Kansas Geological Survey

County-by-county and district-wide tabulated recharge values and related statistics for the Kansas Groundwater Management District regions based on Kansas Geological Survey Bulletins and other publications (Five EXCEL spreadsheets)

By

Marios Sophocleous and Anish Pradhananga

Kansas Geological Survey Open File Report 2003-11
February 2003

GEOHYDROLOGY

The University of Kansas, Lawrence, KS 66047 (785) 864-3965; www.kgs.ukans.edu

KANSAS GEOLOGICAL SURVEY
OPEN-FILE REPORTS

>>>>>>>>>>>NOT FOR RESALE<<<<<<<<<<

Disclaimer

The Kansas Geological Survey made a conscientious effort to ensure the accuracy of this report. However, the Kansas Geological Survey does not guarantee this document to be completely free from errors or inaccuracies and disclaims any responsibility or liability for interpretations based on data used in the production of this document or decisions based thereon. This report is intended to make results of research available at the earliest possible date, but is not intended to constitute final or formal publication.

County-by-county and district-wide tabulated recharge values and related statistics for the Kansas Groundwater Management District regions based on Kansas Geological Survey Bulletins and other publications

(Five EXCEL spreadsheets)

by

Marios Sophocleous and Anish Pradhananga

Kansas Geological Survey Open-File Report 2003-11

Lawrence, KS February 2003

The following set of five EXCEL spreadsheets [by Groundwater Management District (GMD) region] contain county by county recharge estimates and related information based predominantly on three major sources of information: the Kansas Geological Survey (KGS) Bulletins, the 1967 Kansas Water Resources Board (KWRB) Irrigation in Kansas 701-project report, and the USGS 1991 potential natural recharge in Kansas report, although additional sources of information were also used. In addition, summary recharge estimates for each Kansas region (approximately corresponding to each GMD) and related statistics are also given. Based on the aforementioned three major sources of information, the following recharge estimates for the entire Ogallala aquifer of western Kansas (approximately comprised of the regions occupied by GMDs 1, 3, and 4) and their related statistics are given in Table 1 below. The average of those three mean recharge estimates for the Ogallala aquifer of western Kansas is 0.37 inch/yr.

Table 1. Western Kansas Ogallala aquifer recharge estimates and related statistics based on three-agency estimates: Kansas Geological Survey (KGS), Kansas Water Resources Board (KWRB), and United States Geological Survey (USGS).

No.	County	Area (mi^2)	Recharge[1] (in/yr)	Recharge[2] (in/yr)	Recharge[3] (in/yr)
1	Wallace	910	0.2500	0.1030	0.2576
2	Greeley	788	0.1000	0.1428	0.2641
3	Wichita	717	0.1000	0.2615	0.4603
4	Scott	724	0.5000	0.2331	0.4299
5	Lane	720	0.2500	0.2240	0.2487
6	Hamilton	992	*	0.1000	0.1800
7	Kearny	861	*	0.2400	0.5600
8	Finney	1302	*	0.2300	0.5600
9	Gray	873	*	0.3200	0.9400
10	Ford	1082	0.5000	0.6000	0.9400
11	Stanton	685	0.3000	0.3200	0.3900
12	Grant	571	0.3000	0.3000	0.7300
13	Haskell	580	*	0.3100	0.9800
14	Morton	720	*	0.3100	0.4200
15	Stevens	731	*	0.3100	0.7500
16	Seward	643	0.4000	0.2900	0.9900
17	Meade	979	0.2700	0.2800	0.9600
18	Cheyenne	1027	*	0.2227	0.4236
19	Rawlins	1080	*	0.1823	0.7257
20	Decatur	900	0.5000	0.3646	0.7500
21	Norton	880	0.3700	0.3281	0.8757
22	Sherman	1055	0.1000	0.2399	0.2417
23	Thomas	1070	0.2500	0.3627	0.3820
24	Sheridan	893	0.2500	0.2940	0.7391
25	Graham	891	0.5000	0.1473	0.6839
26	Logan	1073	0.1667	0.0874	0.1380
27	Gove	1070	*	0.1928	0.2033
28	Trego	900	0.2100	0.2083	0.2708
Total		24717			
Average			**0.2954**	**0.2573**	**0.5534**
Standard deviation			0.1396	0.1028	0.2803
Area-weighted avg.			**0.2936**	**0.255**	**0.5412**
90% Conf. interval upper limit			0.3176	0.2704	0.5891
90% Conf. interval lower limit			0.2732	0.2442	0.5176

1 : Ogallala aquifer recharge estimates based on KGS Bulletins (* indicates counties for which recharge had not been quantified).

2 : Ogallala aquifer recharge estimates based on KWRB "Irrigation in Kansas" 1967 report.

3 : Ogallala aquifer potential recharge estimates based on USGS-WRIR 87-4230 (Hansen, 1991).

WEST CENTRAL KANSAS (GMD 1 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Soils	Topog	Avg. Depth to Water Table	Vegetation & Land use	Comments
1	**Wallace**	910	KGS B 18 1931 KGS B 161 1963	Alluvium [1d] (present in approx. 2/3 of the county)	17.03	55	[1a]not known but studies in other similar High Plain areas indicate **1/4 in** of recharge. More in southern part than in northern part of the county. 1040 [1d] **(0.02 in/yr)**	most of the streams are influent so contribute appreciable recharge. But less in northern part of the county due to nearness of shale to the land surface	[1b]estimated to be approx. **36500 ac-ft/yr.** Inflow occurs along the western edge of the county	[1b]about **10%** of applied water. Relatively high in alluvial valleys	5000 [1c] **(0.1 in/yr)**	author's estimate soil-water budget	[1a] no reference source mentioned Hodson, W.G.,1963 [1b] Hodson,W.G.,1963 [1c] KWRB' 67 [1d] USGS' 91	silty and silty and loamy	High Plains section of the Great Plains physiographic province	[1e]12 ft-30 ft at alluvium [1e]30 ft-100 ft at Ogallala	crops and grasses farm land & pasture	[1e]KGS B 161
				Ogallala: [1d]														
2	**Greeley**	788	KGS B 108 1954 KGS Irr. Ser.2 1976	Ogallala Fm. (unconsolidated sand and gravel): as much as 300 ft thick, of which as much as 145 ft was saturated. as of 1971-72 Yields 100 to 2000 gpm. Dakota Fm. (sandstone aquifer): 400-550 ft thick. Similar aquifer in adjacent counties yield 30-300 gpm. Ogallala	16.98	52.5	[2a]**0.1 in/yr** [2b]4000 ac ft/yr **(0.05 in/yr)** during 1971-72 [2d]11100 **(0.26 in/yr)**	considerable, but unknown	[2a]estimated to be about 5000 ac-ft/yr. **(0.06 in/yr)**	considered low due to relatively impermeable loess cover [2b]44000 ac-ft/yr **(0.17 in/yr)**	[2b]27000 **(0.28 in/yr)** [2c]6000 **(0.14 in/yr)**	author's estimate (author's estimate) 10% of pcp. in irrigated & 1% of pcp. in nonirrigated land. (163000 ac irrigated & 390000 ac of nonirrigated land in Greeley and Wichita) -1971-72 20% of irr. applied (0.22" in irrigated & 0.05" in nonirr. land) Darcy's Law (irr&nonirr. land)+Lat. in. (0.17+.05)+.06 soil-water budget	[2a] Prescott, G.C., et al., 1954 [2b] Slagle and Weakly, 1976 [2c] KWRB' 67 [2d] USGS' 91	silty	High Plains section of the Great Plains physicgraphic province. Flat to gently rolling upland plains.	[2e]25 ft-40 ft at alluvium [2e]20 ft-80 ft at Ogallala	crops and grasses agriculture	[2e] ref. KGS B 108 [2b] For Greeley and Wichita combined. Lateral Inflow,subsurface outflow & total recharge are for Wichita and Greeley combined
3	**Wichita**	717	KGS B 108 1954 KGS Irr.Ser.2 1976	Ogallala is the principal water bearing fm. Small amount is also obtained from alluvium and Niobrara Ogallala Fm. (unconsolidated sand and gravel) as much as 300 ft thick, of which as much as 145 ft is saturated. Yields 100 to 2000 gpm. Dakota Fm. (sandstone aquifer) 400-550 ft thick. Similar aquifer in adjacent counties yield 30-300 gpm. Ogallala	18.63	52.5	[3a]**0.1 in/yr** [3b]4000ac-ft/yr **(0.05 in/yr)** during 1971-72 [3c]**0.28 in/yr** [3d]1-10% of annual pcp.(120-1200 ac-ft) in intensive study area [3f]17600 ac-ft/yr **(0.46 in/yr)**	44 ac-ft of loss per mile as per the study in Whitewoman Creek in July 1972	[3a]estimated to be about 5000 ac-ft/yr. (0.06 in/yr) occurs at west-ern boundary of the county.	negligibly low	[3b]27000 [3c]10000 **(0.26 in/yr)**	author's estimate Darcy's Law (irr&nonirr. land)+Lat. (0.17+.05)+.06 (author's estimate) 10% of pcp. in irrigated & 1% of pcp. in nonirrigated land. (163000 ac irrigated & 390000 ac of nonirrigated land in Greeley and Wichita) 1971-72 mathematical model (steady state) soil-water budget	[3a] Prescott, G.C., et al., 1954 [3b] Slagle and Weakly, 1976 [3c] Dunlap, L.E., et al., 1980 [3d] Gutentag & Stullken, 1976 [3e] KWRB' 67 [3f] USGS' 91	silty	High Plains section of the Great Plains physicgraphic province. Flat to gently rolling upland plains.	[3g]15 ft-40 ft at alluvium [3g]10 ft-80 ft at Ogallala In the period of 1948-1972 water level declined from 10-50 ft. in places where irrigation is practiced.	crops and grasses agriculture	[3g] ref. KGS B 108 [3b] For Greeley and Wichita combined. Lateral Inflow,subsurface outflow & total recharge are for Wichita and Greeley combined [3c] based on the study in an area of 12 mi^2 in northwestern Wichita ,west-central Kansas referred to by the authors as "intensive study area."

WEST CENTRAL KANSAS (GMD 1 Region)

No.	County	Area mi²	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Soils	Topog	Avg. Depth to Water Table	Vegetation & Land use	Comments
4	Scott	724	KGS B 66 1947 KGS Irr. Ser.1 1976	Alluvium: Thickness ranges from few feet to as much as 200 ft in the southern part. Yields from 250-1500 gpm. Ogallala Fm. is the major aquifer and thickness ranges from few feet to 215 ft in central Scott County. Yield ranges from 100-1000 gpm. Chalk aquifer (Niobrara Fm.)Yields from 500-1000 gpm Sandstone aquifer (Dakota Fm.) 430 ft in southwestern Scott to 710 ft in thickness in southwestern Lane county. Yields from 30-300 gpm. Ogallala	18.61	53.3	[4a]probably less than **1/2 inch** [4b]14000 ac-ft **(0.36")** in 1971 [4b]24000 ac ft **(0.62")** in 1972 [4f]16600 ac-ft/yr **(0.43 in/yr)**		[4b]9000 ac-ft/yr **(0.23 in/yr)**	[4b]30000 ac-ft (0.78") in 1971 19000 ac-ft (0.49") in1972 [4c]about 20% of irr. applied	[4b]53000 **(1.4in/yr)** in1971 [4b]52000 **(1.3 in/yr)** in 1972 [4e]9000 **(0.23 in/yr)**	assuming 10% & 1% of the precipitation to percolate in irrigated and nonirrigated land, respectively during the growing season. based on pumpage figures Darcy's Law A=5834400 sq ft (0.2093 sq mi) I=0.0029 K=64 ft/day experiment in Finney County soil-water budget	[4a] Theis, C. V., 1937 (KGS B 66) [4b] Gutentag & Stullken, 1976 [4c] Meyer, W.R., et al., 1953 [4e] KWRB' 67 [4f] USGS' 91	silty soils and loamy soils	High Plains section of the Great Plains physiographic province. 85% upland plains & 15% stream flood plains & intermediate slopes	Based on depth of water table Scott Co. may be divided into: 1. Shallow water area depth between <25 ft to 75 ft 2. Intermediate depth between <50 ft to 100 ft 3. Deep water area depth >100 ft (as of 1947) [4g] 15 ft-20 ft at alluvium [4g] 30 ft-120 ft at Ogallala In the period from 1940-48 to 1973, in about half of the area in Scott and Lane water level declined from <10 ft to 10 ft , in about 10% of the area decline was >30 ft and the decline of as much as 50 ft was also observed	Agriculture 38% crop-land & 62% for grazing as of 1939 crops and grasses	[4g] ref. KGS B 66 total recharge including seepage of irrigation water. 1972 being a wet year, infilteration is high but irrigation recharge low due to low application lateral inflow along the Scott-Wichita county line Water table depletion: ref. KGS B 27, KGS B 93 and comparing the data with similar data collected in 1973
5	Lane	720	KGS B 93 1951 KGS Irr. Ser.1 1976	Alluvium: Thickness ranges from few feet to as much as 200 ft in the southern part. Yields from 250-1500 gpm. Ogallala Fm. is the major aquifer. Thickness ranges from few feet to 215 ft in central Scott County. The median thickness is 110 ft. Yield ranges from 100-1700 gpm. Sandstone aquifer (Dakota Fm.) 430 ft in southwestern Scott to 710 ft in thickness in southwestern Lane County. Yields from 30-300 gpm. Chalk aquifer (Niobrara Fm.)Thick-ness of about 400 ft. Not an important aquifer as yield is small.	18.77	53.6	[5a]340 **(0.009 in/yr)** [5a]9550 **(0.25 in/yr)** [5b]about **1/4 inch** [5c]3000 ac-ft **(0.08 in)** in 1971 6000 ac-ft **(0.16 in)** in 1972	negligible, as all streams in Lane are ephemeral.		[5c]6000 ac-ft **(0.16")** in 1971 5000 ac-ft **(0.13")** in 1972 [5d]about 20% of irr. applied	18000 in 1971 [5c] **(0.46 in/yr)** 20000 in 1972 [5c] **(0.52 in/yr)** 8600 [5e] **(0.22 in/yr)**	soil-water budget From study in southern High Plains Estimation based on assumption that 10% of pcp. In irrigated and 1% in nonirrigated land percolates down to groundwater table based on pumpage figures pcp+ lat. infl+irr pcp+ lat. infl+irr experiment in Finney County	[5a] USGS' 91 [5b] Frye, J.C., 1942 [5c] Gutentag & Stullken, 1976 [5d] Meyer, W.R., et al., 1953 [5e] KWRB' 67	silty soils and silty and loamy soils		10% to 60% of the sat. thickness has been reduced throughout most of the main body of the unconsolidated aquifer. 1940-48 to 1973 [5f]25 ft-50 ft at alluvium [5f]<25 ft-75 ft at Ogallala	agriculture and pasture 460800 ac farmland. (1946 census) crops and grasses	[5f] ref. KGS B 93

WEST CENTRAL KANSAS (GMD 1 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Soils	Topog	Avg. Depth to Water Table	Vegetation & Land use	Comments
	Summary (District avg.[1])										0.33 in/yr [a] (std. dev. 0.10)	[1]arithmetic avg.	[a] USGS' 91					[1]all averages are calculated considering only the counties included in the GMD.
											0.19 in/yr [b] (std. dev. 0.07)	[1]arithmetic avg.	[b] KWRB' 67					
											0.24 in/yr [c] (std. dev. 0.16)	[1]arithmetic avg.	[c] KGS Bulletins					

Note:

KWRB'67: Irrigation in Kansas. Kansas Water Resources Board,1967. Report no. 16e.
USGS' 91: Hansen, C.V., 1991. Estimates of freshwater storage and potential natural recharge for principal aquifers in Kansas. U.S. Geological Survey, Water-Resources Investigations Report 87-4230.
KGS B: Kansas Geological Survey Bulletin
std. dev.: Standard deviation

EQUUS BEDS AQUIFER (GMD 2 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
1	McPherson	896	KGS B 79 1949		28.91	56					[1a]20% of pcp. 7 in/yr or 365 ac-ft/yr/mi^2 for the period of record 1938-1943 inWichita well field area (85 mi^2)	[1a]Water level fluctuation and sp. yield 20%	[1a]Williams & Lohman 1949	nearly level to gently sloping silty and clayey soils on uplands	10 ft-110 ft	farm and pasture -1945	area covered in B 79 = 2340 mi^2 includes McPherson,and parts of Marion, Harvey, Reno and Sedgwick counties
											6 in/yr or 320 ac-ft/yr/mi2 for normal pcp. in Wichita well field area (0.2*28.91=5.8 =6 in/yr for norm. pcp.)						
											[1b]138000 (2.89in/yr)		[1b]KWRB' 67				
				Alluvium			[1c]9220 (0.19 in/yr)					soil-water budget	[1c]USGS' 91				
				Equus Beds			[1c]70700 (1.47 in/yr)				[1d]0.1-4.5 in/yr	[1d]3-D,finite diff, groundwater flow model	[1d]Spinazola, J.M., et al., 1985				[1d] recharge for predevelopment period (before 1940)
2	Reno	1262	KGS B 79 1949		28.53				quantity not known but small compared to that from pcp.		[2a]20% of pcp. 0.2*28.53=5.7 in/yr	[2a]groundwater level fluctuation and sp. yield (20%)	[2a]Williams & Lohman 1949	nearly level to moderately sloping loamy soils on uplands; nearly level, loamy and sandy soils on floodplains	<10 ft-50 ft	farmland and pasture	area covered in KGS B 79 = 2340 mi^2 includes McPherson,and parts of Marion, Harvey, Reno and Sedgwick counties
			KGS B 64 1946		27.83	54.3					[2b]20% of pcp. 300 ac-ft/sqmi/yr in the Arkansas River valley	[2b]water table fluctuation records and sp. yield estimates	[2b] Williams, C. C. 1946				
									[2c]500 ac-ft/mi into Mcpherson Fm. .=1.07 in/yr		(5.56 in/yr)	[2c]permeability, water table gradient, well logs (Darcy's Law)	[2c] Williams, C. C. 1946				[2c]500*11.4=5700 ac-ft/yr =1.07 in/yr in 100 mi^2 of study area in vicinity of Hutchinson; inflow= 500 ac-ft/mi/yr 11.4 mi=length of inflow boundary for the study area.(approximate) (see pl.1,KGS B 64, part 5)
									about 20000ac-ft/yr .=3.75 in/yr from Arkansas Valley upstream into the Hutchison area (study area of 100 mi^2)		[2d]276400 (4.1 in/yr)		[2d]KWRB' 67				
				Alluvium			[2e]3880 (0.06 in/yr)					soil-water budget	[2e]USGS' 91				
				Equus Beds			[2e]139000 (2.07 in/yr)				[2f]0.1-5.5 in/yr	3-D finite diff, groundwater flow model	[2f]Spinazola, J.M., et al., 1985				[2f] recharge for predevelopment period (before 1940)

EQUUS BEDS AQUIFER (GMD 2 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
3	Harvey	540	KGS B 79 1949								[3a]from 1938-1943 about 20% of pcp. Or 320 ac-ft/sq mi/yr in the well field area = **6 in/yr** (well field area 85 sq mi)	[3a]change in storage and pumpage data estimated area of W/T affected-100 sq. mi.	[3a]Williams & Lohman 1949	nearly level to gently sloping loamy and sillty soils on uplands; nearyl level, loamy and sandy soils on floodplains	10 ft-40 ft	farmlands and pastures	[3a]avg. pcp. For the period 29.7 in-- from the data for Wichita, Sedgwick Co.
			KGS B 119 1956		33.69 (1940-48) 34.18 (1948-52) 33.62 (1938-52) pcp.data for Wichita Sedgwick Co.						[3b]**3.75in/yr** from1940-48 [3b]**8.8 in/yr** from 1948-1952 [3b]**6 in/yr** in avg from 1938-1952	[3b]change in storage sp. yield 20% [3b]change in storage sp. yield 20% [3b]change in storage sp. yield 20%	[3b] Stramel, G. J., 1956				The area covered in this report includes parts of Harvey and Sedgwick counties, referred to as well field area (378 mi^2) Equus Beds area: 2340 mi^2
											[3c]88700 **(3.08 in/yr)**		[3c]KWRB' 67				
				Equus Beds			[3d]61700 **(2.14 in/yr)**					soil-water budget	[3d]USGS' 91				
			[3e]USGS WRIR 87-4097 (Sophocleous and Perry 1987)		29.05 (1966-82)	13.4^{0}C 56.12	[3e]**6.06 in/yr** at Burrton from Feb to Jun 1983 ≡ 154 mm					[3e]Darcy's Law and mass balance	[3e] Sophocleous & Perry, 1987				
											[3f]**0.1-5.0 in/yr**	[3f]3-D,finite diff, groundwater flow model	[3f]Spinazola, J.M., et al., 1985				[3f] recharge for predevelopment period (before 1940)
4	Sedgwick	1000	KGS B 79[4a] 1949 KGS B 119[4a] 1956		30.2 (1917-44)	57					[4a,a']20% of pcp. approx.**6 in/yr** 320 ac-ft/yr/mi^2	[4a,a']groundwater level fluctuation and specific yield (20%)	[4a]Williams & Lohman 1949 [4a'] Stramel, G. J., 1956	nearly level to moderately sloping loamy soils on uplands nearly level, loamy and sandy soils on floodplains	<10 ft-30 ft	farmland and pasture	[4a]Area covered in this report is 2340 sq mi.includes McPherson and part of Marion, Reno, Sedgwick and Harvey
			[4b]USGS WRIR 88-4225-1989		28.6 (1888-1985)	56.3	[4b]avg from **0.1-8.8 in/yr** depending on local condition. (from summary; no source)	[4b]streams are in equilibrium with G/W or are gaining	[4b]no inflow from north but gains from east and west but outflow from southern boundry is probably equal so net effect on recharge is insignificant		[4ba]**0.4-5.5 in/yr** in Arkansas River valley of Sedgwick Co. and adj. areas	[4ba]3-D,finite diff, groundwater flow model	[4ba]Spinazola, J.M., et al., 1985				[4b]The study area includes Sedgwick and parts of Reno, Kingman, Harper, Harvey, Summer, Marion Butler and Cowley counties
											[4c]193000 **(3.59 in/yr)**		[4c]KWRB '67				
				Alluvium			[4d]41900 **(0.78 in/yr)**					soil-water budget	[4d]USGS' 91				
				Equus Beds			[4d]36500 **(0.68 in/yr)**				[4e]**0.4-5.5 in/yr** (2.5-5.5 in/yr in Arkansas River valley of Sedgwick Co. and adj.areas)	[4e]3-D,finite diff, groundwater flow model	[4e]Spinazola, J.M., et al., 1985				[4e] recharge for predevelopment period (before 1940)
	Summary	11523		Lower Arkansas Unit that includes the Equus Beds aquifer	< 22->32	57	[a]20% of pcp. in Equus Beds	streams are effluent	some from adjecent areas to the west but insignificant.		precise estimate cannot be made based on available data(1960). Because of the variable local conditions annual recharge could range from practically zero to as much as 50% of annual pcp. in some areas.		[a] KWRB, 1960				includes Rice, McPherson, Reno Harvey Sedgwick, and Ellsworth counties

EQUUS BEDS AQUIFER (GMD 2 Region)

No.	County	Area mi²	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
	Equus Beds modeling area	**240** (area selected in the report as indicated in cited reference)	[b]KWRRI 1982 (Sophocleous, et al.,)	Equus Beds	30		[b]Non-sand dune Equus Beds model area: 4.2cm/yr or **1.65 in/yr** Sand dune area north of Burrton 16.3 cm/yr or **6.4 in/yr**					[b]groundwater flow model(steady-state groundwater flow in two dimensions) parameters used: transmissivity, areal recharge, leakance of the stream beds and specified head.	[b]Sophocleous, M.A., et al., 1982				
		1406	[c]USGS WRIR 85-4336 (Spinazola and others)	Equus Beds	[c]30.37 preceding 1940 30.58 (1951-80)	56.6	[c]**(1.70 in/yr)** 1940 (predev.) **(1.91 in/yr)** 1971-79 dev. P	**0.02 in/yr** 1940 (predev **0.22 in/yr** 1971-79 dev	[c]**(0.14 in/yr)** 1940(predev.) **(0.19 in/yr)** 1971-79 dev.period		**1.86 in/yr** **2.32 in/yr**	[c]A modular 3-D finite-diff, groundwater flow model (Mc Donald and Harbaugh,1984)	[c]Spinazola, J.M., et al., 1985				[c]parts of Harvey, Marion McPherson,Reno and Sedgwick counties.
							[ca]20% of pcp.					[ca]from fluctuation of water table and specific yield	[ca]Williams & Lohman, 1949				
							[cb]**3.75 in.** (during period Sep 1940 to Jan 48) **8.8 in.** (during period Jan 1948 to Jan 52					[cb]Change in storage	[cb]Stramel, G.J.,1956				
	District avg.[1]	3698									[d]**5.92 in/yr** (std. dev. **0.15**)	[1]arithmetic avg.	[d] KGS Bulletins				[1]all averages are calculated considering only the counties included in the GMD.
											[e]**3.41 in/yr** (std. dev. **0.54**)	[1]arithmetic avg.	[e]KWRB' 67				
											[f]**1.59 in/yr** (std. dev. **0.68**)	[1]arithmetic avg.	[f]USGS' 91				[f]recharge for Equus Beds
											[g]**0.18-5.13 in/yr** (std. dev. **0.15**)	[1]arithmetic avg.	[g] Spinazola, et al.,1985				

Note:

KWRB'67: Irrigation in Kansas. Kansas Water Resources Board,1967. Report no. 16e.
USGS' 91: Hansen, C.V., 1991. Estimates of freshwater storage and potential natural recharge for principal aquifers in Kansas. U.S. Geological Survey, Water-Resources Investigations Report 87-4230.
KGS B: Kansas Geological Survey Bulletin
std. dev.: Standard deviation

SOUTHWESTERN KANSAS (GMD 3 Region)

No.	County	Area mi²	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
1	Hamilton	992	KGS B 49 1943		17.67	53.9	High in sand-hills area due to porous soil and presence of basins without surface drainage. Relatively low in upland area due to impermeable soil		flow occurs southeastwards inflow occurs from Prowers Co., Colorado and from Greeley Co.					nearly level to gently sloping silty soils on uplands; nearly level, loamy & sandy soils on flood-plains; rolling to hummocky sandy soils on uplands;	alluvium <10 ft-25 ft dune sand 25 ft-50 ft rest>50-200 ft		
							[1a]Ark. Valley area 1000 or >1000acft/yr					[1a]water balance inflow=outflow (neglecting the contribution of subsurface flow as it is low)	[1a]McLaughlin, T.G., 1943				
								[1b]**0.96in/yr** (1970-74) **1.59 in/yr** (1975-79)			[1b]**1.95 in/yr**(1970-74) **4.21 in/yr**(1975-79) (pcp.+irr.-ET)	[1b]USGS 2D finite element GW flow model	[1b]Barker, R.A., et al., 1983				[1b]in Ark. River valley in Hamilton & Kearny Co. A=110,000 acres
											[1c]5400 ac-ft /yr **(0.1 in/yr)**		[1c]KWRB' 67				
				alluvium			[1c]2980 **(0.06 in/yr)**					[1c]soil-water budget	[1c]USGS' 91				
				High Plains (Ogallala)			[1c]9410 **(0.18 in/yr)**										
2	Kearny	861	KGS B 49 1943		15.85	53.9	High in sandhills area due to porous soil and presence of basins without surface drainage. Relatively low in upland area due to impermeable soil	[2a]19000 ac-ft/yr **(4.24 in/yr)** over the alluvial area of 53760 ac from Hartland to Garden City along Arkansas River	Inflow occurs in north from Wichita and in west from Hamilton			[2a]difference in discharge at different points along the stream	[2a,2b]McLaughlin, T.G., 1943	sloping silty soils on uplands; nearly level, loamy & sandy soils on flood-plains; rolling to hummocky sandy soils on uplands;	alluvium 10 ft-25 ft dune sand 25 ft-50 ft rest>50-200 ft		
							[2b]Ark. Valley area 1000 or >1000acft/yr					[2b]water balance inflow=outflow (neglecting the contribution of subsurface flow as it is low)					
								[2c]**0.96in/yr** (1970-74) **1.59 in/yr** (1975-79)			[2c]**1.95 in/yr**(1970-74) **4.21 in/yr**(1975-79) (pcp.+irr. -ET)	[2c]USGS 2D finite element GW flow model	[2c]Barker, R.A., et al., 1983				[2c]in Ark. River valley in Hamilton & Kearny Co. A=110,000 acres
							[2d]**2.08in/yr** (1974-80) for sandhills and Ark. River valley . **0.5in/yr** for High Plains	[2d]1.10in/yr (1974-80) for sandhills and Ark. River valley . 0.19in/yr for High Plains				[2d]USGS 3D model (Trescott, 1975)	[2d]Dunlap, L.E., et al., 1985				[2d]Model area of upper aquifer (Ark. River valley+Sand dunes area)=603mi² & for lower aquifer (main High Plains aquifer)= 1227 mi² in Kearny and Finney counties.
											[2e]10800 **(0.24 in/yr)**		[2e]KWRB' 67				
				alluvium			[2f]1750 **(0.04 in/yr)**					[2f]soil-water budget	[2f]USGS' 91				
				High Plains (Ogallala)			[2f]25700 **(0.56 in/yr)**										

SOUTHWESTERN KANSAS (GMD 3 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
3	Finney	1302	KGS B 55 1944		20.22	54.7	[3a]**1.4 in/yr** (1940-52) period of above-normal pcp.		[3b]45000 ac-ft/yr **0.98 in/yr** over the area considered, from the west & north of Scott Co. But the discharge from the co. was 47000 ac/yr (area=552960 ac)	[3c]15% of irrig. applied 10% for ditches		[3a]Change in water lvl. in obs. wells S=0.2 and delta h=7ft [3b]using water lvl. map of Latta-1944 and Q=TIL [3c]Experiment on irr. efficiency and measurement of Q in 2 points of canal.	[3abcd]Meyer, W.R., et al., 1970	Rolling to gently sloping to nearly level sandy, loamy and silty soils on the uplands; nearly level loamy & sandy soils on floodplains.			[3abcd]area under consideration 552960ac
											[3d]124000ac-ft/yr or **2.7 in/yr** (1940-64) **<0.5 in/yr** predev. period (1922-30) considering equilibrium of system **<0.05 in/yr** long term avg. (1940-64)	[3d]water balance equation					[3d]2.7 in/yr reflects additional recharge resulting from recycled G/W for irrigation & an accompanying increase in effective R from pcp. on the irrig. land.
											[3h]16000 ac-ft/yr (**0.23 in/yr**)		[3h]KWRB' 67				
								[3i]max.25300 ac-ft/yr from Ark.River between Hartland & Garden City, (alluvium area of 53760ac) for the period of (Oct 1922-Sep 1942) **5.65 in/yr.**	[3j]max 2100 ac-ft/yr in narrow part of Ark. River valley near Hartland (alluvium was 2250 ft wide and avg. thickness 33')		[3i]Flow difference between Syracure & Garden City	[3i]KGS B 55 [3j] Latta, B.F., 1944			[3i]channel width avg. 0.05 mi; length from Hartland to Garden City 22 miles; channel area where seepage occurs=1.1 mi^2=704 ac
									[3k]approx.1000 ac-ft/yr near Hartland				[3k] McLaughlin, T.G., 1943				
				Alluvium and High Plains (Ogallala)			[3l]600 ac-ft/yr (**0.00006 in/yr**) [3l]38400 ac-ft/yr (**0.55 in/yr**)	[3m]1700ac-ft/yr from Ark. River				[3l]soil-water budget	[3l]USGS' 91 [3m]Meyer, W.R., et al., 1970				
								[3n]37646 ac-ft/yr \ **8.4 in/yr** (1991-1998) for the valley area (53760 ac) between Syracuse & Garden City. 55745 ac-ft/yr \ **10.45 in/yr** (1991-99) for the valley area (64000 ac) between Garden City and Dodge City.			[3n] Water balance of stream	[3n]Whittemore, D.O., et al., 2001				
							[3o]**2.08in/yr** (1974-80) for sandhills and Ark. River valley . **0.5in/yr** for High Plains	[3o]**1.10in/yr** (1974-1980) for sandhills and Ark. River valley . **0.19in/yr** for High Plains				[3o]USGS 3D Model (Trescott 1975)	[3o]Dunlap, L.E., et al., 1985			[3o]model area of upper aquifer & valley=603mi^2 & for lower aquifer .=1227 mi^2 in Kearny and Finney counties
							[3p]**0.5 in/yr** in the vegetated sand dune area but higher in the barren sand dune area				[3q]**0.02-0.04 in/yr** **0.12 in.yr** (for irrigated land	[3p]neutron probe [3q]heat dissipation sensors and Darcy's Law	[3p]Prill, R.C.,1968 [3q]Sophocleous, M., et al., 2002				[3p]study area located in dune sand area in the Ark. River valley near Garnden City, for the period 1964-66 (period of high rainfall)
4	Gray	873	KGS B 55 1944		21.43			Arkansas River is gaining throughout its course in the county.			[4a]14800ac-ft/yr (**0.32 in/yr**)		[4a]KWRB'67	nearly level to gently sloping silty soils on uplands; undulating sandy soils on uplands; nearly level loamy & sandy soils on floodplains.			
				High Plains (Ogallala)			[4b]43700 ac-ft/yr (**0.94 in/yr**)					[4b] soil-water budget	[4b]USGS' 91				

SOUTHWESTERN KANSAS (GMD 3 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
5	Ford	1082	KGS B 43 1942		20.5	54.3	small; estimated to be about <0.5 in/yr due to low permeability high evaporation and high ET. Data not adequate for quantative estimate but considered to be low.	small as Ark. River was effluent (gaining) most of the times in a year and so were other small rivers.		some in places in the vicinity of irrigatioin ditches and fields	[5b]0.6 in/yr (1980-81)	[5b]water budget	[5b]Spinazola & Dealy, 1983	nearly level to gently sloping silty soils on uplands; undulating sandy soils on uplands; nearly level loamy & sandy soils on floodplains.	10 ft->150 ft		[5b]water budget for 1980 conditions over 700 mi^2 underlain by Ogallala aquifer of the Ark. River
											[5c]34700 (0.6 in/yr)		[5c]KWRB' 67				
				Alluvium			[5d]370 (0.006in/yr)					[5d] soil-water budget	[5d]USGS' 91				
				High Plains (Ogallala)			[5d]54400 (0.94 in/yr)										
6	Stanton	685	KGS B 168 1964		15.03		[6a]0.3 in/yr, equivalent to 2% of pcp. (over area of 160mi^2 between Johnson and Ulysses)					[6a]difference in flow at 2 diff. locations underground.	[6a]Fader, S.W., et al., 1964	nearly level to gently sloping silty and loamy soils on uplands	<25 ft-250 ft		
							[6b]< 0.5 in/yr due to impermeable soil.	[6b]large quantity from Bear Creek and possibly Sand Arroyo after rains. But actual quantity not known	[6b]receives some form the rainwater that reaches underground reservoir in southeastern Colorado.				[6b] Theis, C.V., et al., 1935				
											[6c]11700 (0.32 in/yr)		[6c]KWRB' 67				
				High Plains (Ogallala)			[6d]14000 (0.39 in/yr)					[6d] soil-water budget	[6d]USGS' 91				
7	Grant	571	KGS B 168 1964		17.24	54.6	[7a]0.3 in/yr, equivalent to 2% of pcp. (over area of 160mi^2 between Johnson and Ulysses)					[7a]difference in flow at 2 diff. locations underground.	[7a]Fader, S.W., et al., 1964	nearly level to gently sloping silty, loamy and sandy soils on uplands and flood-plains	alluvium 10 ft-50 ft rest <50 ft to >200 ft		
							.-------	[7b]Gain some water from Bear Creek, Lakin Draw & Sand Arroyo, whereas Cimarron River is losing in some regions and gaining in some	[7b]inflow occurs from Stanton Co. on the west & Kearny Co.on the north.				[7b] McLaughlin, T.G., 1946				
											[7c]9300 (0.3 in/yr)		[7c]KWRB' 67				
				High Plains (Ogallala)			[7d]22300 (0.73 in/yr)					[7d] soil-water budget	[7d]USGS' 91				
8	Haskell	580	KGS B 61 1946		18.02	54.6	.------	[8a]Gain some water from Bear Creek, Lakin Draw & Sand Arroyo, whereas Cimarron River is losing in some regions and gaining in others.	[8a]inflow occurs from Grant Co. on the west & Finney Co.on the north.				[8a] McLaughlin, T.G., 1946	nearly level to gently sloping silty and loamy soils on uplands	70 ft-250 ft		
											[8b]9600 (0.31 in/yr)		[8b]KWRB' 67				
				High Plains (Ogallala)			[8c]30200 (0.98 in/yr)					[8c] soil-water budget	[8c]USGS' 91				
9	Morton	720									[9a]12000 (0.31 in/yr)		[9a]KWRB' 67	nearly level to gently sloping silty soils on uplands; nearly level to undulating loamy and sandy soils on uplands and flood-plains.			
				High Plains (Ogallala)			[9b]16300 (0.42 in/yr)					[9b] soil-water budget	[9b]USGS' 91				
											[9c]0.004-0.01 for native grass land	[9c]heat dissipation sensors and Darcy's Law	[9c]Sophocleous, M., et al., 2002				
10	Stevens	731	KGS B 61 1946		17.87	54.6	.------	[10a]Gain some water from Bear Creek, Lakin Draw & Sand Arroyo.	[10a]inflow occurs from Morton Co. on the west				[10a] McLaughlin, T.G., 1946	nearly level to undulating loamy and sandy soils on uplands and flood-plains; nearly level to gently sloping silty soils on uplands.	alluvium <10 ft to 20 ft rest 80 ft-150 ft		
											[10b]12000 (0.31 in/yr)		[10b]KWRB' 67				
				High Plains (Ogallala)			[10c]29200 (0.75 in/yr)					[10c] soil-water budget	[10c]USGS' 91				

SOUTHWESTERN KANSAS (GMD 3 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
11	Seward	643	KGS B 69 1948		19.01		[11a]0.4 in/yr	[11b]some from Cimarron River in northwestern part of the county.	[11b]from Stevens Co. on the west and Haskell Co. on the north but quantity is not known.			[11a]change in water level of 0.22'(1941-44). Sy=15%	[11a,b]Byrne & McLaughlin, 1948	gently sloping loamy & sandy soils on uplands & floodplains; nearly level to gently sloping silty soils on uplands.	<10 ft-20 ft in alluvium rest 50 ft->200 ft		
											[11b]10000 (0.29 in/yr)		[11b]KWRB' 67				
				High Plains (Ogallala)			[11c]34100 (0.99 in/yr)					[11c] soil-water budget	[11c]USGS' 91				
12	Meade	979	KGS B 45 1942		18.43 (17 in. avg. snow)	56	small from the pcp. that falls on the area due to impervious soil.	small due to steep slope of streams		some, as the shallow water table is quite high	[12a]10000 ac-ft/yr (0.27 in/yr) (eqv. to 1.5% of pcp.)	[12a]equating recharge to the discharge from the aquifer.	[12a] Frye, J.C., 1942	nearly level to moderately sloping silty soils on uplands.	<10 ft- > 150 ft		recharge into the artesian aquifer including the upward leakage through the confining beds. Area involved=685 sq. mi (recharge area of artesian water includes Finney, Haskell, Gray,Seward and Meade counties)
											[12b]14800 (0.28 in/yr)		[12b]KWRB' 67				
				Alluvium			[12c]4430 (0.08 in/yr)					[12c] soil-water budget	[12c]USGS' 91				
				High Plains (Ogallala)			[12c]50300 (0.96 in/yr)										
	Summary						[a] 0 to 2 in/yr (0.24 in/yr in avg.) [a]0.25 in/yr in dune sand area to the south & Ark. River valley					[a]2D finite diff USGS model (Trescott1976)	[a,b]Stulken, L.E., et al., 1985				
							[b]0.24 in/yr	[b]0.08 in/yr	[b]0.07 in/yr		[b]0.39 in/yr	[b]simulated steady-state water budget (pre-1950)					
							[c]0.58 in/yr	[c]0.05 in/yr	[c]outflow higher than inflow		[c]0.63 in/yr (pcp.+ stream)	[c]3D MODFLOW (for 1982 period)	[c] Watts, K.R., 1989				[c]active node model area for the High Plains aquifer: 2695680 ac
							[d]0.34 in/yr (0.45 in/yr in Meade, Seward and eastern Stevens but 0.23 in/yr in Morton and westen Stevens)					[d]2D finite diff USGS model (Trescott1976)	[d] Havens & Christenson, 1984				[d]active node model area 14,208,000 ac (includes part of Okhaloma and Morton, Stevens, Seward and Meade Co. in Kansas)
							[e]0.6 in/yr over total area; 175000ac-ft\1.5in/yr in irr area of 1400000ac and 35000ac-ft\ 0.15in/yr in nonirr. area of 2824000ac in 1975 based on 15 in. of pcp. during growing season		[g]inflow from north & west of co. 8400 ac-ft/yr \0.024 in/yr; outflow 15300ac-ft/yr\ 0.04 in/yr-to east	[f]420000ac-ft/yr to 560000ac-ft/yr (1.2-1.6 in/yr) -1975	[e]period (1922-1930) considering equilibrium of system <0.05 in/yr long term avg. (1940-64)	[e]10% of pcp. in irr. land and 1% of pcp. in nonirr. land [f] 20% of applied irr. [g]Darcy's Law	[e,g]Gutentag, E.D., et al., 1981				
											[h]165000 ac-ft/yr (0.29 in/yr)	[h]_____	[h]KS. Governor's Task Force report, 1977				
											[i]0.57 in/yr (0.3 in/yr in nonirr. land and 1.8 in/yr in irr. land)	[i]based on previous recharge estimates from pcp. and irr. to Ogallala aquifer in different subregions in western KS.(1977)	[i]O'Connor & McClain, 1982				
	District avg.[1]										[j]0.70 in/yr (std. dev. 0.26)	[j]arithmetic avg.	[j] USGS' 91				[j]airthemetic average for Ogallala
											[k]0.30 in/yr (std. dev. 0.11)	[k]arithmetic avg.	[k] KWRB' 67				[1]all averages are calculated considering only the counties included in the GMD.
											[l]0.35 in/yr (std. dev. 0.09)	[l]arithmetic avg.	[l] KGS Bulletins				

Note:

KWRB'67: Irrigation in Kansas. Kansas Water Resources Board,1967. Report no. 16e.
USGS' 91: Hansen, C.V., 1991. Estimates of freshwater storage and potential natural recharge for principal aquifers in Kansas. U.S. Geological Survey, Water-Resources Investigations Report 87-4230.
KGS B: Kansas Geological Survey Bulletin
std. dev.: Standard deviation

NORTHWEST KANSAS (GMD 4 Region)

No.	County	Area mi²	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Soils	Topog	Avg. Depth to Water Table	Vegetation & Land use	Comments
1	Cheyenne	1027	KGS B 100 1953		18	52		----------	----------	--------	[1a]12200 (0.22 in/yr)	----------	[1a] KWRB' 67	silty soils and loamy and silty soils	flat to rolling upland plains	90-175 ft along southern border 35-90 ft along southwestern border.	cropland and pasture much of land is pasture	" Data on permeability and transmissibility are not adequate to permit estimating either subsurface flow into or out from the county." (KGS B 100)
				Ogallala			23200 [1b] (0.42 in/yr)				[1b]23200 (0.42 in/yr)	soil-water budget	[1b] USGS' 91					
2	Rawlins	1080	KGS B 117 1956		18.5	52.3		----------	----------	--------	[2a]10500 (0.18 in/yr)		[2a] KWRB' 67	silty soils	gently rolling	<10 ft at valleys to >200 ft at upland areas	cropland and pasture	
				Ogallala			[2b]41800 (0.73 in/yr)					soil-water budget	[2b] USGS' 91				agriculture	
3	Decatur	900	KGS B 196 1969	Ogallala Fm. avg. thickness 200 ft avg.saturated thickness 45 ft Alluvial valleys: yield range from 300 -1450 gpm depending on location.	18.42	53.2	less than 1/2 inch	----------	[3b]5000 ac-ft/yr at western county boundary (0.10 in/yr)	--------	[3a]17500 (0.36 in/yr)	[3b] based on sat. thickness of water bearing strata, water table gradient, and avg. K of 40.1 ft/day	[3a] KWRB' 67	silty soils	gently rolling uplands	about 10-40 ft from surface in valleys to >100 ft in most places & 200 ft or more in high parts Ogallala Fm. avg. tk. 200 ft avg.saturated thickness 45 ft (1962)	cropland and pasture	
				Ogallala			[3c]36000 (0.75in/yr)					soil-water budget	[3c] USGS' 91					
4	Norton	880	KGS B 81 1949	----------	20.81	52.8	[4a]approx. 1/4-1/2 in	----------	----------	--------	[4b]15400 (0.33 in/yr)	----------	[4a] Frye, J.C., 1942 [4b] KWRB' 67	silty soils	Plains border section of the Great Plains physiographic province	40 ft in valleys upto 175 ft in uplands <10 ft in alluvium	cropland and pasture agriculture	
				Alluvium			[4C]2180 (0.05 in/yr)					soil-water budget	[4c] USGS' 91					
				Ogallala			[4C]41100 (0.86 in/yr)											
5	Sherman	1055	KGS B 105 1953		18	51.9		------		--------	0.1 of an inch [5a]		[5a] Frye, J.C., 1942	mostly underlain by deposits of tertiary Ogallala Fm. Silty soils and loamy and silty soils	High Plains section - consists of nearly flat to gently rolling upland plains	in upland areas generally>100 ft <10 ft in stream valleys avg slope is 15 ft/mi	cropland and pasture farmland & pasture	
							Lower than that from lateral inflow		[5a]approx. 21480 ac-ft/yr from west and southwest (0.38 in/yr)			[5a] "estimate based on available data."						
											[5b]13500 (0.24 in/yr)		[5b] KWRB' 67					
				Ogallala			[5c]13600 (0.24 in/yr)					soil-water budget	[5c] USGS' 91					
6	Thomas	1070	KGS B59 1945		17.95	51.8	[6a]1/4 inch	--------	----------	------		----------	[6a] Frye, J.C., 1942	silty soils	flat to gently rolling	>200 ft to only a few feet along valleys <100 ft in east central part	cropland and pasture farmland	
											[6b]20700 (0.36 in/yr)		[6b] KWRB' 67					
				Ogallala			[6c]21800 (0.49 in/yr)					soil-water budget	[6c] USGS' 91					

NORTHWEST KANSAS (GMD 4 Region)

No.	County	Area mi²	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Soils	Topog	Avg. Depth to Water Table	Vegetation & Land use	Comments
7	**Sheridan**	893	KGS B 116 1956		19.35	53.6		---		---	**about 1/4 inch** [7a]	Author's estimate	[7a] Bayne, C.K., 1956	silty soils and silty and loamy soils	nearly flat to gently rolling	<10 ft to 160 ft	cropland and pasture agriculture	
											14000 [7b] **(0.29 in/yr)**		[7b] KWRB' 67					
				Alluvium			390 [7c] **(0.01 in/yr)**				35600 [7c] **(0.75 in/yr)**	soil-water budget	[7c] USGS' 91					
				Ogallala			35200 [7c] **(0.74 in/yr)**											
8	**Graham**	891	KGS B 110 1955		20.55	53.9		---	---	---	[8b] 7000 **(0.15 in/yr)**		[8b] KWRB' 67	silty soils and silty and loamy soils	High Plains section of Great Plains physiographic province	few feet to 140 ft	cropland and pasture agriculture about 40% of land is pasture	[8a] avg. ET from free water surface in growing season is 11.5 inches per month, & 75% of pcp. occurs in the growing season, so recharge is low (KGS B 110 p31)
							[8a] probably **<1/2 inch**					Authors' estimate	[8a] Prescott, G.C., 1955					
				Alluvium			[8c] 2710 **(0.06 in/yr)**					soil-water budget	[8c] USGS' 91					
				Ogallala			[8c] 32500 **(0.68 in/yr)**											
9	**Logan**	1073	KGS B 129 1958		18.97	53.3	[9b] **1/6 inch** (0.85% of the total pcp.)	---	[9a] approx. < 25ac-ft/yr in southern upland, negligible in northern upland	10% of applied		[9a] based on groundwater contour map and saturated thickness	[9a,9b,9c] Johnson, C.R., 1958	silty soils and silty and loamy soils	High Plains section & plains border secn. in east	>40 ft from surface in uplands	cropland and pasture agriculture	[9b] on the northern upland of the county. Based on Darcy's Law at a sec. across N-S direction near eastern border of the county.
											[9c] estimated 3000 in northern upland (calculated value 2600 from precipitation)	[9c] From Darcy's Law at N-S section near eastern county boundary.						
											[9d] 5000 **(0.09 in/yr)**		[9d] KWRB' 67					
				Alluvium			[9e] 1880 **(0.03 in/yr)**				[9e] 9780 **(0.17 in/yr)**	soil-water budget	[9e] USGS' 91			20ft from surface in alluvium aquifer		
				Ogallala			[9e] 7900 **(0.14 in/yr)**											[9e] avg. sat. thickness 30' K_{avg}=58.82 ft/day
10	**Gove**	1070	KGS B 145 1960		20.89	53.2		---	---	---	[10a] 11000 **(0.19 in/yr)**		[10a] KWRB' 67	silty soils and silty and loamy soils	High Plains section	50 ft-150 ft	cropland and pasture agriculture 684000 ac	
				Alluvium			[10b] 1700 **(0.03 in/yr)**					soil-water budget	[10b] USGS' 91					
				Ogallala			[10b] 11600 **(0.20 in/yr)**											
11	**Trego**	900	KGS B 174 1965		21.4		[11a] at least 10000 ac-ft/yr **(0.21 in/yr)**	---	---	---	[11b] 10,000 **(0.21 in/yr)**	Authors' estimate	[11a] Hodson, W.G., 1965	silty and loamy	High Plains section	Alluvium : few feet to 20 feet	cropland and pasture	
													[11b] KWRB' 67			Ogallala: <10 ft to 100 ft	agriculture	
				Alluvium			[11c] 4350 **(0.1 in/yr)**					soil-water budget	[11c] USGS' 91					
				Ogallala			[11c] 13000 **(0.27 in/yr)**											

NORTHWEST KANSAS (GMD 4 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Soils	Topog	Avg. Depth to Water Table	Vegetation & Land use	Comments
	Summary	8050	USGS OFR 4-75 1975	Alluvium has yield of as much as 1500 gal/min Ogallala Fm. has yield of 500-1200 gal/min Dakota Fm. has yield of a few gal/min	[β] 16-21	51-78	**0.25 in/yr** or about 100,000 ac-ft/yr	most streams in western part lose water by infiltration. Runoff is only 1-2% of total pcp.	----------	-------			[β]Jenkins & Pabst, 1975	loessal	flat to gently rolling	Alluvium is as much as 105 ft thick but =< 65 ft is saturated Ogallala Fm. has saturated thickness ranging from 0-270 ft Dakota Fm. lies 600-2600 ft below ground surface and its thickness ranges from 200-300 ft	cropland and pasture	[β] mainly during 6 months of growing season (area is different in Open-file Report from the total area , as it reflects only the area in which the study was carried out.)
	District avg.[1]	9059									[a]**0.48 in/yr** (Std. dev. **0.25**)	[1]arithmetic avg.	[a] USGS' 91					[a]for Ogallala
											[b]**0.23 in/yr** (Std. dev. **0.09**)	[1]arithmetic avg.	[b] KWRB' 67					[1]all averages are calculat considering only the coun included in the GMD.
											[c]**0.29 in/yr** (Std. dev. **0.17**)	[1]arithmetic avg.	[c] KGS Bulletins					

Note: KWRB'67: Irrigation in Kansas. Kansas Water Resources Board,1967. Report no. 16e.
USGS' 91: Hansen, C.V., 1991. Estimates of freshwater storage and potential natural recharge for principal aquifers in Kansas. U.S. Geological Survey, Water-Resources Investigations Report 87-4230.
KGS B: Kansas Geological Survey Bulletin
Std. dev.: Standard deviation

GREAT BEND PRAIRIE (GMD 5 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
1	Barton	892	KGS B 88 1950		24.18		.----	.----	.----	.----	[1a]83100 (1.72in/yr)		[1a]KWRB' 67	nearly level to gently sloping silty soils on uplands	<10 ft->30 ft	farmland	
				GBP aquifer			[1b]33800 (0.71 in/yr)					soil-water budget	[1b]USGS' 91	nearly level silty soils on flood-plains			
											[1c]22700 (2.19 in/yr) for Wallnut Creek valley alluvium	groundwater modeling	[1c]Nuzman, C.,1990				study area includes parts of Ness, Rush and Barton Co.
											[1d]60000 (1.26 in/yr)	modification from KWRB' 67	[1d]Fader & Morton, 1972				
2	Rice	721	KGS B 85 1950		25.86 (1898-1942)	56	.----	.----	.----	.----	.---- [2a]74800 (1.93 in/yr)		[2a]KWRB' 67	nearly level to gently sloping silty soils on uplands	20 ft	farmland	
				GBP aquifer			[2b]43000 (1.11 in/yr)					soil-water budget	[2b]USGS' 91	nearly level loamy & sandy soils on floodplains			
											[2c]75000 (1.95 in./yr)	modification from KWRB' 67	[2c]Fader & Morton, 1972				
3	Pawnee	755	KGS B 80 1949		23.48		.----	mainly in upland areas & the dun sand areas of Arkansas River	from west and southwest	.----	[3a]52600 (1.30 in/yr)		[3a]KWRB' 67	nearly level to gently sloping silty & loamy soils on uplands	dune sand: <10 ft-50 ft alluvium:10 ft-30 ft terrace deposits:	agriculture	
				GBP aquifer			[3b]18800 (0.47 in/yr)					soil-water budget	[3b]USGS' 91	Nearly level silty loamy & sandy soils on flood- plains	<20 ft-60 ft Ogallala: <20 ft->100 ft		
											[3ca]0.6 in/yr for area of 325 mi^2 in Pawnee River valley	[3ca]mass balance (equilibrium of inflow and outflow)	[3ca] Sophocleous, M. A., 1981				
											[3cb]0.39 in/yr	[3cb]soil-moisture budget	[3cb] Sophocleous, M. A., 1981				
											[3cc]0.5 in/yr	avg. of 3ca &3cb above	[3cc] Sophocleous, M. A., 1981				
4	Stafford	794	KGS B 88 1950		24.58		.----	.----	plate 1 shows that the GW flows into the county from Pawnee and Edwards Co.	.----	[4a]187500 (4.42 in/yr)		[4a]KWRB' 67	undulating to gently sloping sandy, loamy & silty soils on uplands	<20 ft-40 ft	farm land	
				GBP aquifer			[4b]80400 (1.9 in/yr)					soil-water budget	[4b]USGS' 91				
											[4c]190000 (4.49 in./yr)	modification from KWRB' 67	[4c]Fader & Morton, 1972				

GREAT BEND PRAIRIE (GMD 5 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
5	Reno	1262	KGS B 79 1949		28.53		.-----	.------	quantity not known but small compared to that from pcp.	.------	[5a]20% of pcp. 0.2*28.53=**5.7 in/yr**	[5a]GW level fluctuation and Sp. Yield (20%)	[5a] Williams & Lohman, 1949	nearly level to moderately sloping loamy soils on uplands; nearly level, loamy and sandy soils on floodplains	<10 ft-50 ft	farmland and pasture	area covered in B79= 2340 mi2 includes McPherson,and parts of Marion, Harvey, Reno and Sedgwick counties
			KGS B 64 1946		27.83	54.3					[5b]20% of pcp. 300 ac-ft/sqmi/yr in the Arkansas River valley **(5.56 in/yr)**	[5b]WT fluctuation records and sp. yield estimates	[5b,5c] Williams, C.C., 1946				
									[5c]500 ac-ft/mi into Equus Beds from dune sand northeast of Hutchinson **.=1.07 in/yr**			[5c]permeability, WT gradient, well logs (Darcy's Law)					[5c]500*11.4=5700 ac-ft/yr =1.07 in/yr in 100 mi^2 of study area in vicinity of Hutchinson; inflow= 500 ac-ft/mi/yr 11.4 mi=length of inflow boundary for the study area.(approximate) (see pl1,Bul 64 part5)
									about 20000ac-ft/yr **.=3.75 in/yr** from Arkansas Valley U/S into the Hutchinson (study area of 100 mi^2)		[5d]276400 **(4.1 in/yr)**		[5d]KWRB' 67				
				Alluvium + Equus Beds & GBP aquifers			[5e]143000 **(2.12 in/yr)**					soil-water budget	[5e]USGS' 91				
											[5f]**0.1-5.5 in/yr**	[5f]3-D,finite diff, groundwater flow model	[5f]Spinazola, J.M., et al., 1985				[5f] recharge for predevelopment period (before 1940)
											[5g]270000 **(4.01 in./yr)**	modification from KWRB' 67	[5g] Fader & Morton, 1972				
6	Edwards	619	KGS B 80 1949		22.44						[6a]84000 **(2.54 in/yr)**		[6a]KWRB' 67	undulating to gently sloping sandy & loamy soils on uplands	dune sand: <10 ft-50 ft Alluvim:10 ft-30 ft terrace deposits: <20 ft-60 ft Ogallala: <20 ft->100 ft	agriculture	
				GBP aquifer			[6b]33100 **(1 in/yr)**					soil-water budget	[6b]USGS' 91				
											[6c]50000 **(1.51 in/yr)**	modification from KWRB' 67	[6c] Fader & Morton, 1972				
7	Kiowa	720	KGS B 65 1948		22.15	56	[7a]in sandhills 2.2% of pcp. **0.58 in/yr**	streams are influent but the amount of recha is not known.	water enters Meade and Ogallala Fms. Of this area from Ford & Clark counties.			change in storage porosity-20%	[7a] Latta, B.F., 1948	gentle to modera slopes & nearly flat surfaces with sandy, loamy & silty soils.	Dune Sand: 10 ft- 70 ft Kingsdown Silt: >100 ft Meade and Ogallala <20 ft-60 ft Ogallala= 20 ft	agriculture farming & stock raising	
									a part of water in Meade and Ogallala Fms. is obtained from Dakota Formation		[7b]99600 **(2.6 in/yr)**		[7b]KWRB' 67				
				Alluvium and GBP aquifer			[7c]50070 **(1.3 in/yr)**					soil-water budget	[7c]USGS' 91				
									[7d]500-1000 **(0.013-0.026 in/yr)**			Darcy's Law	[7d] Fader & Stullken, 1978				
											[7e]50000 **(1.3 in/yr)**	modification from KWRB' 67	[7e] Fader & Morton, 1972				
8	Pratt	729	KGS B205 1973		24.04	avg.monthly 82 in Jul. 34 in Jan.	[8a]5-10% of pcp 1.2-2.4 in/yr avg **1.6 in/yr** higher recharge if for dune sand area.	.----- negligible	[8a]**0.98 in/yr** across the western boundary [8a]about 1500 ac-ft/yr of saline water leaks upward from Permian rocks; actual amount is not known.	5-10% of applied		[8a]Darcy's Law measurement of chemical constituents in streamflow	[8a] Layton & Berry, 1973	nearly level to gently sloping silty and loamy soils on uplands	aluvium:<10'-12' < 10 ft- 12 ft dune sand: <20 ft-50 ft but in southeastern part >50 ft-80 ft Loveland and Crete Fm.: 40 ft->100 ft Sappa and Grand Island Fm.: 20 ft-60 ft	agriculture	
				GBP aquifer			[8c]77800 **(2 in/yr)**				[8b]169000 **(4.35 in/yr)**	soil-water budget	[8b]KWRB' 67 [8c]USGS' 91				
											[8d]150000 **(3.86 in./yr)**	modification from KWRB' 67	[8d] Fader & Morton, 1972				
											[8e]**3.5 in/yr** from model calibrat ratio q/k=8*10^{-6} for k=100 ft/day	STREAM-AQUIFER (Kemblowski,1982) a model utilizing the integrated finite diff. method	[8e] Moya, P., 1985				[8e] q= natural recharge rate k= hydraulic conductivity

GREAT BEND PRAIRIE (GMD 5 Region)

No.	County	Area mi^2	Reference Bulletin & publ. yr	Aquifer	Avg. Precip. (in/yr)	Avg. Temp F	Recharge from ac-ft/yr (in/yr) precip.	stream	lateral inflow	irrig.	Total Recharge ac-ft/yr (in/yr)	Method	Reference	Topography & Soils	Avg. Depth to Water Table	Vegetation & Land use	Comments
9	Kingman	864	KGS B 144 1960		29.28	57.9	-----	streams are effluent	some from Pratt Co. on the west.	negligible (1955-56)	not known			lies in the Great Bend physiographic province.	dune sand: <10 ft-20 ft alluvium: <10 ft Loveland and Crete Fm.:10 ft-20 ft Ogallala:10 ft-20 ft Sappa and Grand Island Fm.: 10 ft-70 ft Fullerton and Holdrege Fm.: 20 ft-40 ft	agriculture farm and cattle raising	
											[9a]201600 (**4.47 in/yr**)		[9a]KWRB' 67				
				Alluvium and GBP aquifer			[9b]62700 (**1.36 in/yr**)					soil-water budget	[9b]USGS' 91	nearly level to moderately sloping loamy soils on uplands			
											[9c]150000 (**3.26 in/yr**)	modification from KWRB' 67	[9c] Fader & Morton,1972				
10	Barber	1146	KGS OFR 29-1 1929		24.89	57.3	-----	-----	-----	-----				High Plains in northern and western parts & Plains border in the eastern part of the co. moderately sloping to nearly level clayey & loamy soil			
											[10a]59100 (**0.97 in/yr**)		[10a]KWRB' 67				
				alluvium and GBP aquifer			[10b]18280 (**0.3 in/yr**)					soil-water budget	[10b]USGS' 91				
											[10c]40000 (**0.65 in/yr**)	modification from KWRB' 67	[10c] Fader & Morton,1972				
11	Summary Great Bend Prairie	5400	KGS IR4 1978	GBP aquifer	22.5 at the western border to 31.5 at the eastern		**2 in/yr** 5-10% of pcp. (1951-71)					water level fluctuation in wells	Fader & Stullken, 1978				Counties included: All of Kiowa, Kingman, Pratt & Stafford & parts of Barber, Barton, Edwards, Pawnee, Reno, and Rice
											0.75 in/yr (1950-75)	USGS -2D finite-difference flow model	Cobb, P.M., et al.,1983				
											0.28 in./yr (1950-80)	regional flow model for the High Plains aquifer(USGS 2-D finite diff. flow model)	Luckey, R.L., et al.,1986				
											4.3 in/yr (1982-83) (Rattlesnake Cr. basin)	daily soil-moisture budget	Sophocleous & McAllister, 1990 (KGS G/W Series 11)				
	District avg.[1]										**2.87 in/yr** (Std. dev. **1.25**)	[1]arithmetic avg.	KWRB' 67				[1]all averages are calculated considering only the counties included in the GMD.
											2.62 in/yr (Std. dev. **1.43**)	[1]arithmetic avg.	Fader & Morton,1972				
											1.33 in/yr (Std. dev. **0.62**)	[1]arithmetic avg.	USGS' 91				
											1.9 in/yr (1985-92) (Std. dev. **0.71**)	arithmetic avg.	Sophocleous, M.,1992				
											1.4 in/yr (1985-90)	area-weighted avg. field measured variables employing Darcy's method and water budget analysis.					

Note:

KWRB'67: Irrigation in Kansas. Kansas Water Resources Board,1967. Report no. 16e.
USGS' 91: Hansen, C.V., 1991. Estimates of freshwater storage and potential natural recharge for principal aquifers in Kansas. U.S. Geological Survey, Water-Resources Investigations Report 87-4230.
KGS B: Kansas Geological Survey Bulletin
Std. dev.: Standard deviation

References

Barker, R.A., Dunlap, L.E., and Sauer, C.G., 1983. Analysis and computer simulation of stream-aquifer hydrology, Arkansas River valley, southwestern Kansas. U.S. Geological Survey Water-Supply Paper 2200, 59 p.

Bayne, C.K., 1956. Geology and groundwater resources of Sheridan County, Kansas. Kansas Geological Survey Bulletin 116, 94 p.

Bevans, H.E., 1989. Water resources of Sedgwick County, Kansas. U.S. Geological Survey Water Resources Investigations Report 88-4225, 119 p.

Byrne, F.E., and McLaughlin, T.G., 1948. Geology and ground-water resources of Seward County, Kansas. Kansas Geological Survey Bulletin 69, 140 p.

Cobb, P.M., Colarullo, S.J., and Heidari, M., 1983. A ground-water flow model for the Great Bend aquifer, south-central Kansas. Kansas Geological Survey Open-file Report 83-20, 229 p.

Dunlap, L.E., Kume, J., and Thomas, J.G., 1980. Geohydrology and model analysis for water supply management in a small area of west-central Kansas. USGS Water- Resources Investigations Report 80-91, 59 p.

Dunlap, L.E., Lindgren, R.J., and Sauer, C.G., 1985. Geohydrology and model analysis of stream-aquifer system along the Arkansas River in Kearny and Finney counties, southwestern Kansas. U.S. Geological Survey Water-Supply Paper 2253, 52 p.

Elias, M.K., 1931.The geology of Wallace County, Kansas. Kansas Geological Survey Bulletin 18, 254 p.

Fader, S.W., and Morton, R.B., 1972. Ground water in the Middle Arkansas River basin, Kansas and Oklahoma—administrative report prepared by the U.S. Geological Survey for the U.S. Army Corps of Engineers. U.S. Geological Survey Open-file Report 75-367, 44 p.

Fader, S.W., and Stullken, L.E., 1978. Geohydrology of the Great Bend Prairie, south-central Kansas. Kansas Geological Survey Irrigation Series 4, 19 p.

Fader, S.W., Gutentag, E.D., Lobmeyer, D.H., and Meyer, W.R., 1964. Geohydrology of Grant and Stanton Counties, Kansas. Kansas Geological Survey Bulletin 168, 147 p.

Fent, O.S., 1950. Geology and groundwater resources of Rice County, Kansas. Kansas Geological Survey Bulletin 85, 142 p.

Frye, J.C., 1942. Geology and ground-water resources of Meade County, Kansas. Kansas Geological Survey Bulletin 45, 152 p.

Frye, J.C., 1945. Geology and groundwater resources of Thomas County, Kansas. Kansas Geological Survey Bulletin 59, 110 p.

Frye, J.C., and Leonard, A.R., 1949. Geology and groundwater resources of Norton County and northwestern Phillips County, Kansas. Kansas Geological Survey Bulletin 81, 144 p.

Gutentag, E.D., and Stullken, L.E., 1976. Ground-water resources of Lane and Scott counties, western Kansas. Kansas Geological Survey Irrigation Series 1, 37 p.

Gutentag, E.D., Lobmeyer, D.H., and Slagle, S.E., 1981, Geohydrology of southwestern Kansas. Kansas Geological Survey Irrigation Series 7, 73 p.

Hansen, C.V., 1991. Estimates of freshwater storage and potential natural recharge for principal aquifers in Kansas. U.S. Geological Survey, Water-Resources Investigations Report 87-4230, 100 p.

Havens, J.S., and Christenson, S.C., 1984. Geohydrology and numerical simulation of the High Plains regional aquifer, northwestern Oklahoma. U.S. Geological Survey Water-Resources Investigations Report 83-4269, 27 p.

Hodson, W.G., 1963. Geology and groundwater resources of Wallace County, Kansas. Kansas Geological Survey Bulletin 161, 108 p.

Hodson, W.G., 1965. Geology and groundwater resources of Trego County, Kansas. Kansas Geological Survey Bulletin 174, 80 p.

Hodson, W.G., 1969. Geology and groundwater resources of Decatur County, Kansas. Kansas Geological Survey Bulletin 196, 41 p.

Hodson, W.G., and Wahl, K.D., 1960. Geology and groundwater resources of Gove County, Kansas. Kansas Geological Survey Bulletin 145, 126 p.

Jenkins, E.D., and Pabst, M.E., 1975. Water development for irrigation in northwestern Kansas. U.S. Geological Survey Open-file Report 4-75, 39 p.

Johnson, C.R., 1958. Geology and groundwater resources of Logan County, Kansas. Kansas Geological Survey Bulletin 129, 175 p.

Kansas Governor's Task Force on Water Resources, 1977. Interim report of the Governor's Task Force on Water Resources. Topeka, Kansas, 83 p.

Kansas Water Resources Board (KWRB), 1960. Preliminary appraisal of Kansas water problems, Kansas Water Plan Studies, Part A, Preliminary Appraisal of Kansas Water Problems,Section 4. Lower Arkansas Unit, Topeka, KS, 177 p.

Kansas Water Resources Board (KWRB), 1967. Irrigation in Kansas. State of Kansas, Planning for Development, 701 project No. Kans. P-43 Report 16(e), Topeka, 128 p.

Kemblowski, M., 1982. Numerical modeling of stream-aquifer Systems. Kansas Geological Survey Open-file Report 82-29, 51 p.

Knight, G.L., 1929. Geology of Barber County, Kansas. Kansas Geological Survey Open-file Report 29-1, 91 p.

Lane, C.W., 1960. Geology and groundwater resources of Kingman County, Kansas. Kansas Geological Survey Bulletin 144, 174 p.

Latta, B.F., 1941. Geology and groundwater resources of Stanton County, Kansas. Kansas Geological Survey Bulletin 37, 119 p.

Latta, B.F., 1944. Geology and groundwater resources of Finney and Gray Counties, Kansas. Kansas Geological Survey Bulletin 55, 272 p.

Latta, B.F., 1948. Geology and groundwater resources of Kiowa County, Kansas. Kansas Geological Survey Bulletin 65, 150 p.

Latta, B.F., 1950. Geology and groundwater resources of Barton and Stafford Counties, Kansas. Kansas Geological Survey Bulletin 88, 228 p.

Layton, D.W., and Berry D.W., 1973. Geology and ground-water resources of Pratt County, south-central Kansas. Kansas Geological Survey Bulletin 205, 33 p.

Luckey, R.L., Gutentag, E.D., Heimes, F.J., and Weeks, J.B., 1986. Digital simulation of groundwater flow in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U.S. Geological Survey Professional Paper 1400-D, 57 p.

McDonald, M.G., and Harbaugh, A.W., 1984. A modular three-dimensional finite-difference groundwater flow model. U.S. Geological Survey Open-file Report 83-875, 528 p.

McDonald, M.G., and Harbaugh, A.W., 1988. A modular three-dimensional finite-difference groundwater flow model. U.S. Geological Survey Techniques of Water Resources Investigations, book 6, ch. A1, 586 p.

McLaughlin, T.G., 1943. Geology and groundwater resources of Hamilton and Kearny Counties, Kansas. Kansas Geological Survey Bulletin 49, 220 p.
McLaughlin, T.G., 1946. Geology and groundwater resources of Grant, Haskell, and Stevens counties, Kansas. Kansas Geological Survey Bulletin 61, 221 p.
McLaughlin, T.G., 1949. Geology and groundwater resources of Pawnee and Edwards counties, Kansas. Kansas Geological Survey Bulletin 80, 189 p.
Meyer, W.R., Grover, B.L., and Carlson, G.W., 1953. 1952 irrigation experiments. U.S. Department of Agriculture Soil Conservation Service Research, 132 p.
Meyer, W.R., Gutentag, E.D., and Lobmeyer, D.H., 1970. Geohydrology of Finney County, southwestern Kansas. U.S. Geological Survey Water-Supply Paper 1891, 117 p.
Moya, P., 1985. Stream-aquifer system of the South Fork Ninnescah River basin in Pratt County, Kansas. M.S. thesis, Department of Civil Engineering, University of Kansas, Lawrence, 216 p.
Nuzman, C., 1990. Appendix E—Hydrologic impact study for Walnut Creek alluvium. In: Engineering/hydrological study, Cheyenne Bottoms Wildlife Area, Barton County, Kansas. Howard, Needles, Tammen and Bergendoff, Inc., Kansas City, MO, 71 p.
O'Connor, H.G., and McClain, T.J., 1982. Ogallala aquifer study in Kansas. Kansas Water Office, 99 p.
Prescott, G.C. Jr., 1951. Geology and groundwater resources of Lane County, Kansas. Kansas Geological Survey Bulletin 93, 126 p.
Prescott, G.C. Jr., 1953a. Geology and groundwater resources of Cheyenne County, Kansas. Kansas Geological Survey Bulletin 100, 106 p.
Prescott, G.C. Jr., 1953b. Geology and groundwater resources of Sherman County, Kansas. Kansas Geological Survey Bulletin 105, 130 p.
Prescott, G.C. Jr., 1955. Geology and groundwater resources of Graham County, Kansas. Kansas Geological Survey Bulletin 110, 98 p.
Prescott, G.C. Jr., Branch, J.R., and Wilson, W.W., 1954. Geology and groundwater resources of Wichita and Greeley counties, Kansas. Kansas Geological Survey Bulletin 108, 134 p.
Prill, R.C., 1968. Movement of moisture in the unsaturated zone in a dune area, southwestern Kansas. U.S. Geological Survey Professional Paper 600-D: D1-D9.
Slagle, S.E., and Weakly, E.C., 1976. Groundwater resources of Greeley and Wichita counties, western Kansas. Kansas Geological Survey Irrigation Series 2, 21p.
Slichter, C.S., 1906. The underflow in Arkansas Valley in western Kansas. U.S. Geological Survey Water Supply Paper 153, 90 p.
Sophocleous, M.A., 1981. The declining ground-water resources of alluvial valleys—a case study: Ground Water, 19(2): 214-226.
Sophocleous, M.A., and McAllister, J.A., 1990. Hydrologic-balance modeling of the Rattlesnake Creek watershed, Kansas. Kansas Geological Survey Ground Water Series 11, 72 p.
Sophocleous, M.A., and Perkins, S.P., 1992. Stream-aquifer and mineral intrusion modeling of the lower Rattlesnake Creek basin with emphasis on the Quivira National Wildlife Refuge. Kansas Geological Survey Open-file Report 92-6, 208 p.
Sophocleous, M.A., and Perry, C.A., 1987. Natural Groundwater Recharge Intrumentation and Computation at sites in South-Central Kansas. U.S. Geological Survey Water-Resources Investigations Report 87-4097, 48 p.

Sophocleous, M.A., Heidari, M., and McElwee, C.D., 1982. Water quality modeling of the Equus Beds aquifer in south-central Kansas. Kansas Water Resources Research Institute, University of Kansas, Lawrence, KS, Contribution No. 231, 68 p.

Sophocleous, M.A., Kluitenberg, G.J., and Healey, J., 2002. Southwestern Kansas High Plains deep vadose zone pilot study to estimate Darcian-based groundwater recharge at three instrumented sites. Kansas Geological Survey Open-file Report 2001-11, 120 p.

Spinazola, J.M., and Dealy, M.T., 1983. Hydrology of the Ogallala aquifer in Ford County, southwestern Kansas. U.S. Geological Survey Water-Resources Investigations Report 83-4226, 58 p.

Spinazola, J.M., Gillespie, J.B., and Hart, R.J., 1985. Ground-water flow and solute transport in the Equus Beds area, south-central Kansas, 1940-1979. U.S. Geological Survey Water-Resources Investigations Report 85-4336, 68 p.

Stramel, G.J., 1956. Progress report on the groundwater hydrology of the Equus Beds area, Kansas. Kansas Geological Survey Bulletin 119, part1, 1-59.

Stullken, L.E., Watts, K.R., and Lindgren, R.J., 1985. Geohydrology of the High Plains aquifer, western Kansas. U.S. Geological Survey Water-Resources Investigations Report 85-4198, 86 p.

Theis, C.V., 1937. Amount of groundwater recharge in the southern High Plains. American Geophysical Union Transactions, 18th Ann. Meeting, part 2, 564-568

Theis, C.V., Burleigh, H.P., and Waite, H.A., 1935. Groundwater in the southern High Plains. U.S. Dept. Interior Memorandum for the Press, 1-4. (cited in Latta, B.F. 1941).

Trescott, P.C., 1975. Documentation of finite-difference model for simulation of three-dimensional groundwater flow. U.S. Geological Survey Open-File Report 75-438, 32 p.

Trescott, P.C., Pinder, G.F., and Larson, S.P., 1976. Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments. U.S. Geological Survey Techniques of Water Resources Investigations, book 7, ch. C1, 116 p.

Waite, H.A., and Holmes, E.H., 1947. Geology and groundwater resources of Scott County, Kansas. Kansas Geological Survey Bulletin 66, 216 p.

Walters, K.L., 1956. Geology and groundwater resources of Rawlins County, Kansas. Kansas Geological Survey Bulletin 117, 100 p.

Watts, K.R., 1989. Potential hydrologic effects of groundwater withdrawals from the Dakota aquifer, southwestern Kansas. U.S. Geological Survey, Water-Supply Paper 2304, 47 p.

Whittemore, D.O., Tsou, M.S., Perkins, S., McElwee, C., Zhan, X., and Young, D.P., 2001. Conceptual model and numerical simulation of groundwater salinization in the Arkansas River Corridor, southwest Kansas. Kansas Geological Survey Open-file Report 2001-2, 211p.

Williams, C.C., 1946. Groundwater conditions in Arkansas River valley in the vicinity of Hutchinson, Kansas. Kansas Geological Survey Bulletin 64, part 5, 145-216.

Williams, C.C., and Lohman, S.W., 1949. Geology and groundwater resources of a part of south-central Kansas. Kansas Geological Survey Bulletin 79, 455p.