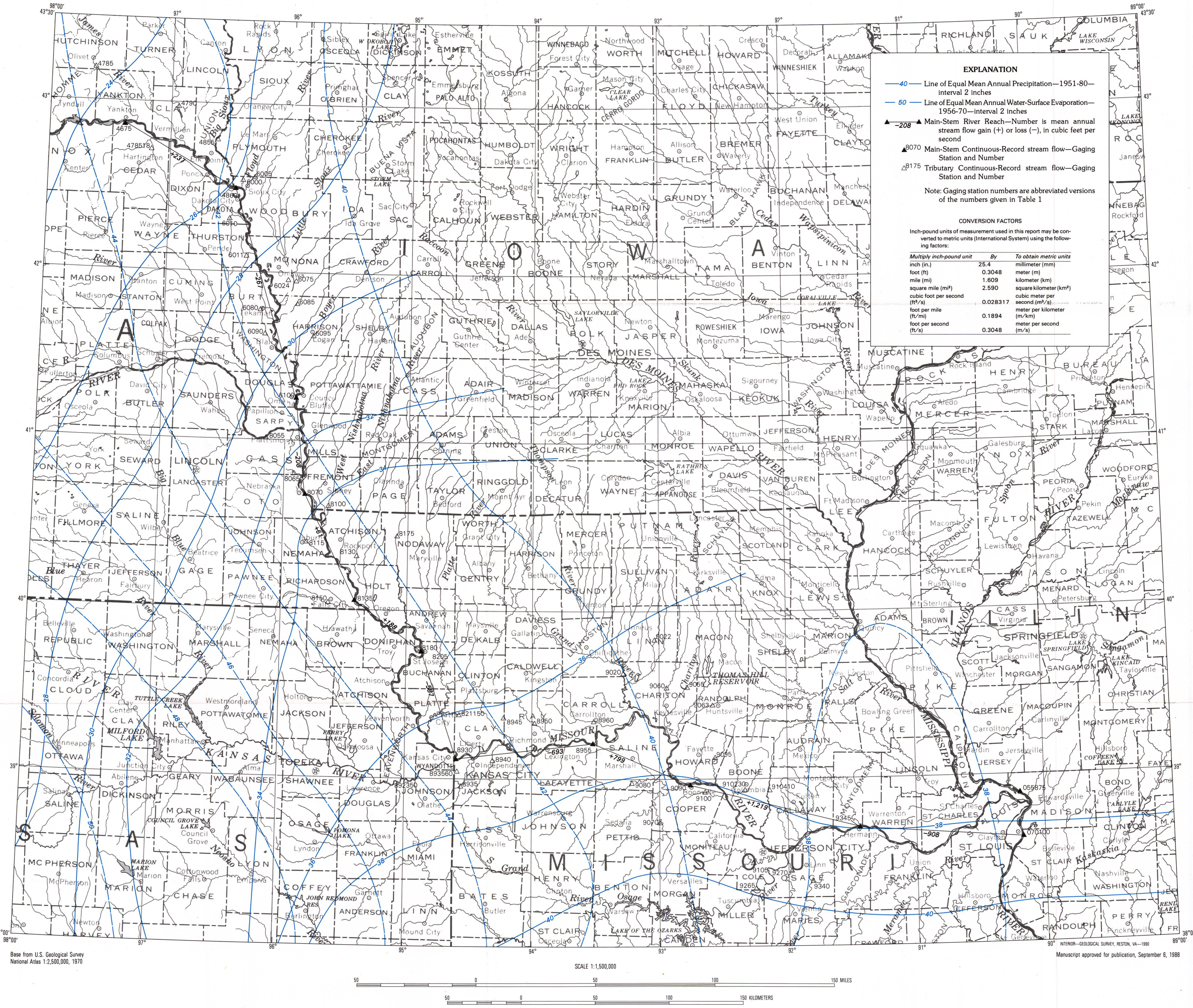
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS
ATLAS HA–721



CONVERSION FACTORS

Inch-pound units of measurement used in this report may be converted to metric units (International System) using the following factors:

Multiply inch-pound unit	*By*	*To obtain metric units*
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi²)	2.590	square kilometer (km²)
cubic foot per second (ft³/s)	0.028317	cubic meter per second (m³/s)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
foot per second (ft/s)	0.3048	meter per second (m/s)

Base from U.S. Geological Survey National Atlas 1:2,500,000, 1970

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1990

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INTRODUCTION

The U.S. Geological Survey began a study of the Central Midwest regional aquifer system in October 1980 to: (1) describe the hydrologic system, (2) create a regional data base, (3) describe the historic, present (1987), and future problems associated with the use of water in the aquifers, and (4) evaluate aquifer-system response to future conditions. This report analyzes streamflow gains and losses of the Missouri River Valley aquifer between Yankton, South Dakota, and St. Louis, Missouri.

The study area is in the Interior Plains and Interior Highlands physiographic divisions (Fenneman, 1946) and includes parts of Iowa, Kansas, Missouri, Nebraska, and South Dakota (fig. 1). Land-surface elevation ranges from about 400 feet above sea level in the southeast to about 1,100 feet above sea level in the northwest. Mean annual precipitation ranges from about 24 inches in the northwest near Yankton, South Dakota, to about 40 inches in the southeast near St. Louis, Missouri.

The Missouri River Valley aquifer occurs in the flood plain of the Missouri River. The aquifer consists of water-bearing alluvial sediments—mostly sand and clay; however, sand and gravel of glacial origin form a basal zone that is present at most locations. The typical thickness of the aquifer material is from 50 to 300 feet. The typical width is from 4 to 15 miles. The aquifer is in close hydraulic connection with the Missouri River, which courses over the aquifer.

There are three regional geohydrologic units in contact with the Missouri River Valley aquifer (fig. 2):

(1) The Great Plains aquifer system, formerly termed the "Dakota" aquifer in Cretaceous rocks;
(2) The Western Interior Plains confining system consisting mostly of shale and limestone of Permian and Pennsylvanian age.
(3) The Ozark Plateaus aquifer system consisting mostly of limestone and dolostone of Cambrian and Ordovician age.

The Missouri River Valley aquifer is in contact with the Great Plains aquifer system in the upstream reaches, the Western Interior Plains confining system in the middle reaches, and the Ozark Plateaus aquifer system in the downstream reaches (fig. 2). The Western Interior Plains confining system consists of layers of permeable material, such as limestone or sandstone that may be water-yielding, and layers of very small permeability, such as shale. However, collectively the layers confine or restrict to some degree the flow to and from the underlying Western Interior Plains aquifer system (Jorgensen and others, in press).

HYDROLOGIC BUDGET

The elements of the hydrologic budget for the Missouri River Valley aquifer include exchange of surface water and ground water, as well as recharge from precipitation, evaporation from open-water surfaces and wetlands, underflow from adjacent uplands, and consumptive use of municipal, domestic, and irrigation water. The interaction between the Missouri River Valley aquifer and the regional geohydrologic units (Great Plains aquifer system, the Western Interior Plains confining system, and the Ozark Plateaus aquifer system) can not be directly measured because the interface across which flow occurs is in the subsurface. Thus, the interaction was evaluated indirectly from analysis of the hydrologic budget. Quantities for each element in the budget were measured or estimated; the interaction due to the regional aquifer system was unknown and was calculated as a residual term.

Although the primary objective of this type of analysis is to determine the exchange of water between the Missouri River Valley aquifer and the regional geohydrologic units, this exchange had to be calculated by analyzing the water budget in reaches of the Missouri River.

Elements of gain and loss to the Missouri River Valley aquifer except for gain or loss from regional geohydrologic units were discriminated, and then these elements were evaluated by appropriate estimating techniques or by measurements. Thus, the gain or loss from the regional geohydrologic units was the unknown variable in a steady-state analysis of the water-budget equation for the Missouri River.

Analysis of streamflow gain and loss in this report generally followed established techniques in hydrology. The analysis involved defining streamflow gain and loss between 11 selected continuous-record stations on the Missouri and Mississippi Rivers. A 30-year period, the 1951–80 water years (October 1 to September 30), was used for the analysis because average annual precipitation data already were available (Hedman and others, 1987; Hedman and Engel, 1989); the relation used to estimate ground-water recharge to the water table was developed for this period (Dugan and Peckenpaugh, 1985); and the regulation of upstream reservoirs was relatively constant during most of the period.

The following procedure was used to evaluate gain and loss between 11 main-stem continuous-record gaging stations for the 30-year period:

(1) Determine the mean annual discharge at each main-stem Missouri and Mississippi River continuous-record gaging station in the study area.
(2) Determine the mean annual discharge at continuous-record gaging stations on nearby tributary streams.
(3) Estimate the mean annual discharge for the ungaged drainage areas adjacent to the Missouri River.
(4) Estimate the net mean annual recharge, which includes consideration of consumptive use and many other factors, that infiltrates to the water table of the Missouri River Valley aquifer.
(5) Estimate the mean annual water use for the major cities on the Missouri River where the water is diverted upstream from the gaging station and discharged as sewage effluent downstream of the gage.
(6) Estimate the mean annual evaporation losses from open-water surfaces and wetlands.
(7) Estimate the mean annual consumptive use of the ground water from the Missouri River Valley aquifer used for irrigation.
(8) Estimate the mean annual underflow to and from the Missouri River Valley aquifer. Underflow occurs between the reaches along the main channel of the Missouri River and its tributaries, and to the Missouri River Valley aquifer through the valley walls.

As stated previously, in analyzing the hydrologic budget of the Missouri River, the unaccounted-for streamflow gain or loss from each reach between main-stem gaging stations (Q) are equivalent to the water from the interaction between the Missouri River Valley aquifer and the subjacent geohydrologic units, such as the Great Plains aquifer system, the Western Interior Plains confining system, and the Ozark Plateaus aquifer system. Gain or loss (Q) was computed by subtracting from the discharge of the downstream main-stem gage (Q_{dn}), the discharge of the upstream main-stem gage (Q_{up}), the discharge of the tributary gages (Q_t), the estimated discharge of the ungaged drainage area (Q_u), the estimated accretion of recharge (Q_r), the estimated discharge of any water that has bypassed an upstream Missouri River gage and is discharged downstream as sewage effluent (Q_{cd}), and by adding the estimated discharge that is withdrawn upstream from the gage for city water use (Q_{ci}), the estimated discharge that is evaporated (Q_e), and the estimated discharge of consumptive use (Q_c), The resulting equation is:

$$Q = Q_{dn} - Q_{up} - Q_t - Q_u - Q_r - Q_{cd} + Q_{ci} + Q_e + Q_c. \qquad (1)$$

Streamflow-gaging-station data used for the analysis are from files of the U.S. Geological Survey.

MEAN ANNUAL DISCHARGE

The 11 main-stem gaging stations used in the analysis had continuous-discharge record for the 30-year period, 1951–80. The mean annual discharge, in cubic feet per second, was computed for the 30-year period for each station and is shown in table 1.

Most of the gaging stations on the major tributary streams also had continuous-discharge record for the 30-year period (table 1). Some records less than 30 years were used because the mean annual discharge was generally small and was believed to be more accurate than discharge computed from the regression equation that is presented below. For these tributary stations the mean annual discharge was computed for either the 30-year period or for the available period of record as shown in table 1.

Regression analysis was used to develop an equation to compute mean annual discharge for the ungaged, upland drainage areas adjacent to the Missouri River. Data from the continuous-record gaging stations on nearby tributary streams (table 1) were used in the analysis. Only the downstream subareas were used for the large tributary streams that have two continuous-record gaging stations. The discharge and drainage areas for these subareas were computed by subtracting the comparable values for the upstream gages from the values for the downstream gage. The mean annual discharge values then were related to the drainage areas or subareas and mean annual precipitation for each of the drainage areas or subareas with regression analysis.

The resulting equation has a standard error of estimate of 21 percent and is:

$$Q_a = 0.0165\, A^{0.966}\, (P\text{–}20)^{1.297} \qquad (2)$$

where Q_a is mean annual discharge, in cubic feet per second; A is drainage area, in square miles; and P–20 is mean annual precipitation, in inches minus 20 inches. Subtracting 20 inches from all precipitation values improved the standard error of estimate by making the relation more linear. Precipitation values were greater than 20 inches in all subareas used in the analysis. This equation was used to compute the ungaged inflow shown in table 2.

MEAN ANNUAL RECHARGE

A relation between precipitation and recharge developed by Dugan and Peckenpaugh (1985) using a modified Jensen-Haise algorithm (Jensen and Haise, 1963) was used to estimate mean annual recharge to the water table (fig. 3). The recharge is water from precipitation that falls on the Missouri River valley and valleys downstream from gages on tributary streams and infiltrates to the water table after consumptive-use losses. The areas of the valleys, in square miles, were measured with a planimeter from U.S. Geological Survey topographic quadrangles (7.5-minute series) and did not include open-water surfaces and wetlands. Mean annual precipitation, in inches, was estimated from the lines of equal precipitation. Both the relation of Dugan and Peckenpaugh (1985) and the lines of equal precipitation were developed for the 30-year period. Mean annual recharge to the Missouri River Valley aquifer is shown in table 2.

MEAN ANNUAL WATER USE

Most cities, overlying the Missouri River Valley aquifer and adjacent to the valley, pump water for municipal use directly from the river or from shallow wells that are in the aquifer adjacent to the river. Generally, this water is withdrawn upstream from a city and discharged downstream as treated sewage effluent. The streamflow-gaging stations on the Missouri River are located in the cities, so the water that is removed upstream and discharged downstream bypasses these gaging stations.

Each of the major cities in the study area provided estimates of withdrawals and sewage-effluent discharge. The estimates of sewage effluent were based on winter periods, so they did not include storm runoff. However, discharge of storm runoff was included in the computations of mean annual discharge for ungaged areas, described in previous paragraphs. Mean annual discharges for water withdrawn upstream and water released downstream for the major cities are shown in table 2.

Ground and surface water are used for irrigation in the Missouri River valley. Data for 1985 were used to represent consumptive use from irrigation. Consumptive-use data for 1985 were used directly when available or computed as 70 percent of irrigation withdrawals when not available. Mean annual consumptive use for the study area is shown in table 2.

MEAN ANNUAL WATER–SURFACE EVAPORATION

Annual evaporation losses from open-water surfaces and wetlands for the 30-year period were computed by subtracting the mean annual precipitation from the potential evaporation. Potential evaporation and precipitation were estimated from the lines of equal evaporation (Farnsworth and others, 1982) and the lines of equal precipitation (Hedman and others, 1987; Hedman and Engel, 1989). The areas of the open-water surfaces and wetlands in the Missouri River valley and valleys downstream from the gages on the tributaries were planimetered from U.S. Geological Survey topographic quadrangles (7.5-minute series). The mean annual water-surface evaporation for each of the 10 reaches is shown in table 2.

MEAN ANNUAL UNDERFLOW

The Darcy equation was used to estimate the underflow along the main and tributary channels of the Missouri River and the underflow through the valley walls for each river reach. Because the gradients of the valleys are very small (1 ft/mi), the calculated underflow for the channels was also very small, generally less than 1 ft^3 for each reach and considered insignificant for this study. Likewise, the hydraulic conductivity for the valley walls was small (estimated to be 1×10^{-7} ft/s), so the calculated valley-wall underflow to the Missouri River valley aquifer was considered insignificant for this study.

STREAMFLOW GAINS AND LOSSES

The streamflow gains (positive values) and losses (negative values) in Missouri River reaches are the discharge (Q) not accounted for by tributary inflow, recharge, domestic use, evaporation, and consumptive use as determined by equation 1. The analysis indicates which reaches gain or lose water. The location of the gaining and losing reaches is consistent with prediction of gains and losses from numerical model studies of the regional aquifers of the Central Midwest area (D. C. Signor, U.S. Geological Survey, oral commun. 1987) and are generally consistent with regional water-level maps (Jorgensen and others, 1986).

The accuracy of the results, which will be discussed later, can not be fully evaluated. The gains and losses range from –908 to + 1,219 ft^3/s (see table 2). These values are approximately equivalent to but opposite in sign to the gains and losses to the Missouri River Valley aquifer from the subjacent regional geohydrologic units. The Q value of +237 ft^3/s for the Missouri River reach between Yankton, South Dakota, and Sioux City, Iowa, indicates that water is recharged to the Missouri River Valley aquifer from the Great Plains aquifer (fig. 2), which is consistent with measured hydraulic-head relations. The loss of 267 and 208 ft^3/s between Sioux City, Iowa, and Nebraska City, Nebraska, approximates leakage downward from the Missouri River Valley aquifer to Western Interior Plains confining system. The gains of 61 and 188 ft^3/s between Nebraska City, Nebraska, and St. Joseph, Missouri, indicate a gain of water to the Missouri River Valley aquifer from the Western Interior Plains confining system. The losses of 587 and 693 ft^3/s in the reach between St. Joseph and Waverly, Missouri, indicate a significant flow of water from the Missouri River Valley aquifer to the water-bearing units in the underlying Western Interior Plains confining system. The gain of 799 and 1,219 ft^3/s in the reach between Waverly and Hermann, Missouri, indicates significant flow into the Missouri River Valley aquifer from the underlying Ozark Plateaus aquifer system and is consistent with measured hydraulic-head relations in the aquifer system (Jorgensen and others, 1986). The loss of water in the reach between Hermann and St. Louis, Missouri, indicates a loss from the Missouri River Valley aquifer. Here it is likely that water from the Missouri River Valley aquifer flows southeastward to the Mississippi River Valley aquifer, which has a significantly lower water level.

ACCURACY OF STUDY RESULTS

In assessing the accuracy of the study results, accuracy of the individual items needed for the hydrologic budget must be addressed. For example, the accuracy of the differences between the 30-year mean annual discharge between two gaging stations on the same stream is, of course, relevant to the accuracy of the entire analysis of gains and losses as determined for this report. The errors at any single gaging station can be attributed to random errors, systematic errors (inconsistency and bias), and nonhomogeneity errors (nonstationary errors for a time series). If it is assumed that the nonstationary errors are the same for both gages on the same stream, the difference between discharges for the two gages will tend to minimize or remove the effects of these errors. Systematic errors due to inconsistency can be assumed to be nearly equal because the procedure for determining discharge at each gaging station, in general, is the same. Again, because the analysis is based on the difference between the two station discharges, the effect of inconsistency errors will be eliminated or attenuated. Errors due to bias are difficult to evaluate. If bias does not exist or, if it does exist, that bias error for each discharge at each gage is the same, the effect of bias on the difference between two stations will be minimal.

Random errors are always in data. It is often either assumed or proven by repeated experiments that random errors are approximately symmetrically distributed about the true values (Yevjevich, 1972). Random errors also affect the accuracy of the differences between measurement at two gaging stations. Assuming random errors at both gaging stations, the errors can occur in three ways: (1) random errors at both gages are positive, (2) random errors at both gages are negative, or (3) random errors at each station have different signs. The first two of the three conditions tend to reduce the magnitude of the differences between the two stations due to random errors at each station.

It remains to evaluate the errors or accuracy at a gaging station. For the purpose of analysis, assume that the record at the station is good (that is, 95 percent of the mean daily discharge are within (±) 10 percent of the actual value, the difference being due to random error). Thus, assuming normal distribution of the error, the standard deviation (σ) is 0.051 percent. The expected deviation of the measured mean of the data ($\bar{x}$) from the true mean (μ),

$$E(\bar{x}-\mu) = \sigma/n^{0.5}\,, \qquad (2)$$

where n is the number of daily discharge values during the 30-year period or (30)(365)=10,950. Thus,

$$E(\bar{x}-\mu) = (0.05)/(10{,}950)^{0.5} = 4.87 \times 10^{-4} \text{ (of one } \sigma\text{)}.$$

However, not all daily observations are independent of each other, therefore in effect reducing n. However, even if n was reduced an order of magnitude, $E(\bar{x}-\mu)$ would still be 1.5×10^{-3} of one σ. Remembering that the differences due to random errors between two gaging stations are expected to be less than errors at any gaging station because for two of the three conditions, errors will be of the same sign. Considering the above, random errors of differences between observation of daily discharge at two gaging stations should be very small.

Examination of table 2 indicates that mean annual ungaged inflows, which have a standard error of estimate of 21 percent, are approximately equal to the mean annual gains or losses. Thus, these errors are expected to be significantly less than the magnitude of the calculated gains and losses.

Data points shown by Dugan and Peckenpaugh (1985, figure 35) imply that recharge values calculated using the Jensen and Haise algorithm (Jensen and Haise, 1963) typically deviate less than 40 percent from the curve shown in figure 3.

Information on the accuracy of mean annual city discharge, mean annual city intake, and mean annual water-surface evaporation are not available. However, individually, these values are typically only 5 to 25 percent of the corresponding mean annual gain or loss in any reach.

SUMMARY

The thickness and width of the Missouri River Valley aquifer differ greatly in the study reaches of the Missouri River; thickness of the aquifer ranges from more than 50 feet to less than 300 feet, and the width ranges from about 4 miles to more than 15 miles.

Analysis of the elements of the hydrologic budget indicates that the Missouri River Valley aquifer gains water in five of the reaches and loses water in five others. The Missouri River Valley aquifer is in hydraulic connection with three regional geohydrologic units (Great Plains Aquifer system in the upstream reaches, Western Interior Plains confining system in the middle reaches, and Ozark Plateaus aquifer system in the downstream reaches). The gains and losses in flow determined in this study are related to the regional geohydrology and, therefore, are assumed to be due to interaction between the Missouri River-Missouri River Valley aquifer and the regional geohydrologic units rather than other unevaluated sources or sinks. Gains and losses in the 10 reaches ranged from −908 to +1,219 ft^3/s; however, the accuracy of the calculated gains and losses can not be fully ascertained.

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Table 1. ***Discharge and basin characteristics of selected streams***

Station number	Station name	River miles	Period of record (water years)	Mean annual discharge (cubic feet per second)	Drainage area (square miles)
*06467500	Missouri River at Yankton, South Dakota	805.8	1951–80	27,140	279,500
06478500	James River near Scotland, South Dakota	–	1951–80	419	21,550
06479000	Vermillion River near Wakonda, South Dakota	–	1951–80	112	1,680
06485500	Big Sioux River at Akron, Iowa	–	1951–80	917	9,030
*06486000	Missouri River at Sioux City, Iowa	732.3	1951–80	29,110	314,600
06600000	Perry Creek at Sioux City, Iowa	–	1951–69	14	65
06600500	Floyd River at James, Iowa	–	1956–80	194	889
06601000	Omaha Creek at Homer, Nebraska	–	1951–80	33	168
06602400	Monona-Harrison Ditch near Turin, Iowa	–	1951–80	465	900
06607500	Lower Sioux River near Turin, Iowa	–	1951–80	856	3,526
06608000	Tekamah Creek at Tekamah, Nebraska	–	1951–80	6	23
06608500	Soldier River at Pisgah, Iowa	–	1951–80	123	407
06609000	New York Creek at Herman, Nebraska	–	1951–68	7	25
06609500	Boyer River at Logan, Iowa	–	1951–80	306	871
*06610000	Missouri River at Omaha, Nebraska	615.9	1951–80	31,090	322,800
06805500	Platte River at Louisville, Nebraska	–	1954–80	5,700	85,800
06806500	Weeping Water Creek at Union, Nebraska	–	1951–80	84	241
*06807000	Missouri River at Nebraska, City, Nebraska	562.6	1951–80	37,300	410,000
06810000	Nishnabotna River at Hamburg, Iowa	–	1951–80	1,140	2,806
06811500	Little Nemaha River at Auburn, Nebraska	–	1951–80	277	793
06813000	Tarkio River at Fairfax, Missouri	–	1951–80	224	508
*06813500	Missouri River at Rulo, Nebraska	498.0	1951–80	39,450	414,900
06815000	Big Nemaha River at Falls City, Nebraska	–	1951–80	581	1,340
06817500	Nodaway River near Burlington Junction, Missouri	–	1951–80	540	1,240
*06818000	Missouri River at St. Joseph, Missouri	448.2	1951–80	41,750	420,300
06820500	Platte River near Agency, Missouri	–	1951–80	978	1,760
06821150	Little Platte River at Smithville, Missouri	–	1966–80	152	234
06892350	Kansas River at DeSoto, Kansas	–	1951–80	7,720	59,756
*06893000	Missouri River at Kansas City, Missouri	366.1	1951–80	50,810	485,200
06893500	Blue River near Kansas City, Missouri	–	1951–80	141	188
06893560	Brush Creek at Kansas City, Missouri	–	1971–78	8	15
06894000	Little Blue River near Lake City, Missouri	–	1951–80	135	184
06894500	East Fork Fishing Creek at Excelsior Springs, Missouri	–	1952–72	12	20
06895000	Crooked River near Richmond, Missouri	–	1951–70	100	159
*06895500	Missouri River at Waverly, Missouri	293.4	1951–80	51,480	487,200
06896000	Wakenda Creek at Carrollton, Missouri	–	1951–70	138	248
06902000	Grand River near Sumner, Missouri	–	1951–80	3,580	6,880
06902200	West Yellow Creek near Brookfield, Missouri	–	1960–77	101	135
06905500	Chariton River near Prairie Hill, Missouri	–	1950–80	1,130	1,870
06906000	Mussel Fork near Musselfork, Missouri	–	1963–80	209	267
06906300	East Fork, Lower Chariton River near Huntsville, Missouri	–	1963–80	167	220
06907000	Lamine River at Clifton, Missouri	–	1951–71	384	598
06908000	Blackwater River at Blue Lick, Missouri	–	1951–80	668	1,120
*06909000	Missouri River at Booneville, Missouri	196.6	1951–80	60,030	501,700
06909500	Moniteau Creek near Fayette, Missouri	–	1951–69	36	81
06910000	Petite Saline Creek near Booneville, Missouri	–	1951–67	87	182
06910230	Hinkson Creek at Columbia, Missouri	–	1967–80	51	70
06910410	Cedar Creek near Columbia, Missouri	–	1965–75	41	45
06910500	Moreau River near Jefferson City, Missouri	–	1951–74	361	531
06926500	Osage River near St. Thomas, Missouri	–	1951–80	9,210	14,500
06927000	Maries River at Westphalia, Missouri	–	1951–70	197	257
06934000	Gasconade River near Rich Mountain, Missouri	–	1951–59	2,480	3,180
*06934500	Missouri River at Hermann, Missouri	97.9	1951–80	75,580	52,420
*05587500	Mississippi River at Alton, Illinois	**202.7	1951–80	102,100	171,500
*07010000	Mississippi River at St. Louis, Missouri	**180.0	1951–80	177,800	697,000

*Main-stem continuous-record gaging station.
**Upstream from Ohio River.

Table 2. ***Streamflow gains and losses for Missouri River***

[Values are in cubic feet per second]

Missouri River reaches	Mean annual discharge (downstream main stem)	Mean annual gaged inflow (upstream main stem)	Mean annual gaged inflow (tributary)	Mean annual ungaged inflow	Mean annual valley recharge	Mean annual city discharge	Mean annual city intake	Mean annual water-surface evaporation	Mean annual consumptive use	Mean annual Missouri River valley aquifer
064675 Yankton, South Dakota to 064862 Sioux City, Iowa	29,110	−27,140	−1,448	−310	−64	–	+17	+45	+27	+237
064860 Sioux City, Iowa to 066100 Omaha, Nebraska	31,090	−29,110	−2,012	−210	−166	−13	+58	+23	+73	−267
066100 Omaha to 068070 Nebraska City, Nebraska	37,300	−31,090	−5,784	−352	−258	−39	–	+9	+6	−208
068070 Nebraska City to 068135 Rulo, Nebraska	39,450	−37,300	−1,641	−265	−196	–	–	+6	+7	+61
068135 Rulo, Nebraska to 068180 St. Joseph, Missouri	41,750	−39,450	−1,121	−960	−69	–	+25	+12	+1	+188
068180 St. Joseph to 068930 Kansas City, Missouri	50,810	−41,750	−8,850	−861	−78	−20	+150	+9	+3	−587
068930 Kansas City to 068955 Waverly, Missouri	51,480	−50,810	−396	−756	−89	−128	–	+6	–	−693
068955 Waverly to 069090 Booneville, Missouri	60,030	−51,480	−6,377	−1,212	−167	–	–	+5	–	+799
069090 Booneville to 069345 Hermann, Missouri	75,580	−60,030	−12,463	−1,812	−56	–	–	–	–	+1,219
069345 Hermann to 070100 St. Louis, Missouri	177,800	−75,580	−102,100	−1,143	−120	–	+235	–	–	−908

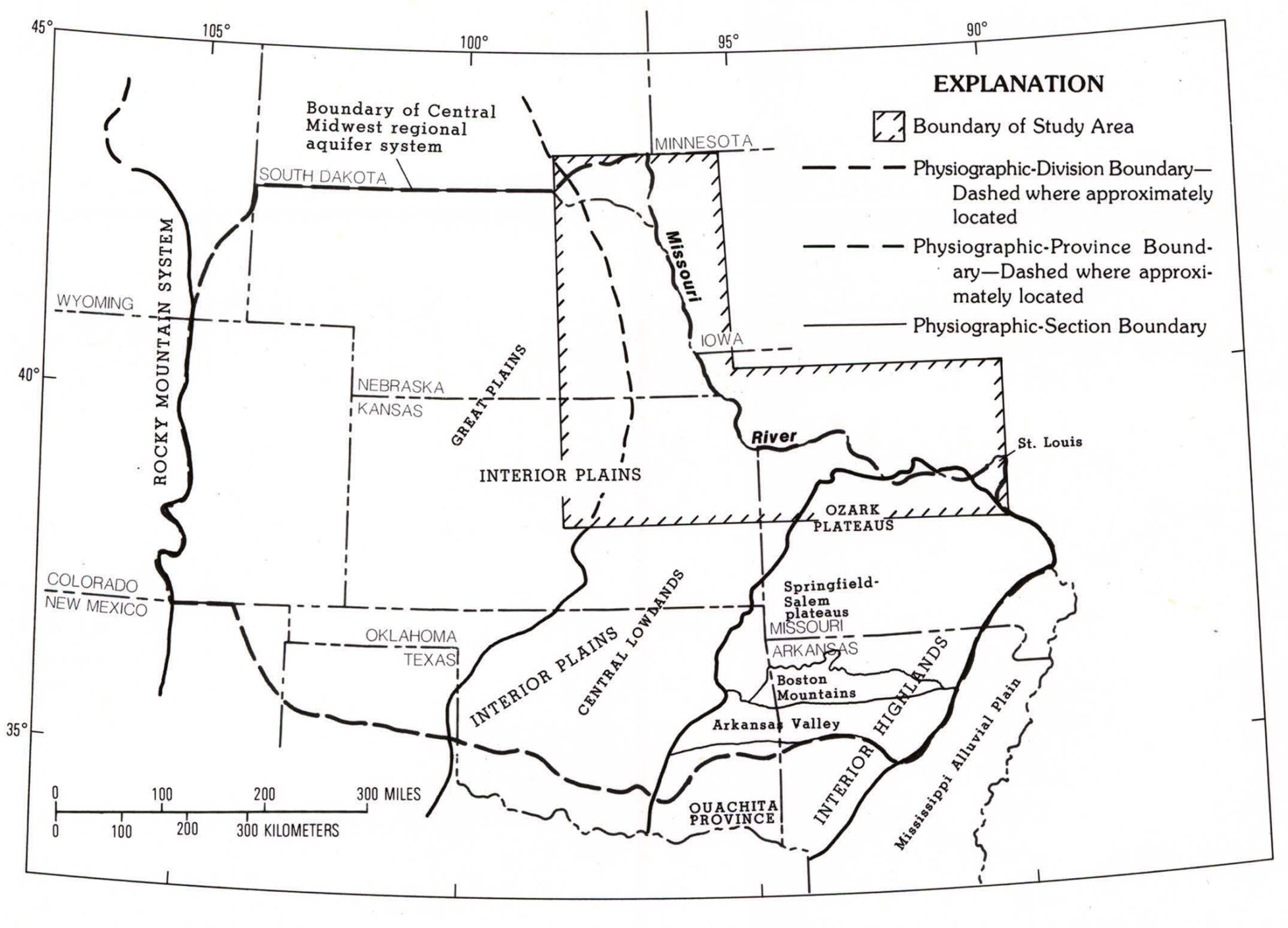

Figure 1. Boundary of study area and location of Central Midwest regional aquifer system.

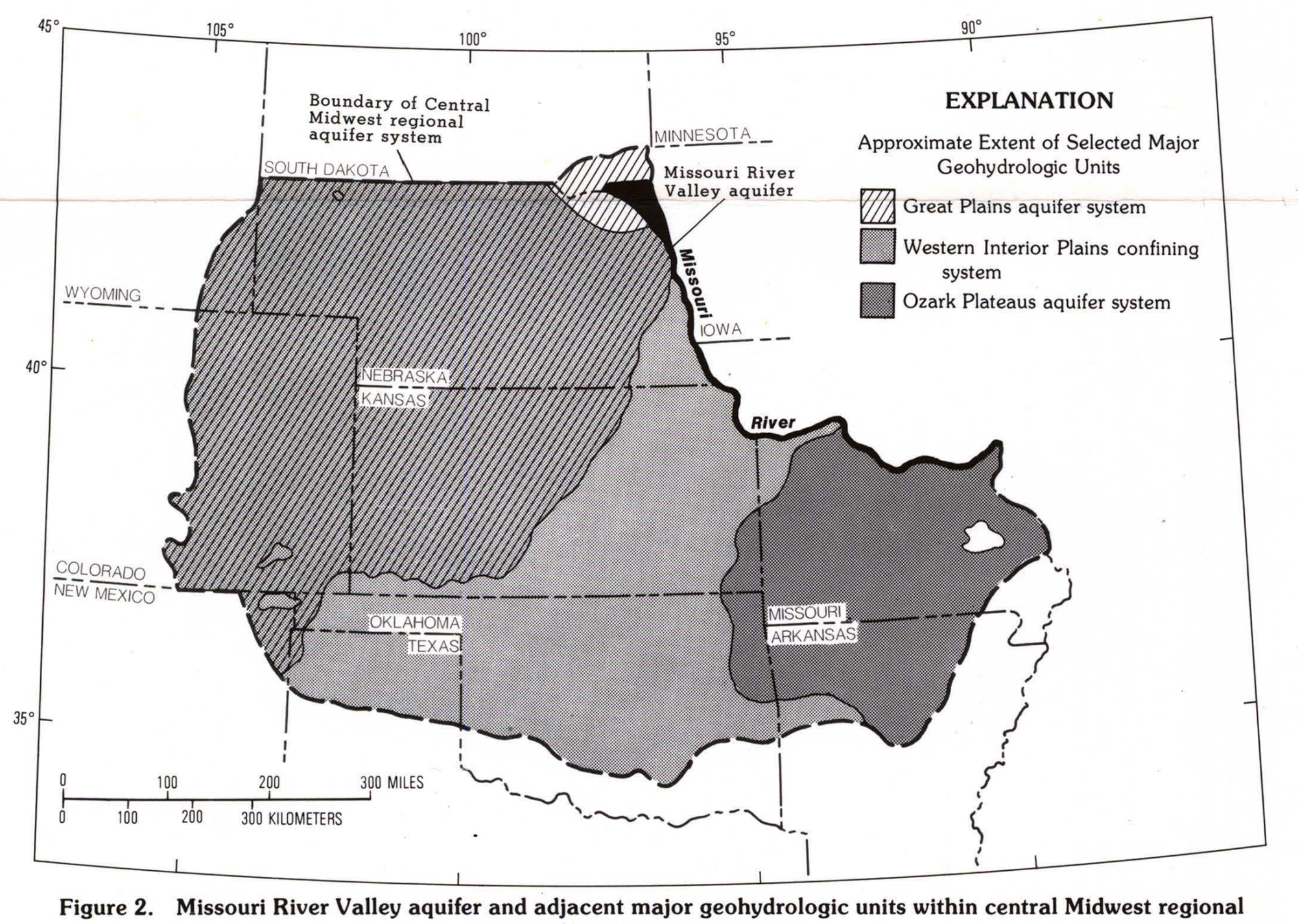

Figure 2. Missouri River Valley aquifer and adjacent major geohydrologic units within central Midwest regional aquifer system study area.

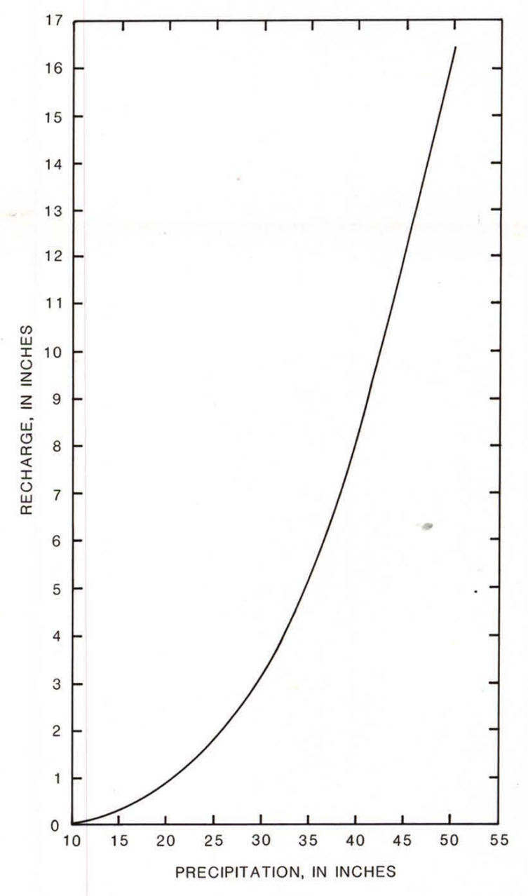

Figure 3. Computed mean annual recharge as a function of precipitation (modified from Dugan and Peckenpaugh, 1985).

SURFACE– AND GROUND–WATER INTERACTION AND HYDROLOGIC BUDGET OF THE MISSOURI RIVER VALLEY AQUIFER BETWEEN YANKTON, SOUTH DAKOTA, AND ST. LOUIS, MISSOURI

By

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