Kansas Farm Bureau
Helping Feed the World

Stafford County Farm Bureau Association

306 N. Main, Box 308, St. John, Kansas 67576 / (620) 549-3292

Earl D. Lewis Jr. P.E.

Chief Engineer
Division of Water Resources
Kansas Department of Agriculture
1320 Research Park Drive
Manhattan, Ks. 66502

April 26, 2023

Dear Chief Engineer Lewis,

The Stafford County Farm Bureau board is glad to hear that you will review the impairment investigation that was completed in 2016. It was with great concern that our members received your correspondence of April 10th, 2023. Our communities were under the impression that a **Memorandum of Agreement (MOA)** was in place and moving forward. We are enclosing our original letter to then chief engineer Barfield, as we believe the facts in that letter are worth reviewing.

The Stafford County Farm Bureau board supports our GMD5 boards efforts to move as quickly as roadblocks have allowed. We know that an incredible amount of time and money has been spent leading to a **MOA** that is the primary solution to the impairment issue. The timing of water at the refuge is a major factor, which augmentation is the only solution that is reliable to solve this. Great strides have been made and will continue to be made to cut our consumptive use and retire some water rights. The **MOA** is sound, developed with science behind it.

On September 14, 2022 Kansas Association of Conservation Districts, KFB ENR committee and others toured Quivira, the little salt marsh was very dry, large cracks visible across the bottom. A question was posed to Mike Oldham refuge manager; how did this happen? Informed that the refuge had been draining all their water so they could put in meters and do maintenance. February 17, 2023 a trip to the Little Salt Marsh revealed what appeared to be a at near capacity Little Salt Marsh, 7 days after the Request to Secure Water was received.

This raises questions.

First, with our area being in a D4 drought designation and rainfall records in 2021, 2022 and 2023 showing shortages of 9-17 inches over this district and irrigation being used more intensely during this period; does this not imply the stream was healthy enough to still fill the Little Salt Marsh?

Second, we again restate these two comments from our original letter to former Chief Engineer Barfield;

"In 1993, (Guy Ellis and Larry Sheets Hydrologist DWR) "It is quite probable that the natural flows of water to full extent of this water right <u>will not</u> be available most normal years. Management plans for the refuge

area should be based on probable flows of Rattlesnake creek." (3) "In most years the available quantity will be considerably less." (7)

May 27, 1994 David Pope cautioned the service,

> "Even under pristine conditions, most of the streams in Central and Western Kansas are not continuously dependable sources of supply. Particularly in the case of very large water rights, such as the Quivira Refuge right, the water holder should not expect to be able to fully exercise the right each and every year. I should also point out that a certificate states the maximum quantity of water that may be diverted in any year. Because certificates are based on the maximum year of record, no water right holder should expect to need or have available the maximum authorized quantity every year." (5) pg.4"

Third, we would like a definition of impairment. We have been told that the refuge has been impaired. With the two previous comments from DWR employees above, how is this impairment being measured? Is it possible the FWS will request to secure a full allocation of water every year even when DWR set forth the system would not likely provide? Again, augmentation would greatly improve water availability and operational management if just given the time/resources to develop.

Our board is very concerned about our communities. The letter requesting to secure water was a real stab in the back to our communities and efforts to get the **MOA** to completion. It comes at a time when our communities have suffered a poor 2022 wheat crop, 2022 row crops were a disaster, a 2023 wheat crop that is worse than 2022 and the probability that 2023 row crops will not be planted. Members of our communities that lived through the 50's have commented that this drought is worse than the 50's. Our ability to irrigate has helped our communities to cope, grow grain to be used as food and feed for livestock unlike the 50's which were prior to most of the irrigation development. We believe our district to be very stable, complement the job GMD5 previous boards and the current one has done. We believe our district has done exactly what the intentions of the 1945 Water Act were, put our water resource to beneficial use, and worked to satisfy the Quivira water right to the extent promised by DWR when certified.

Stafford County Farm Bureau would extend an invitation and welcome the opportunity to visit with you and further discuss the issues we have raised. Our communities and viable farming operations depend upon your fair and reasonable enforcement of Kansas water law.

Respectfully,

Tyler Alpers	Stafford County Farm Bureau President
Brian Dunn	Stafford County Farm Bureau Vice-President
Cammie Vaupel	Stafford County Farm Bureau Secretary-Treasurer
Justin Vosburgh	Stafford County Farm Bureau board member
Merlyn Spare	Stafford County Farm Bureau board member
Billy Milton	Stafford County Farm Bureau board member
Christa Milton	Stafford County Farm Bureau board member

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David W. Barfield, P.E.
Chief Engineer
Division of Water Resources
Kansas Department of Agriculture
1320 Research Park Drive
Manhattan, Ks. 66502

January 18, 2019

Dear Chief Engineer Barfield,

The Stafford County Farm Bureau board feels there are a lot of misconceptions out there about Quivira National wildlife refuge and Stafford County. We offer these statements.

Quivira National Wildlife Refuge

In the late 1920's or early 1930's a ditch was constructed to divert Rattlesnake creek water to the Little Salt Marsh (LSM). (CCP) pg.51

In 1954, 4266 acres of farm ground existed, and several farmsteads existed between the LSM and the Big Salt Marsh (BSM). (CCP) pg.36, 51 (NCRS maps)

In May 1955 the Migratory Bird Conservation Commission purchased Big Salt Marsh and Little Salt Marsh. (CCP) pg.13

In 1957, a water permit (#7571) was filed requesting 22,200 acre feet of water. (CCP) pg.14

In 1958 the name of the refuge became Quivira National Wildlife Refuge. (CCP) pg.13

Acquisitions continued through 1969 to bring the refuge to 21,820 acres. (CCP) pg.14 Some of these acquisitions were done through eminent domain proceedings. (Farmers names withheld)

Refuge infrastructure occurred over decades. During these years 25 miles of manmade drainage canals and 103 water control structures were constructed to move water around between the LSM and the BSM, to more than 30 natural and manmade water holding units. (CCP) pg.15, 29, 36, 37, 47, 64

In 1978, Notice of Proof of completion was filed. (6)

In 1982, Notice of Proof of completion was filed. (CCP) pg.14 (6)

1987 was chosen as the perfection year. This is the year that set the record for Max daily discharge at the Zenith gauge. It was the eighth wettest year out of 100 years of data. (6) The amount of water available for perfection was 1.8 times greater than the maximum quantity authorized by the Permit to Appropriate Water. (11) The capability to use more water was not demonstrated in 1987. (CCP) pg.14

In 1991 and 1998 additional land was acquired bringing the total to 22,135 acres. (CCP) pg.14

In 1993, (Guy Ellis and Larry Sheets Hydrologist DWR) "It is quite probable that the natural flows of water to full extent of this water right will not be available most normal years. Management plans for the refuge area should be based on probable flows of Rattlesnake creek." (3) "In most years the available quantity will be considerable less." (7)

May 27, 1994 David Pope cautioned the service,

> "Even under pristine conditions, most of the streams in Central and Western Kansas are not continuously dependable sources of supply. Particularly in the case of very large water rights, such as the Quivira Refuge right, the water holder should not expect to be able to fully exercise the right each and every year. I should also point out that a certificate states the maximum quantity of water that may be diverted in any year. Because certificates are based on the maximum year of record, no water right holder should expect to need or have available the maximum authorized quantity every year." (5) pg.4

On April 9th, 1996 Certificate of Appropriation for Beneficial Use of Water for Water Right no. 7571, with Priority date August 15, 1957 was issued. 3 points of diversion were noted with a combined maximum diversion rate of 300 cfs and quantity now to exceed 14,632 acre-feet. (CCP) pg.14 (4) This sentence was placed on the certificate. "The right of the appropriator shall relate to a specific quantity of water and such right must allow for a reasonable raising or lowering of the static water level and for reasonable increase or decrease of the stream flow at the appropriator's point of diversion." (4)

In 2000 KDA-DWR approved the Refuge conservation plan. (6) pg.8

June 2001 and January 2003 the Service requested that the Zenith gauge be used as a "means of measuring the volume of water entering the refuge." The difficulty designing and implementing an accurate metering system at Refuge diversions is acknowledged several times in the record. (6) pg.8

2011 survey of Quivira shows 10,819 acres of herbaceous wetland zones (48.6%), 3,005 acres open water (13.5%), 4,898 acres grassland (22.0%), 1,469 acres shrubland (6.6%) and 868 acres riparian and woodlands (3.9%). 2008 map shows 886 acres of farmland. (CCP) pg.37, 39

In 2012, according to Megan Estep USF&W Service, the biggest issue is timing of water availability for the refuge needs, specifically late summer/fall period. (14)

April 8th, 2013 the Service requested an impairment investigation (9)

May 2014, a Stafford field office visit finds meters that are not on the "approved flow meter list" and only one meter was actually installed. (12)

In 2015 Comprehensive Conservation Plan was adopted by the Service. This plan conflicts with the 2000 plan. (6) pg.9

Employment and visitor spending add approximately $1.015 million dollars of added value to the 5 county area around Quivira. (CCP) pg.61

Quivira National Wildlife Refuge is not on the Stafford County tax roll. (10)

Stafford County Kansas

Conservation efforts that have evolved from the dust bowl days of the 1930's have resulted in higher farm field residue levels, leading to less soil erosion and less runoff. Streamflow has been affected by conservation programs paid in part by state and federal programs.

GMD#5 was the first to cut back water appropriations during development in the State of Kansas, and then closed the district to further appropriations in 1993. (9) This was a great vision that began long before anyone else in the state of Kansas acted.

The August 2011-July 2012 period was the warmest 12-month period of any 12-months on record for the contiguous U.S. since 1895. (15) 2012 has the distinction of the lowest 4-month cumulative rainfall deficit (2.7 Std deviations from the norm) in the 6 state central Great Plains area in 117 years eclipsing 1988, 1934 and 1936. (1) pg.271, 278

This was not the first time creeks and rivers dried up in Kansas. Stream gauging data recorded prior to 1956 (predevelopment) showed no streamflow at Garden City and Great Bend on the Arkansas river and only 6 cfs on the Arkansas river at Wichita. (2) pg.66 table 9

Stafford County, as evidenced by the water level measurements of GMD#5 over time and the Great Bend Prairie Regional Planning Area Usable Lifetime of the High Plains Aquifer map, is very close to equilibrium with regards to irrigation withdrawals and recharge rates in the county. (9)

Kansas Geological Survey report in March 2018, pumping needs to be reduced by about 2% for sustainability in GMD5 based on the last dozen years of water level and water use data. (8)

Stafford county aquifer is full, a reasonable raising or lowering of the static water level is occurring. There are irrigation wells that were established in the 60's that in 2010 and 2019 were equal or exceeded the static water level of the day they were drilled. (9)

Since Stafford county aquifer is full and GMD5 is within 2% of sustainability, we ask the question could there be other forces affecting streamflow outside of GMD5? Could the lack of baseflow from the west of the Arkansas river, which contributes to the lack of streamflow in Arkansas river contribute to a lack of head pressure thereby limiting baseflow movement and streamflow in GMD5?

Irrigation increased agricultural land values in GMD5 by $1.44 billion in 2015. The ability to irrigate provides a 73% premium to the land price average. Losing irrigation in GMD5 would annually decrease animal sales by $236 million, cattle on feed by 213,000 head, fertilizer expenditures by $22.6 million, chemical expenditures by $10.7 million, and total farm expenditures by $259.8 million. (13) pg.i

Solution

Quivira National Wildlife Refuge is a man made refuge that has only existed in its current condition since 1982. Water delivered directly to the ponds in the most efficient manner possible seems to be the most sensible solution to achieve and solve this issue while fulfilling the needs of Quivira National Wildlife Refuge and maintaining the livelihoods of all in GMD5.

One of the duties of the Chief engineer is to administer water law so that the use of the state's water is put to beneficial use. The current state of GMD5 district with a 2% cut in pumping reductions would lead to sustainability and the maximizing of putting the state's water to beneficial use in our area. Any cuts greater than this, would lead to a failure of the Chief engineer of his duties of putting the state's water to beneficial use.

The GMD5 board has a solution, funded locally that will maintain current water tables for years to come and provide water to Quivira National Wildlife Refuge in a manner that will furnish water when the refuge needs it. We ask that you support the people of Stafford county and GMD5 LEMA proposal.

Respectfully,

Marlyn Spare	Stafford County Farm Bureau President
Tyler Alpers	Stafford County Farm Bureau Vice-President
Cammie Vaupel	Stafford County Farm Bureau Secretary-Treasurer
Justin K. Vosburgh	Stafford County Farm Bureau board member
Brian Dunn	Stafford County Farm Bureau board member
Shon Meschberger	Stafford County Farm Bureau board member
Jessica Neeland	Stafford County Farm Bureau board member

cc: Mike Beam Secretary of Kansas Department of Agriculture
Richard Felts Kansas Farm Bureau President
Senator Pat Roberts
Senator Jerry Moran
Representative Ron Estes
Kansas Senator Mary Jo Taylor
Kansas Representative Greg Lewis
GMD#5
Waterpack
Stafford County Commissioners

References:

(CCP) Comprehensive Conservation Plan Quivira National Wildlife Refuge October 2013

(1) Causes and Predictability of the 2012 Great Plains Drought

(2) Drought of the 1950's

(3) Letter from DWR to Cheryl Willis Fish and Wildlife Denver Co. August 18, 1993

(4) Certificate of Appropriation For Beneficial Use of Water Water Right #7571

(5) Letter from DWR to Ralph Morgenweck Fish and Wildlife Denver Co. May 27, 1994

(6) GMD5 Impairment Response Letter May 12, 2016

(7) Memorandum Larry M. Sheets Hydrologist May 11, 1993

(8) Status of the High Plains Aquifer in Kansas March 2018

(9) GMD5 records and maps

(10) Stafford county treasurer

(11) Letter from DWR to Terry Grosz Fish and Wildlife Denver Co. April 10, 1996

(12) Quivira Water Right #7571 Page 33 0f 894

(13) The Value of Water in GMD5 December 20, 2018

(14) Email correspondence Meg Estep to Chris Beightel March 23, 2012

(15) NOAA's National Climatic Data Center July 2012 Statewide ranks

Drought of the 1950's with Special Reference to the Midcontinent

By R. L. NACE *and* E. J. PLUHOWSKI

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1804

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

rising in much of Iowa, but the level in a well at Marion was still a foot lower than in 1955.

KANSAS

Average annual precipitation in Kansas ranges from 16 inches in the west to 42 inches in the extreme southeast. All sections of the State except the northeast had precipitation deficiencies during 40 or more months of the 60-month drought period in 1952–56. Large areas in southern and central Kansas had deficiencies in 45–49 months. The cumulative 5-year rainfall deficiency ranged from 100 percent of normal annual precipitation in the extreme northeast to 200 percent in the south-central section.

The severity of the drought is illustrated by statewide precipitation averages, which show that each of the 5 drought years ranked among the 15 driest of record (since 1887). Prior to 1887, severe droughts had occurred in the 1840's, 1860's, and 1870's. Flora (1948) considered the drought of the 1860's to be about as severe as that of the 1930's. The driest year of record in Kansas was 1956, when the statewide average rainfall was about 15.5 inches—nearly 3 inches less than in 1936, the driest year of record before 1956. Average precipitation was about 19.5 inches during 1952–56, which was the driest 5-year period of record in the history of the State. The previous driest 5-year period was 1933–37, when the statewide average precipitation was about 22 inches. The north-central region was the only part of the State where average rainfall during 1952–56 was as high as that recorded in 1933–37. Average yearly rainfall in other sections during the recent drought ranged from 0.6 inch below the 1933–37 average in the northwest to 8.8 inches below in the southeast.

In terms of precipitation, runoff, and ground-water recharge, the severity of the drought of the 1950's exceeded that of the drought of the 1930's in parts of Kansas. These factors do not each indicate the same degree of drought severity because of differences in the lengths of records, extent of areal coverage, and degree to which each factor was affected by man's activities after 1930. Also significant in an evaluation of the effects of drought severity are the intensity and time distribution of precipitation, antecedent soil-moisture conditions, reservoir storage, and ground-water levels prior to the drought period.

The worst drought in much of western Kansas was that of 1892–94, which lasted 27 months. The drought of the 1930's was less severe but was noteworthy in its duration. In terms of precipitation, the drought of the 1950's did not affect western Kansas until March 1954 (Palmer, 1956, p. 7), but by 1956 it had become one of the worst droughts of record in that part of the State. Runoff and precipitation

deficiencies in the north-central region were more severe in the 1930's than during the recent drought. The few data available seem to show that ground-water levels in that part of Kansas were lower during the 1930's than during the 1950's. Throughout much of the eastern part of the State, the drought of the 1950's was probably the worst of record. In September 1955, record-breaking low flows were measured along the main stem of the Kansas River below Wamego. Runoff was extremely deficient throughout the eastern part of the State during 1953–56; by the end of 1956 nearly every river in the area except the Kansas was dry or nearly so.

Sharply reduced runoff during the drought caused acute water-supply problems in many areas of eastern Kansas. To conserve available supplies, many municipalities imposed compulsory restrictions on water use. Some communities adopted higher water rates to finance emergency water-supply operations. Despite all restrictions, supplies from several reservoirs were exhausted, and water had to be hauled by rail and by truck to stricken communities. The financial burden of these emergency operations was considerable; for example, the cost of water in Osage City during the period when water had to be imported increased to 5–10 times the normal rate. By late 1956 the city of Chanute (population 10,000) had a critical water shortage because its source of supply, the Neosho River had ceased flowing. To maintain a supply of water, the city added treated sewage effluent to the water supply for reuse. Recirculation of effluent was begun in October 1956 and continued until March 1957.

Surface water was not the only water-supply source affected by the drought, for ground-water supplies to many municipalities also were deficient. Thus, supply and distribution systems clearly needed expansion and improvement, not only to provide for development of the region, but also in anticipation of future drought.

STREAMFLOW

After record-breaking heavy rainfall in 1951, the water situation in Kansas deteriorated rapidly. Although rainfall in some areas in 1951 was as much as twice that normally expectable, rainfall the following year was less than half of normal in the southwestern part of the State. However, despite rainfall deficiencies, runoff in 1952 was generally at or near average. For example, Beaver Creek near Beaver City, Nebr. (pl. 1), had slightly above average runoff in 1952 although precipitation on the river basin was only about 75 percent of normal. The principal part of the drainage area above this gage is in northwestern Kansas, which had record-breaking high runoff in 1951. Thus, a considerable part of the recorded runoff in

1952 was generated during the wet year 1951, when soil moisture and ground-water storage were brought to high levels. Streamflow continued to decrease rapidly in 1953 as the drought intensified and as carryover water from previous wet periods became depleted. The extraordinarily small amount of runoff in 1955—only about 1 percent of average—indicated the severity of the drought in this basin. Furness (1962, p. 6–16) plotted multiyear low-flow frequency curves for most gaged Kansas streams for recurrence intervals of up to 50 years. By comparing recorded minimum average low flow for a 4-year period during the 1950's drought with that computed statistically for selected return periods, one can estimate the drought severity. During the 1953–56 water years, streamflow at Beaver Creek near Beaver City averaged 0.0014 cfs per sq mi (cubic feet per second per square mile), whereas mean flow for a similar period may be expected to fall below 0.0025 cfs per sq mi only once every 50 years, on the average. Evidently, the drought in this basin had a recurrence interval of substantially more than 50 years.

Discharge in the Kansas River at Topeka (pl. 1) includes runoff from most of northern Kansas and from small areas in Nebraska and Colorado. The hydrograph indicates that deficiencies during the 1950's were somewhat greater than those of the 1930's but shorter in duration. For example, in 1955 the 5-year moving average was below the previous record-low levels reached in the late 1930's; moreover, 1956 had the lowest streamflow of record. However, the 5-year moving average rose sharply late in the 1950's, forming a V-type curve, whereas the U-type curve representing the 1930's shows that the low average persisted for several years. The substantial runoff in 1942–51, which culminated in the extraordinary record-high runoff in 1951, separates the two drought periods.

Extremely low runoff in eastern Kansas in the 1950's caused water deficiencies greater than those of the 1930's, as is shown by the hydrograph for Marais des Cygnes River near Ottawa (pl. 1). In 1955 the 5-year moving average at this station reached its lowest level—about 63 percent of the runoff of the 1930's. Analysis of the unprecedented low runoff during 1953–56 indicates that the recent drought had an estimated recurrence interval of 50 years. Recovery during 1957–60 was only partial, as has been indicated by the continuation of less-than-normal flow.

Averages and extremes of recorded flow at long-term stations on selected streams in Kansas are shown in table 9. With but one exception, the maximum yearly runoff of record for these stations in the Kansas River and Marais des Cygnes River basins occurred in 1951 immediately preceding the drought. Of the 13 gaging stations

TABLE 9.—*Summary of discharge data at selected stations in Kansas and adjacent areas* [1]

Stream	Gaging station location	Discharge (cfs)			Annual runoff				
		Average	Maximum instantaneous	Minimum daily	Average (acre-ft)	Maximum		Minimum	
						Water year	Acre-ft	Water year	Acre-ft
Kansas River basin									
Republican River	Hardy, Nebr.	766	225,000	0	554,600	1951	1,277,000	1956	82,900
Do.	Clay Center	1,100	195,000	1	794,200	1951	2,423,000	1956	146,400
Smoky Hill River	Ellsworth	233	61,000	.6	169,000	1951	997,000	1901	31,300
Saline River	Tescott	218	61,400	0	158,000	1951	1,151,000	1924	30,700
Solomon River	Beloit	430	125,000	0	311,000	1951	1,931,000	1956	56,900
Do.	Niles	594	178,000	1	430,000	1951	2,978,000	1956	78,800
Smoky Hill River	Enterprise	1,690	233,000	38	1,220,000	1951	6,411,000	1956	213,000
Big Blue River	Barnston, Nebr.	740	57,700	1	536,000	1951	1,600,000	1934	83,200
Kansas River	Wamego	4,650	400,000	116	3,366,000	1951	16,130,000	1934	821,700
Little Blue River	Waterville	631	50,400	27	457,000	1951	1,769,000	1940	89,500
Big Blue River	Randolph	1,620	98,000	42	1,170,000	1951	4,615,000	1934	242,000
Kansas River	Topeka	5,150	469,000	192	3,730,000	1951	17,410,000	1956	826,000
Do.	Bonner Springs	6,420	510,000	235	4,650,000	1951	21,250,000	1956	962,000
Marais des Cygnes River basin									
Marais des Cygnes	Ottawa	612	142,000	0	443,000	1945	1,540,000	1956	18,900
Do.	Trading Post	1,690	148,000	0	1,220,000	1951	3,970,000	1939	66,200
Marmaton River	Fort Scott	301	37,400	0	218,000	1951	615,000	1939	16,800
Arkansas River basin									
Arkansas River	Syracuse	398	62,000	1	288,000	1942	1,412,000	1940	24,900
Do.	Garden City	218	33,500	0	158,000	1942	1,223,000	1940	1,340
Do.	Great Bend	485	20,200	0	351,000	1942	1,133,000	1956	63,900
Little Arkansas River	Valley Center	227	32,000	2.6	164,000	1951	706,000	1934	18,000
Arkansas River	Wichita	1,030	27,600	6	744,000	1951	2,635,000	1954	163,000
Do.	Arkansas City	1,640	66,000	4	1,190,000	1951	4,221,000	1934	265,000
Walnut River	Winfield	701	105,000	0	508,000	1951	1,600,000	1954	19,000
Chicaskia River	Blackwell, Okla.	445	85,000	0	129,600	1951	1,052,000	1954	51,400
Verdigris River	Independence	1,560	117,000	0	1,130,000	1951	2,972,000	1953	47,500
Neosho River	Council Grove	123	121,000	0	89,000	1951	361,000	1953	3,900
Cottonwood River	Cottonwood Falls	496	196,000	0	359,000	1951	1,673,000	1956	11,000
Neosho River	Iola	1,560	436,000	0	1,130,000	1951	4,800,000	1956	102,000
Do.	Parsons	2,370	410,000	0	1,720,000	1951	6,000,000	1953	125,000

[1] The averages, maxima, and minima are based on stream-gaging data recorded through the 1956 water year.

in the Arkansas River basin, 10 reported a record maximum yearly runoff in 1951; only 3 reported record maxima in other years.

Greatly deficient streamflow occurred early during the recent drought in the southeastern part of the State. Record-breaking minimum annual runoff was measured in the Verdigris and Neosho River basins during 1953, and severe drought spread westward into the Arkansas River basin in 1954. Before 1950 the lowest runoff of record in most streams in southeastern Kansas had occurred in 1934, but many of these long-standing records were broken during the 1950's. For example, table 9 shows that the lowest annual runoff of record at Walnut River at Winfield was 19,000 acre-feet in 1954. The previous record low had been 73,000 acre-feet in 1934—nearly four times the volume in 1954. After some local relief in 1955, the drought intensified in the northeastern and north-central parts of the State during 1956. Record-breaking low flows were reported throughout the Kansas River basin during that year, the last and worst year of the drought.

Furness (1962, p. 17–20) presented a unique method of evaluating the severity of the drought in Kansas. He prepared mass curves for stream flow during periods of low flow and compared storage requirements that would be needed to sustain selected draft rates with computed storage requirements based upon frequency-mass curves. He prepared storage-required frequency curves for all nonregulated streams for 2-, 5-, 10-, 20-, and 50-year recurrence intervals and superimposed on these the storage requirements for the recent drought. On the basis of these studies, the recurrence interval (or return period) of the drought was 50 years or more throughout eastern Kansas, except in the extreme north and in parts of the Marais des Cygnes River basin, where the drought was somewhat less severe. Similarly large storage deficiencies developed during the 1950's in the Beaver Creek, Sappa Creek, and Prairie Dog Creek basins in the northwest, where the drought apparently had a recurrence interval of 50 years or more. The drought was less severe in the central and southwestern parts of the State, where the estimated recurrence intervals of the storage deficiencies during the 1950's commonly ranged from 10 to 40 years.

GROUND WATER

After the drought began in Kansas in the fall of 1951, the water table declined almost continually for 6 years, dropping below the bottoms of thousands of stock, domestic, and municipal wells throughout the State. Ground-water levels receded to new record-low stages in 1956; they were as much as 17 feet below the record-high stages of 1951 and as much as 5 feet below the previous record-low levels of the

late 1930's and early 1940's. Many wells were deepened, but some had already been drilled or dug to the base of the water-bearing materials. A survey of water-supply sources in southwestern Kansas during 1954 showed that only 30 percent of the wells could adequately meet the severe demands placed on them. Domestic water was hauled to about 29,000 farms at a cost of more than $7 million in 1954, and the cost of hauling water in one eastern Kansas county alone was about $1 million.

Records of a few representative wells show the effects of drought on ground-water levels. Water levels in most shallow aquifers were at low stages in 1940 following the drought of the 1930's. Fairly abundant precipitation during the 1940's caused water levels to rise, and excessive rainfall during the summer of 1951 led to record-high ground-water stages. During the drought which began later in 1951, lack of rainfall resulted in sharply reduced recharge, and ground-water levels declined steadily. In the spring and early summer of 1957, abundant rain produced substantial recharge and some large recoveries in water levels.

Although storage in many shallow acquifers declined sharply during the 1950's, water levels in some of the deep acquifers in western Kansas actually rose during the drought. Owing to the time lag in the response of deep aquifers to recharge and to the slow movement of water within the aquifers, this seemingly anomalous rise in water levels reflects heavy recharge during 1951 and earlier years. These deep aquifers are important in the economy of western Kansas because they provide a large reserve of water that may be tapped during droughts.

The record for a well at Valley Center, near Wichita in south-central Kansas (pl. 2), represents essentially natural conditions, as the well is unaffected by pumping. In the late 1930's, when observations were started, the water level was nearly 19 feet below land surface as a result of a prolonged period of drought. Increased recharge during 1941–51 caused an irregular upward trend in the water level, so that by mid-1951 the stage was only 10 feet below land surface and about 9 feet higher than in 1938. Thereafter, except for minor interruptions, the water level declined steadily until early 1957, initially as a natural recession from the record-high stage of 1951 but, after 1951, principally because of the drought. Thus, except late in 1955, the record of continuous decline in water level shows that there was no appreciable recharge during the drought. The evidence of "no recharge" is that the water level declined almost uniformly during a period of years without even temporary rises during normal recharge seasons, as had occurred in earlier, more normal periods. The water level was at record-low stage early in 1957, when it was about 1.5 feet lower than the previous low, recorded in 1938, and 10.5 feet below the high, recorded in 1951.

Water-level fluctuations in a key well near Garden City in southwestern Kansas (pl. 2) were somewhat similar to those in the Valley Center well, although in recent years the Garden City well has been affected by heavy pumping. The decline of 17 feet in the water level in this well from mid-1951 to late 1956 was caused partly by regional pumping for irrigation, so that the decline was greater than would have occurred otherwise. The water level rose during the late-fall and early-winter periods of the drought years because, when the heavy withdrawals for irrigation were stopped each year, the depleted zone of the aquifer was refilled partly by inflow from the surrounding aquifer and partly by recharge from the Arkansas River. The rises probably do not indicate seasonal recharge.

The pattern of ground-water fluctuations in north-central Kansas is illustrated by the hydrograph for a well near Beloit (pl. 2). The water level reached extreme low stages in both 1935 and 1941, rose irregularly to a peak height in 1951, and then declined until early 1957. The lowest level reached during the drought was about 2.1 and 2.5 feet, respectively, above the lows of 1935 and 1941. Thus, in this part of the State the effect of the drought of the 1950's on ground-water resources was less severe than that of the 1930's.

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Average annual precipitation in Missouri ranges from 32 inches in the extreme northwest to 48 inches in the extreme southeast. Precipitation was less than normal in 40–44 months during the 60-month drought period of 1952–56 in most parts of the State; only the southeast and small areas of the north had fewer monthly deficiencies. The accumulated 5-year rainfall deficiencies during the drought ranged from 25 percent of normal annual precipitation in the southeast to 125 percent in the southwest.

The most severe effects of the drought in most parts of Missouri occurred during 1953. Although annual runoff was somewhat lower in 1954 and 1956 in some areas, the summer of 1953 was one of the hottest and driest of record. Temperatures as much as 8°F above normal were reported in June 1953 in the southwest, and from June through September 1953 a large part of the State received less than 25 percent of normal rainfall. Pronounced drought effects were general during the growing season in 1954 and 1956, but some relief occurred locally during 1955. However, drought effects in Missouri during 1952–56 were, in some respects, more severe than in any other 5-year period (H. C. Bolon, written commun., 1957). In 1956, a drought committee recommended that 93 of Missouri's 114 counties be designated as drought disaster areas and that the Federal Government