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) OAH NO. 23AG0003 AG
FROM EDWARDS COUNTY, KANSAS)
PURSUANT TO THE KANSAS WATER)
TRANSFER ACT.)
______________________________________)
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: David Barfield
David Barfield, P.E.

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

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.
1481 East 660 Road
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.

Groundwater models.

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.

Summary of Larson's opinions

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.

Evaluation of Mr. Larson’s Review

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.

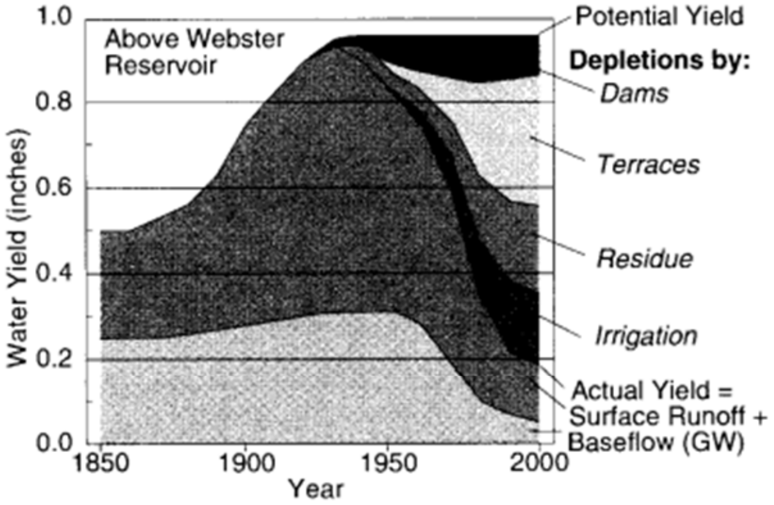

FIGURE 7.3—Historical perspective of the effect of agricultural technology on water yield above Webster Reservoir showing increases caused by conversion to cropland and depletions caused by various soil- and water-conservation practices and changes in agricultural technology (adapted from Koelliker,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

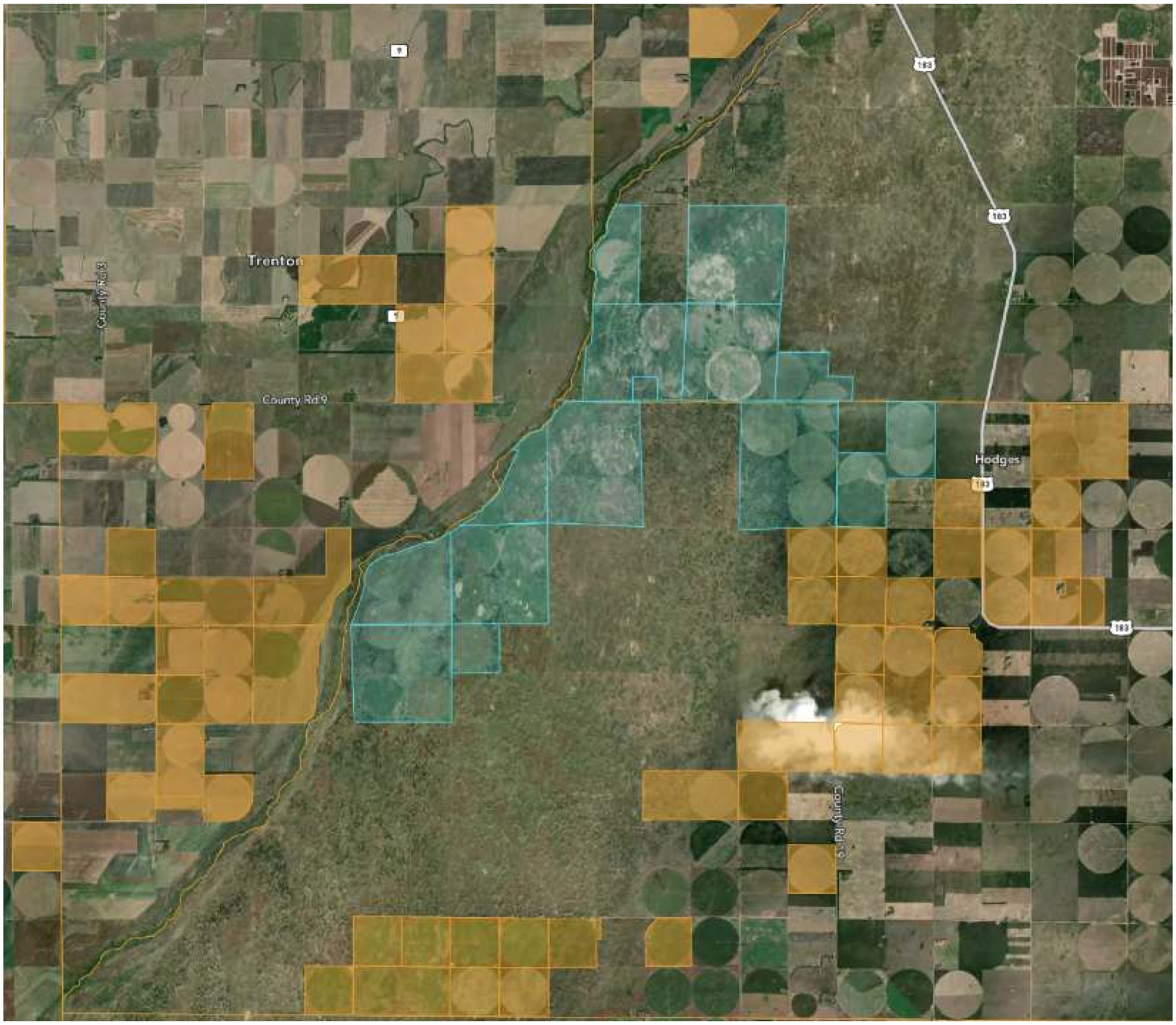
I have been involved in a number of Kansas model development projects by the Kansas Geological Survey for Kansas Groundwater Management Districts (GMDs). In some cases, no enhancement of precipitation recharge was included (the 2006 Middle Arkansas River Model and 2022 GMD 2 model). In other cases (the 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

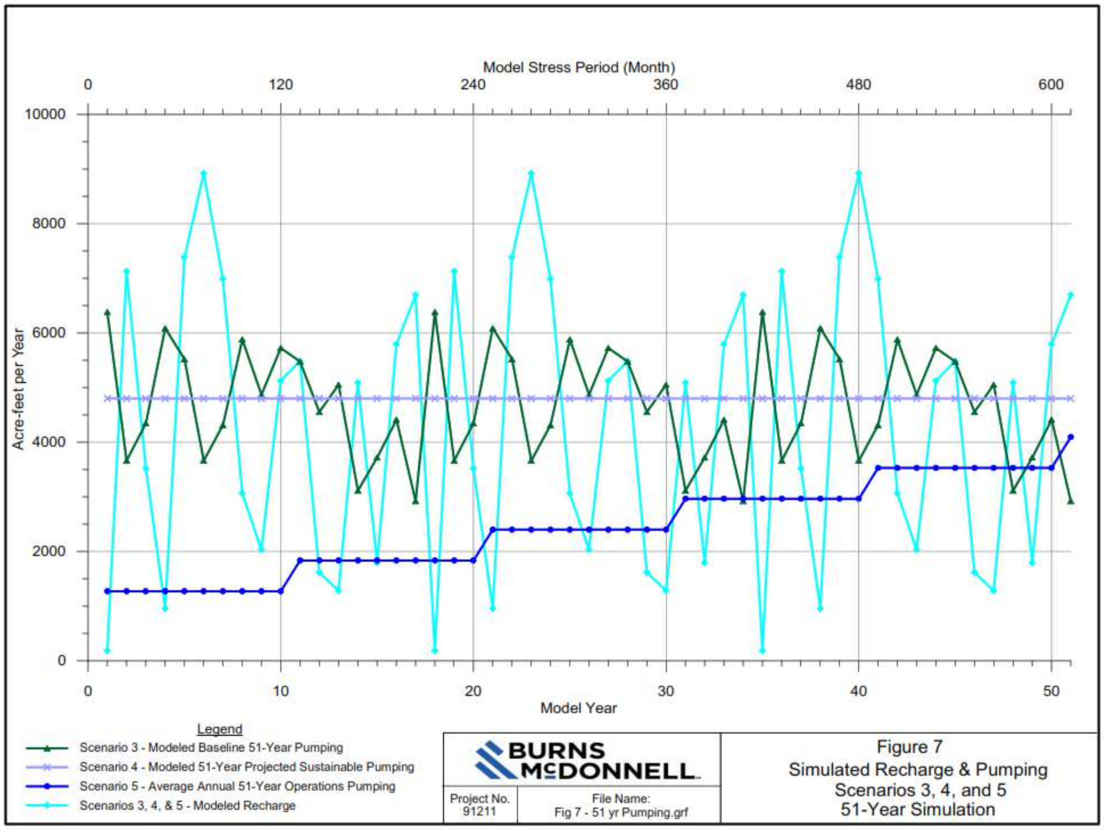
Even given the reduction in recharge from natural precipitation from Mr. Larson's analysis, the effects on the Ranch and vicinity are quite limited.

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.

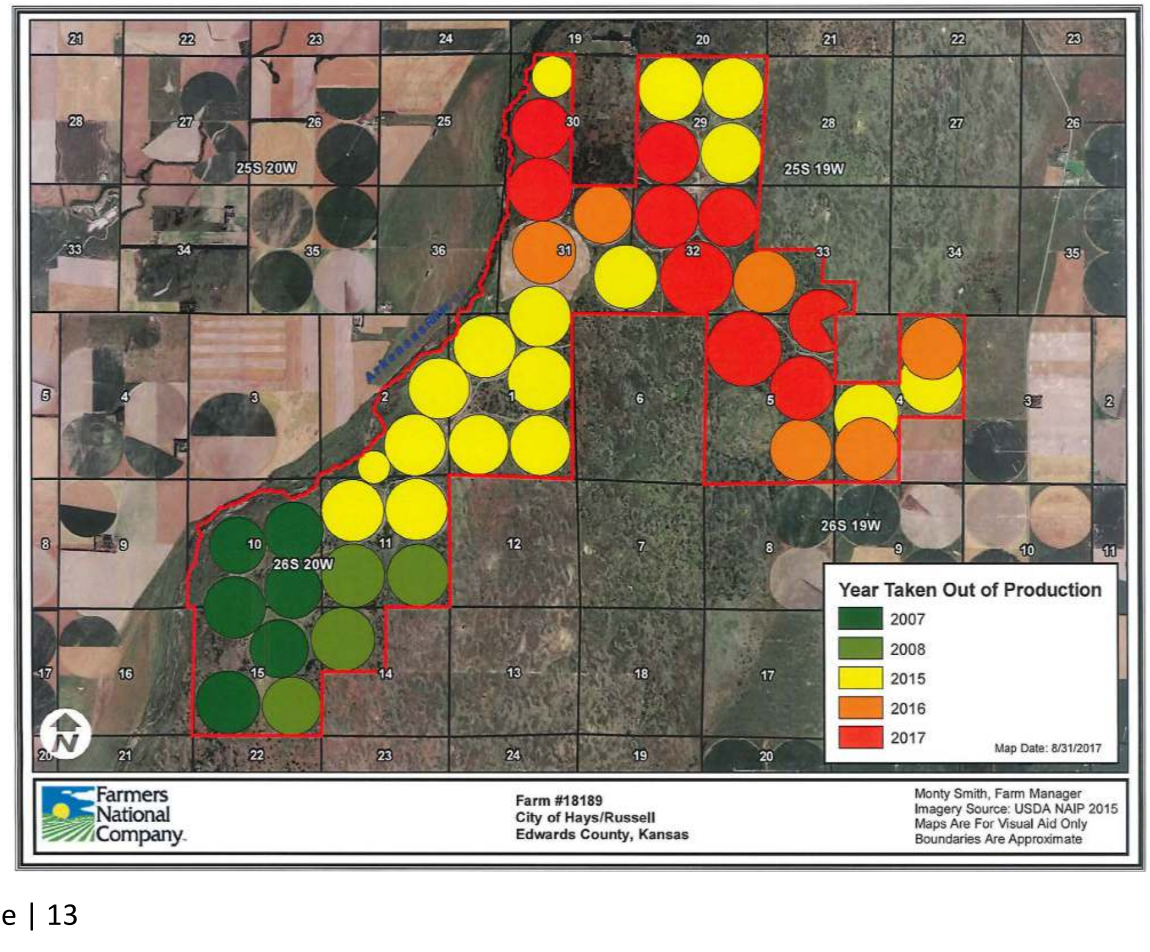


BURNS McDONNELL

Project No.
91211

File Name:
Fig 7 - 51 yr Pumping.grf

Figure 7
Simulated Recharge & Pumping
Scenarios 3, 4, and 5
51-Year Simulation



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

David W. Barfield, P.E.
Kansas Water Resources Consulting
1481 E. 660 Road, Lawrence, KS 66049
phone (785) 766-2105
David.Barfield@kwrconsulting.com

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 Kansas v. Colorado regarding the Arkansas River Compact and Kansas v. Nebraska and Colorado 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

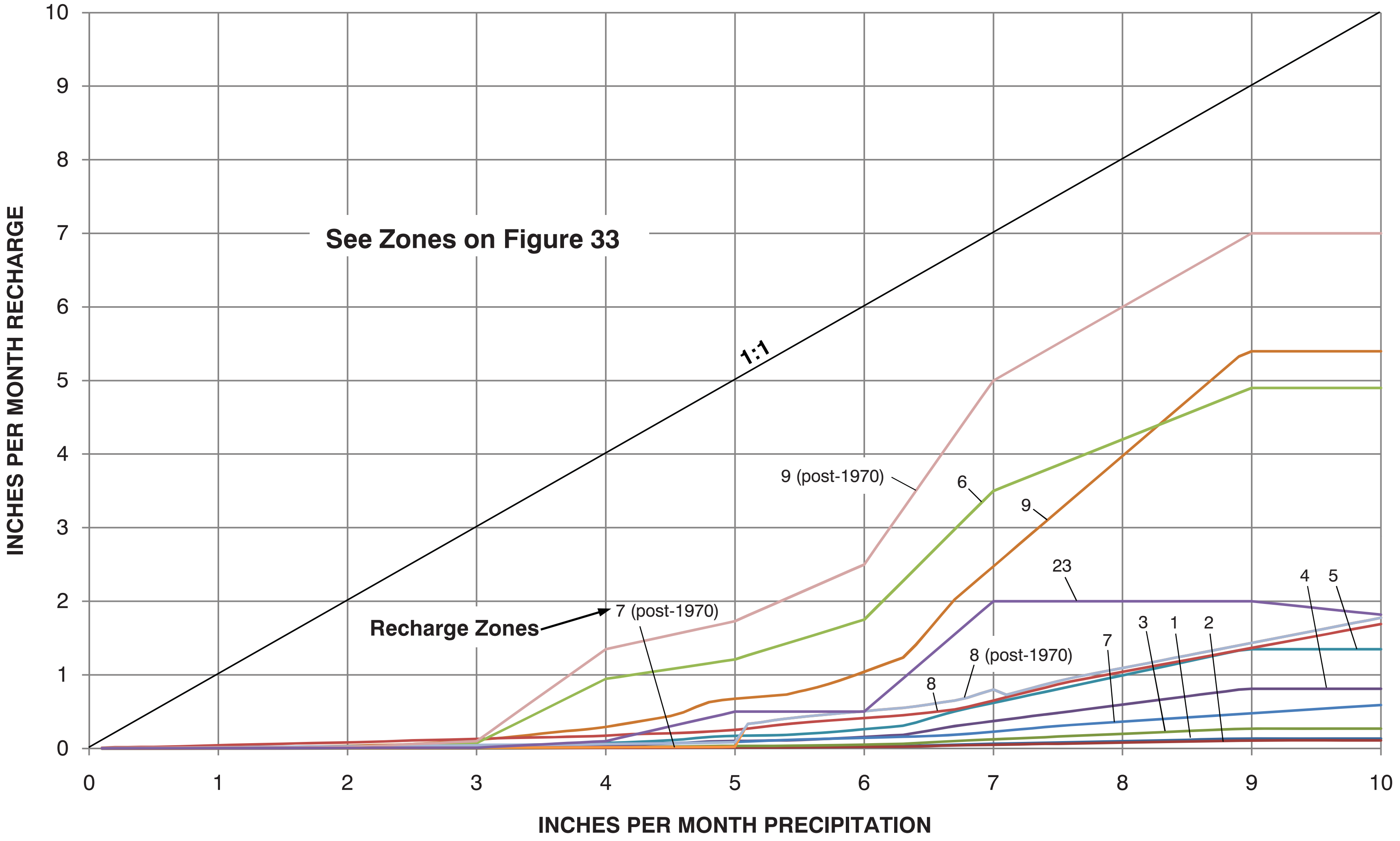
Revised: June 2023

Barfield Rebuttal Report
Attachment 2

GMD #5

MODEL

FIGURE 32
MONTHLY PRECIPITATION-RECHARGE RELATIONSHIPS



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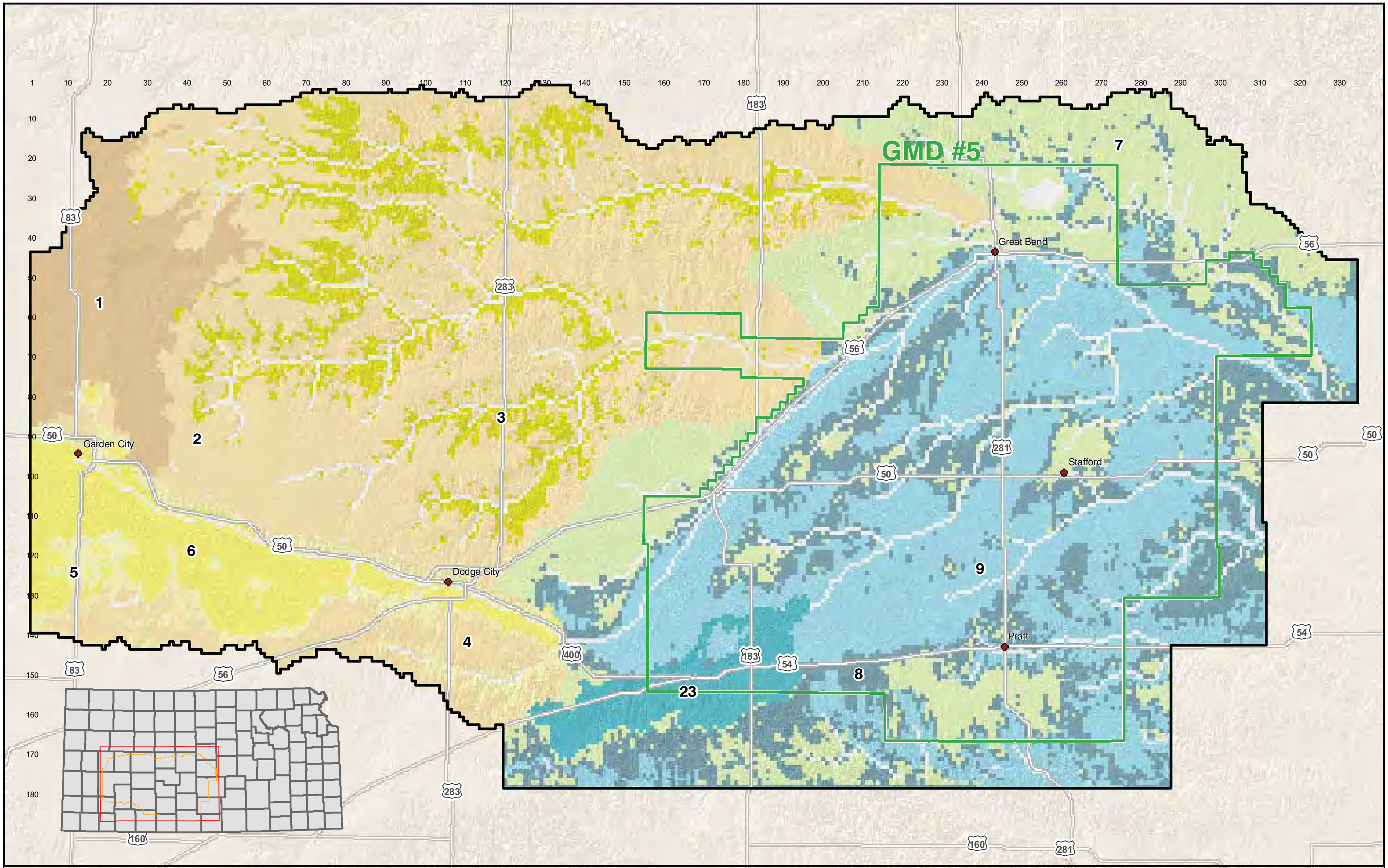
BALLEAU GROUNDWATER, INC.



EXPLANATION

Recharge Zones (See Curves on Figure 32)

1	2	3	4	5	6	7	8	9	23

0 5 10 15 20 25 Miles

N S E W

5/19/2010 ses/WPB Figure33.mxd

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 streamflow 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 streamflow 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

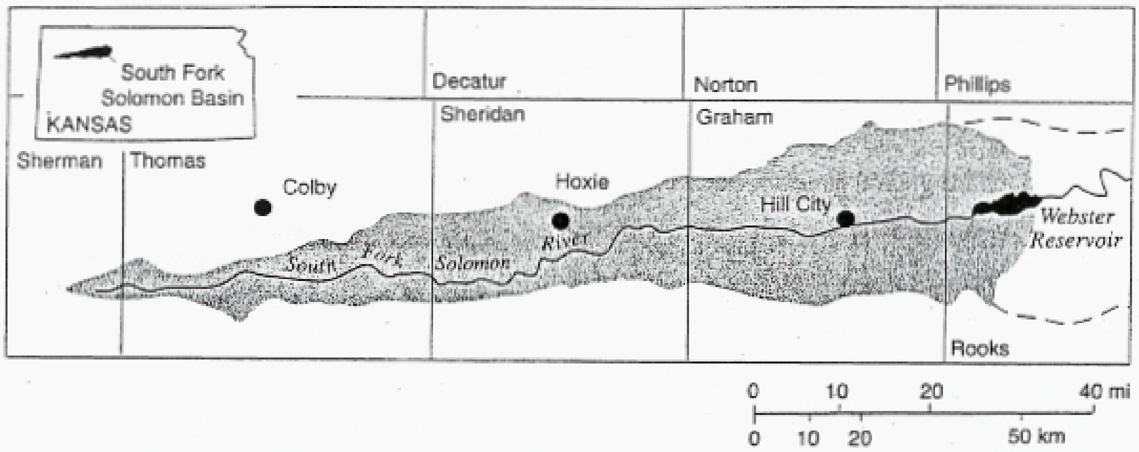


FIGURE 7.1—MAP OF THE SOUTH FORK SOLOMON RIVER BASIN (Koelliker et al., 1981).

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 northwestern 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 Reservoir. 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

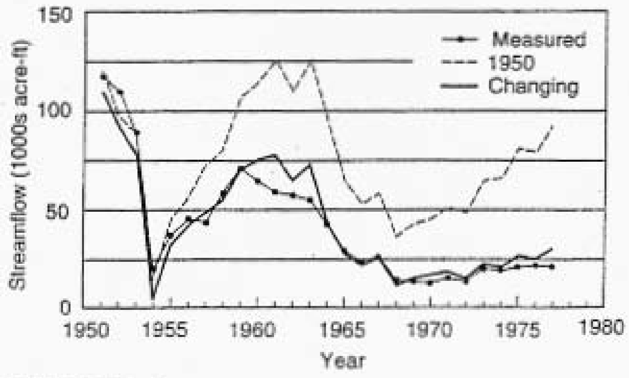


FIGURE 7.2—COMPARISON OF THE THREE-YEAR MOVING AVERAGE ACTUAL STREAMFLOW ABOVE WEBSTER RESERVOIR with streamflow predicted with changing conditions, and when 1950 conditions were held constant (adapted from Koelliker et al., 1981).

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

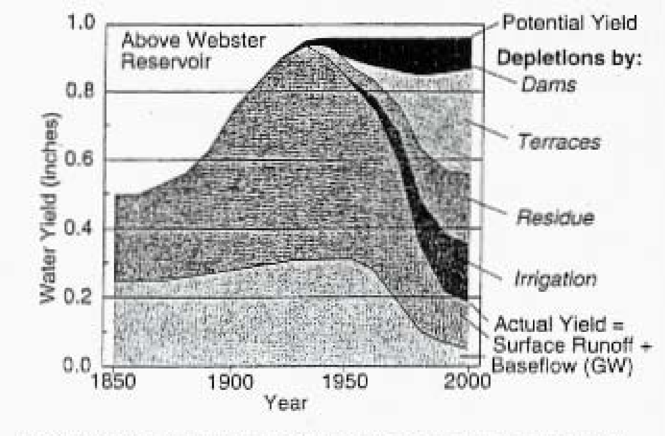


FIGURE 7.3—Historical perspective of the effect of agricultural technology on water yield above Webster Reservoir showing increases caused by conversion to cropland and depletions caused by various soil- and water-conservation practices and changes in agricultural technology (adapted from Koelliker,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

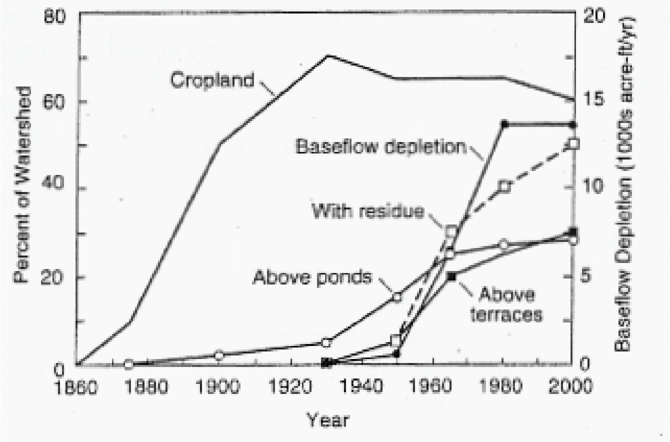


FIGURE 7.4—Historical amounts of cropland, conservation practices, and baseflow depletions in the South Fork Solomon Basin above Webster Reservoir (adapted from Koelliker, 1984).

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

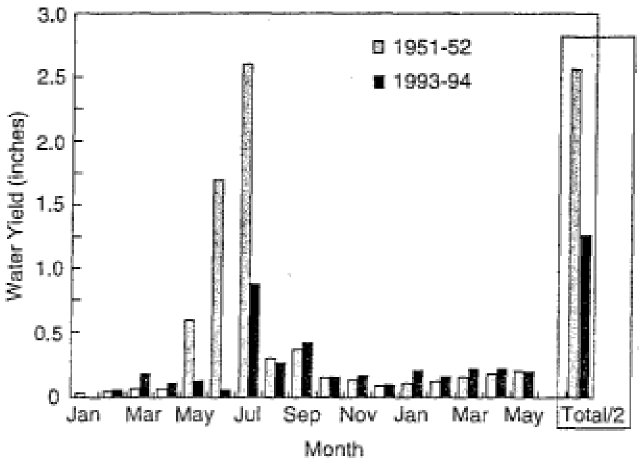


FIGURE 7.5—Comparison of monthly inflow to Webster Reservoir for the floods of 1951 and 1993.

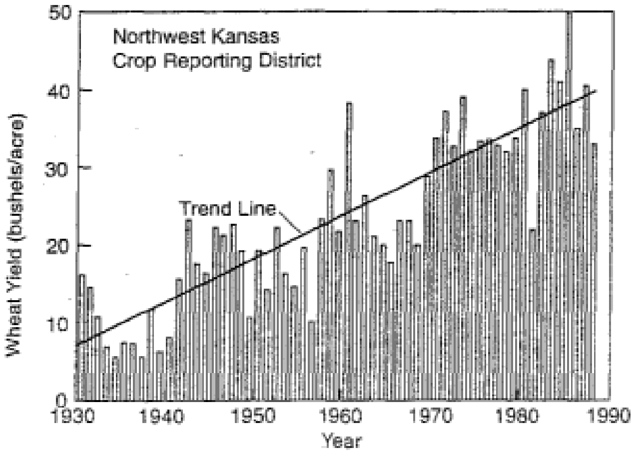


FIGURE 7.6—Dryland wheat yields in the Northwest Kansas Crop Reporting District (data from Kansas State Board of Agriculture).

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 streamfiow. 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 streamflow 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

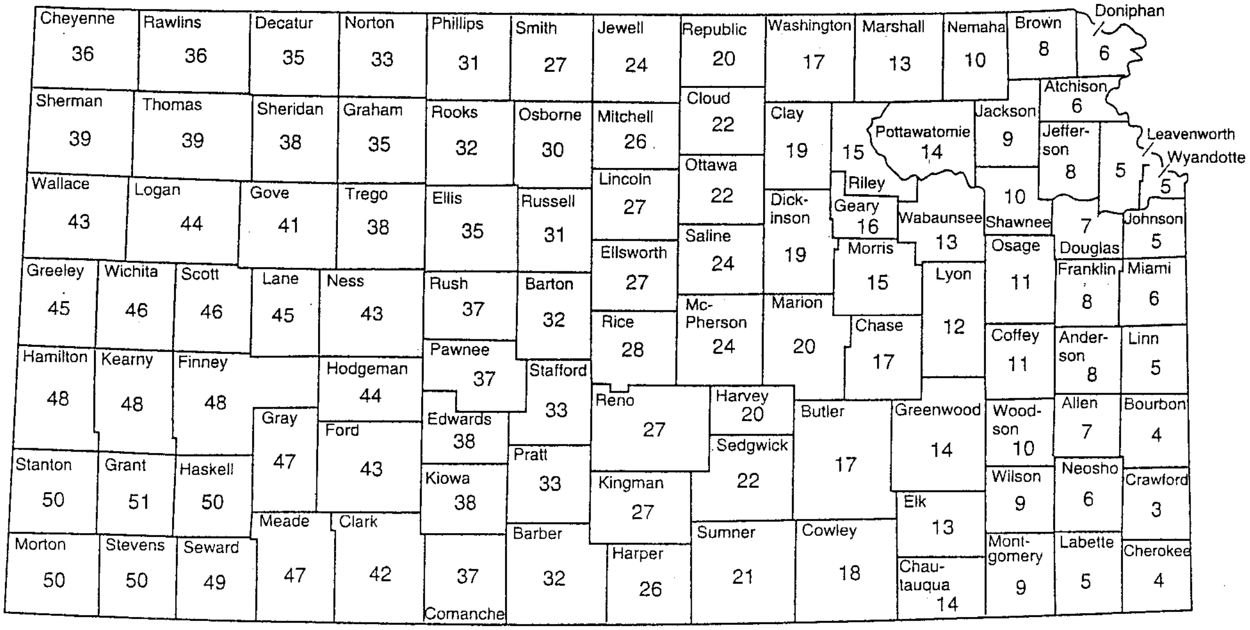


FIGURE 7.7—POTENTIAL NET Evaporation For KANSAS counties (Division of Water Resources, 1994).

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 conservation 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 evaluated. Other measures such as watershed projects and irrigation withdrawals from alluvial aquifers along streams add further to potential depletions of streanflow. 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

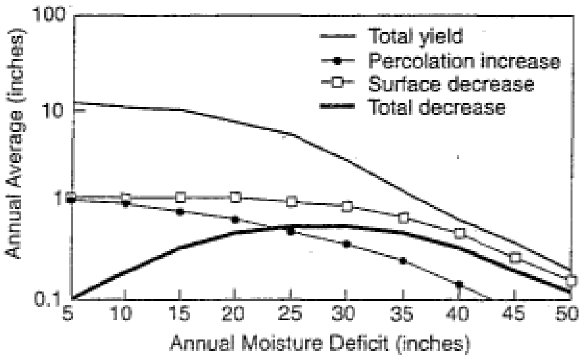


FIGURE 7.8—Simulated effects on aspects of the water budget when the RCN value for continuous wheat is reduced from 75 to 70 on a silt loam soil as related to the MD across Kansas.

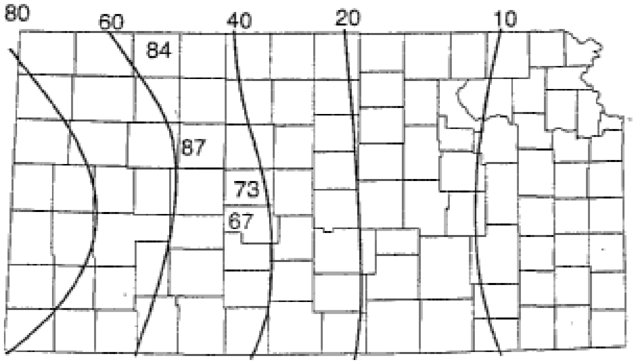


FIGURE 7.9—Generalized potential of soil and water conservation practices and agricultural technology to reduce streamflow below the amount measured in the 1930–1950 period, by percent.

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	55.65	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	42.86
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		75	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	0.30	0.00
31.	hay (alfalfa)		76	4.61	1.74	3.54	0.56	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.

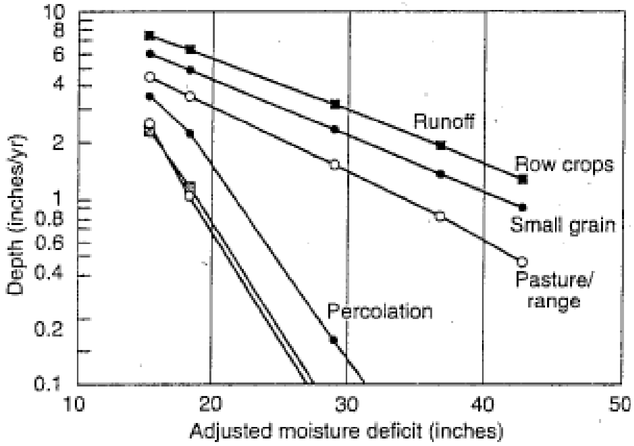


FIGURE 7.10—Simulated average annual depth of runoff and percolation from row crops and small-grain production with straight-row conservation practice compared with pasture/range as affected by moisture deficit (Koelliker, 1994b).

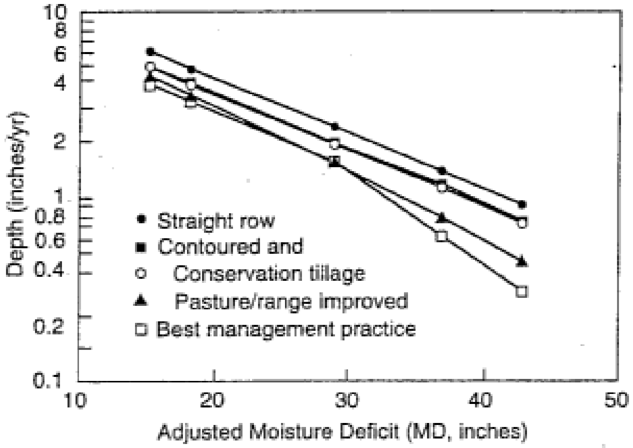


FIGURE 7.11—Comparison of simulated average annual runoff from small-grain production with various conservation practices to pasture/range as affected by moisture deficit (Koelliker, 1994b).

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

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

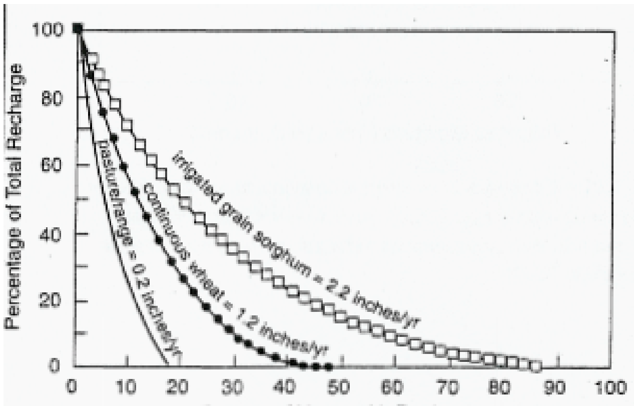


FIGURE B7.1.1—SUMMARY OF SIMULATED PERCENT OF ACCUMULATED PERCOLATION FROM THREE LAND USES AT GREAT BEND ON A SILT LOAM SOIL VERSUS THE PERCENT OF YEARS WITH PERCOLATION.

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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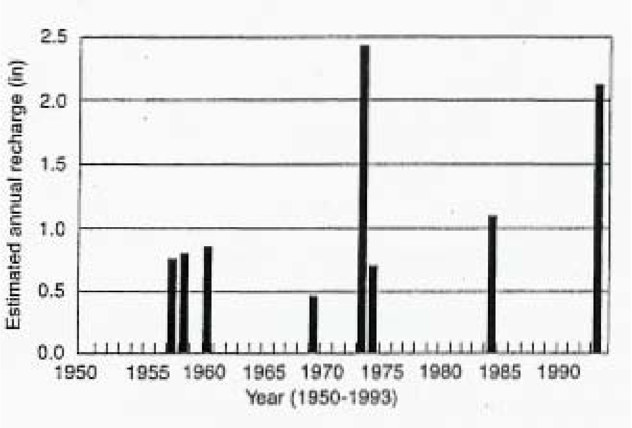

FIGURE B7.1.2—SUMMARY OF PREDICTED ANNUAL AMOUNT OF RECHARGE (PERCOLATION) FROM RANGE/PASTURE AT GREAT BEND ON A SILT LOAM SOIL.

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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 evapotranspiration (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 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.

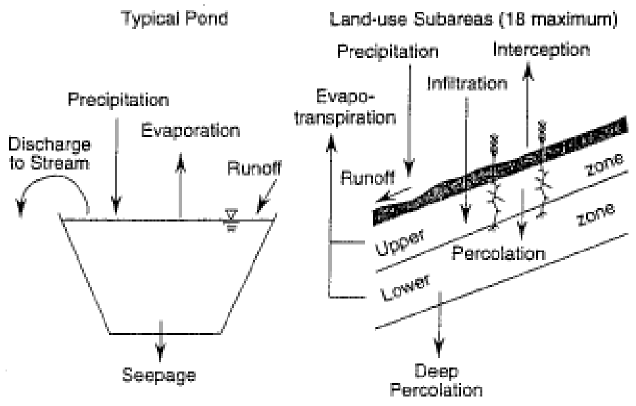


FIGURE 7.A1—Schematic of POTYLD water-budget model (adapted from Zovne and Koelliker, 1979).

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 simulated 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 relationship 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 specified 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 streamflow in order to compare with actual streamflow 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.

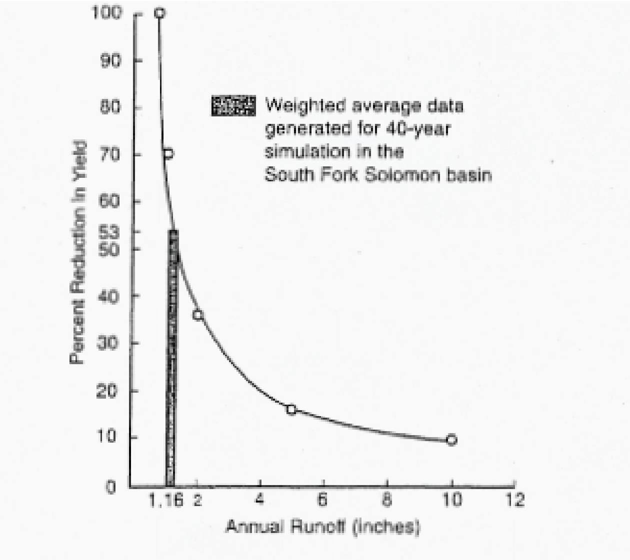


FIGURE 7.A2—Function of percent reduction in watershed yield due to ponds as a function of annual runoff in the watershed.

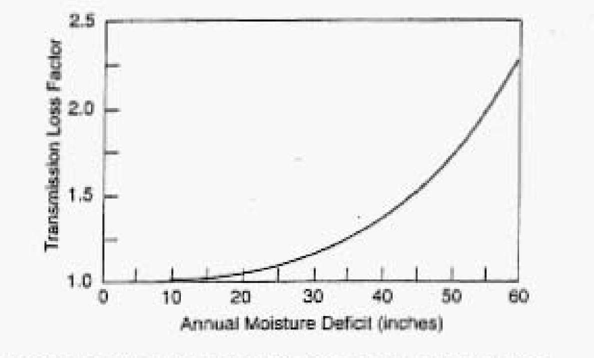


FIGURE 7.A3—Transmission loss factor for reducing upstream runoff to compare with measured runoff at a downstream streamflow gaging station [adapted by Koelliker et al. (1995) from Sharp et al. (1966)].

Attachment 4: Review of Soils information for the R9 Ranch

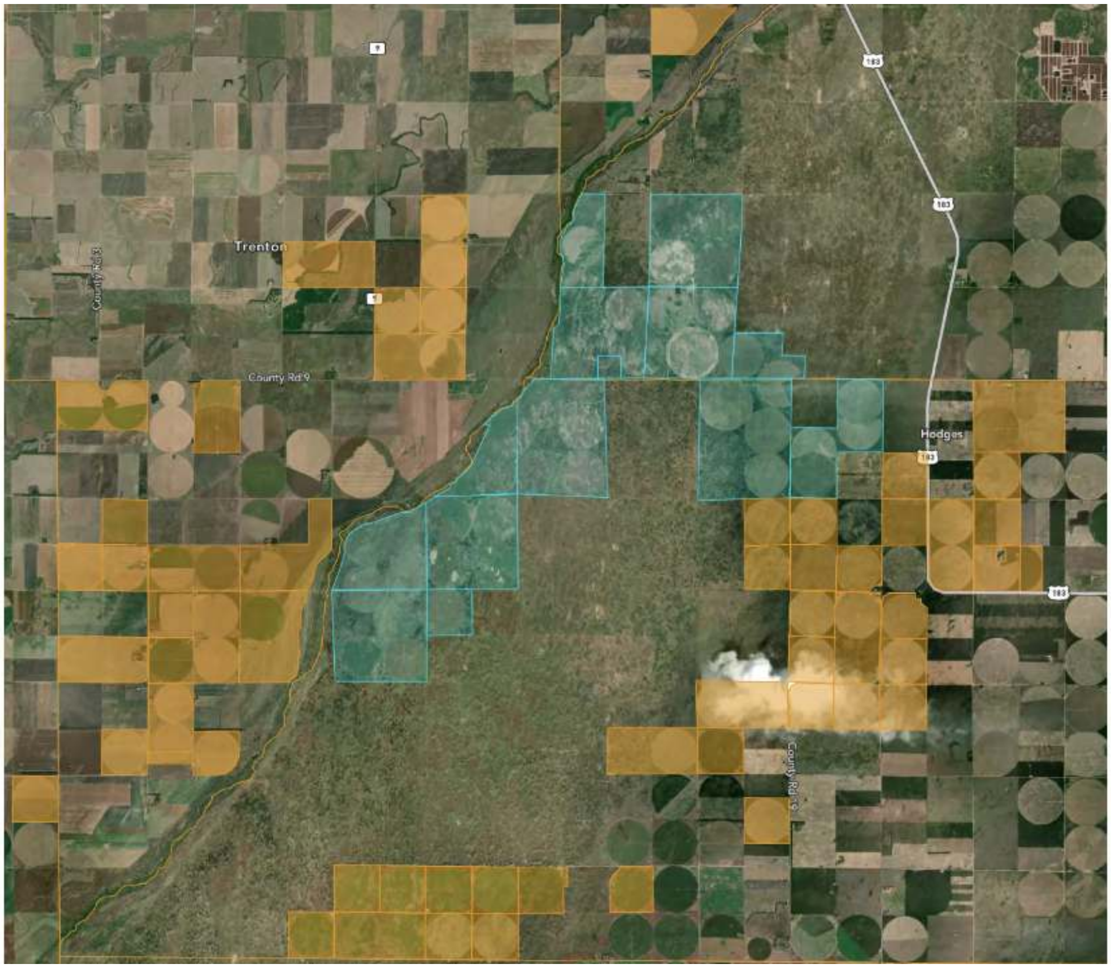
Introduction and overview

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.

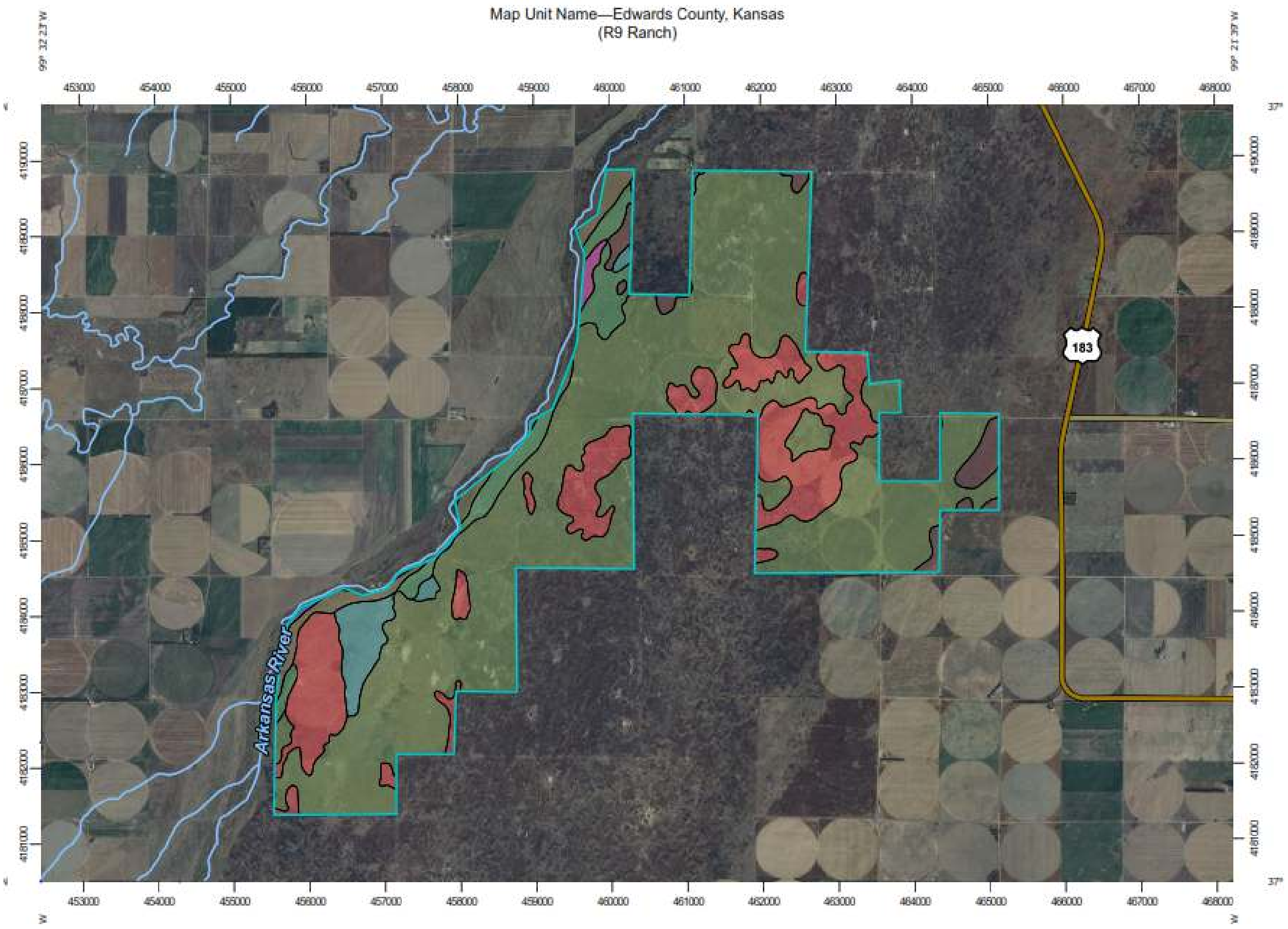
The **Soil Map Tab** was used produce the map inserted below, the summary table below of the soils of the Ranch, as well as enclosed **Exhibit 1**: **"**Map Unit Name: R9 Ranch.pdf."

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.

Part 2: Summary of September 1973 Soil Survey of Edwards County Kansas regarding dominate soils of the R9 Ranch

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

Pratt-Tivoli loamy fine sands (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.*

<u>Tivoli fine sand</u> (**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."*

<u>Pratt loamy fine sand</u>, *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.* Described 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 VIe-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.*

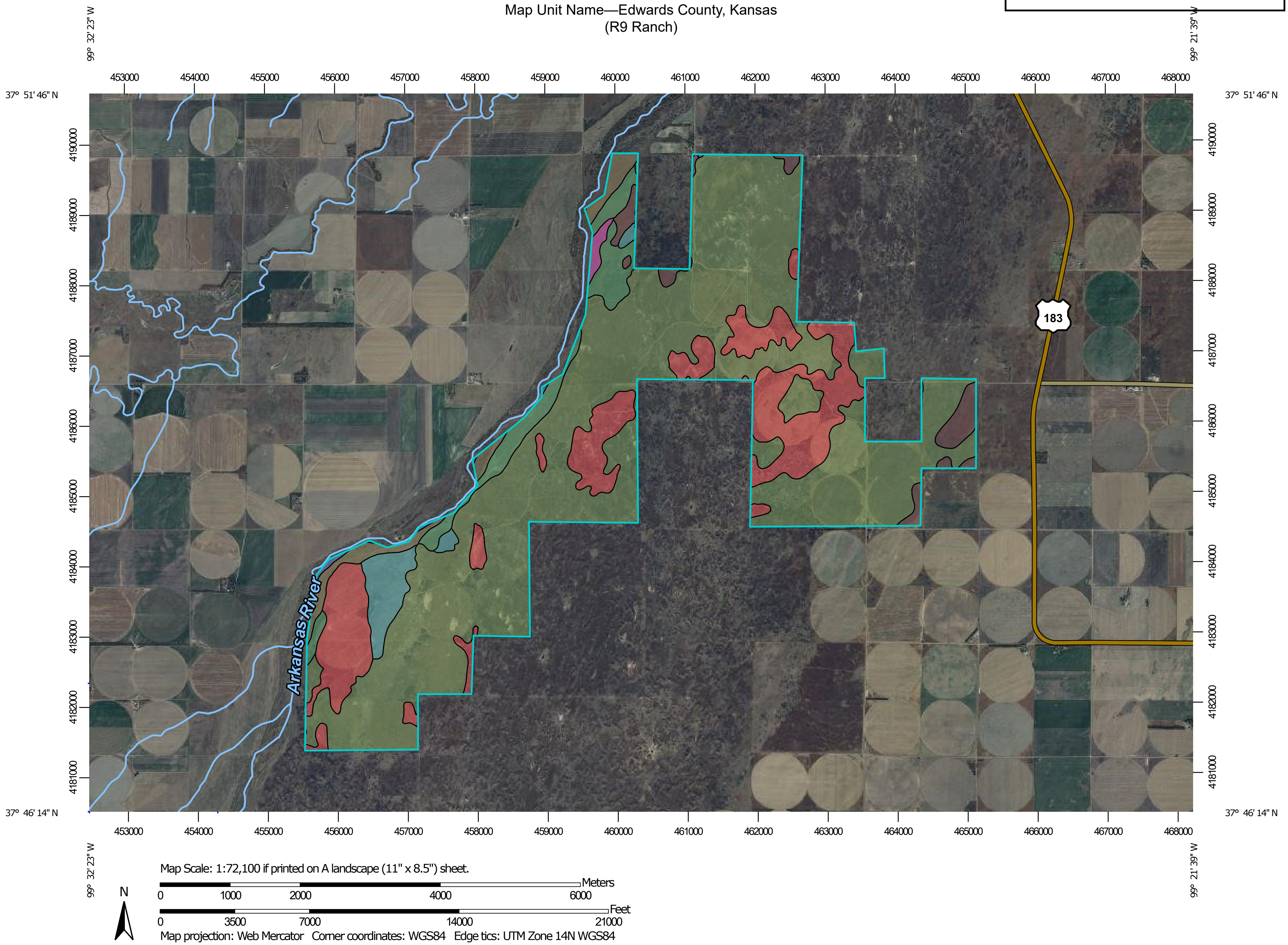
Proper range use and deferred grazing help in controlling erosion and in maintaining or increasing the more desirable native grasses. Proper location of fences, salt, and water helps distribute the livestock so that the range is grazed uniformly. Blowouts should be fenced off from livestock. Native grasses 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 Scale: 1:72,100 if printed on A landscape (11" x 8.5") sheet.

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

- ■ 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

Barfield Rebuttal Report
Exhibit 2 to Attachment 4

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

Barfield Rebuttal Report
Exhibit 3 to Attachment 4

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

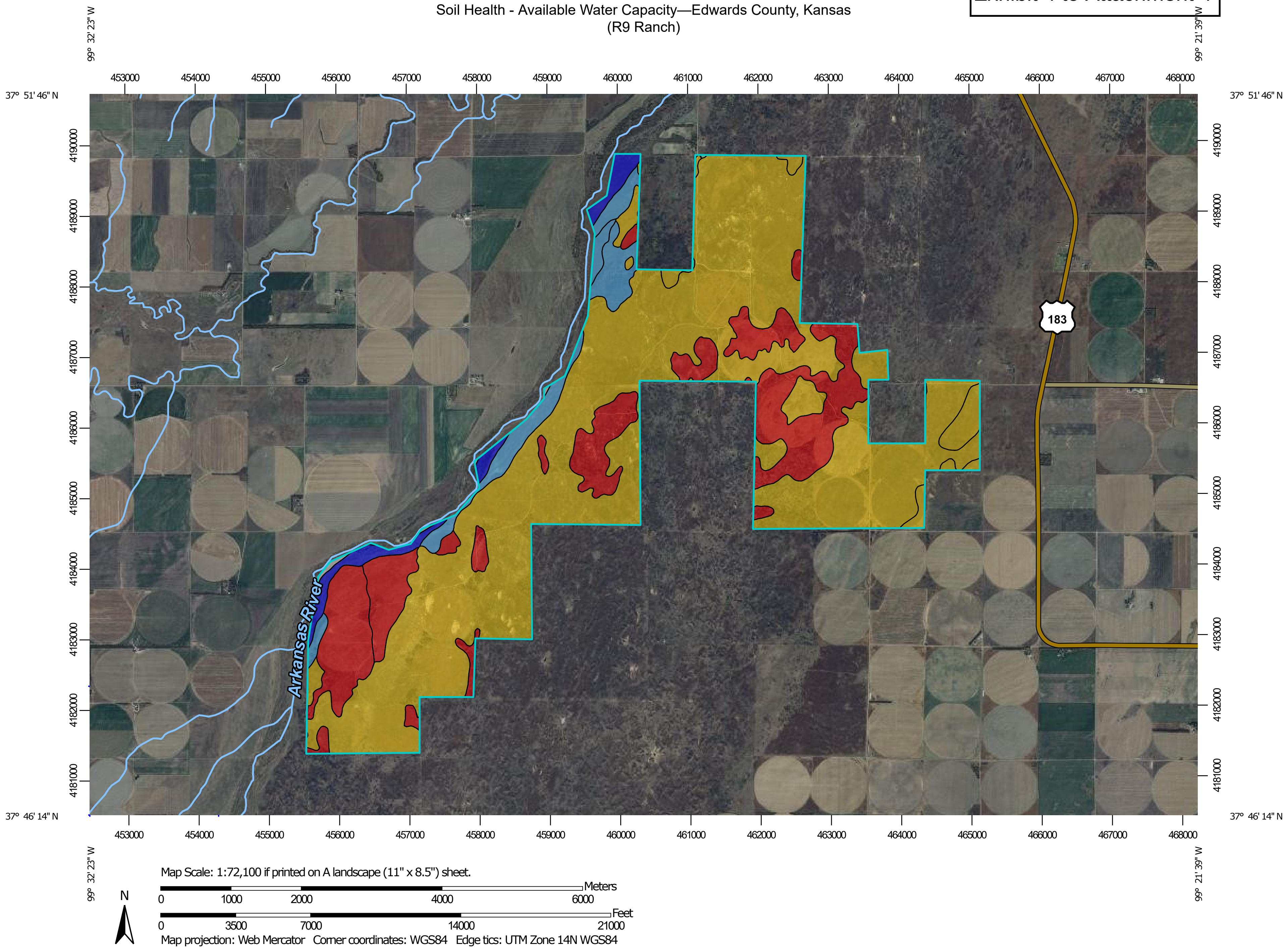
Percent of map unit: 1 percent
Landform: Depressions on interdunes on paleoterraces
Down-slope shape: Concave, linear
Across-slope shape: Concave, linear
Ecological site: R079XY133KS - Wet Subirrigated
Hydric soil rating: Yes

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.

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

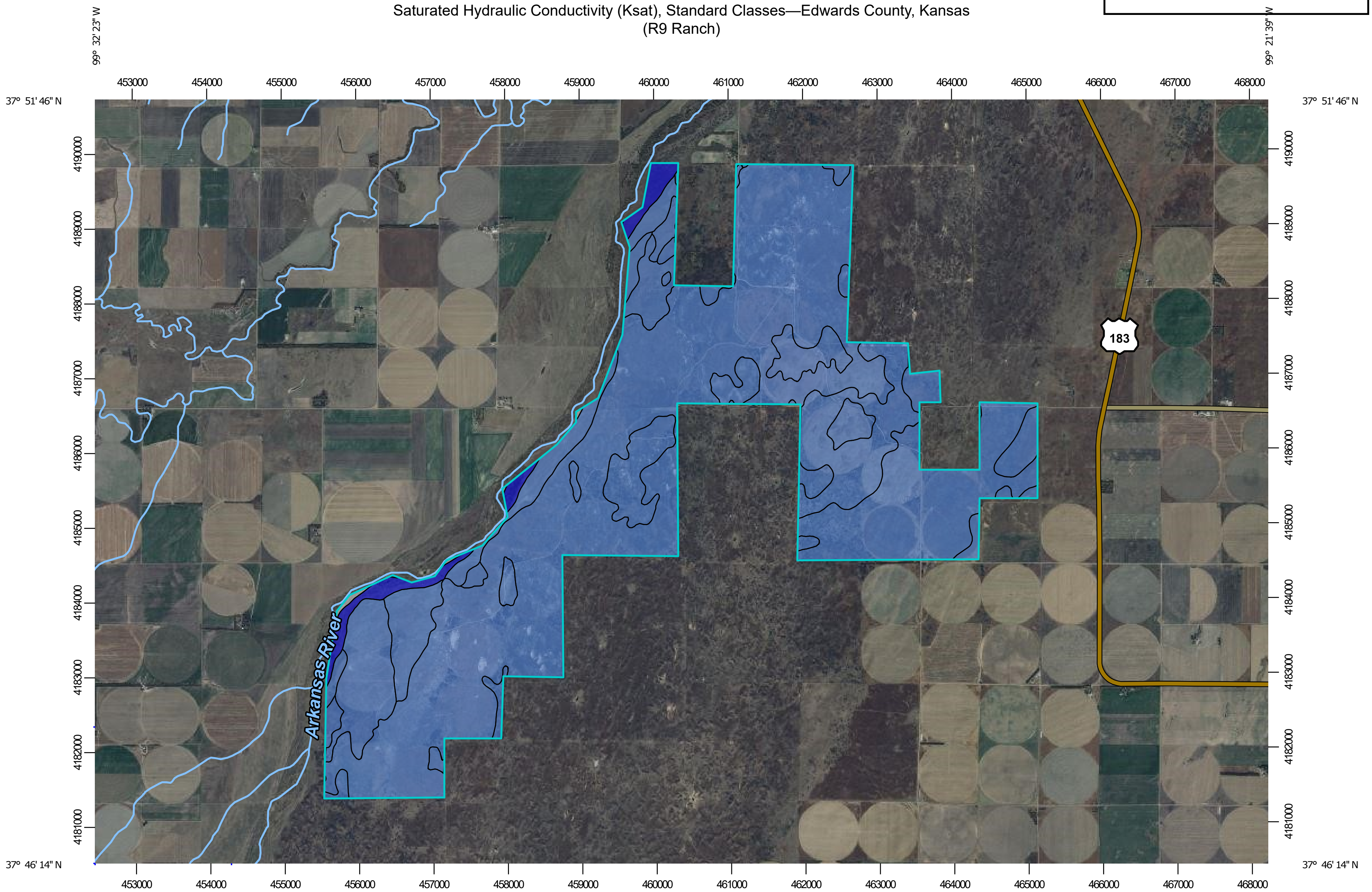
Tie-break Rule: Higher

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.

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)

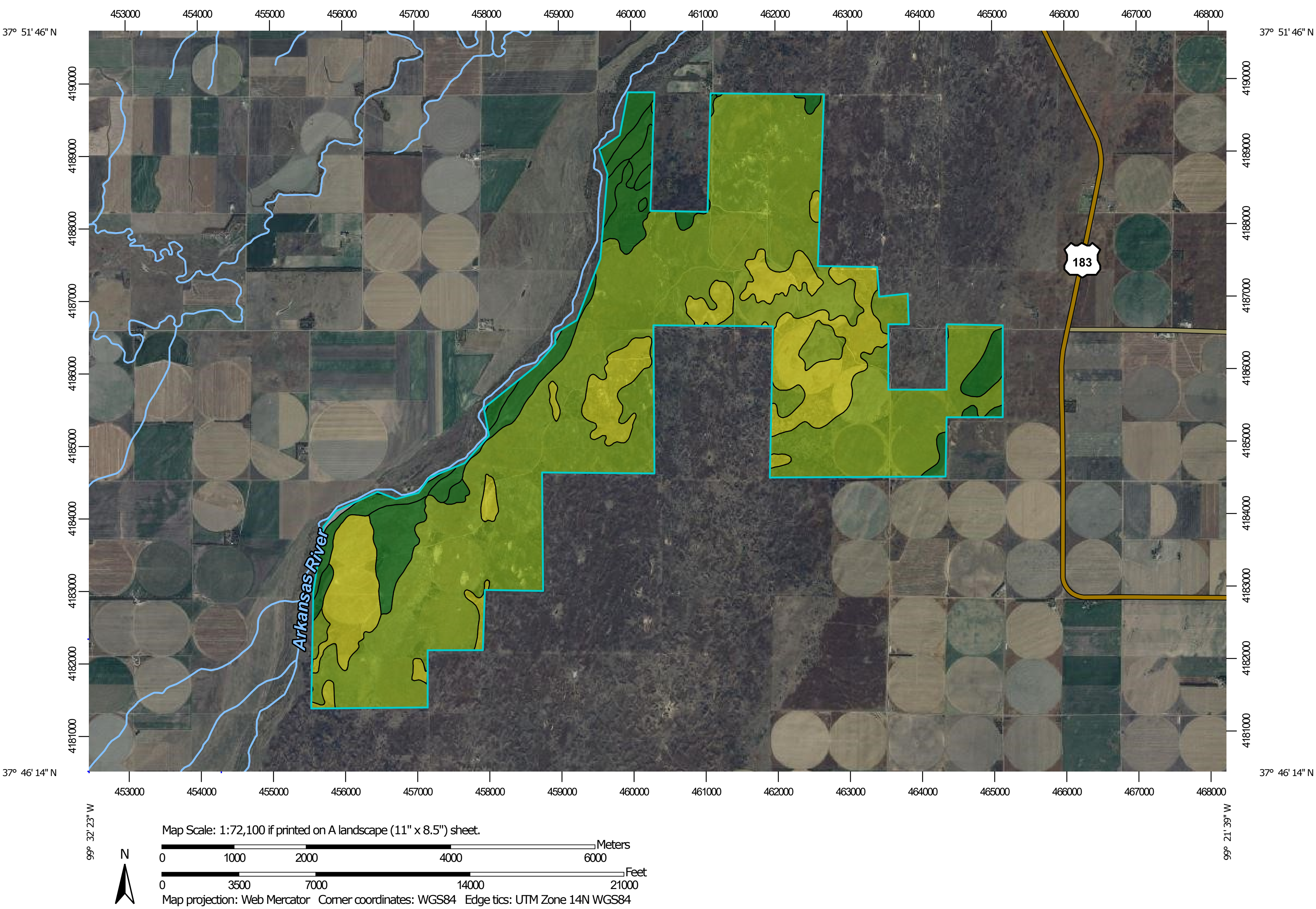
Top Depth: 0

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.

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