 | 172155 | 50546 | 107543 | 17698 | 140647 | 213664 | 46146 | 31727 |
| 1985 | 22984.4 | 0 | 135963.7 | 1908 | 48664.3 | 4574.6 | 92157.2 | 70505.4 | 71163.5 | 45825.4 | 63354 | 64505.3 | 48945 | 37736 | 170432 | 52323 | 110532 | 18947 | 136334 | 220045 | 58026 | 31314 |
| 1986 | 23255.8 | 0 | 121457.5 | 1750.2 | 42625.6 | 4689.1 | 88474.9 | 71350.7 | 63544.3 | 45729 | 54761.5 | 67595.4 | 35520 | 30536 | 166114 | 49641 | 97451 | 16960 | 109641 | 198230 | 46629 | 29972 |
| 1987 | 21875.6 | 0 | 130591 | 1568.2 | 39288.4 | 4554.9 | 80286.1 | 64529.3 | 55655.3 | 43115.2 | 54006.2 | 60187.8 | 32495 | 28639 | 152340 | 41034 | 83974 | 14427 | 110558 | 192837 | 51606 | 27314 |
| 1988 | 23146.9 | 0 | 139294.2 | 1631 | 42046.3 | 4553.5 | 77789.6 | 66288.2 | 55782.4 | 41558.7 | 60679.5 | 58483.6 | 29152 | 29023 | 158552 | 40396 | 88736 | 14602 | 110442 | 200921 | 50549 | 32794 |
| 1989 | 26106.3 | 0 | 145921.3 | 1734.5 | 44269.8 | 4555.8 | 87795.1 | 73832.1 | 63186.7 | 52247.3 | 67544.3 | 65793.7 | 29532 | 28438 | 183407 | 43015 | 103051 | 14824 | 119569 | 229312 | 53941 | 34399 |
| 1990 | 26597.3 | 0 | 156631.7 | 1752.6 | 44276.6 | 4560.9 | 86160 | 73371.7 | 61665.1 | 50211.1 | 69516.5 | 67628.8 | 34540 | 30814 | 182412 | 47138 | 103252 | 15035 | 117733 | 232014 | 57457 | 35634 |
| 1991 | 27531.6 | 0 | 163325.1 | 1776.5 | 44901.2 | 4560.6 | 92413.7 | 74376.3 | 60495.3 | 49157.3 | 70680.4 | 66367.5 | 34189 | 32193 | 184200 | 47006 | 109104 | 15978 | 118452 | 237586 | 55672 | 36792 |
| 1992 | 27560.5 | 0 | 164480.5 | 1771.1 | 42221.8 | 4555.8 | 84010.2 | 74620.7 | 60837.3 | 46919.6 | 68106.7 | 66265.8 | 33652 | 28839 | 188482 | 43743 | 109409 | 16310 | 123924 | 224240 | 58835 | 37528 |
| 1993 | 26648.8 | 0 | 147971.9 | 1721.5 | 42520.9 | 4553 | 92871 | 74431.9 | 58594.2 | 44728.4 | 66846.5 | 64647.9 | 27373 | 26528 | 174338 | 42161 | 101380 | 16361 | 123511 | 214104 | 58594 | 39358 |
| 1994 | 27993.6 | 0 | 157213.1 | 1768.4 | 44200.3 | 4554.8 | 86927.3 | 78166.5 | 59579 | 50573.2 | 69376.3 | 67223.3 | 34107 | 28322 | 188694 | 44525 | 111946 | 16847 | 129112 | 241873 | 60211 | 41129 |
| 1995 | 27550.6 | 0 | 156750.9 | 1752.9 | 43557.5 | 4613.4 | 88991.4 | 74969.9 | 55168.1 | 48838.5 | 68590.2 | 67004.3 | 32530 | 25564 | 186590 | 44504 | 114930 | 16958 | 133297 | 232077 | 54592 | 39046 |
| 1996 | 27665.6 | 0 | 166981.9 | 1819 | 43935.6 | 4556.8 | 89496.4 | 75178 | 61925.5 | 51167.7 | 71178.1 | 70369.2 | 33894 | 29105 | 192590 | 48043 | 128269 | 18150 | 132746 | 238142 | 56041 | 40315 |
| 1997 | 28693.6 | 0 | 169136.6 | 1856.2 | 44115.2 | 4557.7 | 86164.2 | 85366.2 | 60125.7 | 54269.6 | 71393.4 | 80222.9 | 36486 | 30872 | 193137 | 49670 | 125117 | 17621 | 126295 | 239964 | 58849 | 37798 |
| 1998 | 28410.7 | 0 | 158646 | 1856 | 43368.8 | 4558.6 | 83431.2 | 82785.8 | 63447.9 | 52049.2 | 74399.8 | 76016.5 | 38629 | 29996 | 191820 | 50803 | 125084 | 19679 | 133944 | 232870 | 57347 | 45298 |
| 1999 | 29392.2 | 0 | 161675.7 | 1850.2 | 44909.5 | 4497.2 | 77595.6 | 84487.9 | 63331 | 48702.2 | 72385 | 74278 | 39503 | 29606 | 195800 | 50200 | 120066 | 21892 | 134191 | 239267 | 56045 | 46494 |
| 2000 | 30212.9 | 0 | 165365.4 | 1881.8 | 46482.7 | 4495.1 | 84797.1 | 85623.3 | 58717.8 | 60434.2 | 76230.3 | 76626.1 | 44337 | 32213 | 200797 | 49197 | 128381 | 19981 | 138275 | 246269 | 58153 | 45982 |

# APPENDIX L

CROP IRRIGATION REQUIREMENTS

# Net Crop Irrigation Requirement

(potential consumptive use minus effective rainfall minus gain in soil moisture from winter and spring precipitation) (inches)

| | County (or portion of County in the Republican River Basin study area) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Cheyenne | Kit Carson | Lincoln | Logan | Phillips | Sedgwick | Wash-ington | Yuma |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| 1940 | 12.55 | 13.86 | 14.82 | 11.21 | 10.94 | 10.67 | 17.73 | 10.32 |
| 1941 | 13.55 | 16.46 | 17.25 | 13.54 | 13.29 | 13.28 | 17.15 | 13.07 |
| 1942 | 18.94 | 18.56 | 19.71 | 22.26 | 22.39 | 21.91 | 19.61 | 20.34 |
| 1943 | 20.27 | 18.26 | 19.22 | 20.08 | 20.14 | 19.57 | 20.35 | 18.21 |
| 1944 | 13.56 | 13.46 | 13.86 | 10.25 | 9.74 | 9.62 | 14.95 | 11.64 |
| 1945 | 20.11 | 17.71 | 18.91 | 17.58 | 17.34 | 17.07 | 16.80 | 15.28 |
| 1946 | 18.05 | 17.32 | 17.76 | 17.04 | 17.36 | 16.92 | 22.95 | 15.82 |
| 1947 | 12.69 | 13.47 | 17.52 | 21.50 | 22.57 | 22.56 | 19.30 | 14.00 |
| 1948 | 11.13 | 13.18 | 15.56 | 15.13 | 14.97 | 14.78 | 12.41 | 12.79 |
| 1949 | 16.95 | 16.83 | 17.30 | 17.78 | 17.53 | 17.82 | 14.03 | 12.74 |
| 1950 | 17.89 | 12.46 | 14.23 | 11.88 | 11.84 | 12.13 | 13.80 | 12.00 |
| 1951 | 22.10 | 19.74 | 23.10 | 24.55 | 26.55 | 24.26 | 20.27 | 22.55 |
| 1952 | 19.30 | 18.18 | 21.04 | 19.50 | 20.21 | 18.54 | 18.27 | 21.81 |
| 1953 | 20.05 | 23.68 | 27.01 | 20.18 | 20.44 | 19.57 | 22.36 | 20.62 |
| 1954 | 20.81 | 18.43 | 22.67 | 19.18 | 18.46 | 19.31 | 16.38 | 16.77 |
| 1955 | 26.02 | 24.74 | 25.93 | 22.88 | 22.52 | 22.62 | 21.77 | 19.39 |
| 1956 | 15.54 | 14.30 | 15.21 | 20.89 | 20.84 | 20.83 | 16.67 | 15.88 |
| 1957 | 11.09 | 14.72 | 13.60 | 16.25 | 16.77 | 14.27 | 18.18 | 14.65 |
| 1958 | 15.16 | 23.44 | 24.10 | 21.13 | 20.70 | 20.71 | 20.40 | 19.29 |
| 1959 | 17.61 | 19.91 | 18.99 | 21.57 | 20.64 | 20.84 | 20.82 | 16.13 |
| 1960 | 13.90 | 18.48 | 18.06 | 18.18 | 17.33 | 17.07 | 16.40 | 13.83 |
| 1961 | 16.46 | 16.06 | 17.72 | 16.74 | 15.88 | 16.58 | 18.39 | 10.51 |
| 1962 | 20.89 | 19.50 | 23.06 | 21.23 | 20.51 | 19.01 | 18.84 | 16.99 |
| 1963 | 20.57 | 20.41 | 22.21 | 24.34 | 22.74 | 23.40 | 20.69 | 19.86 |
| 1964 | 13.25 | 9.75 | 9.94 | 14.51 | 13.98 | 13.98 | 15.31 | 11.20 |
| 1965 | 17.25 | 17.84 | 19.08 | 16.74 | 15.53 | 15.12 | 17.97 | 12.28 |
| 1966 | 16.93 | 16.38 | 15.58 | 15.10 | 14.77 | 14.93 | 16.12 | 15.91 |
| 1967 | 19.11 | 19.40 | 19.31 | 22.21 | 21.22 | 20.23 | 18.47 | 16.53 |
| 1968 | 14.33 | 19.97 | 19.40 | 20.15 | 18.79 | 18.92 | 17.64 | 16.70 |
| 1969 | 17.16 | 21.22 | 20.99 | 24.27 | 21.68 | 22.09 | 18.49 | 18.23 |
| 1970 | 18.85 | 21.78 | 19.96 | 18.54 | 17.10 | 17.36 | 19.49 | 19.21 |
| 1971 | 16.95 | 18.21 | 16.61 | 17.25 | 16.93 | 16.20 | 16.75 | 16.42 |
| 1972 | 18.99 | 19.65 | 16.79 | 19.37 | 18.06 | 18.01 | 16.51 | 13.71 |
| 1973 | 23.06 | 23.48 | 21.00 | 24.60 | 23.81 | 23.16 | 22.13 | 20.98 |
| 1974 | 19.37 | 20.19 | 19.33 | 21.44 | 20.81 | 20.24 | 17.43 | 19.29 |
| 1975 | 19.75 | 23.49 | 22.01 | 23.97 | 23.75 | 22.61 | 19.80 | 19.52 |
| 1976 | 20.28 | 19.84 | 16.88 | 20.08 | 20.05 | 19.64 | 22.98 | 18.22 |
| 1977 | 20.15 | 19.19 | 18.89 | 25.28 | 25.29 | 24.80 | 18.67 | 22.18 |
| 1978 | 18.49 | 15.72 | 13.31 | 18.19 | 18.54 | 18.30 | 15.37 | 18.06 |
| 1979 | 18.31 | 17.29 | 16.97 | 22.17 | 21.31 | 22.01 | 18.76 | 16.35 |
| 1980 | 17.01 | 19.08 | 17.16 | 18.47 | 18.33 | 18.43 | 17.41 | 17.50 |
| 1981 | 16.71 | 14.89 | 13.49 | 14.65 | 14.69 | 14.83 | 14.95 | 13.94 |
| 1982 | 21.54 | 15.43 | 17.40 | 20.81 | 20.07 | 20.08 | 18.05 | 17.56 |
| 1983 | 19.77 | 19.02 | 20.57 | 22.81 | 21.56 | 21.76 | 16.20 | 20.91 |
| 1984 | 18.68 | 15.43 | 14.99 | 21.22 | 20.99 | 19.52 | 16.25 | 15.92 |
| 1985 | 18.31 | 18.79 | 19.55 | 20.97 | 20.43 | 19.79 | 19.12 | 16.85 |
| 1986 | 17.20 | 15.67 | 16.18 | 18.29 | 18.61 | 18.37 | 15.40 | 18.04 |
| 1987 | 16.46 | 18.15 | 18.54 | 20.10 | 20.20 | 20.20 | 19.07 | 20.18 |
| 1988 | 13.14 | 16.31 | 16.64 | 15.41 | 14.96 | 15.55 | 16.42 | 14.45 |
| 1989 | 17.60 | 18.56 | 18.72 | 18.82 | 18.51 | 19.06 | 15.25 | 15.73 |
| 1990 | 16.82 | 16.05 | 15.62 | 17.89 | 18.70 | 18.72 | 19.62 | 13.04 |
| 1991 | 17.63 | 16.77 | 17.07 | 16.76 | 16.32 | 16.85 | 17.57 | 14.78 |
| 1992 | 19.48 | 16.02 | 15.86 | 13.38 | 13.14 | 13.48 | 16.82 | 14.38 |
| 1993 | 18.64 | 17.43 | 16.88 | 22.77 | 22.63 | 22.78 | 24.45 | 16.66 |
| 1994 | 17.09 | 15.10 | 14.26 | 17.23 | 17.11 | 17.63 | 15.24 | 14.52 |
| 1995 | 16.66 | 16.29 | 15.48 | 9.03 | 8.84 | 9.67 | 14.46 | 12.53 |
| 1996 | 16.37 | 16.80 | 16.02 | 18.98 | 18.53 | 18.89 | 17.70 | 14.58 |
| 1997 | 17.39 | 15.33 | 14.36 | 17.35 | 16.09 | 17.13 | 20.42 | 16.75 |
| 1998 | 17.33 | 14.39 | 14.34 | 14.74 | 14.26 | 14.41 | 13.07 | 14.15 |
| 1999 | 21.47 | 20.73 | 20.45 | 25.31 | 23.31 | 23.83 | 22.14 | 18.04 |
| 2000 | 17.70 | 17.73 | 18.00 | 18.90 | 18.52 | 18.37 | 17.96 | 16.36 |
| Avg | 17.71 | 17.71 | 17.97 | 18.90 | 18.51 | 18.37 | 18.00 | 16.33 |

# COMPOSITE CONSUMPTIVE USE OF IRRIGATION WATER FOR ALL CROPS

## Republican Basin Counties in Kansas

Inches

| | KS, Cheyenne | KS, Decatur | KS, Gove | KS, Graham | KS, Jewell | KS, Logan | KS, Norton | KS, Phillips | KS, Rawlins | KS, Rooks | KS, Sheridan | KS, Sherman | KS, Thomas | KS, Trego | KS, Wallace |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 19.28 | 21.61 | 15.94 | | | | | | 22.25 | | 16.90 | 16.21 | | 16.86 | |
| 1941 | 17.24 | 11.63 | 13.69 | | | 14.10 | | | 16.01 | | 13.78 | 16.01 | | 13.10 | |
| 1942 | 18.82 | 17.35 | 15.43 | | | 13.70 | 18.02 | | 18.89 | | 15.34 | 17.48 | 20.01 | 15.19 | 18.18 |
| 1943 | 19.85 | 19.09 | 17.20 | | | 17.81 | 18.63 | | 20.48 | | 17.78 | 17.54 | 19.10 | 18.80 | 19.06 |
| 1944 | 15.76 | 12.33 | 12.61 | | | 11.63 | 15.23 | | 16.02 | | 12.73 | 16.18 | 15.26 | 11.98 | 14.97 |
| 1945 | 16.77 | 16.31 | 15.51 | | | 17.24 | 17.57 | | 16.25 | | 16.14 | 16.81 | 18.61 | 16.82 | 17.90 |
| 1946 | 20.36 | 17.27 | 16.76 | | | 18.35 | 19.12 | | 20.63 | | 17.56 | 20.28 | 20.40 | 17.20 | 19.53 |
| 1947 | 18.43 | 17.31 | 16.92 | | | 14.79 | 16.60 | | 18.62 | | 16.40 | 17.60 | 17.28 | 20.05 | 17.13 |
| 1948 | 16.46 | 15.50 | 13.79 | | | 15.29 | 17.90 | | 16.79 | | 14.36 | 16.51 | 19.07 | 11.92 | 16.03 |
| 1949 | 15.85 | 14.11 | 14.56 | | | 12.88 | 16.84 | | 16.08 | | 13.99 | 15.03 | 17.73 | 14.70 | 14.47 |
| 1950 | 18.11 | 18.08 | 13.46 | | | 12.24 | 17.53 | 15.20 | 18.76 | | 13.67 | 18.49 | 18.66 | 12.38 | 19.47 |
| 1951 | 12.65 | 11.01 | 10.53 | | | 7.84 | 12.12 | 11.45 | 11.90 | | 9.44 | 13.04 | 12.49 | 9.66 | 12.65 |
| 1952 | 21.94 | 20.57 | 17.99 | | | 18.74 | 19.62 | 19.38 | 22.68 | | 18.74 | 21.03 | 19.95 | 19.35 | 20.85 |
| 1953 | 19.76 | 15.19 | 13.88 | | | 13.38 | 16.35 | 15.66 | 19.35 | | 14.09 | 17.96 | 16.35 | 13.51 | 18.34 |
| 1954 | 21.24 | 18.69 | 16.00 | 17.54 | | 18.56 | 17.42 | 18.15 | 20.50 | | 16.74 | 20.27 | 17.21 | 16.07 | 19.58 |
| 1955 | 21.39 | 19.05 | 15.59 | 17.08 | | 18.96 | 18.74 | 18.42 | 19.45 | 17.10 | 16.92 | 21.00 | 19.22 | 14.65 | 20.32 |
| 1956 | 21.23 | 18.63 | 18.35 | 18.93 | 24.06 | 18.71 | 20.07 | 18.27 | 20.04 | 17.84 | 17.85 | 21.87 | 20.91 | 16.19 | 22.86 |
| 1957 | 15.78 | 15.21 | 11.33 | 12.20 | 13.72 | 14.61 | 11.82 | 14.02 | 14.63 | 12.17 | 11.91 | 17.37 | 12.10 | 10.45 | 17.29 |
| 1958 | 16.41 | 13.75 | 11.51 | 13.28 | 13.52 | 13.55 | 14.46 | 13.19 | 14.12 | 12.06 | 12.14 | 18.29 | 13.59 | 10.38 | 17.56 |
| 1959 | 18.58 | 16.93 | 14.28 | 15.13 | 16.26 | 16.06 | 18.29 | 17.10 | 16.78 | 13.90 | 14.52 | 18.43 | 17.36 | 12.10 | 18.00 |
| 1960 | 20.32 | 17.40 | 14.06 | 14.14 | 13.51 | 14.67 | 16.50 | 14.78 | 18.86 | 13.70 | 14.35 | 20.98 | 16.17 | 12.74 | 20.39 |
| 1961 | 15.37 | 15.77 | 10.12 | 11.18 | 16.73 | 15.12 | 15.34 | 15.25 | 15.01 | 10.20 | 11.48 | 15.31 | 15.10 | 5.77 | 15.48 |
| 1962 | 12.09 | 10.96 | 11.44 | 13.26 | 17.33 | 12.05 | 12.09 | 11.39 | 10.87 | 11.57 | 11.43 | 16.04 | 12.29 | 11.85 | 16.03 |
| 1963 | 18.89 | 17.28 | 13.60 | 16.39 | 17.54 | 13.79 | 16.21 | 16.21 | 17.79 | 13.97 | 13.64 | 18.64 | 15.34 | 14.55 | 19.16 |
| 1964 | 20.39 | 15.17 | 17.29 | 19.77 | 15.99 | 18.26 | 20.12 | 18.91 | 18.42 | 18.22 | 17.76 | 21.62 | 20.41 | 17.02 | 20.95 |
| 1965 | 15.04 | 10.55 | 9.29 | 11.06 | 15.87 | 11.16 | 11.14 | 11.33 | 14.61 | 9.98 | 9.92 | 17.39 | 11.67 | 8.93 | 16.16 |
| 1966 | 18.26 | 13.84 | 14.76 | 17.53 | 19.71 | 12.72 | 17.21 | 15.71 | 18.66 | 15.10 | 14.44 | 19.36 | 17.14 | 14.03 | 19.72 |
| 1967 | 18.58 | 14.84 | 15.09 | 13.97 | 16.47 | 12.15 | 19.36 | 12.56 | 18.91 | 12.52 | 14.35 | 18.19 | 19.42 | 12.11 | 18.41 |
| 1968 | 18.58 | 12.60 | 12.34 | 16.80 | 12.36 | 13.54 | 15.69 | 15.18 | 18.35 | 13.53 | 13.22 | 18.91 | 14.54 | 11.09 | 18.31 |
| 1969 | 18.60 | 16.88 | 13.70 | 15.16 | 13.99 | 14.38 | 16.21 | 14.16 | 17.38 | 14.60 | 14.56 | 17.96 | 15.90 | 13.62 | 17.25 |
| 1970 | 19.90 | 17.19 | 14.96 | 16.61 | 18.13 | 17.59 | 18.13 | 19.58 | 18.26 | 16.85 | 16.66 | 21.05 | 17.33 | 13.79 | 19.76 |
| 1971 | 20.22 | 16.01 | 17.05 | 19.70 | 19.60 | 18.59 | 19.26 | 18.51 | 20.80 | 19.76 | 18.41 | 21.66 | 19.24 | 18.07 | 20.28 |
| 1972 | 15.15 | 13.27 | 15.13 | 15.67 | 15.69 | 16.07 | 16.47 | 14.69 | 14.51 | 15.10 | 14.84 | 17.04 | 17.37 | 14.20 | 16.19 |
| 1973 | 18.16 | 17.07 | 14.98 | 18.36 | 14.45 | 20.12 | 15.87 | 16.70 | 18.03 | 18.77 | 16.91 | 19.23 | 16.42 | 15.94 | 18.87 |
| 1974 | 19.08 | 17.46 | 18.78 | 21.17 | 22.07 | 21.84 | 18.66 | 20.26 | 18.16 | 22.41 | 19.94 | 22.43 | 18.76 | 21.11 | 21.80 |
| 1975 | 18.05 | 12.94 | 12.91 | 13.97 | 12.79 | 15.01 | 13.51 | 13.98 | 16.51 | 14.92 | 13.75 | 19.80 | 13.65 | 13.43 | 18.87 |
| 1976 | 21.36 | 19.06 | 19.87 | 21.06 | 20.68 | 24.25 | 22.46 | 22.44 | 20.81 | 22.52 | 22.39 | 23.19 | 22.81 | 19.20 | 23.20 |
| 1977 | 15.88 | 12.63 | 13.61 | 14.54 | 14.84 | 16.13 | 13.56 | 14.44 | 13.50 | 16.47 | 14.82 | 17.46 | 13.85 | 13.69 | 17.12 |
| 1978 | 20.12 | 17.41 | 17.70 | 17.66 | 18.40 | 19.65 | 19.81 | 15.92 | 18.43 | 19.34 | 19.06 | 21.19 | 20.41 | 16.72 | 21.57 |
| 1979 | 16.08 | 10.68 | 13.33 | 14.58 | 21.01 | 13.78 | 14.27 | 13.30 | 15.74 | 15.36 | 14.00 | 15.22 | 13.81 | 14.10 | 15.69 |
| 1980 | 15.26 | 19.44 | 18.11 | 20.48 | 24.65 | 21.31 | 20.66 | 20.63 | 17.09 | 21.13 | 20.26 | 14.23 | 19.84 | 18.77 | 14.32 |
| 1981 | 16.10 | 16.68 | 16.62 | 15.50 | 16.44 | 14.52 | 18.47 | 13.53 | 14.13 | 15.50 | 16.21 | 18.71 | 17.77 | 16.66 | 19.34 |
| 1982 | 13.98 | 14.90 | 12.95 | 14.20 | 13.97 | 15.41 | 12.80 | 15.20 | 14.25 | 14.44 | 14.06 | 12.84 | 12.89 | 14.18 | 13.26 |
| 1983 | 18.33 | 17.15 | 16.87 | 17.20 | 17.34 | 19.05 | 18.63 | 19.89 | 19.48 | 18.39 | 18.52 | 16.77 | 18.84 | 17.32 | 17.25 |
| 1984 | 16.97 | 15.92 | 15.52 | 17.41 | 18.28 | 21.86 | 18.04 | 21.84 | 17.58 | 19.06 | 18.43 | 15.71 | 17.69 | 15.91 | 15.69 |
| 1985 | 15.58 | 14.18 | 15.38 | 16.88 | 14.07 | 18.28 | 16.15 | 17.54 | 14.62 | 18.19 | 16.71 | 14.54 | 15.71 | 16.92 | 14.53 |
| 1986 | 17.65 | 13.30 | 15.59 | 15.08 | 15.05 | 16.88 | 20.04 | 15.75 | 17.59 | 15.50 | 16.45 | 18.25 | 18.86 | 13.83 | 18.06 |
| 1987 | 15.54 | 14.24 | 14.12 | 15.50 | 16.68 | 16.35 | 15.91 | 15.07 | 16.62 | 15.91 | 15.20 | 16.21 | 15.65 | 14.97 | 16.20 |
| 1988 | 16.69 | 13.45 | 17.57 | 18.52 | 22.74 | 18.70 | 18.80 | 15.31 | 18.34 | 19.15 | 18.35 | 16.30 | 19.23 | 17.45 | 16.83 |
| 1989 | 16.69 | 14.86 | 14.46 | 15.66 | 17.11 | 15.84 | 16.01 | 15.21 | 20.47 | 18.83 | 15.53 | 14.84 | 16.33 | 15.56 | 15.23 |
| 1990 | 18.11 | 17.95 | 16.20 | 16.88 | 17.02 | 18.92 | 20.54 | 16.97 | 20.72 | 20.13 | 17.71 | 17.31 | 19.76 | 16.00 | 18.11 |
| 1991 | 13.66 | 13.27 | 16.38 | 16.98 | 19.05 | 17.57 | 17.49 | 17.38 | 16.14 | 22.75 | 17.07 | 13.13 | 17.18 | 18.33 | 13.62 |
| 1992 | 14.00 | 13.65 | 11.85 | 13.84 | 10.59 | 13.07 | 14.47 | 13.07 | 16.93 | 16.05 | 13.01 | 14.25 | 14.15 | 12.74 | 14.81 |
| 1993 | 11.71 | 8.74 | 9.74 | 11.04 | 6.77 | 10.06 | 12.59 | 7.64 | 12.47 | 11.36 | 10.01 | 11.24 | 12.60 | 9.36 | 11.58 |
| 1994 | 18.03 | 13.60 | 17.12 | 17.26 | 17.86 | 14.21 | 17.76 | 13.75 | 18.25 | 19.12 | 16.78 | 19.26 | 18.11 | 18.56 | 20.30 |
| 1995 | 16.72 | 19.84 | 15.98 | 17.10 | 15.31 | 19.68 | 17.23 | 18.92 | 18.56 | 19.02 | 17.61 | 15.20 | 17.54 | 15.06 | 16.05 |
| 1996 | 12.21 | 9.43 | 9.83 | 10.86 | 14.46 | 10.39 | 10.39 | 8.62 | 9.68 | 11.28 | 10.27 | 14.92 | 10.23 | 10.90 | 15.45 |
| 1997 | 15.99 | 17.66 | 14.01 | 15.13 | 15.08 | 15.69 | 17.02 | 16.76 | 17.38 | 15.91 | 14.92 | 16.29 | 16.77 | 12.75 | 16.78 |
| 1998 | 16.78 | 15.88 | 13.97 | 16.80 | 22.74 | 16.52 | 16.33 | 15.98 | 18.49 | 19.18 | 15.05 | 17.49 | 15.86 | 14.10 | 17.84 |
| 1999 | 14.42 | 11.22 | 14.26 | 14.04 | 17.45 | 13.10 | 16.39 | 12.41 | 15.00 | 15.35 | 13.52 | 15.00 | 15.67 | 14.50 | 15.17 |
| 2000 | 21.83 | 22.19 | 20.03 | 20.25 | 20.65 | 17.73 | 24.27 | 17.57 | 23.99 | 21.67 | 19.54 | 20.87 | 23.65 | 20.26 | 21.09 |
| 40-00 Avg | 17.41 | 15.51 | 14.79 | 16.03 | 16.84 | 15.91 | 16.92 | 15.79 | 17.40 | 16.43 | 15.45 | 17.60 | 16.97 | 14.71 | 17.64 |

**APPENDIX M**

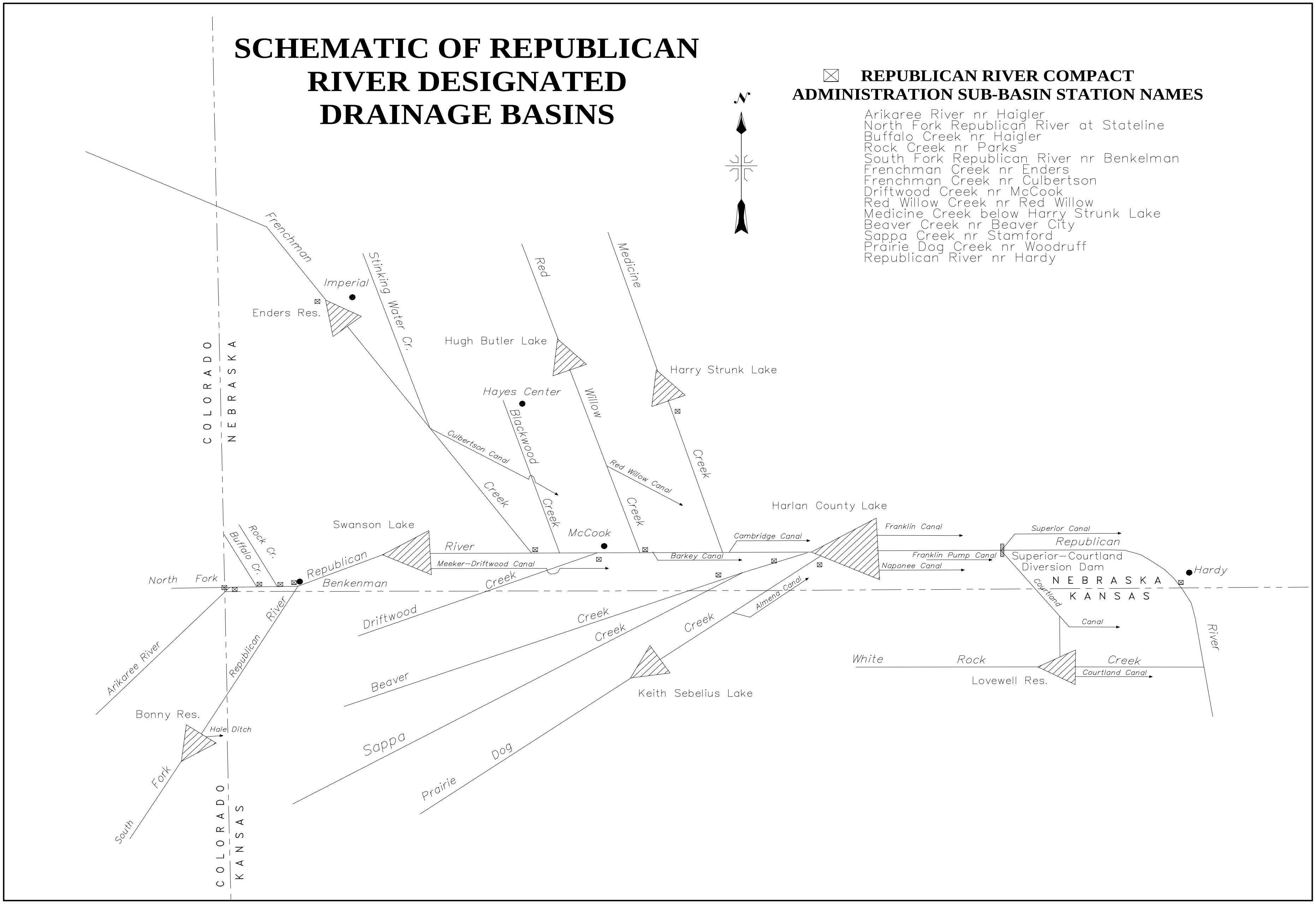
SCHEMATIC OF REPUBLICAN RIVER
DESIGNATED DRAINAGE BASINS

M1

# SCHEMATIC OF REPUBLICAN RIVER DESIGNATED DRAINAGE BASINS

**REPUBLICAN RIVER COMPACT ADMINISTRATION SUB-BASIN STATION NAMES**

Arikaree River nr Haigler
North Fork Republican River at Stateline
Buffalo Creek nr Haigler
Rock Creek nr Parks
South Fork Republican River nr Benkelman
Frenchman Creek nr Enders
Frenchman Creek nr Culbertson
Driftwood Creek nr McCook
Red Willow Creek nr Red Willow
Medicine Creek below Harry Strunk Lake
Beaver Creek nr Beaver City
Sappa Creek nr Stamford
Prairie Dog Creek nr Woodruff
Republican River nr Hardy



# APPENDIX N

PHREATOPHYTE DISTRIBUTION

# Appendix N – Phreatophyte Distribution

*Colorado* – The Colorado Gap Analysis Project (CO-GAP) was initiated in 1991 as a cooperative effort among federal, state, and private natural resource groups in Colorado. The major objectives of the project are to: map actual land cover as closely as possible and make all GAP Project information available to users in a readily accessible format to institutions, agencies, and private land owners. Landsat imagery was acquired or interpreted to establish a baseline map of vegetation and land cover. Attributes were assigned to each polygon describing primary, secondary, and other land cover, crown closure for forested primary types, and the types of wetlands and/or disturbance found in the polygon, if any. Polygon attributes were assigned using image interpretation, existing maps, field reconnaissance, digital reference layers from Federal land management agencies, and literature sources.

*Kansas* – Landsat TM7 imagery from 2000 was obtained covering most of the RRCA Model area, except for the far south-central and far eastern portions. Tributaries with visible phreatophyte cover were mapped as a subset of the hydrographic drainage network available as a digital line graph from the USGS. Tributaries were then divided according to the relative width of the riparian cover. Within each of these discrete reaches, cross sections from the outside boundaries of the riparian vegetation were then mapped and the average cross section within the reach was calculated. One-half of this average cross section was used as the distance from the hydrographic channel mapped by the USGS to map a polygon to enclose the riparian phreatophyte corridor along the reach. These polygons were merged with the Nebraska polygons denoting woody phreatophytes because some areas mapped as woody phreatophytes lay well outside of the riparian corridor.

*Nebraska* – The Nebraska Department of Natural Resources (NDNR), in association with the Nebraska Conservation and Survey Division maintain a collection of digitally rectified aerial photography for landscape analysis. This data has a resolution of 20-ft. and was projected in UTM, Nad83. The NDNR digitized the 1993 Digital Orthophoto Quarter Quadrangle to identify phreatophyte forests from visual examination of the black and white aerial photography at a scale of 1:15,000. Polygons were fit over the photographs in ESRI's Arc View GIS then reprojected into the RRCA Model projection (UTM, Nad27). Approximately 100 sites were visually inspected during field reconnaissance to verify the distribution of woody phreatophytes obtained from the aerial photography. The polygon output provided by Kansas was combined with the aerial photography analysis by Nebraska to include wetland areas in the minor tributaries, with corrections to exclude polygons of irrigated croplands. To accommodate the synoptic biases due to scale, polygon correction was performed at a scale of 1:50,000. Polygons to represent the phreatophyte areas downstream of Red Cloud, Nebraska and the extended groundwater mound area in Kearney and Adams County, Nebraska were derived from aerial photography at a scale of 1:50,000.

Appendix N Phreatophyte Evapotranspiration Rates (example)

Phreatophyte Monthly ET Rates (inches)

| Month | Akron | McCook | RedCloud |
|---|---|---|---|
| 19180100 | 0.19 | 0.24 | 0.07 |
| 19180200 | 0.63 | 0.72 | 0.51 |
| 19180300 | 1.69 | 2.25 | 1.66 |
| 19180400 | 1.60 | 2.62 | 2.00 |
| 19180500 | 7.26 | 7.31 | 4.25 |
| 19180600 | 9.47 | 11.13 | 9.07 |
| 19180700 | 8.37 | 7.90 | 7.05 |
| 19180800 | 6.22 | 6.74 | 7.14 |
| 19180900 | 4.67 | 5.62 | 5.13 |
| 19181000 | 2.74 | 2.06 | 1.88 |
| 19181100 | 0.74 | 1.00 | 0.46 |
| 19181200 | 0.04 | 0.14 | 0.00 |
| 19190100 | 0.54 | 0.61 | 0.98 |
| 19190200 | 0.47 | 0.00 | 0.00 |
| 19190300 | 1.40 | 1.15 | 1.35 |
| 19190400 | 0.95 | 1.61 | 0.89 |
| 19190500 | 5.41 | 6.41 | 4.57 |
| 19190600 | 7.81 | 7.58 | 5.82 |
| 19190700 | 10.69 | 9.80 | 10.33 |
| 19190800 | 10.27 | 7.88 | 9.16 |
| 19190900 | 5.94 | 7.32 | 2.09 |
| 19191000 | 3.00 | 2.58 | 1.54 |
| 19191100 | 0.78 | 0.31 | 0.00 |
| 19191200 | 0.46 | 0.44 | 0.26 |
| 19200100 | 0.61 | 0.81 | 0.76 |
| 19200200 | 0.87 | 0.85 | 0.59 |
| 19200300 | 1.20 | 1.98 | 2.13 |
| 19200400 | 0.00 | 0.95 | 1.23 |
| 19200500 | 4.29 | 5.64 | 5.30 |
| 19200600 | 5.40 | 8.35 | 8.16 |
| 19200700 | 7.26 | 10.35 | 9.16 |
| 19200800 | 8.22 | 6.84 | 5.09 |
| 19200900 | 6.78 | 6.72 | 4.99 |
| 19201000 | 5.36 | 2.54 | 2.45 |
| 19201100 | 1.68 | 0.78 | 0.33 |
| 19201200 | 0.82 | 0.48 | 0.54 |
| 19210100 | 0.24 | 0.38 | 0.60 |
| 19210200 | 1.00 | 1.15 | 1.07 |
| 19210300 | 1.36 | 2.03 | 2.23 |
| 19210400 | 2.38 | 4.47 | 2.85 |
| 19210500 | 7.84 | 7.21 | 6.07 |
| 19210600 | 8.56 | 9.19 | 8.63 |
| 19210700 | 9.31 | 9.19 | 7.50 |
| 19210800 | 8.77 | 7.15 | 8.17 |
| 19210900 | 6.62 | 5.46 | 3.48 |
| 19211000 | 2.38 | 1.82 | 2.18 |
| 19211100 | 1.16 | 1.07 | 1.16 |
| 19211200 | 0.65 | 0.91 | 0.87 |
| 19220100 | 0.56 | 0.66 | 0.65 |
| 19220200 | 0.82 | 0.81 | 0.86 |
| 19220300 | 1.67 | 1.38 | 0.96 |
| 19220400 | 0.79 | 2.05 | 2.41 |
| 19220500 | 5.11 | 7.01 | 5.17 |
| 19220600 | 8.68 | 8.64 | 9.74 |
| 19220700 | 8.32 | 8.68 | 7.98 |
| 19220800 | 9.81 | 9.10 | 9.78 |
| 19220900 | 8.15 | 6.69 | 5.84 |
| 19221000 | 3.20 | 2.63 | 1.82 |
| 19221100 | 0.12 | 0.30 | 0.65 |
| 19221200 | 0.98 | 0.67 | 0.83 |
| 19230100 | 1.08 | 0.92 | 0.98 |
| 19230200 | 0.77 | 0.78 | 0.92 |
| 19230300 | 0.91 | 1.13 | 0.77 |
| 19230400 | 1.77 | 1.56 | 1.89 |
| 19230500 | 3.18 | 1.75 | 4.42 |
| 19230600 | 7.13 | 6.09 | 4.50 |
| 19230700 | 7.26 | 6.10 | 7.56 |
| 19230800 | 8.57 | 6.29 | 6.56 |
| 19230900 | 6.89 | 5.87 | 4.50 |
| 19231000 | 2.06 | 1.36 | 1.55 |
| 19231100 | 1.35 | 2.15 | 1.01 |
| 19231200 | 0.10 | 1.03 | 0.75 |

Appendix N Sub-Basin Factors

| YEAR | SWANSON | HARLAN | FRENCHMAN | MEDICINE | PRAIRIEDOG | REDWILLOW | SFABVBONNY | SFBLWBONNY | SAPPA | NORTHFORK | BEAVER | ARIKAREE | BUFFALO | ROCK | DRIFTWOOD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1938 | 1.00 | 0.67 | 1.00 | 0.40 | 0.67 | 1.00 | 0.28 | 0.03 | 0.67 | 0.47 | 0.67 | 0.47 | 0.30 | 0.13 | 0.27 |
| 1939 | 1.00 | 0.67 | 1.00 | 0.42 | 0.67 | 1.00 | 0.28 | 0.06 | 0.67 | 0.49 | 0.67 | 0.49 | 0.33 | 0.16 | 0.30 |
| 1940 | 1.00 | 0.67 | 1.00 | 0.43 | 0.67 | 1.00 | 0.28 | 0.09 | 0.67 | 0.52 | 0.67 | 0.52 | 0.35 | 0.19 | 0.32 |
| 1941 | 1.00 | 0.67 | 1.00 | 0.45 | 0.67 | 1.00 | 0.28 | 0.11 | 0.67 | 0.55 | 0.67 | 0.55 | 0.38 | 0.22 | 0.34 |
| 1942 | 1.00 | 0.67 | 1.00 | 0.47 | 0.67 | 1.00 | 0.28 | 0.14 | 0.67 | 0.58 | 0.67 | 0.58 | 0.41 | 0.25 | 0.36 |
| 1943 | 1.00 | 0.67 | 1.00 | 0.49 | 0.67 | 1.00 | 0.28 | 0.17 | 0.67 | 0.61 | 0.67 | 0.61 | 0.44 | 0.28 | 0.39 |
| 1944 | 1.00 | 0.67 | 1.00 | 0.51 | 0.67 | 1.00 | 0.28 | 0.20 | 0.67 | 0.63 | 0.67 | 0.63 | 0.47 | 0.31 | 0.41 |
| 1945 | 1.00 | 0.67 | 1.00 | 0.53 | 0.67 | 1.00 | 0.28 | 0.23 | 0.67 | 0.66 | 0.67 | 0.66 | 0.50 | 0.34 | 0.43 |
| 1946 | 1.00 | 0.67 | 1.00 | 0.55 | 0.67 | 1.00 | 0.28 | 0.25 | 0.67 | 0.69 | 0.67 | 0.69 | 0.53 | 0.36 | 0.46 |
| 1947 | 1.00 | 0.67 | 1.00 | 0.57 | 0.67 | 1.00 | 0.28 | 0.28 | 0.67 | 0.72 | 0.67 | 0.72 | 0.56 | 0.39 | 0.48 |
| 1948 | 1.00 | 0.67 | 1.00 | 0.59 | 0.67 | 1.00 | 0.28 | 0.31 | 0.67 | 0.74 | 0.67 | 0.74 | 0.58 | 0.42 | 0.50 |
| 1949 | 1.00 | 0.67 | 1.00 | 0.61 | 0.67 | 1.00 | 0.28 | 0.34 | 0.67 | 0.77 | 0.67 | 0.77 | 0.61 | 0.45 | 0.53 |
| 1950 | 1.00 | 0.67 | 1.00 | 0.63 | 0.67 | 1.00 | 0.28 | 0.37 | 0.67 | 0.80 | 0.67 | 0.80 | 0.64 | 0.48 | 0.55 |
| 1951 | 1.00 | 0.67 | 1.00 | 0.65 | 0.67 | 1.00 | 0.31 | 0.39 | 0.67 | 0.83 | 0.67 | 0.83 | 0.67 | 0.51 | 0.57 |
| 1952 | 1.00 | 0.67 | 1.00 | 0.67 | 0.67 | 1.00 | 0.33 | 0.42 | 0.67 | 0.86 | 0.67 | 0.86 | 0.70 | 0.54 | 0.59 |
| 1953 | 1.00 | 0.67 | 1.00 | 0.69 | 0.67 | 1.00 | 0.35 | 0.45 | 0.67 | 0.88 | 0.67 | 0.88 | 0.73 | 0.57 | 0.62 |
| 1954 | 1.00 | 0.67 | 1.00 | 0.71 | 0.67 | 1.00 | 0.37 | 0.48 | 0.67 | 0.91 | 0.67 | 0.91 | 0.76 | 0.60 | 0.64 |
| 1955 | 1.00 | 0.67 | 1.00 | 0.73 | 0.67 | 1.00 | 0.40 | 0.51 | 0.67 | 0.94 | 0.67 | 0.94 | 0.78 | 0.63 | 0.66 |
| 1956 | 1.00 | 0.67 | 1.00 | 0.75 | 0.67 | 1.00 | 0.42 | 0.53 | 0.67 | 0.97 | 0.67 | 0.97 | 0.81 | 0.66 | 0.69 |
| 1957 | 1.00 | 0.67 | 1.00 | 0.77 | 0.67 | 1.00 | 0.44 | 0.56 | 0.67 | 1.00 | 0.67 | 1.00 | 0.84 | 0.69 | 0.71 |
| 1958 | 1.00 | 0.67 | 1.00 | 0.79 | 0.67 | 1.00 | 0.47 | 0.59 | 0.67 | 1.02 | 0.67 | 1.02 | 0.87 | 0.72 | 0.73 |
| 1959 | 1.00 | 0.67 | 1.00 | 0.81 | 0.67 | 1.00 | 0.49 | 0.62 | 0.67 | 1.05 | 0.67 | 1.05 | 0.90 | 0.75 | 0.76 |
| 1960 | 1.00 | 0.67 | 1.00 | 0.83 | 0.67 | 1.00 | 0.51 | 0.65 | 0.67 | 1.06 | 0.67 | 1.06 | 0.92 | 0.78 | 0.78 |
| 1961 | 1.00 | 0.67 | 1.00 | 0.85 | 0.67 | 1.00 | 0.53 | 0.67 | 0.67 | 1.06 | 0.67 | 1.06 | 0.94 | 0.81 | 0.80 |
| 1962 | 1.00 | 0.67 | 1.00 | 0.87 | 0.67 | 1.00 | 0.56 | 0.67 | 0.67 | 1.07 | 0.67 | 1.07 | 0.95 | 0.83 | 0.82 |
| 1963 | 1.00 | 0.67 | 1.00 | 0.89 | 0.67 | 1.00 | 0.58 | 0.67 | 0.67 | 1.08 | 0.67 | 1.08 | 0.97 | 0.86 | 0.85 |
| 1964 | 1.00 | 0.67 | 1.00 | 0.91 | 0.67 | 1.00 | 0.60 | 0.67 | 0.67 | 1.09 | 0.67 | 1.09 | 0.99 | 0.89 | 0.87 |
| 1965 | 1.00 | 0.67 | 1.00 | 0.91 | 0.67 | 1.00 | 0.62 | 0.67 | 0.67 | 1.09 | 0.67 | 1.09 | 1.01 | 0.92 | 0.89 |
| 1966 | 1.00 | 0.67 | 1.00 | 0.91 | 0.67 | 1.00 | 0.65 | 0.67 | 0.67 | 1.10 | 0.67 | 1.10 | 1.01 | 0.93 | 0.90 |
| 1967 | 1.00 | 0.67 | 1.00 | 0.92 | 0.67 | 1.00 | 0.67 | 0.67 | 0.67 | 1.11 | 0.67 | 1.11 | 1.02 | 0.93 | 0.91 |
| 1968 | 1.00 | 0.67 | 1.00 | 0.92 | 0.67 | 1.00 | 0.68 | 0.67 | 0.67 | 1.11 | 0.67 | 1.11 | 1.02 | 0.93 | 0.92 |
| 1969 | 1.00 | 0.67 | 1.00 | 0.92 | 0.67 | 1.00 | 0.70 | 0.67 | 0.67 | 1.12 | 0.67 | 1.12 | 1.03 | 0.93 | 0.93 |
| 1970 | 1.00 | 0.67 | 1.00 | 0.92 | 0.67 | 1.00 | 0.71 | 0.67 | 0.67 | 1.09 | 0.67 | 1.09 | 1.01 | 0.94 | 0.92 |
| 1971 | 1.00 | 0.67 | 1.00 | 0.93 | 0.67 | 1.00 | 0.72 | 0.67 | 0.67 | 1.08 | 0.67 | 1.08 | 1.01 | 0.94 | 0.92 |
| 1972 | 1.00 | 0.67 | 1.00 | 0.93 | 0.67 | 1.00 | 0.73 | 0.67 | 0.67 | 1.10 | 0.67 | 1.10 | 1.01 | 0.94 | 0.92 |
| 1973 | 1.00 | 0.67 | 1.00 | 0.93 | 0.67 | 1.00 | 0.75 | 0.67 | 0.67 | 1.09 | 0.67 | 1.09 | 1.01 | 0.94 | 0.93 |
| 1974 | 1.00 | 0.67 | 1.00 | 0.94 | 0.67 | 1.00 | 0.76 | 0.67 | 0.67 | 1.09 | 0.67 | 1.09 | 1.01 | 0.95 | 0.93 |
| 1975 | 1.00 | 0.67 | 1.00 | 0.94 | 0.67 | 1.00 | 0.77 | 0.67 | 0.67 | 1.08 | 0.67 | 1.08 | 1.02 | 0.95 | 0.95 |
| 1976 | 1.00 | 0.67 | 1.00 | 0.94 | 0.67 | 1.00 | 0.78 | 0.67 | 0.67 | 1.08 | 0.67 | 1.08 | 1.01 | 0.95 | 0.94 |
| 1977 | 1.00 | 0.67 | 1.00 | 0.95 | 0.67 | 1.00 | 0.80 | 0.67 | 0.67 | 1.07 | 0.67 | 1.07 | 1.01 | 0.96 | 0.95 |
| 1978 | 1.00 | 0.67 | 1.00 | 0.95 | 0.67 | 1.00 | 0.81 | 0.67 | 0.67 | 1.07 | 0.67 | 1.07 | 1.01 | 0.96 | 0.95 |
| 1979 | 1.00 | 0.67 | 1.00 | 0.95 | 0.67 | 1.00 | 0.82 | 0.67 | 0.67 | 1.06 | 0.67 | 1.06 | 1.01 | 0.96 | 0.95 |
| 1980 | 1.00 | 0.67 | 1.00 | 0.96 | 0.67 | 1.00 | 0.84 | 0.67 | 0.67 | 1.06 | 0.67 | 1.06 | 1.01 | 0.96 | 0.96 |
| 1981 | 1.00 | 0.67 | 1.00 | 0.96 | 0.67 | 1.00 | 0.85 | 0.67 | 0.67 | 1.05 | 0.67 | 1.05 | 1.01 | 0.97 | 0.96 |
| 1982 | 1.00 | 0.67 | 1.00 | 0.96 | 0.67 | 1.00 | 0.86 | 0.67 | 0.67 | 1.05 | 0.67 | 1.05 | 1.01 | 0.97 | 0.96 |
| 1983 | 1.00 | 0.67 | 1.00 | 0.97 | 0.67 | 1.00 | 0.87 | 0.67 | 0.67 | 1.05 | 0.67 | 1.05 | 1.01 | 0.97 | 0.97 |
| 1984 | 1.00 | 0.67 | 1.00 | 0.97 | 0.67 | 1.00 | 0.89 | 0.67 | 0.67 | 1.04 | 0.67 | 1.04 | 1.01 | 0.97 | 0.97 |
| 1985 | 1.00 | 0.67 | 1.00 | 0.97 | 0.67 | 1.00 | 0.90 | 0.67 | 0.67 | 1.04 | 0.67 | 1.04 | 1.01 | 0.98 | 0.97 |
| 1986 | 1.00 | 0.67 | 1.00 | 0.97 | 0.67 | 1.00 | 0.91 | 0.67 | 0.67 | 1.03 | 0.67 | 1.03 | 1.01 | 0.98 | 0.98 |
| 1987 | 1.00 | 0.67 | 1.00 | 0.98 | 0.67 | 1.00 | 0.92 | 0.67 | 0.67 | 1.03 | 0.67 | 1.03 | 1.00 | 0.98 | 0.98 |
| 1988 | 1.00 | 0.67 | 1.00 | 0.98 | 0.67 | 1.00 | 0.94 | 0.67 | 0.67 | 1.02 | 0.67 | 1.02 | 1.00 | 0.98 | 0.98 |
| 1989 | 1.00 | 0.67 | 1.00 | 0.98 | 0.67 | 1.00 | 0.95 | 0.67 | 0.67 | 1.02 | 0.67 | 1.02 | 1.00 | 0.99 | 0.99 |
| 1990 | 1.00 | 0.67 | 1.00 | 0.99 | 0.67 | 1.00 | 0.96 | 0.67 | 0.67 | 1.01 | 0.67 | 1.01 | 1.00 | 0.99 | 0.99 |
| 1991 | 1.00 | 0.67 | 1.00 | 0.99 | 0.67 | 1.00 | 0.97 | 0.67 | 0.67 | 1.01 | 0.67 | 1.01 | 1.00 | 0.99 | 0.99 |
| 1992 | 1.00 | 0.67 | 1.00 | 0.99 | 0.67 | 1.00 | 0.99 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 0.99 | 0.99 |
| 1993 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1994 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1995 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1996 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1997 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1998 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1999 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 |
| 2000 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 1.00 | 1.00 | 0.67 | 0.67 | 1.00 | 0.67 | 1.00 | 1.00 | 1.00 | 1.00 |

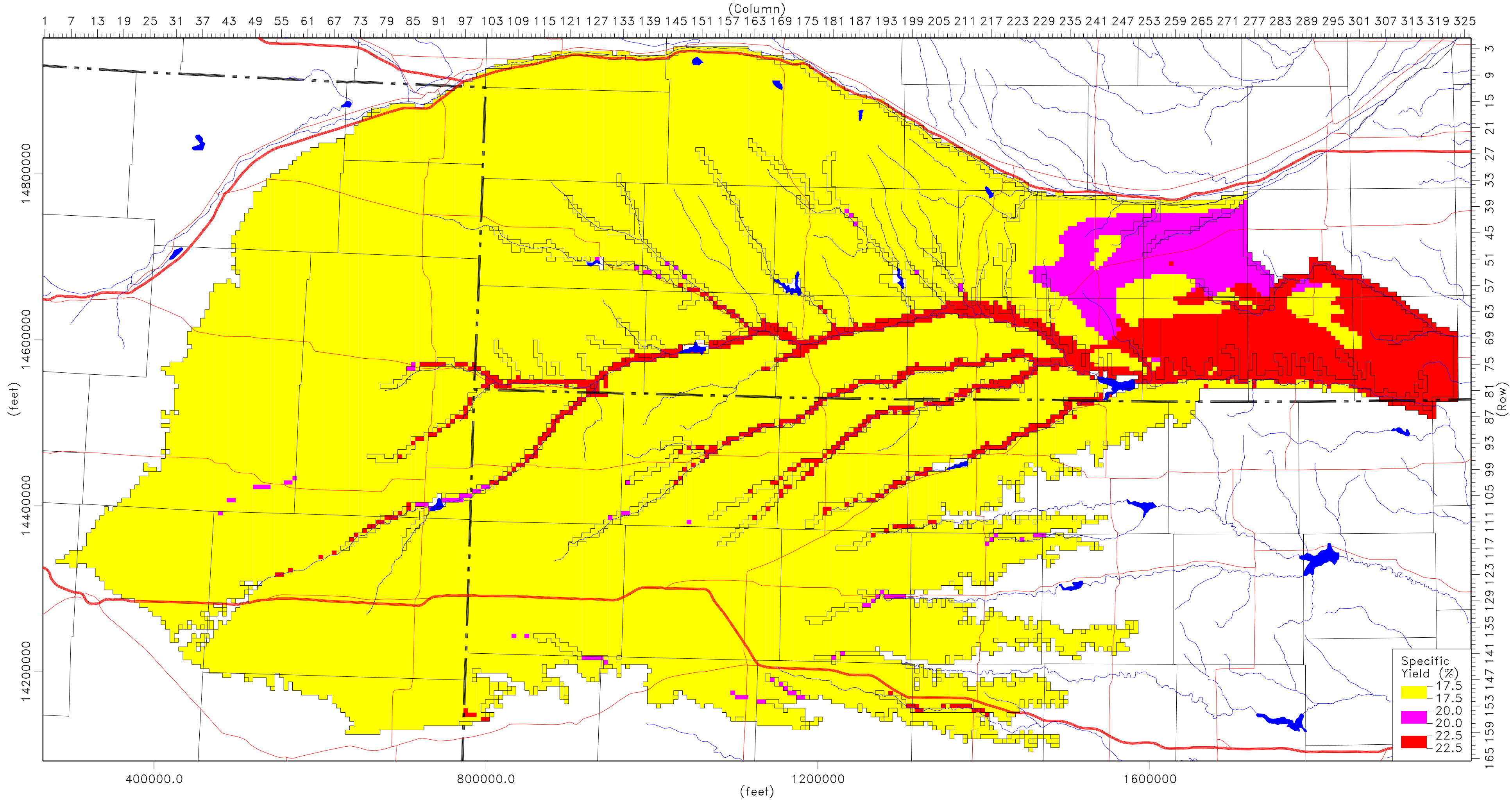
## APPENDIX O

DISTRIBUTION OF SPECIFIC YIELDS

O1

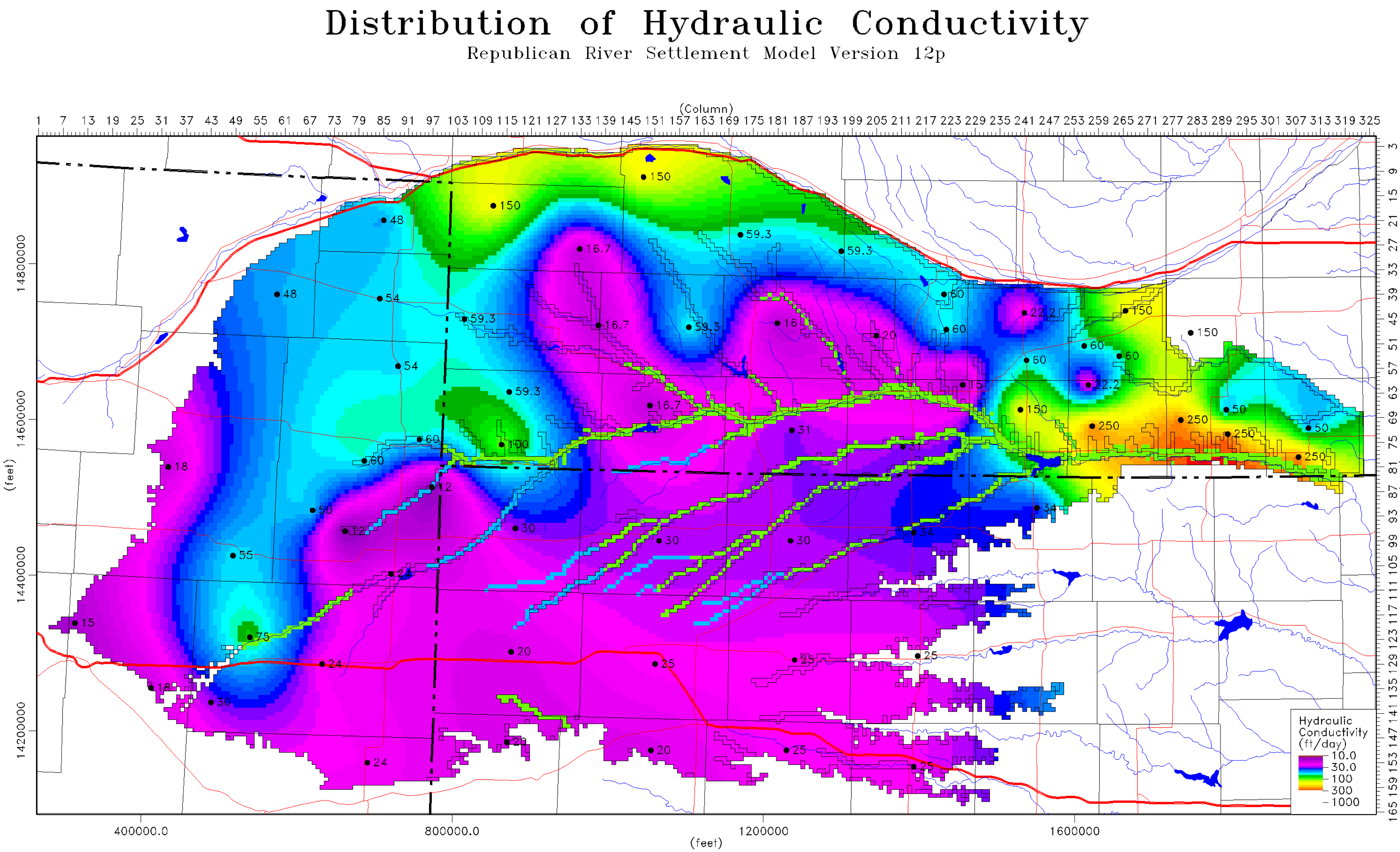
# Distribution of Specific Yield

Republican River Settlement Model Version 12p



# APPENDIX P

DISTRIBUTION OF HYDRAULIC CONDUCTIVITIES


Distribution of Hydraulic Conductivity
Republican River Settlement Model Version 12p
(Column)
(Row)
(feet)
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800000.0
1200000.0
1600000.0
14200000
14400000
14600000
14800000
Hydraulic Conductivity (ft/day)
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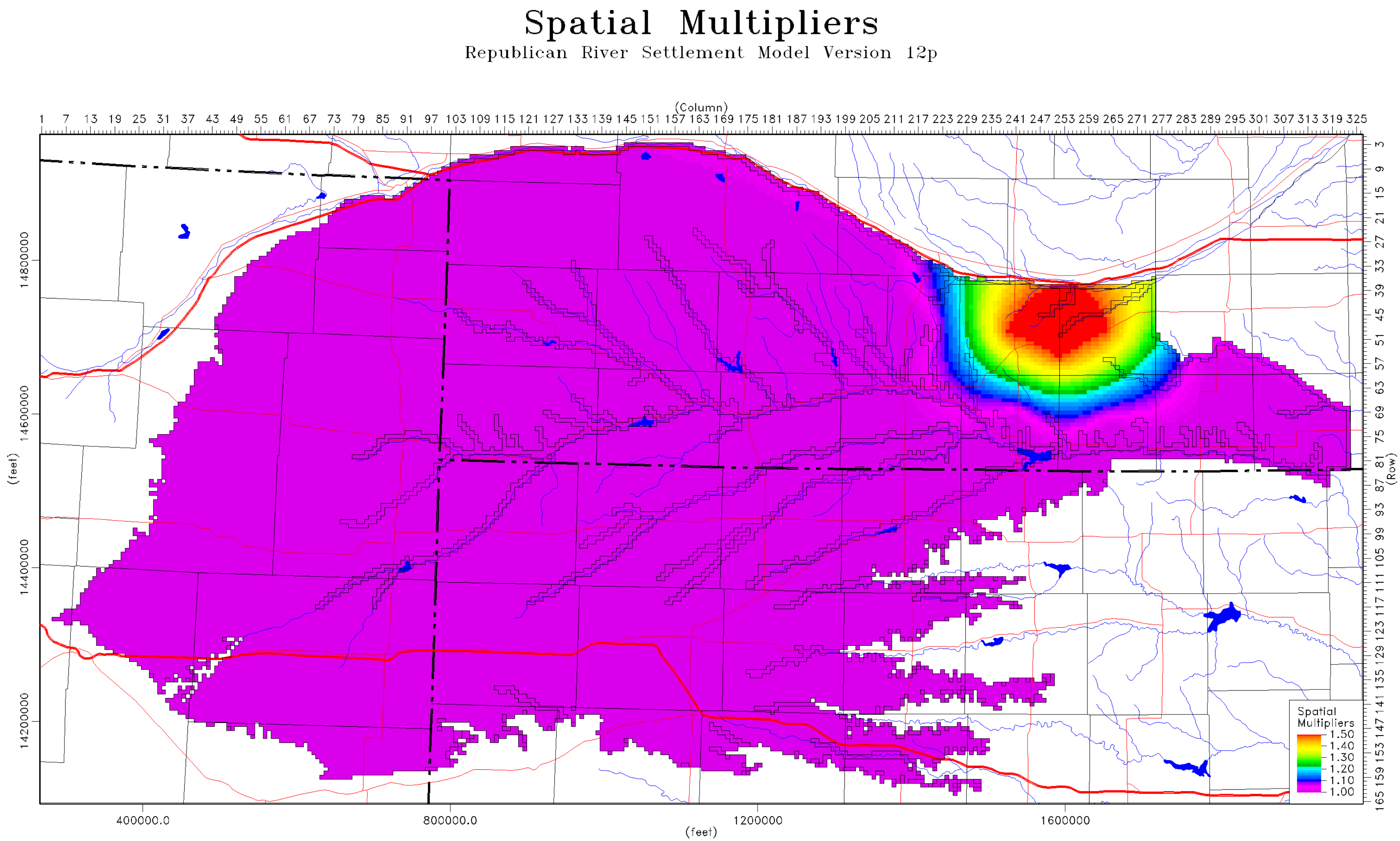
30.0
100
300
1000

## APPENDIX Q

SPATIAL MULTIPLIERS

Q1



Spatial Multipliers
Republican River Settlement Model Version 12p
(Column)
(Row)
(feet)
400000.0
800000.0
1200000
1600000
14800000
14600000
14400000
14200000
Spatial Multipliers
1.50
1.40
1.30
1.20
1.10
1.00

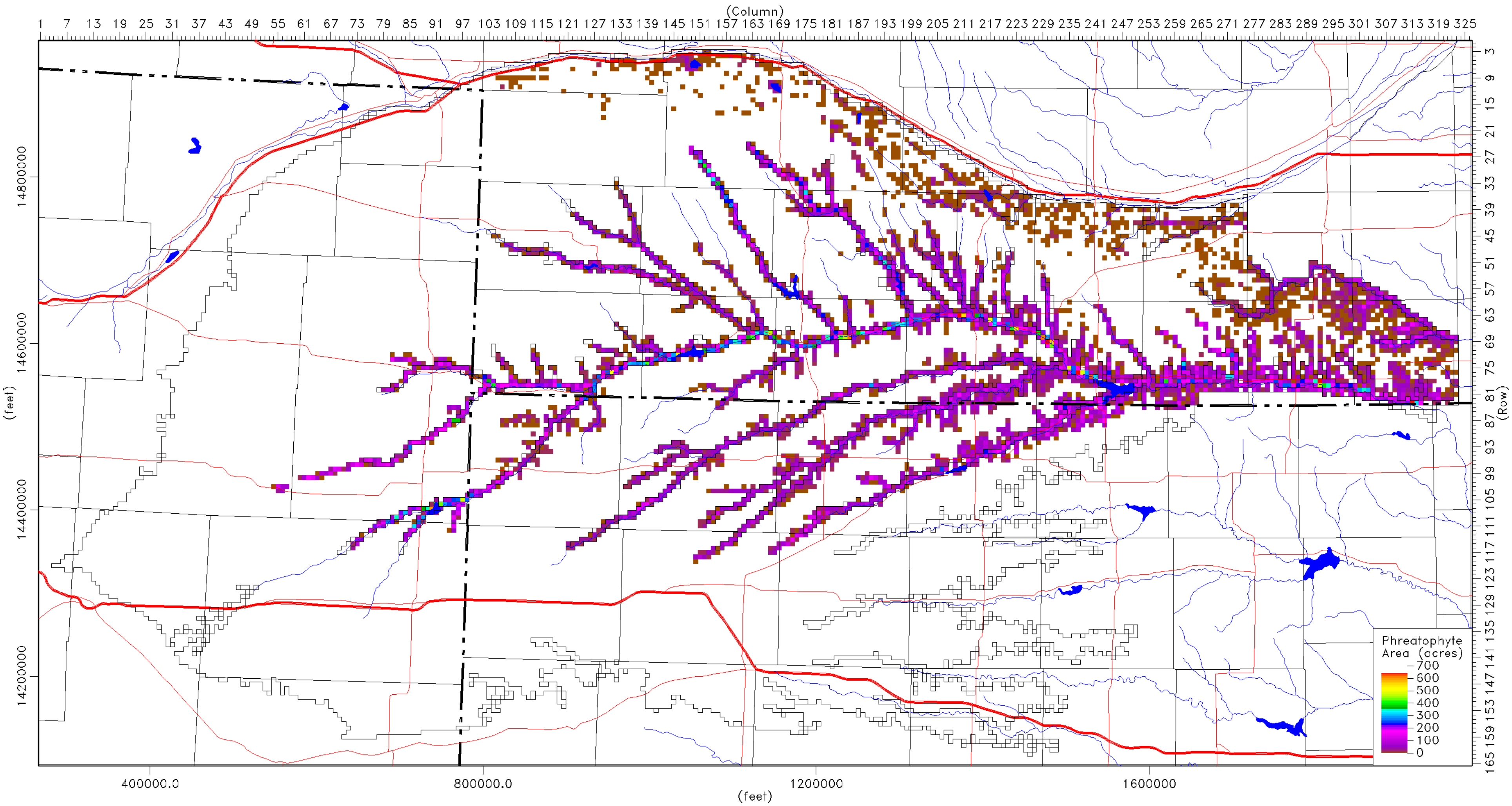
## APPENDIX R

PHREATOPHYTE AREA AND LOCATION OF PHREATOPHYTE SUB-BASINS

R1

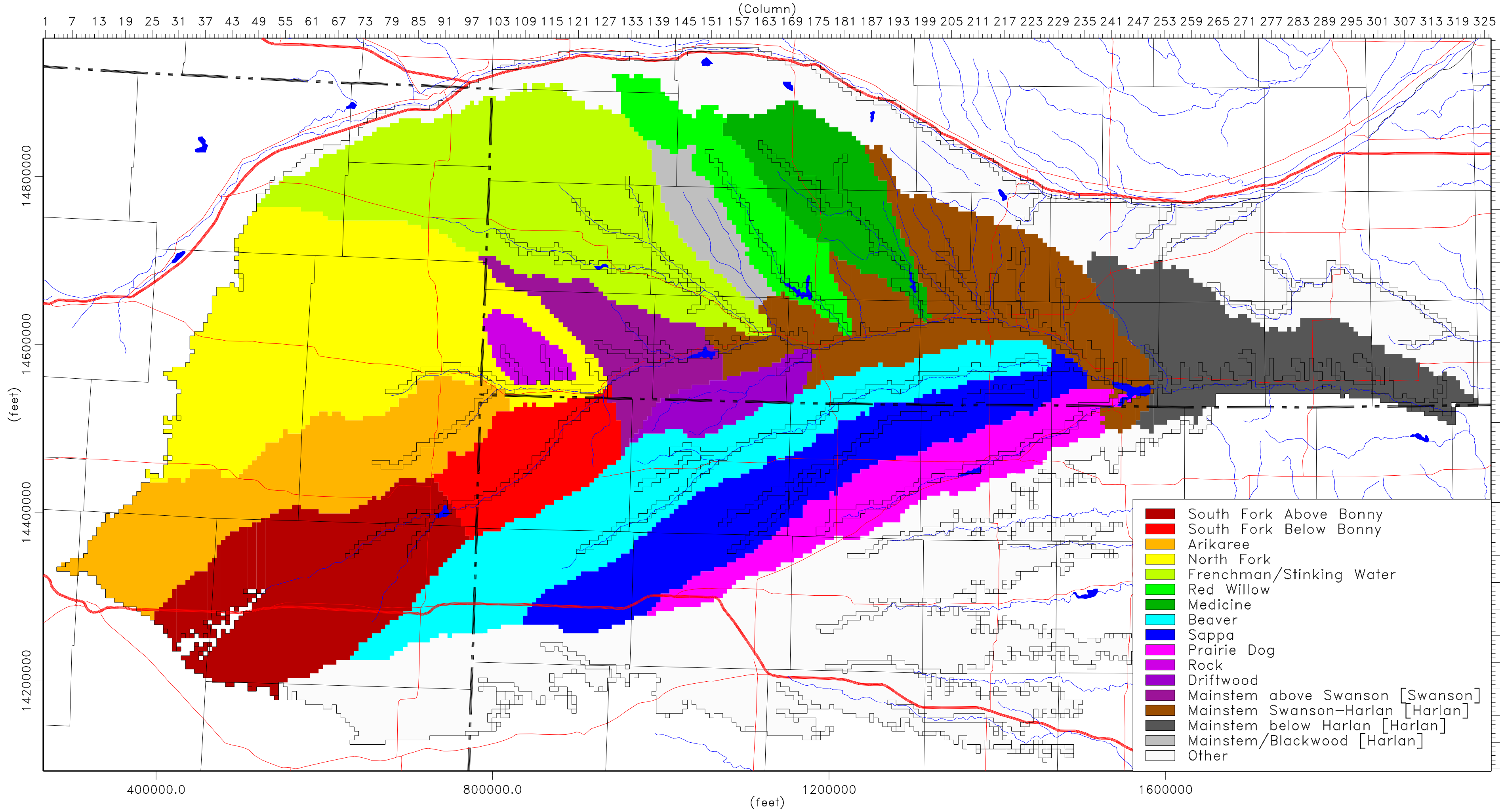
# Phreatophyte Area

Republican River Settlement Model Version 12p



# Location of Phreatophyte Sub-Basins

Republican River Settlement Model Version 12p

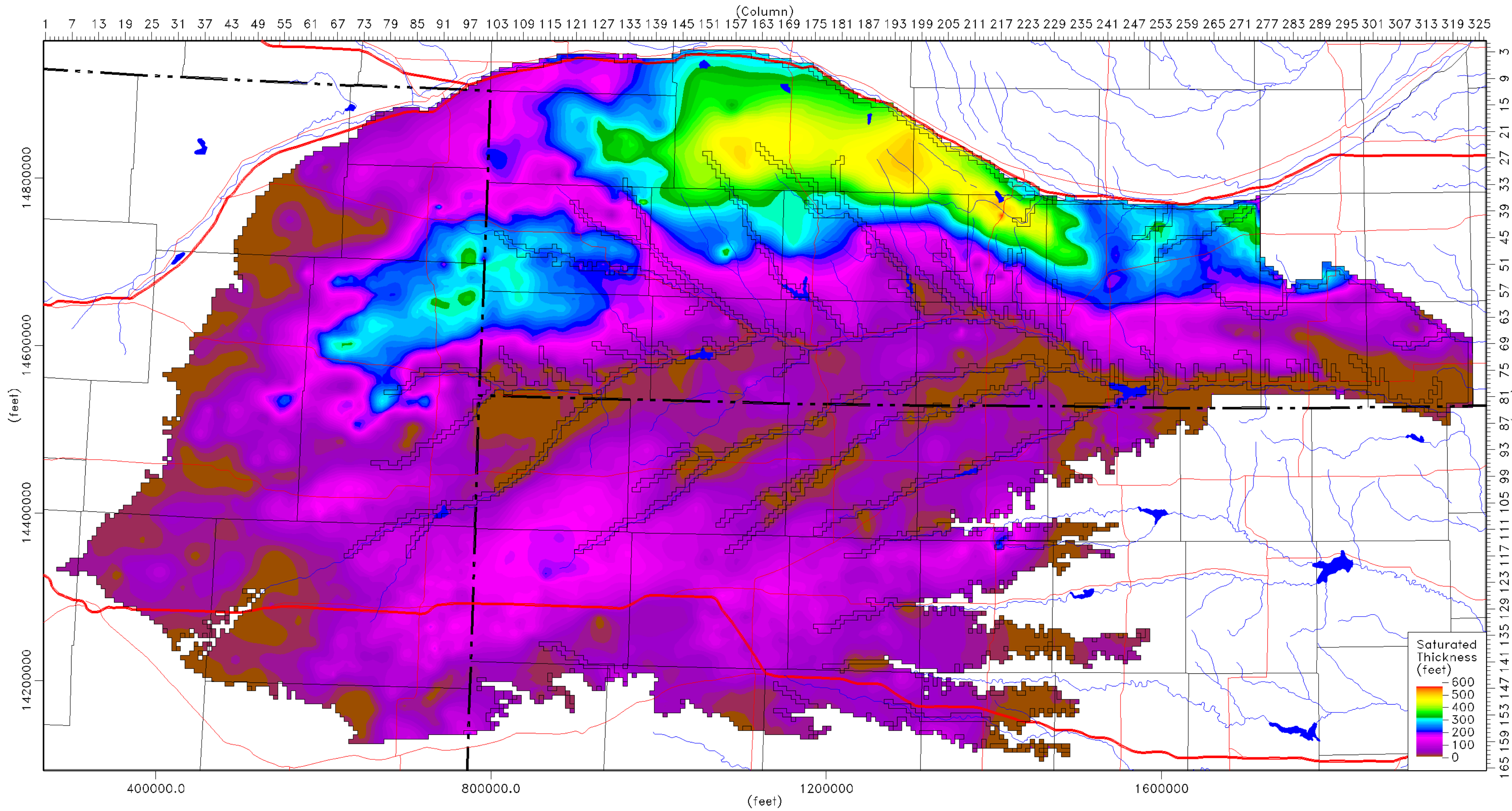


**APPENDIX S**

SATURATED THICKNESS

# Saturated Thickness

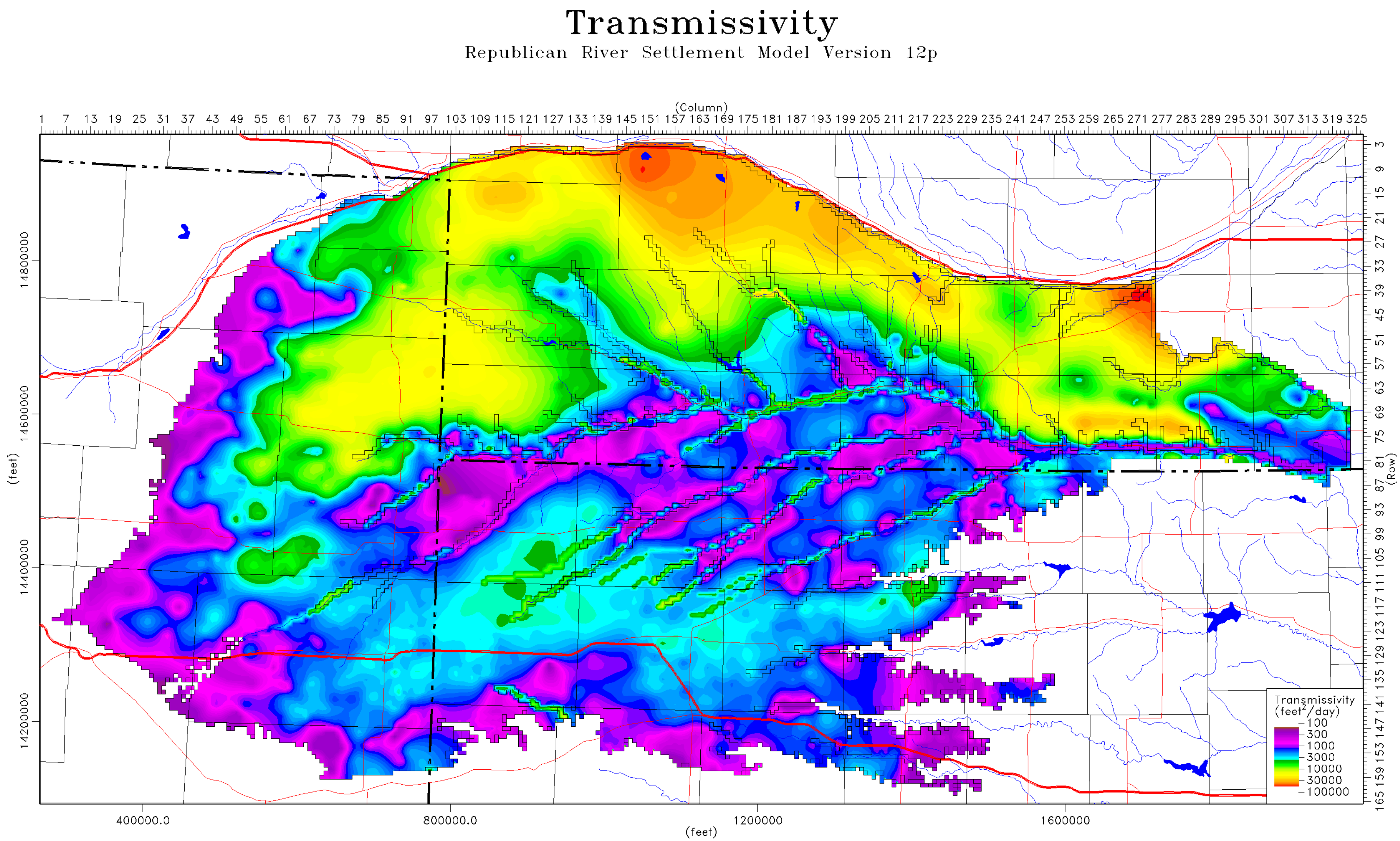
Republican River Settlement Model Version 12p



**APPENDIX T**

TRANSMISSIVITY

T1



Transmissivity
Republican River Settlement Model Version 12p
(Column)
(Row)
(feet)
(feet)
14800000
14600000
14400000
14200000
400000.0
800000.0
1200000
1600000
Transmissivity (feet²/day)
100
300
1000
3000
10000
30000
100000

**APPENDIX U**

RRCA MODEL IMPACTS

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 | 0 | 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 | -20 | 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 |

Appendix U RRCA Model Impacts

## 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 |

# 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 |