R9 Ranch Consumptive Use Analysis

Prepared for

Water Protection Association of Central Kansas

Prepared by

Keller-Bliesner Engineering, LLC
78 East Center
Logan, UT 84321

November 24, 2016
Corrected November 12, 2017

Keller-Bliesner Engineering, LLC
78 East Center
Logan, Utah 84321
435-753-5651 (435-753-6139 Fax)

TABLE OF CONTENTS

LIST OF TABLES .... **II**

LIST OF FIGURES .... **II**

LIST OF APPENDIX A 2012 HYDROGRAPHS AND FLOW TABLESERROR! BOOKMARK NOT DE

BACKGROUND **1**

METHODOLOGY **3**

RESULTS **5**

CONCLUSION **7**

REFERENCES **8**

APPENDIX A – RULES AND REGULATIONS KANSAS WATER APPROPRIATION ACT SECTIONS 5-5-9 AND 5-5-12 .... **9**

APPENDIX B – R9 RANCH TRANSFERABLE RIGHT PER CHIEF ENGINEER HANDOUT 24 MARCH 2016 .... **13**

APPENDIX C – CLIMATE DATA AND CONSUMPTIVE IRRIGATION REQUIREMENT (CIR) ANALYSES **16**

CONSUMPTIVE IRRIGATION REQUIREMENT (CIR) CALCULATIONS **17**

WEATHER DATA INTEGRITY ASSESSMENT **17**

- Data Filling and Parameter Assessment 17
  - Solar Radiation 20
  - Air Temperature 20
  - Dew Point Temperature 20
  - Wind 20

REFERENCE ET CALCULATIONS **23**

- Comparison of ASCE and Hargreaves ET_o 23

CROP CONSUMPTIVE IRRIGATION REQUIREMENT CALCULATIONS **25**

- Calibrated Crop ET 25
- Effective Precipitation 25
  - Effective Precipitation (Probability of Occurance) 26

RESULTS **26**

- Crop ET and CIR 26

APPENDIX D – METRIC ETRF ESTIMATION BACKGROUND AND METHODOLOGY **29**

LIST OF TABLES

Table 1. Average Crop ET, Effective Precipitation and CIR for Kinsley 1980 to 2009 5
Table 2. R9 Ranch Summary by Center Pivot Circle of Acres by GIS, Kansas Chief Engineer Preliminary Apportionment of Acres and Crop, FSA 1984 and 1985 Acres and Crop, and Average 1984 and 1985 Evapotranspiration Reduction, Ks, per METRIC Remote Sensing Analysis 6
Table C1. Climatic Data used in CIR Analysis...19
Table C2. Data Filling Summary 19
Table C3. Results of Annual Reference ET Calculations by Station (units = inches/year) 24
Table C4. Monthly Hargreaves ET_o Calibration Coefficients (CC_i = Monthly ASCE ET_o Divided by Monthly Hargreaves 1985 ET_o) 24
Table C5. Usable Soil Water Storage Values Used in Effective Precipitation Calculations......26
Table C6. Crop Curve Parameters for CIR Calculations 27
Table C7. Average Crop ET, Effective Precipitation and CIR for Kinsley 2E 1980 to 2009......28
Table C8. Average Prairie Grass ET, Annual Precipitation, Effective Precipitation and Deep Percolation for Kinsley 2E 1980-2009...28
Table D1. Landsat 5 Scene Dates and Row and Path Used for 1984 and 1985 METRIC ET Mapping 31

LIST OF FIGURES

Figure 1. R9 Ranch Layout..2
Figure 2. Map of the ETrF for the Area of R9 Ranch from the METRIC Model for May 25, 1984 Landsat 5 row 29 path 34 4
Figure C1. Annual Plots of Daily Solar Radiation with Simple and Complex Clear-Sky Shortwave Solar Radiation Envelope Curves 21
Figure C3. Plot of Minimum Temperature–Dew Point Temperature, Dodge City Reg. Airport ..22
Figure C4. Cumulative Wind Run using Raw Data, Anemometer Height: 33-ft (4/21/1961-10/16/1990) 26-ft (10/17/1990-8/31/1992) 33-ft (9/1/1992-Curent) Dodge City Regional AP 22
Figure C5. Cumulative Wind Run with Wind Data Adjusted to a 2-meter Anemometer Height Dodge City Regional AP..23

R9 Ranch Consumptive Use Analysis

BACKGROUND

The Cities of Hays and Russell, Kansas are applying to transfer irrigation water rights they own on the R9 Ranch (Figure 1) in southwestern Edwards County to municipal use in the two cities approximately 70 miles north of the ranch.

Kansas Administrative Regulations (K.A.R.) article 5-5-9 (see Appendix A of this report for K.A.R. excerpt) limits the quantity of water that can be transferred from irrigation to any other type of beneficial use to "the net consumptive use from the same local source of water supply by the original irrigation".

"The maximum annual quantity of water to be allowed by the change approval shall be the net irrigation requirement (NIR) for the 50% chance rainfall for the county of origin, as set forth in K.A.R. 5-5-12, multiplied by the maximum acreage legally irrigated under the authority of the water right in any one calendar year during the perfection period (K.A.R. 5-5-9(a)(1))." According to K.A.R. 5-5-12, the NIR for the 50% chance rainfall for Edwards County is 13 inches (1.08 ac-ft/ac). (See Appendix A.)

The Cities are requesting per acre transfer quantities of 18.9 inches (1.57 ac-ft/ac) for corn and 20.9 inches (1.74 ac-ft/ac) for alfalfa. Initial findings from the Chief Engineer's office, while indicating they are per K.A.R 5-5-9, offer primarily but not consistently, 13 inches (1.08 ac-ft/ac for corn and 18.0 inches (1.50 ac-ft/ac) for alfalfa. (See Appendix B – R9 Ranch Transferable Right per Chief Engineer handout 24 March 2016.)

It is doubtful that the R9 Ranch's historical consumptive water use was on par with other irrigated properties in Edwards County because of its sporadic farming history and the very low water-holding capacity of its soils. Consequently, the Water Protection Association of Central Kansas (Water PACK) is concerned that the out-of-the-basin transfer, as set forth in K.A.R. 5-5-9 subsection (a) and, particularly the preliminary (24 March 2016 handout) of the Chief Engineer's Office, could impair member water rights and have other negative hydrologic and socio-economic impacts in the vicinity of the ranch.

K.A.R. 5-5-9 subsection (c) states, "if the methods set forth in subsection (a) produce an authorized annual quantity of water which appears to be unrealistic and could result in impairment of other water rights, the chief engineer shall make a site-specific net consumptive use analysis to determine the quantity of water which was actually beneficially consumed under the water right." (See Appendix A of this report.) Accordingly, Water PACK contracted Keller-Bliesner Engineering, LLC (KB) to perform a site-specific consumptive use analysis of the R9 Ranch. This report documents that study.

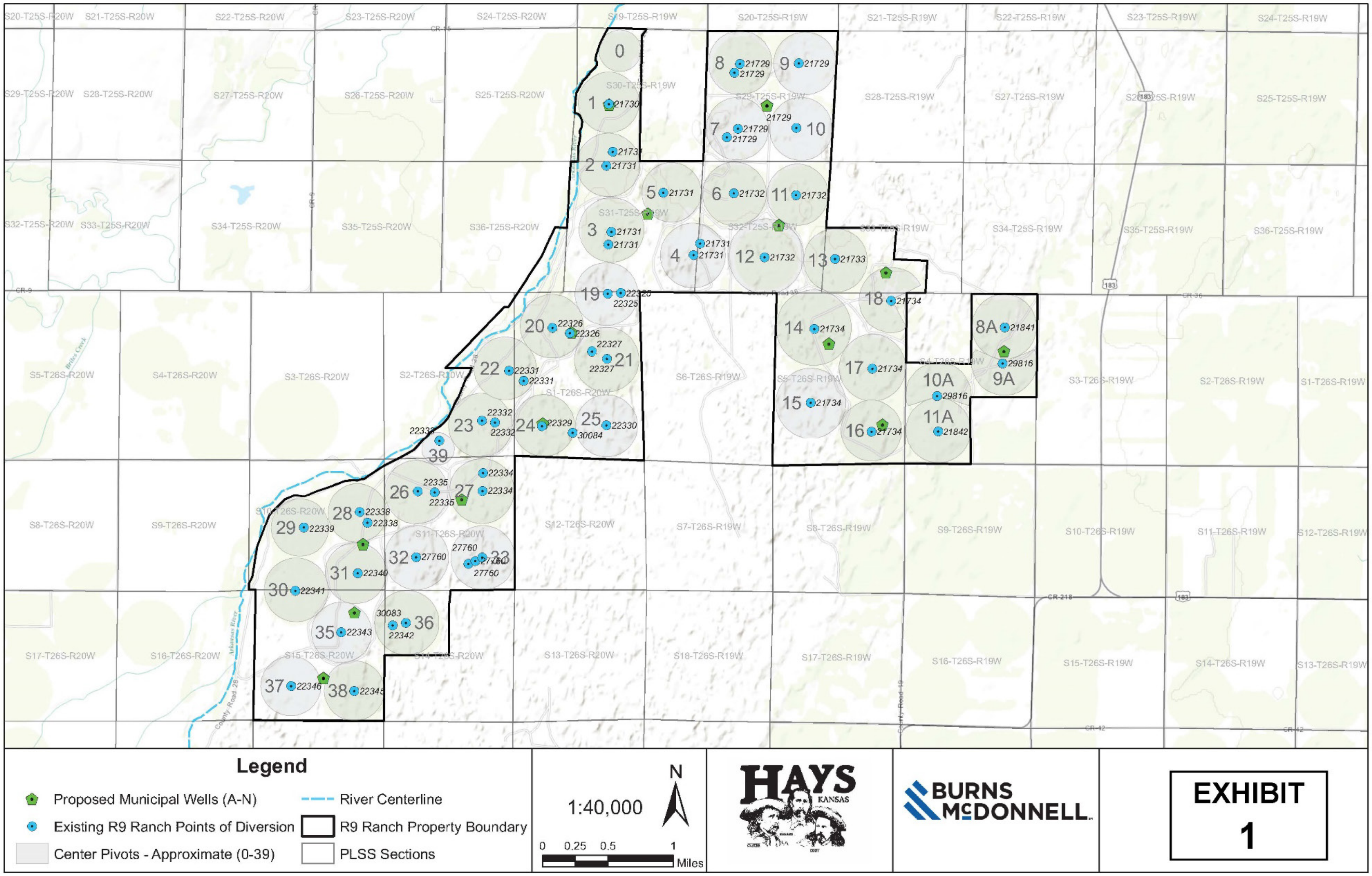

Figure 1. R9 Ranch Layout.

METHODOLOGY

The net consumptive irrigation use is calculated by subtracting the effective rainfall depth from the actual evapotranspiration (ET) under irrigation. Because the effective rainfall is greater under post-transfer dryland/natural grassland conditions than under pre-transfer irrigated conditions (i.e. more rainfall is consumed by dryland/natural grasslands than irrigated land), the effective rainfall used in the net consumptive irrigation use calculation for transferable water should be equivalent to the consumptive use under dryland conditions. This is the approach we (KB) used in this consumptive use study to calculate the transferable water to the cities of Hays and Russel, Kansas from drying up irrigation on the R9 Ranch.

We used the ASCE Standardized Reference Evapotranspiration Equation (Allen, 2005) for estimating reference evapotranspiration (ETr) at Dodge City, Kansas, Regional Airport where the required climate data (maximum and minimum temperature, maximum and minimum humidity or dew point, wind, and solar radiation) were available. We then calibrated the 1985 Hargreaves (H85) evapotranspiration equation, which only requires maximum and minimum temperature, to the ASCE Standardized ETr at Dodge City. Next we used this calibrated H85 equation with 1980-2009 temperature data from Kinsley, Kansas, to estimate the associated 30-year potential crop evapotranspiration (ETc) for alfalfa and corn at Kinsley. Finally, we calculated the 30-year consumptive irrigation requirement (CIR) for alfalfa and corn at Kinsley by computing and subtracting the effective precipitation at 50% and 80% probabilities. (See Appendix C of this report for details on the ETr methodology, climate data analysis, H85 calibration, and calculation of ETc, effective precipitation, and CIR for alfalfa and corn at Kinsley.)

The computed ETc and CIR represent the evapotranspiration and consumptive irrigation requirement for crops grown under standard conditions. "The standard conditions refer to crops grown in large fields under excellent agronomic and soil water conditions." (Allen et. al., 1998) The soils on the R9 Ranch are "Tivoli Fine sand" and "Pratt-Tivoli loamy fine sands" with very low-water holding capacities. Standard conditions usually cannot be maintained on such soils and the actual evapotranspiration (ETa) will be less than ETc. We used the METRIC model to map ETa during the growing seasons for eight days in 1984 and seven days 1985 from historical Landsat 5 TM satellite data. (See Appendix D for details.)

The ratio of ETa to ETr, referred to as ETrF, ranges between zero and the maximum crop coefficient of 1.2 for crops at full cover under standard conditions. A map of the ETrF for the area of R9 Ranch from the METRIC model for May 25, 1984 Landsat 5 row 29 path 34 is presented in Figure 2.

We computed the average soil moisture stress for each center pivot circle on the R9 Ranch for 1984 and 1985 as the ratio of the maximum ETrF within each circle to the average ETrF for the buffered[1] circle. If the maximum ETrF for a circle for all dates in a year was less than 1.2 (the maximum crop coefficient), we adjusted the computed stress factors for the circle and year by multiplying by the ratio of the maximum ETrF for the year to 1.2.

[1] To avoid the effects of thermal contamination around the outer edge of each circle we buffered each circle by the satellite image pixel dimension of 30 meters.

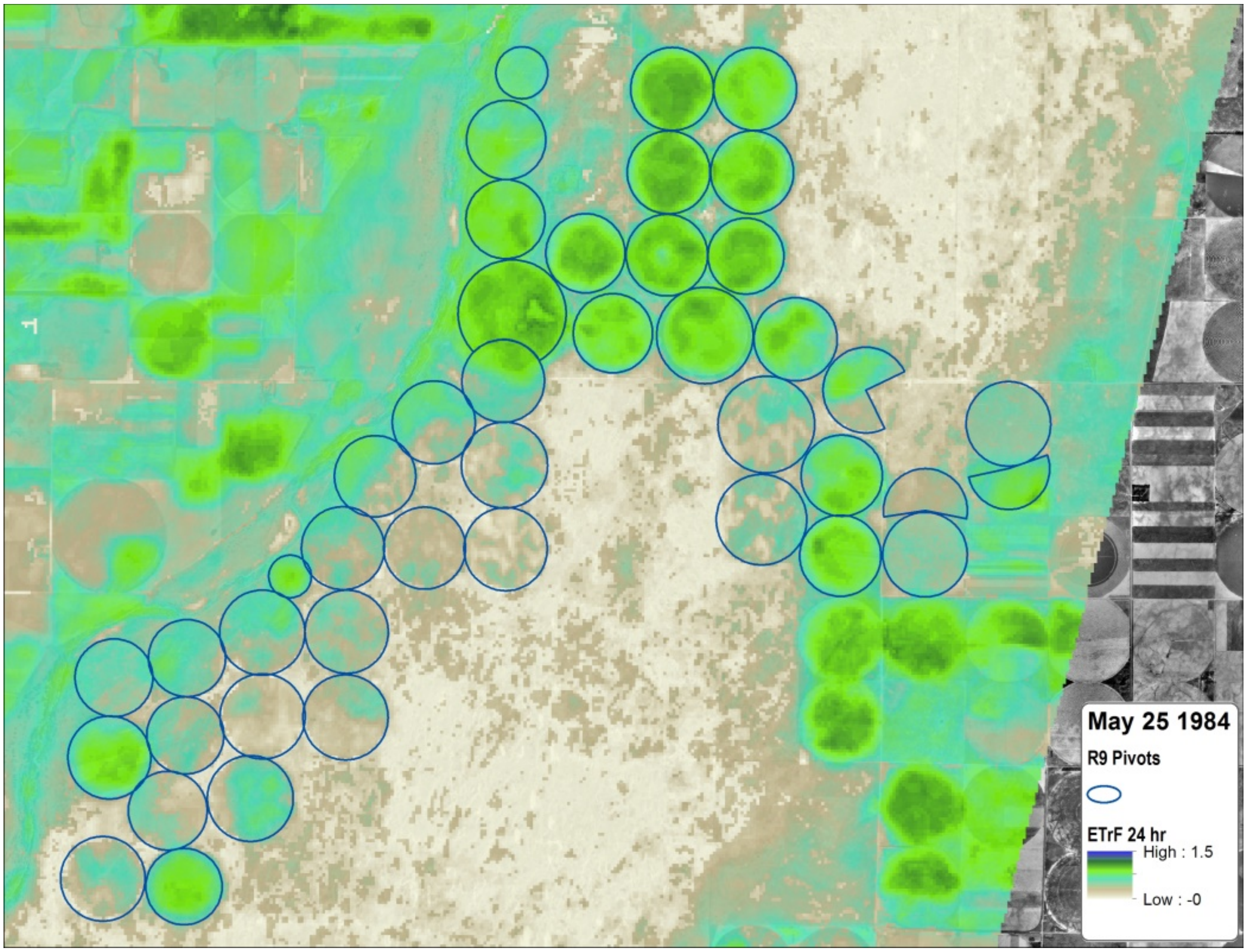

Figure 2. Map of the ETrF for the Area of R9 Ranch from the METRIC Model for May 25, 1984 Landsat 5 row 29 path 34

We then calculate the net consumptive irrigation[2] by multiplying the crop ET (ETc) from the climatic analysis by the mean water stress obtained for the METRIC remote sensing analysis and subtracting the natural prairie grassland evapotranspiration. We conducted a daily soil water balance for January 1, 1980 through December 31, 2009 to determine the natural grassland evapotranspiration. This soil water balance limits the grassland ET to the available soil water from precipitation storage with in the grass root zone and accounts for moisture stress and the resulting reduction in grassland ET as the soil water is depleted. (See Appendix C for details.)

[2] The transferable water to the cities of Hays and Russel, Kansas from drying up irrigation on the R9 Ranch is limited to the net consumptive irrigation to be hydrologically neutral at the source.

Table 1. Average Crop ET, Effective Precipitation and CIR for Kinsley 1980 to 2009

Units = inches	Kinsley 2E (NWS) (1980-2009)				
Crop	Crop ET	50% Probable Effective Precipitation	80% Probable Effective Precipitation	Crop CIR (using 50% Probable Effective Precipitation)	Crop CIR (using 80% Probable Effective Precipitation
Alfalfa Hay	46.0	15.4	12.5	30.6	33.5
Grain Corn	35.9	12.2	10.0	23.7	25.9

RESULTS

Summary results of the 30-year (1980-2009) climate based crop evapotranspiration and consumptive irrigation requirement (CIR) analysis for alfalfa hay (five cuttings) and grain corn for Kinsley, Kansas are given in Table 1. The 1984 and 1985 METRIC remote sensing ET fraction analysis, FSA cropping pattern and irrigated area, and Chief Engineer's allowed crop and irrigated area for the R9 Ranch center pivot circles are summarized in Table 2.

The METRIC remote sensing mapping of actual evapotranspiration (Eta) to full crop evapotranspiration (ETc) is the Ks fraction averaged for 1984 and 1985 by center pivot circle in Table 2. Ks values close to 1 indicated little stress, i.e. ETa is close to ETc, while smaller fractions indicated greater stress. We equate Ks to water stress, primarily as a result of the difficult sandy soils on the ranch, but other crop factors, e.g. agronomic and environmental, could be reducing crop water use. Because the Ks is greater (lower fraction) for crops other than alfalfa, it also may be that the irrigation and/or well pumping capacity was insufficient to keep up with the full water requirements of the ranch and priority was given to the alfalfa. Alfalfa also has a deeper root system than other crops once established and, therefore, greater access to stored soil water to better meet full ET requirements. The average Ks for alfalfa for 1984 and 1985 was 0.79 and for other crops 0.63. However, because we are not certain of the reason for the difference in Ks between crops, we took the average for all circles for both years, 0.72.

The 30-year average annual CIR for grain corn at 50% probable effective precipitation is 23.7 inches (see Table 1). This is considerably greater than the NIR at 50% rainfall probability of 13.0 inches for Edwards County given in K.A.R. 5-5-12. However, when the average grain corn ETc of 35.9 inches (Table 1) is multiplied by the average water stress factor from the METRIC remote sensing analysis (0.72 from Table 2) and the 50% probable effective precipitation (12.2 inches from Table 1) is subtracted, the result is nearly identical, 13.6 inches versus 13.0 inches.

The prairie grass daily soil water balance for January 1, 1980 through December 31, 2009 resulted in an average grassland annual consumptive use of 21.1 inches out of an annual average of 26.3 inches of precipitation with the balance, 5.2 inches, of precipitation going to groundwater recharge. It is presumed here that with time the center pivot circles dried up with the transfer of irrigation water rights to Hays and Russell, Kansas, will revert back to grasslands. Accordingly, the effective precipitation to use in the net consumptive use analysis for the water transfer should be that of the grass land consumptive use of precipitation. In other words, we estimate the annual average effective precipitation under water transfer conditions on the R9 Ranch will be 21.1 inches, as opposed to the 15.4 inches for irrigated alfalfa and 12.2 inches for irrigated corn (Table 1).

Table 2. R9 Ranch Summary by Center Pivot Circle of Acres by GIS, Kansas Chief Engineer Preliminary Apportionment of Acres and Crop, FSA 1984 and 1985 Acres and Crop, and Average 1984 and 1985 Evapotranspiration Reduction, Ks, per METRIC Remote Sensing Analysis

Circle No.	GIS Acres	Chief Engineer Acres	Chief Engineer Crop	FSA Acres	1984 FSA Crop	1984 METRIC Ks	1985 FSA Crop	1985 METRIC Ks
0	48.6	49	alfalfa	54.2	wheat	0.75	alfalfa	0.92
01	109.6	114	alfalfa	118.8	wheat	0.81	alfalfa	0.82
02	108.9	114	alfalfa	127.7	wheat	0.75	alfalfa	0.81
03	191.6	212	alfalfa	267	alfalfa	0.75	alfalfa	0.69
04	102.1	114	alfalfa	121.1	alfalfa	0.70	alfalfa	0.71
05	98.3	114	alfalfa	106.3	alfalfa	0.73	alfalfa	0.81
06	119.3	121	alfalfa	122.5	alfalfa	0.83	alfalfa	0.88
07	115.8	125	alfalfa	126.9	alfalfa	0.78	alfalfa	0.88
08	112.7	125	alfalfa	125.9	alfalfa	0.85	alfalfa	0.90
08A	115.1	130	alfalfa	130	alfalfa	0.83	alfalfa	0.83
09	113.8	125	alfalfa	124.6	alfalfa	0.84	alfalfa	0.79
09A	73.9	61	alfalfa	61	alfalfa	0.80	alfalfa	0.87
10	84.5	125	alfalfa	123	alfalfa	0.85	alfalfa	0.84
10A	71.7	64	alfalfa	64	alfalfa	0.64	alfalfa	0.85
11	102.2	105	alfalfa	108.3	alfalfa	0.90	alfalfa	0.89
11A	123.2	130	alfalfa	130	alfalfa	0.79	alfalfa	0.84
12	125.0	169	alfalfa	157.2	alfalfa	0.76	alfalfa	0.78
13	112.2	126	alfalfa	115.5	alfalfa	0.77	na	0.78
14	158.0	170	alfalfa	162.8	wheat	0.51	na	0.59
15	150.8	148.7	corn	148.7	not farmed	0.69	na	0.77
16	108.2	120	corn	121	alfalfa	0.80	na	0.80
17	120.8	120	corn	125	alfalfa	0.78	na	0.75
18	92.3	100	alfalfa	101.5	milo	0.67	na	0.72
19	116.3	124	alfalfa	74.9	milo	0.71	alfalfa	0.54
20	115.0	125	corn	121.2	wheat	0.72	alfalfa	0.72
21	119.4	135	corn	127.5	wheat	0.65	wheat	0.55
22	112.9	120	alfalfa	118.7	wheat	0.62	wheat	0.59
23	111.4	125	corn	122.2	wheat	0.62	wheat	0.57
24	110.3	122	corn	110.4	corn	0.67	corn	0.76
25	119.1	126	corn	124.9	corn	0.66	corn	0.76
26	122.3	132	corn	132.1	wheat	0.58	wheat	0.51
27	118.6	126	corn	124.8	wheat	0.66	wheat	0.47
28	101.1	108	corn	106.5	wheat	0.67	wheat	0.59
29	98.8	110	corn	104	wheat	0.62	wheat	0.50
30	110.3	125	alfalfa	125.3	alfalfa	0.70	alfalfa	0.81
31	96.1	108	corn	111.2	wheat	0.66	wheat	0.59
32	114.4	132	corn	125.3	corn	0.64	corn	0.72
33	121.5	132	corn	127.2	corn	0.68	corn	0.73

Table 2 continued

Circle No.	GIS Acres	Chief Engineer Acres	Chief Engineer Crop	FSA Acres	1984 FSA Crop	1984 METRIC Ks	1985 FSA Crop	1985 METRIC Ks
35	109.2	113	corn	125.9	wheat	0.55	wheat	0.65
36	123.8	134	corn	132.1	wheat	0.66	wheat/milo	0.82
37	103.7	130	corn	116	wheat	0.58	wheat/milo	0.71
38	96.2	106	alfalfa	105.2	alfalfa	0.84	alfalfa	0.79
39	31.6	33	alfalfa	33.3	alfalfa	0.79	alfalfa	0.79
Summary of All Center Pivot Circles:								
Alfalfa	**2,646.0**	**2,901.0**		**2,889.9**		**0.79**		**0.80**
Corn	**2,064.5**	**2,246.7**		**2,221.8**		**0.62**		**0.64**
Total	**4,710.5**	**5,147.7**		**5,111.7**		**0.71**		**0.73**

Values in red were assumed.

Thus, for center pivot irrigation circles apportioned an alfalfa water right, the transferable water right would be an Etc of 46.0 inches (Table 1) times an average actual ET fraction on the R9 Ranch of 0.72 minus an effective grassland consumptive precipitation use of 21.1 inches. Similarly, for circles apportioned a corn water right, the transferable water would be an Etc of 35.9 inches (Table 1) times an average actual ET fraction of 0.72 minus an effective precipitation of 21.1 inches. These yield transferable quantities of 12.0 inches (1.00 ac-ft/ac) for alfalfa circles and 4.7 inches (0.40 ac-ft/ac) for corn circles. Accordingly, and based on the Chief Engineer's Office preliminary findings of 2,901 acres of irrigated alfalfa and 2,246.7 acres of irrigated corn water rights, the total transferable water from the R9 Ranch would be 3,790 ac-ft per year.

It is noteworthy from Table 2 that the total irrigated area by GIS (geographic information system) analysis of aerial photography of the R9 Ranch is substantially (437 acres) less than the area allowed by the Chief Engineer's Office preliminary findings of water rights (see Appendix B), 4,710.5 acres versus 5,147.7 acres. Furthermore, it appears that since at least 1984 there were always some irrigation circles that were fallow or had limited irrigation in some years.

CONCLUSION

K.A.R. 5-5-9 subsection c allows for a "a site-specific net consumptive use analysis to determine the quantity of water which was actually beneficially consumed" by a proposed change of type and place of use irrigation water right. Keller-Bliesner Engineering has completed a net consumptive use analysis for the R9 Ranch. The net consumptive use we computed is the 30-year (1980 through 2009) mean crop evapotranspiration based on Kinsley, Kansas climate data and adjusted for the observed (via Landsat satellite remote sensing analysis of the average crop water stress on the R9 Ranch for 1984 and 1985) and accounting for the increased effective precipitation that will occur under non-irrigated grassland conditions that the dried up irrigation circles will revert to over time. Thus, we compute transferable quantities of 12.0 inches (1.00 ac-ft/ac) for irrigated alfalfa and 4.7 inches (0.40 ac-ft/ac) for irrigated corn. Based on the Chief Engineer's Office preliminary findings of 2,901 acres of irrigated alfalfa and 2,246.7 acres of irrigated corn water rights, the total transferable water from the R9 Ranch would be 3,790 ac-ft per year.

It is important to note that this result is based on continuous farming and irrigation of all 43 center pivot circles on the R9 Ranch, which has not been the case for at least the past 33 years. Consequently, the R9 Ranch has historically consumed less net water than the amount estimated by this analysis. Accordingly, transfer of even 3,790 ac-ft/year to the Cities of Hays and Russell, Kansas, will likely represent an increase in net depletion from the R9 Ranch and put further hydrologic stress on the fragile water resource in the ranch's vicinity.

REFERENCES

Allen, R.G., L.S. Pereira, D. Raes, D., and M. Smith. (1998) "Crop evapotranspiration, guidelines for computing crop water requirements." FAO Irrig. and Drain. Paper 56, Food and Agric. Orgn. of the United Nations, Rome, Italy. 300 pp.

Allen, R. G., et al., (2005) "The ASCE Standardized Reference Evapotranspiration Equation".Prepared by the Task Committee on Standardization of Reference Evapotranspiration of the Environmental and Water Resource Institute of the American Society of Civil Engineers.

Hargreaves, G. H., and Hargreaves, G. L. (1985) "Irrigation Scheduling and Water Management," Proceedings of the 12th Congress, International Commission on Irrigation and Drainage, pp. 1047-1061

Jensen, M.E., R.G. Allen, T.A. Howell, D.L. Martin, R. Synder, and I.A. Walter (2016)/ "Evaporation, Evapotranspiration, and Irrigation Water Requirements." *Manual of Practice 70 2nd Edition,* ASCE, Virginia

SCS, (1970). Irrigation Water Requirements, Technical Release No. 21, Soil Conservation Service, Engineering Division, revised, September 1970.

USDA (1993) "Irrigation Water Requirements." In *National Engineering Handbook,* Part 623 Chapter 2. Washington, DC: USDA Natural Resources Conservation Service

Walter, I.A. (2011) "Report on Recommendations for Determination of Crop Evapotranspiration in the Lower Rio Grande, New Mexico," Ivan's Engineering, April 2011.

Walter, I.A. (2010). "Calibration for Historical ET Estimates – A Process.", Power Point Presentation, Colo. St. Uni. and USDA Ag. Res. Serv. Evapotranspiration Workshop, Fort Collins, CO March 12, 2010.

White, Andrew, personal communication, 2016 National Weather Service Regional Office, Dodge City, KS.

APPENDIX A – RULES AND REGULATIONS KANSAS WATER APPROPRIATION ACT SECTIONS 5-5-9 AND 5-5-12

K.A.R. 5-5-9. Criteria for the approval of an application for a change in the use made of water from irrigation to any other type of beneficial use of water. (a) The approval of a change in the use made of water from irrigation to any other type of beneficial use shall not be approved if it will cause the net consumptive use from the local source of water supply to be greater than the net consumptive use from the same local source of water supply by the original irrigation use based on the following criteria:

(1) The maximum annual quantity of water to be allowed by the change approval shall be the net irrigation requirement (NIR) for the 50% chance rainfall for the county of origin, as set forth in K.A.R. 5-5-12, multiplied by the maximum acreage legally irrigated under the authority of the water right in any one calendar year during the perfection period. For vested rights, the acreage used shall be the maximum acreage irrigated prior to June 28, 1945; or

(2) if the applicant establishes to the satisfaction of the chief engineer the need for more flexibility in the authorized annual quantity, the application may be approved subject to the following limits.

(A) The maximum annual quantity of water to be allowed by the change approval shall be the NIR for the 80% chance rainfall for the county of origin, as set forth in K.A.R. 5-5-12, multiplied by the maximum acreage legally irrigated in any one calendar year during the perfection period. For vested rights the acreage used shall be the maximum acreage irrigated prior to June 28, 1945.

(B) The new type of beneficial use shall be further limited by a five year fixed allocation of water in which the NIR for a 50% chance rainfall for the county of origin, as set forth in K.A.R. 5-5-12, is multiplied by five times the maximum acreage lawfully irrigated in any one calendar year during the perfection period. For vested rights, the acreage used shall be the maximum acreage irrigated prior to June 28, 1945.

(C) An application for a term permit which will circumvent the five year allocation of water limit shall not be approved by the chief engineer.

(3) In determining whether the net consumptive use of water will be increased by the proposed change in the use made of water, the applicant shall be given credit by the chief engineer for any return flows from the proposed type of beneficial use which will return to the same local source of supply as the return flows from the originally authorized type of beneficial use as substantiated by the applicant to the satisfaction of the chief engineer by an engineering report or similar type of hydrologic analysis.

(4) The authorized quantity to be changed to the new type of beneficial use shall never exceed the maximum annual quantity authorized by the water right.

(5) If a water right which overlaps the authorized place of use of one or more other water rights, either in whole or in part, is being changed to a different type of beneficial use, the total net consumptive use of all water rights after the change is approved shall not exceed the total net consumptive use of all of the rights before the change is approved.

(6) The approval for a change in the use made of water shall also be limited by that quantity reasonable for the use proposed by the change in the use made of water.

(b) Upon request of the applicant, the historic net consumptive use actually made during the perfection period, or prior to June 28, 1945 in the case of vested rights, under the water right proposed to be changed shall be considered by the chief engineer, but the burden shall be on the owner to document that historic net consumptive use with an engineering study, or an equivalent documentation and analysis, and demonstrate to the satisfaction of the chief engineer that the analysis submitted by the applicant is a more accurate estimate of the historic net consumptive use than the net consumptive use calculated using the methodology set forth in paragraph (a)(1).

(c) If the methods set forth in subsection (a) produce an authorized annual quantity of water which appears to be unrealistic and could result in impairment of other water rights, the chief engineer shall make a site-specific net consumptive use analysis to determine the quantity of water which was actually beneficially consumed under the water right. The quantity approved shall be limited to the quantity determined to be reasonable by the chief engineer's analysis. (Authorized by K.S.A. 82a-706a; implementing K.S.A. 1993 Supp. 82a-708b; effective Nov. 28, 1994.)

K.A.R. 5-5-12. Net irrigation requirements (NIR). The following amounts shall be used as the net irrigation requirements (NIR).

County	50% Chance Rainfall	80% Chance Rainfall
Allen	7.1" = 0.59'	9.9" = 0.83'
Anderson	6.1" = 0.51'	9.4" = 0.78'
Atchison	7.2" = 0.60'	10.3" = 0.86'
Barber	12.6" = 1.05'	14.6" = 1.22'
Barton	12.0" = 1.00'	14.4" = 1.20'
Bourbon	6.8" = 0.57'	9.6" = 0.80'
Brown	7.1" = 0.59'	10.6" = 0.88'
Butler	9.2" = 0.77'	12.0" = 1.00'
Chase	8.7" = 0.73'	11.4" = 0.95'
Chautauqua	8.6" = 0.72'	11.4" = 0.95'
Cherokee	7.0" = 0.58'	9.9" = 0.83'
Cheyenne	13.7" = 1.14'	15.4" = 1.28'
Clark	13.7" = 1.14'	15.7" = 1.31'
Clay	9.2" = 0.77'	12.2" = 1.02'
Cloud	10.3’’ = 0.86'	12.7" = 1.06'
Coffey	6.8" = 0.57'	9.9" = 0.83'
Comanche	13.0" = 1.08'	15.1" = 1.26'
Cowley	9.7" = 0.81'	12.3" = 1.03'
Crawford	7.0" = 0.58'	9.8" = 0.82'
Decatur	12.7" = 1.06'	14.8" = 1.23'
Dickinson	9.4" = 0.78'	12.3" = 1.03'
Doniphan	7.3" = 0.61'	10.3"= 0.86'
Douglas	6.8" = 0.57'	9.8" = 0.82'
Edwards	13.0" = 1.08'	15.1" = 1.26'
Elk	8.7" = 0.73'	11.3" = 0.94'

APPENDIX B – R9 RANCH TRANSFERABLE RIGHT PER CHIEF ENGINEER HANDOUT 24 MARCH 2016

AUTHORIZED RATES AND QUANTITY BY WELL AND RIGHT			PROPOSED RATES AND QUANTITY BY WELL AND RIGHT				RATE AND QUANTITY ALLOWED BY K.A.R. 5-5-9 BY WELL AND RIGHT				
FILE NO FILE NO	QUANTITY AF PER WELL	RATE GPM PER WELL	PROPOSED WELL	PROPOSED TOTAL Q & R BY WELL	QUANTITY BY RIGHT	RATE BY RIGHT	PERF ACRES	CROP	RATE	QUANTITY	NOTES
21,729	114	635	A	870.83 AF @ 2,900 gpm	870.83	2,900		ALFALFA			Quantity to be allowed by K.A.R. 5-5-9 752 AF
8,9,10,	102	325	A					ALFALFA			
	188	720	A					ALFALFA			Modify paragraph Nos. 8, 9 & 10 to reflect a total allowed Quantity of 752 AF for the proposed well
4 wells	74	360	A					ALFALFA			
	86	275	A					ALFALFA			
	188	615	A					ALFALFA			
TOTALS	752	Limit to 2900			870.83	2,900	500		2,900	752.0	
21,730	176	795	G	426.7 Af @ 1,870 gpm	203.77	795		ALFALFA			Quantity to be allowed by K.A.R. 5-5-9 176AF. Modify paragraph No. 8 to reflect a total allowed Quantity of 176 AF for the proposed well
TOTALS	176	795			203.77	795	114		795	176.0	
21,731	87	380	H	Total well H 768.07 AF @ 2,490 gpm	768.07	2,490		ALFALFA			We found maximum acres to be 554 acres
	56	245	H					ALFALFA			Quantity to be allowed by K.A.R. 5-5-9 880 AF
2,3,4,	126	525	H					ALFALFA			Modify paragraph Nos. 8, 9 & 10 to reflect a total allowed Quantity of 880 AF for the proposed well.
5,7,	177	735	H					ALFALFA			
	162	605	H					ALFALFA			Assign portions of 880 AF to Wells G & H
	192	625	G	Total well G 426.7 Af @ 1,870 gpm	222.93	1,075		ALFALFA			
	80	450	G					ALFALFA			
TOTALS	880	3,565			991.00	3,565	554		3,565	880.0	
21,732	240	885	B	Total well B 687.96 AF @ 2,380 gpm	687.96	2,380		ALFALFA			Modify paragraph Nos. 8, 9 & 10 to reflect a total allowed Quantity of 593 AF for the proposed well
6,11,12	188	715	B					ALFALFA			
	165	780	B					ALFALFA			
TOTALS	593	2,380			687.96	2,380	395		2,380	593.0	
21,733	189	915	C	Total well C 367.49 Af @ 1,693 gpm	219.45	915		ALFALFA			Quantity to be allowed by K.A.R. 5-5-9 189 AF; Modify paragraph No. 8 to reflect a total allowed Quantity of 189 AF for the proposed well
TOTALS	189	915			219.45	915	126		915	189.0	
21,734	?334	?1,035	E	Total well E 518.92 AF @ 2,561 gpm	226.41	861	388.7	CORN #16		419.8	We show 658.7 total acres, Circles 14 & 18 afalfa, circles 15, 16 & 17 corn
14,16,	213 218	1,500	D	Total well D 522.6 AF @ 3,161.18 gpm	522.50	3,161		CORN #15			
17,18	235 367	1,050	D					CORN #17			Modify paragraph Nos. 8, 9 & 10 to reflect the total quantity allowed Quantity per well. Quantity allowed by K.A.R. 5-5-9 is 889.1 AF
	255 399	1,250	D				170	ALFALFA #14		296.1	
	198 310	935	C	Total well C 367.49 Af @ 1,1693 gpm	148.04	778	100	ALFALFA #18		174.2	
TOTALS	Limit to 1040	Limit to 4,800			896.95	4,800	658.7		4,800	889.1	
21,841	195	890	F	Total F 285 AF 1,640 gpm	195.00	890		ALFALFA			No changes to application necessary
TOTALS	195	890			195.00	890	130		890	195.0	
21,842	195	900	E	Total well E 518.92 AF @ 2,561 gpm	195.00	900		ALFALFA			No changes to application necessary
TOTALS	195	900			195.00	900	130		900	195.0	
22,325	108	805	I	Total well I 587.78 AF @ 2,950 gpm	215.97	1,000		ALFALFA			No changes to application necessary
	78	530	I					ALFALFA			
TOTALS	186	Limit to 1,000			215.97	1,000	124		1,000	186.0	
22,326	103	690	I	Total well I 587.78 AF @ 2,950 gpm	196.71	1,000		CORN			Quantity allowed by K.A.R. 5-5-9 135 AF ; Modify paragraph Nos. 8 & 9 to reflect the total Quantity of 135 AF
	85	565	I					CORN			
TOTALS	188	Limit to 1,000			196.71	1,000	125		1,000	135.0	
22,327	100	475	I	Total well I 587.78 AF @ 2,950 gpm	175.10	950		CORN			Quantity allowed by K.A.R. 5-5-9 145.8 AF ; Modify paragraph Nos. 8 & 9 to reflect the total Quantity of 145.8 AF
	103	490	I					CORN			
TOTALS	203	Limit to 950			175.10	950	135		950	145.8	
22,329	108	570	J	Total well J 678.44 AF @ 3,170 gpm	150.48	570		CORN			Quantity allowed by K.A.R. 5-5-9 108 AF; Modiy paragraph No. 8 to reflect total Quantity of 108 AF
TOTALS	108	570			150.48	570	122		570	108.0	
22,330	117	620	J	Total well J 678.44 AF @ 3,170 gpm	152.64	620		CORN			Quantity allowed by K.A.R. 5-5-9 117 AF; Modify paragraph No. 8 to reflect total Quantity of 117 AF
TOTALS	117	620			152.64	620	126		620	117.0	

AUTHORIZED RATES AND QUANTITY BY WELL AND RIGHT			PROPOSED RATES AND QUANTITY BY WELL AND RIGHT				RATE AND QUANTITY ALLOWED BY K.A.R. 5-5-9 BY WELL AND RIGHT				
FILE NO FILE NO	QUANTITY AF PER WELL	RATE GPM PER WELL	PROPOSED WELL	PROPOSED TOTAL Q & R BY WELL	QUANTITY BY RIGHT	RATE BY RIGHT	PERF ACRES	CROP	RATE	QUANTITY	NOTES
22,331	90 90	640 645	J J	Total well J 678.44 AF @ 3,170 gpm	209.00	1,000		ALFALFA ALFALFA			Quantity allowed by K.A.R. 5-5-9 180 AF; Modify paragraph Nos. 8 & 9 to reflect total Quantity of 180 AF. Change in PD may be over half mile
TOTALS	180	LIMIT TO 1,000			209.00	1,000	120		1,000	180.0	
22,332	77 111	460 655	J J	Total well J 678.44 AF @ 3,170 gpm	166.32	980		CORN CORN			Quantity allowed by K.A.R. 5-5-9 135 AF; Modify paragraph Nos. 8 & 9 to reflect total Quantity of 135 AF
TOTALS	188	Limit to 980			166.32	980	125		980	135.0	
22,333	50	520	K	Total well K 533.2 AF @ 3,380 gpm	57.47	520		ALFALFA			Quantity allowed by K.A.R. 5-5-9 50 AF; Modify paragraph No. 8 to reflect total Quantity of 50 AF
TOTALS	50	520			57.47	520	33		520	50.0	
22,334	95 95	639 630	K K	Total well K 533.2 AF @ 3,380 gpm	162.88	890		CORN CORN			Quantity allowed by K.A.R. 5-5-9 136.1 AF; Modify paragraph Nos. 8 & 9 to reflect total Quantity of 136.1 AF
TOTALS	190	Limit to 890			162.88	890	126		890	136.1	
22,335	109 89	680 555	K K	Total well K 533.2 AF @ 3,380 gpm	171.36	1,000		CORN CORN			Quantity allowed by K.A.R. 5-5-9 142.6 AF; Modify paragraph Nos. 8 & 9 to reflect total Quantity of 142.6 AF
TOTALS	198	Limit to 1,000			171.36	1,000	132		1,000	142.6	
22,338	89 73	950 785	L L	Total well L 426.24 AF @ 2,430 gpm	141.12	950		CORN CORN			Quantity allowed by K.A.R. 5-5-9 116.6 AF; Modify paragraph Nos. 8 & 9 to reflect total Quantity of 116.6 AF
TOTALS	162	Limit to 950			141.12	950	108		950	116.6	
22,339	165	680	L	Total well L 426.24 AF @ 2,430 gpm	142.56	680		CORN			Quantity allowed by K.A.R. 5-5-9 118.8 AF; Modify paragraph No. 8 to reflect total Quantity of 118.8 AF
TOTALS	165	680			142.56	680	110		680	118.8	
22,340	162	950	M	Total well M 475.5 AF @ 3,500 gpm	140.40	950		CORN			Quantity allowed by K.A.R. 5-5-9 116.6 AF; Modify paragraph No. 8 to reflect total Quantity of 116.6 AF
TOTALS	162	950			140.40	950	108		950	116.6	
22,341	188	920	M	Total well M 475.5 AF @ 3,500 gpm	190.38	920		ALFALFA			Quantity allowed by K.A.R. 5-5-9 188 AF; Modify paragraph No. 8 to reflect total Quantity of 188 AF
TOTALS	188	920			190.38	920	125		920	188.0	
22,342	75	630	M	Total well M 475.5 AF @ 3,500 gpm	100.80	630		CORN			Quantity allowed by K.A.R. 5-5-9 75 AF; Modify paragraph No. 8 to reflect total Quantity of 75 AF
TOTALS	75	630			100.80	630	134		630	75.0	
22,343	169	810	N	Total well N 467.87 AF @ 2,230 gpm	146.16	810		CORN			Quantity allowed by K.A.R. 5-5-9 122 AF; Modify paragraph No. 8 to reflect total Quantity of 122 AF
TOTALS	169	810			146.16	810	113		810	122.0	
22,345	159	820	N	Total well N 467.87 AF @ 2,230 gpm	184.62	820		ALFALFA			Quantity allowed by K.A.R. 5-5-9 159 AF; Modify paragraph No. 8 to reflect total Quantity of 159 AF
TOTALS	159	820			184.62	820	106		820	159.0	
22,346	162	600	N	Total well N 467.87 AF @ 2,230 gpm	146.90	600		CORN			We show 130 acres; Quantity allowed by K.A.R. 5-5-9 140.4 AF; Modify paragraph No. 8 to reflect total Quantity of 140.4 AF
TOTALS	162	600			146.90	600	130		600	140.4	
27,760	244 227	670 800	K L	Total well K 533.2 AF @ 3,380 gpm Total well L 426.24 AF @ 2,430 gpm	142.56 141.49	(670) 970 800		CORN CORN	670 800		Quantity allowed by K.A.R. 5-5-9 285.1 AF; Modify paragraph Nos. 8 & 9 to reflect total Quantity per individual well to equal 285.1 AF. There is a rate discrepncy 670 not 970.
TOTALS	Limit to 396	1,470			284.05	(1,470)1,770	264		1,470	285.1	
29,816	90 98	750 800	F E	Total F 285 @ 1,640 GPM Total E 518.92 AF 2,561 gpm	90.00 97.50	750 800		ALFALFA ALFALFA			Quantity allowed by K.A.R. 5-5-9 188 AF; Modify paragraph Nos. 8 & 9 to reflect total Quantity per individual well to equal 188 AF
TOTALS	188	1,550			187.50	1,550	125		188	188.0	
30,083	126	1,000	M	Total well M 475.5 AF @ 3,500 gpm	43.92	(455) 1,000					There are no additional acres contributed by this file the quantity will be no more than 22,342. Right should be dismissed
TOTALS	126	Limit to 1,085 455 add			43.92	(455) 1,000	0		44	0.0	
30,084	147	795	J	Total well J 678.44 AF @ 3,170 gpm	0.00	0					There are no additional acres contributed by this file the quantity will be no more than 22,329. Right should be dismissed
TOTALS	147	795			0.00	0	0			0.0	
TOTAL	7,727.00	35,510.00			7626.30	(35,510)36,35			35,206	7604.2	

APPENDIX C – CLIMATE DATA AND CONSUMPTIVE IRRIGATION REQUIREMENT (CIR) ANALYSES

CONSUMPTIVE IRRIGATION REQUIREMENT (CIR) CALCULATIONS

There have been many methods advanced over the years to determine reference evapotranspiration (ET). The currently suggested method given suitable weather data is the Penman-Monteith method, also referred to as the ASCE Standardized Reference Evapotranspiration Equation (Allen, 2005, Jensen et.al 2016). This method is data intensive, requiring maximum and minimum temperature, maximum and minimum humidity or dew point, wind, and solar radiation. To obtain accurate estimates of ASCE reference evapotranspiration (ET_o), it is critical that weather data be high quality. Weather data are “to be measured above an extensive grass crop that is actively evapotranspiring, or in an environment with healthy vegetation not short of water.” These conditions are referred to as reference conditions. Few stations seem to be located in such environments.

In a CIR analysis we typically run 30 plus years in an effort to capture warmer/cooler or wetter/drier periods in the climatic record. Often, the climatic data for the ASCE method does not exist prior to the past 20 or 25 years in the location of interest. Also, the data that does exist may not be collected under reference conditions, and an alternative approach is required. FAO-56 suggests using the 1985 Hargreaves (H85) method when solar radiation, relative humidity and/or wind speed data are missing (Allen, 1998).

The 1985 Hargreaves (Hargreaves, 1985) method requires maximum and minimum temperature with solar radiation being estimated from latitude. However, since the Hargreaves method does not explicitly account for measured solar radiation, wind, or humidity, we suggest calibrating the Hargreaves method to the ASCE method under local conditions. This has been done for the area of the Kinsley Kanas. A description of the calibration procedures used in this analysis, and a description of the weather data integrity assessment are included in following sections of this document.

WEATHER DATA INTEGRITY ASSESSMENT

Before using weather data from any station to calculate $ET_{o,}$ it is imperative that it be assessed for quality. We have used guidelines outlined in Annex D of the Environmental Water Resource Institute of the ASCE Standardized Reference Evapotranspiration Equation publication (Allen, 2005, referred to as the ASCE manual) to assess the quality of the weather data and determine if it exhibits the characteristics of reference conditions. If the station data are not indicative of reference conditions, then they should be corrected prior to use if it is feasible. In our assessment of the weather data, very few corrections were needed.

Data Filling and Parameter Assessment

The weather stations used in this analysis are shown in Table C1. Dodge City Regional airport was found to be the nearest location to Kinsley, KS with the historic climatic data required for the ASCE Standardized reference evapotranspiration (ET_o) equation. The data at this location was gathered from three different climatic networks (Table C1) and combined into a daily data set.

When performing daily evapotranspiration calculations based on historical data, it is not unusual to find days with missing observations that need to be filled or estimated prior to ET calculations. Several procedures are published in the FAO-56 (Allen et. al 1998) and the ACSE

Standardized Reference Evapotranspiration (Allen et. al 2005) manuals. In this study, missing data values primarily existed at the Kinsley 2E station. These missing data were filled using a linear regression technique, where stations used to fill missing data are selected based on the homogeneity of the data sets. This procedure is described in detail in Annex 4 of FAO-56, and was implemented using a software tool (CLIME) developed by Keller-Bliesner. The process requires at least two data sets from separate climate stations and involves the following series of steps:

1. Identify a nearby weather station/stations with a data set that covers all periods for which data are missing. In CLIME up to three additional weather stations may be selected.
2. For each of the weather stations selected, compute the mean and standard deviation over a common time period.
3. Perform regression for the periods where both data sets are present and then plot all the points for the range of the observed values.
4. Calculate the correlation coefficient (r^2) for the regression.
5. Evaluate the homogeneity of the data sets. An r^2 value greater than 0.7 and a slope that is greater than 0.7 and less than 1.3 indicates that these two sites may have similar behavior and may be homogeneous. In CLIME up the three stations may be compared at a time, and the station with the best slope and highest r^2 is selected as the first station to be used in data filling.
6. Using the best station, fill the missing values using the regression equation calculated previously. In CLIME, if not all values can be filled using the best station, the values that can be filled using the best station are used, then the next best station or stations are used to fill the remaining missing values.

Missing data (Table C2) at the Dodge City Regional Airport site were filled using substitution from the GSOD climatic data. Missing Data at the Kinsley 2E Station were filled using a linear regression relationship with the Dodge City Regional Airport. No data extension was done outside the listed period of record.

Table C1. Climatic Data used in CIR Analysis

Station	Network	Period of Record	Daily Climatic Parameters Used
Dodge City Regional Airport	GHCN/COOP[1]	1980-2009	Max/Min Temperature, and Precipitation
Dodge City Regional Airport	GSOD[2]	1980-2009	Dew point Temperature, Wind Speed
Dodge City Regional Airport	NSRDB[3]	1980-2009	Solar Radiation
Kinsley Kansas 2E[4]	COOP[1,4]	1980-2009	Max/Min Temperature, and Precipitation

Table Notes:

1. GHCN/COOP Data - Global Historical Climatology Network (GHCN)Cooperative Observer Program (COOP) as of April 2011 COOP has been superseded by the Global Historical Climatology Network (GHCN) data were obtained from the Utah State University Climate Center website http://climate.usurf.usu.edu/mapGUI/mapGUI.php.
2. GSOD Data – Global Summary of the Day hourly data summarized on GMT data obtained from the Utah State University Climate Center website http://climate.usurf.usu.edu/mapGUI/mapGUI.php. Wind data were all adjusted to a standard 2-m anemometer height. The anemometer at the Dodge City Regional airport was at 58-ft from 1941 to 4/11/1961. Then it moved to 33-ft from 4/21/1961 - 10/16/1990. Then moved to 26-ft on 10/17/1990 through 8/31/1992. The complete station was commissioned and relocated by the Automated Surface Observing System (ASOS) on 9/1/1992 to a higher ground elevation of 11-ft, and the anemometer was raised again on that date to 10-meters where it remains at the date of this report.
3. NSRDB Data – Hourly Solar Radiation Data was obtained from the Nation Solar Radiation Data Base http://rredc.nrel.gov/solar/old_data/nsrdb/.
4. This COOP station was discontinued in 2010.

Table C2. Data Filling Summary

Station	Network	Period of Record	Number of Days		Tmax	Tmin	Tdew	Precip	Wind Speed	SR
Dodge City Regional Airport	GHCN/COOP, GSOD, NSRDB	1980-2009	10,958	Filled Values	0	2	0	1	0	0
				% Filled	0%	0.015%	0%	0.008%	0%	0%
Kinsley 2E	GHCN/COOP	1950-2009	21,915	Filled Values	537	688		328		
				% Filled	2.5%	3.1%		1.5%		

Table Notes:

1. Tmax = maximum temperature, Tmin = minimum temperature, Tdew = dew point temperature, , SR = solar radiation

The assessment of the integrity of the weather data was completed using a software package developed by Keller-Bliesner Engineering called KB-ET. KB-ET calculates reference ET and crop ET, and has a variety of utilities for assessing the quality of weather data. As the software, has been developed over the past decade, we frequently compare the results between KB-ET and Dr. Rick Allen's RefET software to ensure that they are producing the same results.

KB-ET facilitates visual inspection of weather data to identify problems and inconsistencies in the record. The purpose of this assessment was to identify problems in the climatic data that may cause errors in the calculation of reference evapotranspiration.

Solar Radiation

Daily measured solar radiation was compared to clear-sky solar radiation envelope curves. The simplified version of the curve results from equation 4-5 in the 2016 ASCE manual and is plotted in red in Figures C1 and C2. A more detailed procedure is employed using equation 4-10 in ASCE manual 70 (Jensen, 2016). The detailed procedure is a function of the actual vapor pressure of the air, and hence varies with weather conditions resulting in a range of values (shown by the green line in Figure C1 or the light colored dots in Figure C2). The measured data should correlate with the green curve line and may exceed it occasionally. Figures C1 and C2 indicate reasonable solar radiation data, and no corrections were required for the Dodge City Regional Airport solar radiation data set.

Air Temperature

Air temperature is one of the more reliably collected parameters at any weather station. In this assessment, the air temperature corrections were only to correct rare instances where maximum temperature was less than minimum temperature. While this will occasionally occur from the data filling process, it can also occur in the GHCN/COOP service records from a data transcription error.

Dew Point Temperature

Per guidelines in Appendix H of the ASCE manual 70 (Jensen, 2016), indicators of reference conditions are:

- Minimum Temperatures under these circumstances will approach the dew point temperature.
- The dew point temperature should be less than 3 - 4°C below minimum temperature for a substantial portion of the growing season.
- In arid and semi-arid conditions the dew point temperature should not be more than 2 to 5°C higher than the minimum temperature.

For the Dodge City station, we looked at plots (Figure C3) of the minimum temperature (Tmin) minus the dew point temperature (Tdew). At the bottom of the plot is included the percentage of points that fall in the -5°C to 4°C range. For this station 77% of the points fall within the indicated range.

Wind

Plots of daily wind speed and wind run are viewed for shifts in the average daily wind speed or breaks in the slope of the annual cumulative wind run plots. Preliminary screening of wind data indicated slope breaks in the cumulative wind run data. This is typically indicative of the wind speed being measured at different anemometer heights over the historical period. Communication with the NWS office in Dodge City found that this was indeed the case (White, Andrew, personal communication, 2016). The anemometer at the Dodge City Regional airport was at 58-ft from 1941 to 4/11/1961. The height then moved to 33-ft on 4/21/1961 - 10/16/1990. It then changed to 26-ft on 10/17/1990 through 8/31/1992. The complete station was commissioned and relocated by the Automated Surface Observing System (ASOS) on 9/1/1992 to a higher ground elevation of 11-ft, and the anemometer was raised again on that date to 10-meters (33-ft), where it remains at the date of this report. Figures C4 and C5 show the wind speed data with and without adjustment.

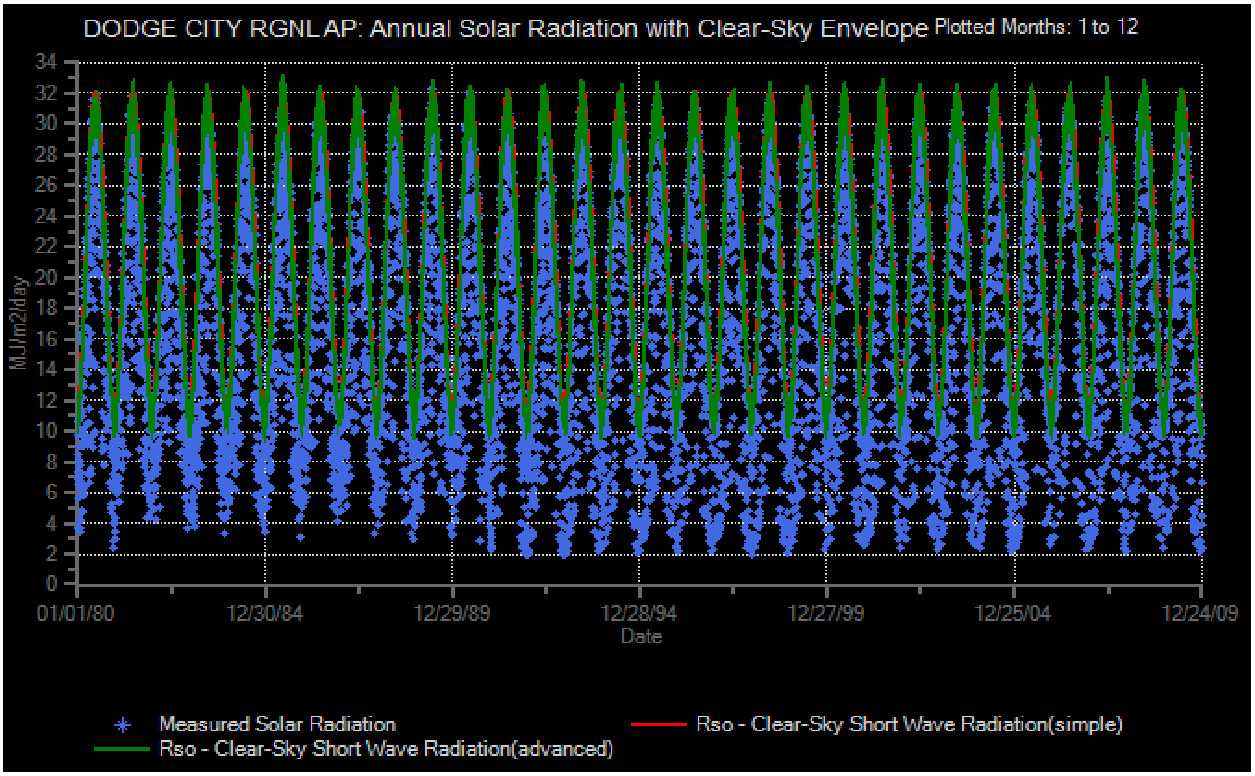

Figure C1. Annual Plots of Daily Solar Radiation with Simple and Complex Clear-Sky Shortwave Solar Radiation Envelope Curves

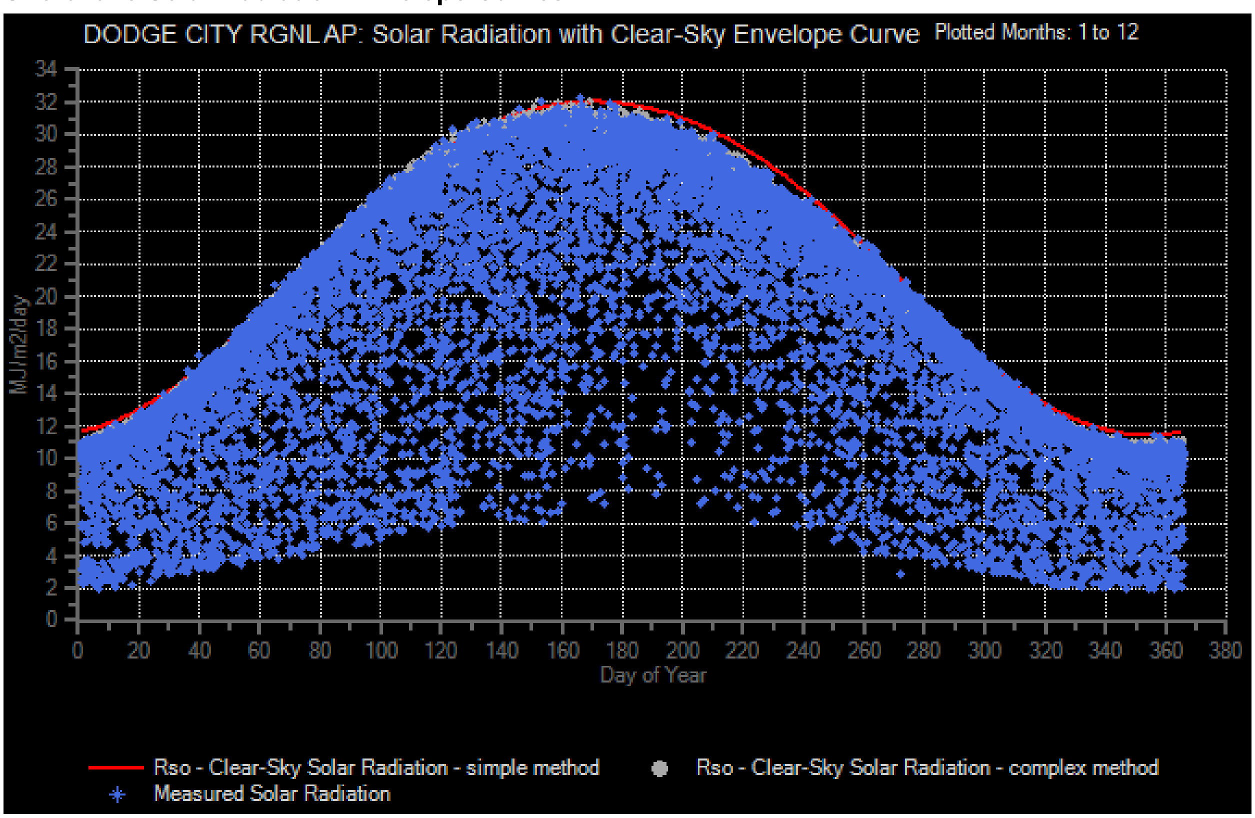

Figure C2. Day of Year Plots of Daily Solar Radiation with Simple and Complex Clear-Sky Shortwave Solar Radiation Envelope Curves

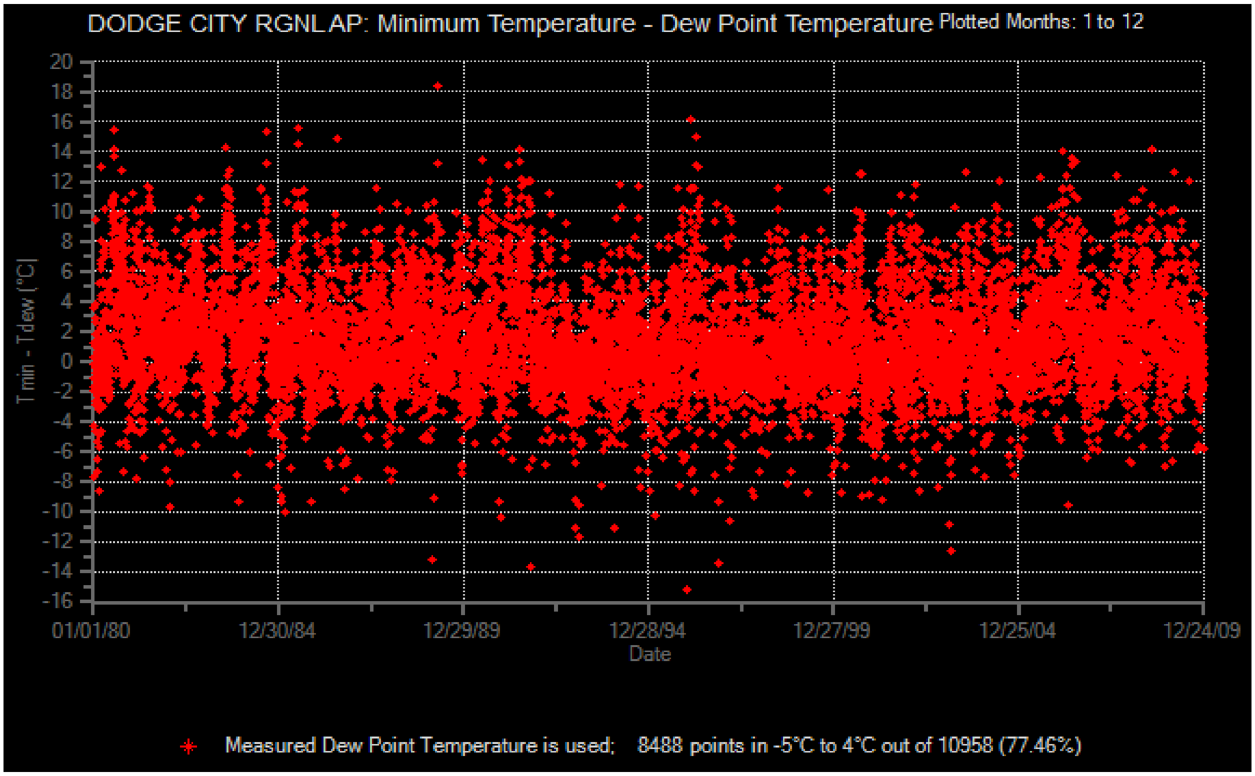

Figure C3. Plot of Minimum Temperature–Dew Point Temperature, Dodge City Reg. Airport

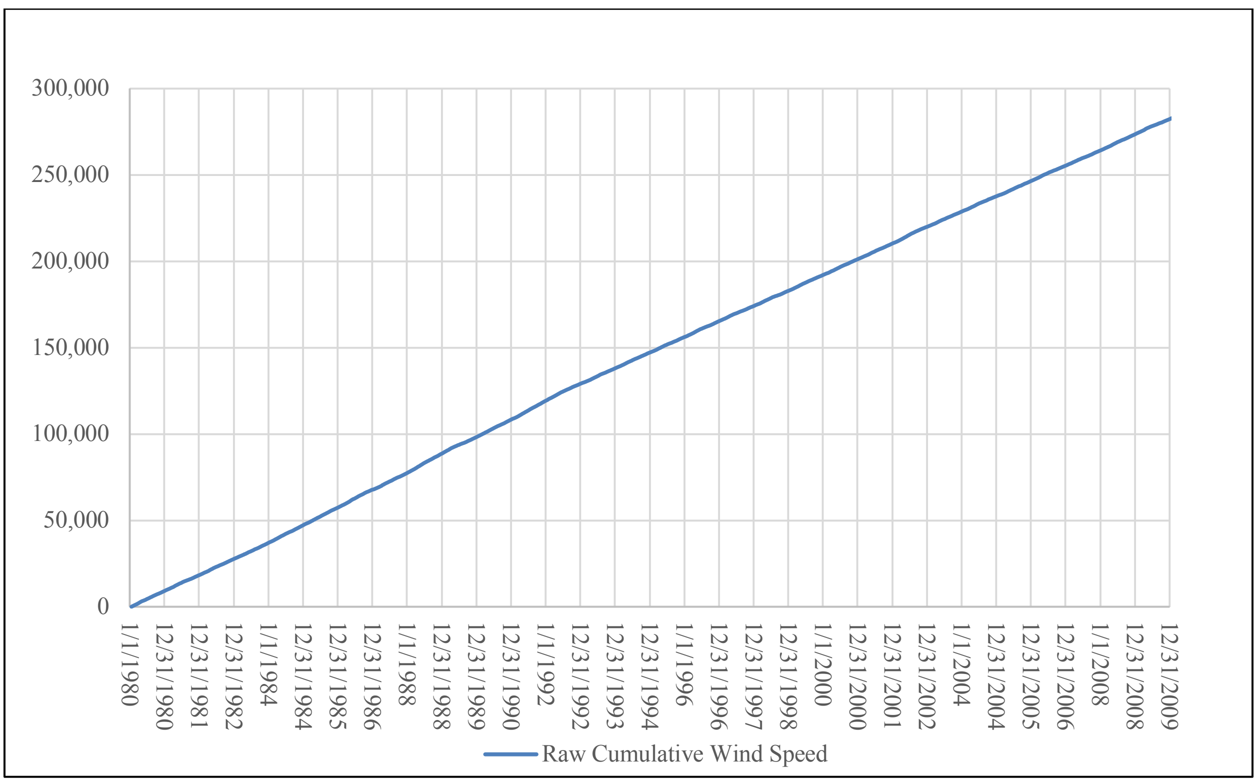

Figure C4. Cumulative Wind Run using Raw Data, Anemometer Height: 33-ft (4/21/1961-10/16/1990) 26-ft (10/17/1990-8/31/1992) 33-ft (9/1/1992-Curent) Dodge City Regional AP

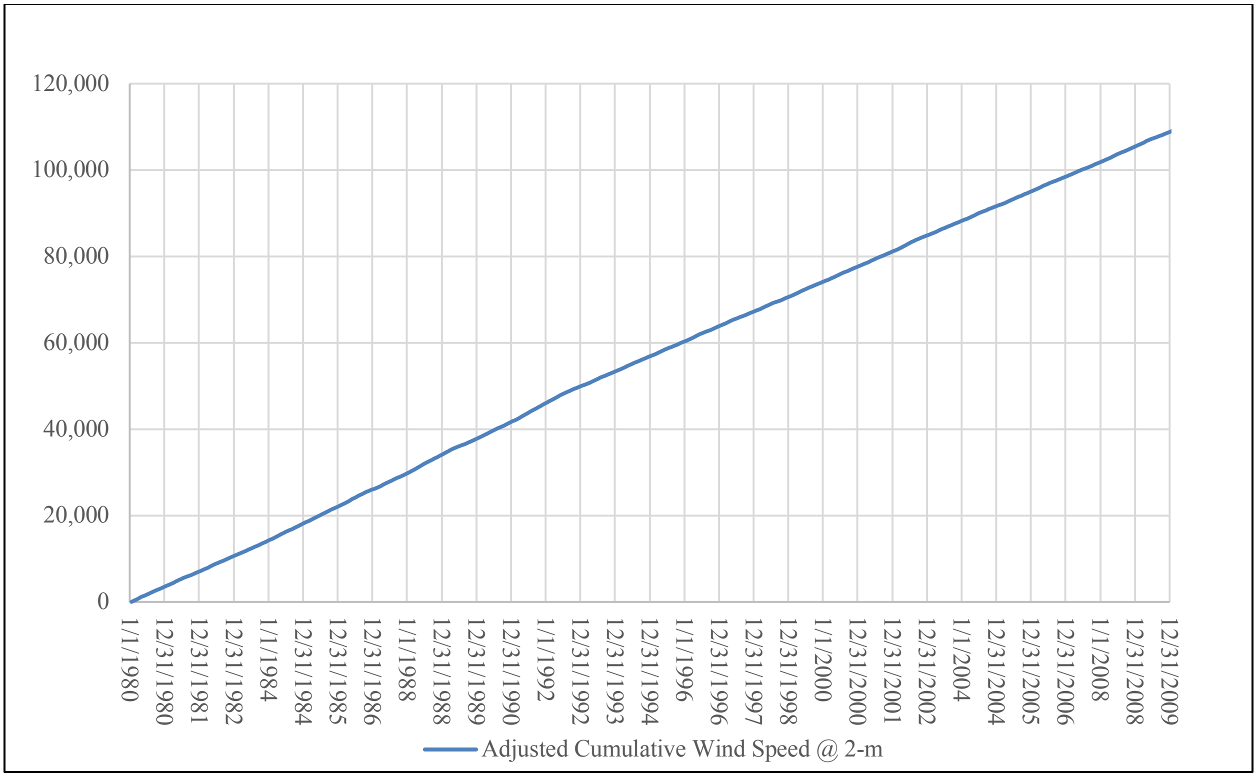

Figure C5. Cumulative Wind Run with Wind Data Adjusted to a 2-meter Anemometer Height Dodge City Regional AP

REFERENCE ET CALCULATIONS

Comparison of ASCE and Hargreaves ET_o

After the weather data were assessed and corrected, the daily reference ET was calculated using KB-ET, and the annual average results are presented in Table C3. Ideally the American Society of Civil Engineers' (ASCE) standardized reference evapotranspiration (Allen, 2005, Jensen, 2016) equation would be utilized for each station. However, the acceptable data required for ASCE standardized reference calculations were not available at the climatic stations within the Kinsley study area. Thus, the approach applied to CIR calculation was based on the recognized standard evapotranspiration (ET) calculation methods as described by Walter (2010, 2011) in the following recommendations:

1. For the time period when all data parameters required by the ASCE standardized ET equation (Allen, 2005, Jensen, 2016) are available, reference ET should be calculated using the ASCE standardized equation;
2. For the time period when only temperature data are available, reference ET should be calculated using monthly calibration coefficients multiplied by the daily 1985 Hargreaves ET values (Hargreaves, 1985);
3. Monthly calibration coefficients should be calculated based on the ratio of the ASCE ET divided by the Hargreaves ET;
4. The stations used in the calibration depend on the data available at each station for the period of record.

The ASCE method was used to calculate ET_o at the Dodge City Regional Airport station. The 1985 Hargreaves method was used at the Kinsley 2E station. The 1985 Hargreaves method at Kinsley was calibrated to the ASCE method and the results are also shown in Table C3 ("H85 Cal" column).

The Kinsley 2E weather station was selected for calibration. At this station, calibration coefficients were calculated by dividing the monthly ASCE ET_o at the Dodge City Regional Airport by the monthly Hargreaves 1985 ET_o for each year. For example, at the Dodge City Regional Airport climatic station, 30 years of data (1980-2009) were available. For the month of July, 30 ratios were developed, one ratio for each year. These 30 values were then averaged to represent a single calibration coefficient that could be applied to the 1985 Hargreaves estimates in July. The calibration coefficients that were developed for the Kinsley study area are shown in Table C4.

Table C3. Results of Annual Reference ET Calculations by Station (units = inches/year)

Station	Network	Analysis Period	ASCE ET_o	H85 Un Cal	H85 Cal	Calibration Station
Dodge City Regional Airport	GHCN/COOP, GSOD, NSRDB	1980-2009	62.4	49.8	62.3	Dodge City Regional Airport
Kinsley 2E	GHCN/COOP	1980-2009	N/A	51.1	62.3	Dodge City Regional Airport

Table C4. Monthly Hargreaves ET_o Calibration Coefficients (CC_i = Monthly ASCE ET_o Divided by Monthly Hargreaves 1985 ET_o)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dodge City Regional Airport	1.56	1.37	1.28	1.17	1.08	1.13	1.20	1.17	1.25	1.31	1.44	1.57

CROP CONSUMPTIVE IRRIGATION REQUIREMENT CALCULATIONS

Calibrated Crop ET

As described in the previous section, the 1985 Hargreaves method was calibrated for local conditions using the ASCE method to calculate a daily short grass reference evapotranspiration. When combined with a daily grass based crop coefficient (K_c) the daily crop evapotranspiration (ET_c) may be estimated as:

$$ET_c = K_c * ET_o * CC_i$$

Where;

ET_o = 1985 Hargreaves reference evapotranspiration

CC_i = Hargreaves calibration coefficient for month i

The consumptive irrigation requirement (CIR) reduces the ET_c by the effective precipitation (P_e):

$$CIR = ET_c - P_e$$

Effective precipitation is a monthly calculation based on the SCS TR-21 (TR-21, 1970). The monthly CIR is calculated by summing the daily ET_c values to monthly values and then subtracting the monthly effective precipitation

Effective Precipitation

Effective precipitation is the amount of precipitation that is stored in the soil and used by the crop to meet the crop evapotranspiration. It does not include surface runoff or percolation below the crop root zone. Effective precipitation is estimated based on actual precipitation, the mean monthly consumptive use, and the usable soil water storage in the root zone. The effective precipitation (P_e) was computed using the SCS TR21 method (1970) as follows:

$$P_e = SF(0.70917 P_t^{0.82416} - 0.11556)\left(10^{0.02426 ET_c}\right)$$

where:

P_e = average monthly effective monthly precipitation (in)

P_t= monthly mean precipitation (in)

ET_c= monthly consumptive use for a particular crop

SF = soil water storage factor 0.531747 + 0.295164 D - 0.057697 D^2 + 0.003804 D^3

D = the usable soil water storage in the root zone in inches

The usable soil water storage values used in the effective precipitation calculations by crop are shown in Table C5. This value varies by crop, based on crop rooting depth and its management allowed deficit. In this table, the usable soil water storage values were calculated as the water holding capacity multiplied by the average rooting depth and the depletion fraction.

Table C5. Usable Soil Water Storage Values Used in Effective Precipitation Calculations

Crop	Water Holding Capacity (inches/ft)[1]	FAO-56 Avg. Rooting Depth (ft)[2]	FAO-56 Depletion Fraction[3]	Usable Soil Water Storage (D) (inches)[4]
Alfalfa Hay	0.99	5.0	0.55	2.7
Prairie Grass[5]	0.99	5.7	0.60	3.6
Grain Corn	0.99	4.4	0.55	2.4

Table Notes:

1. Adapted from USDA Soil Survey books for Edwards County. R-9 ranch soil types are "Tivoli Fine sand" and "Pratt-Tivoli loamy fine sands" http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx
2. Data Source: FAO-56 Table 22 (Allen et al. 1998)
3. Depletion Fraction is the average fraction of the Total Available Soil Water (TAW) that can be depleted from the root zone before moisture stress occurs. Data Source: FAO-56 Table 22 (Allen et al. 1998)
4. Usable soil water storage is generally calculated as 40 to 60 percent of the available soil water capacity in the crop root zone, depending on the irrigation management practices used. (USDA, 1993)
5. Kansas SwitchGrass ASCE Manual 70 Table B-1 (Jensen, 2016)

Effective Precipitation (Probability of Occurance)

Once effective precipitation is calculated using the TR-21 method, the desired percent chance of occurrence (50% or 80%) of effective precipitation can be calculated using the average annual rainfall in inches (26.3 inches at Kinsley) multiplied by a ratio taken from the National Engineering Handbook Chapter 2 Table 2-46 (USDA, 1993).

The ratios used for Kinsley are 0.97 for a 50% probability of occurrence and 0.79 for a 80% probability of occurrence

RESULTS

Crop ET and CIR

The crop ET and CIR were estimated for Alfalfa Hay and Grain Corn.

FAO-56 style crop curves have been used. The crop coefficients (K_c) and development periods, along with season start and stop date triggers, are shown in Table C6. The crop ET, effective precipitation and CIR are shown in Table C7.

For natural (unirrigated) Prairie Grass, the ET was calculated by running a daily water balance from January 1, 1980 through December 31, 2009. In the daily water balance, precipitation in excess of the soil water storage capacity within the grass root zone was treated as deep percolation. The daily grass ET was limited to the available soil water and linearly reduced towards zero when the readily available soil water content was less than 30% of full capacity. Results from the Prairie Grass ET analysis by water balance are summarized in Table C8.

Table C6. Crop Curve Parameters for CIR Calculations

Crop	Start Date	End Date	Start Temp °F	End Temp °F	Initial (Days)	Development (Days)	Mid-Season (Days)	Late-Season (Days)	Kc_ini	Kc_mid	Kc_end	Useable Soil Water Storage (inches)	Start Season Offset[6] (Days)	End Season Offset[6] (Days)
Alfalfa Hay 1st Cutting[1]	-	-	25	25	10	20	20	10	0.4	1.2	1.15	2.7	-	-
Alfalfa Hay Other Cuttings[1]	-	-	25	25	5	10	10	10	0.4	1.2	1.15	2.7	-	-
Alfalfa Hay Averaged Cutting Effect[2]	-	-	25	25	10	30	170	10	0.4	0.95	0.95	2.7	-	-
Grain Corn[3]	4/28	10/14	-	-	30	40	50	50	0.3	1.2	0.35	2.4	-	-
Prairie Grass[4]	-	-	25	25	20	45	40	60	0.2	1.05	0.2	3.4	-	-

Table Notes:

1. Alfalfa Hay. The development periods were taken from FAO-56 Table 11 for the 1st Cutting Cycle using a 60 day development period; subsequent cuttings use a 35 day cutting cycle. Kc coefficients were taken from FAO-56 Table 12. Start dates are temperature based and vary from year to year. The season starts based on the last day that measures 25°F (-4°C) in the spring. The season end date is based on first day 25°F (-4°C) temperature in the fall. Local grower information: The average number of alfalfa cutting per year is 5.
2. Alfalfa Hay Averaged Cutting Effect. The development periods were taken from FAO-56 Table 11 for the total alfalfa season. Kc coefficients were taken from FAO-56 Table 12 for averaged cutting effects. Start dates are temperature based and vary from year to year. The season starts based on the last day that measures 25°F (-4°C) in the spring. The season end date is based on first day 25°F (-4°C) temperature in the fall. Local grower information: The average number of alfalfa cutting per year is 5.
3. Corn - Grain. The development periods were taken from FAO-56 Table 11 for grain corn, 170-day curve. FAO-56 Table 12 Kc Coefficients. Average season start is based on typical planting dates (USDA, 1997 "Usual Planting and Harvesting Dates for U.S. Field Crops"). Season end is based on the end of the curve.
4. Prairie Grass. The development periods were taken from ASCE-70 (Jensen, 2016) Table C-1 for Switchgrass (mixed Kansas Praire Grass), Kc Coefficients for Switch Grass from ACSE-70 Table B-1. Season begin/end based on last occurrence of 25°F (-4°C) temperature in the spring and the first occurrence of 25°F (-4°C)

Table C7. Average Crop ET, Effective Precipitation and CIR for Kinsley 2E 1980 to 2009

Units = inches	Kinsley 2E (NWS) (1980-2009)				
Crop	Crop ET	50% Probable Effective Precipitation	80% Probable Effective Precipitation	Crop CIR (using 50% Probable Effective Precipitation)	Crop CIR (using 80% Probable Effective Precipitation
Alfalfa Hay	46.0	15.4	12.5	30.6	33.5
Alfalfa Hay Average Cutting Effects	44.8	15.3	12.5	29.5	32.3
Grain Corn	35.9	12.2	10.0	23.7	25.9

Table C8. Average Prairie Grass ET, Annual Precipitation, Effective Precipitation and Deep Percolation for Kinsley 2E 1980-2009

Units = inches	Kinsley 2E (NWS) (1980-2009)			
Crop	Crop ET	Annual Precipitation	Effective Precipitation	Deep Percolation
Rain fed Prairie Grass	21.1	26.3	21.1	5.2

APPENDIX D – METRIC ETRF ESTIMATION BACKGROUND AND METHODOLOGY

To map the distribution of evapotranspiration (ET) on and around the R9 ranch, we used the METRIC model developed at the University of Idaho by Dr. Richard Allen and others. METRIC is an acronym of "Mapping EvapoTranspiration at high Resolution using Internal Calibration". The model originated from versions of the Surface Energy Balance Algorithm for Land (SEBAL), a previous energy balance model. METRIC is designed to produce high-quality, accurate maps of estimated ET for regions up to the size of a Landsat scene at the high resolution pixel size of the satellite data. The METRIC model requires Landsat 4, 5, 7 or 8 image data and hourly weather observations including temperature, wind speed, dew point, incoming solar radiation, etc. that can be assumed to be consistent over the area of interest. The weather data is needed to model reference evapotranspiration for the station site and set ground parameters for the METRIC model.

ET in METRIC is calculated using a balance of energy available at the surface of the earth. Total net radiation energy from the sun and the atmosphere represents the energy available at the ground to: warm the surrounding air, warm the soil, or change the state of water from liquid to vapor. Vaporization of water uses energy in both in plant transpiration and evaporation from the soil surface. The combination of these is Evapotranspiration (ET) or the amount of water used in and around the plant. Net radiation can be calculated from satellite images. Landsat satellites continuously acquire space-based images of the Earth's land surface, scanning every location on Earth on a 16-day schedule. Because of overlap in the scenes recorded, data is usually available every 9 days for areas smaller than a half-scene. For Landsat 5, the images are in seven layers representing different wavelengths of visible and infrared light plus a thermal infrared band. The visible and infrared pixels recorded represent a grid spaced at 30 meters on the ground with a radiance value for each of the six layers for each pixel. The thermal band sensor reads on a 120 m grid with one thermal value covering 16 of the 30 m pixels. Using the data from each of the wavelength bands and known properties of the atmosphere, estimates for surface reflectance, vegetation index and net radiation (R_n) available at the surface can be calculated.

The METRIC model uses the vegetation index, surface temperature and reflectance to calculate the energy spent in warming the ground (G). Estimates for energy that warms the air (H) come from surface weather observations of wind and temperature at the same time as the satellite image. Subtracting G and H from the R_n calculated from the Landsat bands gives the leftover energy available for evapotranspiration called the Latent Heat flux (LE). Once this is calculated for each pixel in the area of interest, an equivalent amount of instantaneous ET can be found by dividing by the latent heat of vaporization of water.

The ET calculated in METRIC is then used to map the ratio of the Landsat pixel ET to a reference Evapotranspiration (ET_r) calculated at the weather station site at the time of the satellite overpass. The ratio is the Evapotranspiration Reference Fraction or ETrF. Grounding to the ET_r from the weather station, the "Internal Calibration" part of METRIC, helps to reduce the uncertainty of ET estimates using satellite data alone. The ETrF ratio can then be extended to the full day and interpolated between satellite images to provide daily and seasonal values of ET. A map of the ETrF for the area of R9 Ranch from the METRIC model for May 25, 1984 Landsat 5 row 29 path 34 is presented in Figure 2 in the main body of this report.

For the R9 Ranch, 15 Landsat 5 images were used for the growing seasons of 1984 and 1985. Scenes were taken from rows 29 & 30, path 34. Other scenes were found to have too much cloud cover in the area of R9 Ranch to accurately calculate the energy balance parameters at the surface. Table D1 below lists the 15 dates and scene row and path.

Table D1. Landsat 5 Scene Dates and Row and Path Used for 1984 and 1985 METRIC ET Mapping

	Landsat 5			Landsat 5	
Date	Row	Path	Date	Row	Path
4/14/1984	30	34	3/25/1985	29	34
5/25/1984	29	34	5/3/1985	30	34
6/1/1984	30	34	5/12/1985	29	34
6/10/1984	29	34	8/7/1985	30	34
8/4/1984	30	34	9/8/1985	30	34
8/13/1984	29	34	9/17/1985	29	34
9/5/1984	30	34	10/3/1985	29	34
9/21/1984	30	34			