

**KANSAS GEOLOGICAL SURVEY
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Solomon Basin Study

Report to the Kansas Water Office

by

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Introduction

Initially, one reason for doing the Solomon Study was to determine at what stage of water resource development was the basin in and to try and answer the following questions:

1. What are the hydrologic conditions of the aquifers and streams?
2. Are there parallels in other Kansas stream systems which could be used as a model for management of the Solomon?

These questions applied particularly to the alluvial valley portion of the basin and, to a lesser degree, to the hydrologic conditions in the Ogallala Aquifer in the western part of the basin. The alluvial aquifers are dynamic systems where ground water and streamflow are closely tied to recharge and discharge in the basin. The Solomon is perhaps unique in that it is one of the few stream-aquifer systems in western Kansas which still has significant streamflow. Other systems have ground water but much of the streamflow has disappeared.

Additionally, two other questions needed to be answered for the hydrologic inventory :

1. What are the various water budget parameters in the various reaches of the river system?
2. What are the limiting hydrologic factors for the reaches?

1. Data base Construction and Map Output

In order to conduct such a study, a compilation of available geologic and hydrologic data for the study area is an absolute necessity. The GIS technology is used extensively in this study to create a comprehensive data base. A study area base map is displayed in plate 1. Appendix 1 documents this data base. Some basic data are briefly reviewed here.

Geologic Map

The geologic map for the Solomon basin was prepared from existing geologic maps compiled by the Kansas Geological Survey and the U.S. Geological Survey. The final report for the study will contain a bibliography of these studies. Where no geologic maps were available (e.g. Rooks County), soils maps from the USDA-SCS were used as a direct reflection of the underlying geologic units. The above maps at various scales were manually transferred to 1:100,000 mylar base maps produced by the KGS Digital Cartography group. The mylar maps were then digitized, checked for accuracy, joined at the county borders, scaled to 1:250,000, and produced as one map for the basin. Plate 2 displays the principal aquifers of the Solomon River basin.

Ground-Water Level Measurements

Historical data on ground water levels in the Ogallala Aquifer portion of the basin and in the alluvial valley of the Solomon River were taken from records of the water level measurement program funded by the Kansas Geological Survey, the Division of Water Resources, and the U.S. Geological Survey. Records are available from the 1940's to the present. These records were supplemented by water level measurements supplied by the Bureau of Reclamation in Grand Island, Nebraska. The Bureau's data are primarily in the portions of the alluvial valleys below Kirwin, Webster, and Glen Elder reservoirs and date from the 1950's to the present. Plates 3 and 4 display the water table altitude and configuration for 1989, and the water table change from 1950 to 1989, respectively.

Bedrock Elevation Data

Bedrock is defined in this study as the consolidated Cretaceous rock formations at the base of the unconsolidated Ogallala formation and alluvial deposits. Except in the eastern portion of the basin where the Dakota formation occurs, bedrock is relatively impermeable and does not allow water in overlying units to pass through it. Since the bedrock surface is hidden by the overlying

unconsolidated deposits it must be defined by using logs of wells drilled in the area. These logs have been compiled by many state and federal agencies since the 1940's. The present data base consists of bedrock elevations derived from logs of irrigation, domestic, industrial, and municipal wells, and test holes in the basin. In addition, many data points were available from geophysical companies that drilled shot holes in the area. By subtracting bedrock elevation data from water table elevation data, one can obtain aquifer thickness data which can then be contoured and displayed. Plate 5 shows the Ogallala aquifer saturated thickness in the Solomon basin.

Precipitation and Temperature Data

Precipitation and temperature data for 20 selected stations in northwestern Kansas were retrieved from the NOAA climatic data files at KGS. Most of the stations have data from the 1950's to the present; however, some stations go back as far as 1900.

2. Water Budget Modeling

Water budget models using the USGS model MODFLOW were run in order to get a regional picture of the inputs and outputs of various reaches of the alluvial valley portion of the river basin. Appendix 2 contains the data bases used in the modeling, as well as the modeling results.

The valley was subdivided into five different subreaches. Subreach 1 includes the area from Waconda Reservoir to the river junction with the Smoky Hill river. Subreach 2 includes the North Fork of the Solomon between Waconda Reservoir and Kirwin Reservoir. Subreach 3 includes the South Fork of the Solomon between Waconda Reservoir and Webster Reservoir. Subreach 4 covers the area above Kirwin Reservoir to T. 27 W. Subreach 5 includes the area above Webster Reservoir to T. 27 W. The modeled areas include the areal extent of the alluvial aquifer.

Subreaches 4 and 5 were modeled somewhat differently than the lower three subreaches; however, a similar approach was used for the development of the input data for the models in each of the five Subreaches. In each case, the model input was developed within ARC/INFO.

ARC/INFO coverages, which were used to construct the Grid coverage attributes, were generated from the Kansas Cartographic Data Base. These coverages include alluvial aquifer boundaries, township boundaries, and hydrography. Bedrock elevation data were derived from existing studies. Water table coverages were constructed from the KGS water level data base.

The modeling grid was aligned with township and range lines and consisted of grids 5,280 feet E-W by 2,640 feet N-S for reaches 1, 2, and 3. Reaches 4 and 5 were modeled using a grid of 2,640 feet E-W by 1,320 feet N-S. The smaller grid was used on reaches 4 and 5 because the valley is narrower in these reaches. Each grid cell was assigned values of water table and bedrock to determine the saturated thickness. In addition, ground water appropriations were totaled for each cell.

Aquifer Parameters

Recharge - Discharge

Recharge - Recharge occurs in the form of infiltration from precipitation and seepage from the surface water sources along the Solomon River and the small alluvial tributaries entering the valley. Recharge that is contributed by infiltration from precipitation is influenced by many factors such as soil saturation, evapotranspiration, etc. The majority of water that occurs as precipitation is therefore lost before it reaches the aquifer. Total precipitation is approximately 23 inches annually with estimates of less than 10 percent of this infiltrating to the aquifer (Jorgensen and Stullken, 1981).

Discharge - Discharge from the aquifer occurs in the form of leakage to the Solomon River, evapotranspiration, pumping, and subsurface outflow. Leakage to the Solomon River represents the primary form of natural discharge from the aquifer. Withdrawal of ground water by pumping may reduce discharge to the river in areas of high pumping, and in some cases, the pumping may induce recharge to the aquifer from the river.

Aerial recharge to the aquifer from precipitation was assumed to be approximately 1 inch throughout the Solomon basin. This accounts for the factors which influence the infiltration of precipitation such as the soil saturation and evapotranspiration which may either intercept the water before it reaches the aquifer or provide effective discharge from areas of the aquifer with a shallow water table.

Hydraulic Conductivity and Specific Yield

Jorgensen and Stullken (1981) reported a range in the hydraulic conductivity of the aquifer material in the subreach from Kirwin to Waconda from nearly zero to more than 500 ft/d. An average hydraulic conductivity was estimated by Jorgensen and Stullken to be slightly less than 150 ft/d. The range in hydraulic conductivity reported for the subreach from Kirwin to Waconda represents a reasonable estimate for the hydraulic conductivity throughout the basin, and the average hydraulic conductivity was estimated at 150 ft/d.

The specific yield for most unconfined ground-water aquifers ranges from 0.1 to 0.2. Jorgensen and Stullken (1981) identified this range for the subreach from Kirwin to Waconda because the specific yield could not be determined from available pump test data. A specific yield of 0.15 will be assumed for the alluvial valley aquifer throughout the Solomon basin.

Water Table, Bedrock, and Saturated Thickness

Water table data for model use were derived from the most recent and reliable data available. Data were obtained from the KGS water level data base file. When enough data were acquired to compile an ARC-INFO coverage using the data as control points, average water table values were computed and assigned to each grid cell.

Bedrock data were obtained from previously published reports covering the appropriate reach. In some cases bedrock elevations from wells and test holes were used. In other cases existing bedrock contours were used to determine the elevation of the base of the aquifer. An ARC-INFO bedrock coverage was compiled from this data, then the values were averaged to

obtain a value for each model cell. Bedrock values were then subtracted from water table values to obtain a saturated thickness for each cell.

Model Parameters

Each of the lower three subreaches was modeled using a rectangular grid. Each grid node was 1/2 mile in the north-south direction and 1 mile in the east-west direction. The grid was generally aligned with the federal system of rectangular surveys of public lands. Boundary conditions specified within the model include: (1) no-flow boundaries, which identified the aerial termination of the alluvial aquifer deposits; (2) constant head boundaries, which were used to simulate the Solomon River; and (3) constant flow boundaries, which were used to simulate constant pumping rates from the total appropriations within each grid cell.

Model sensitivity was evaluated for each of the subreaches by running multiple simulations in which the aquifer parameters were varied independently to determine the effects on the model simulation. Three sets of simulations were completed for assessing the model sensitivity to each of the parameters: hydraulic conductivity, specific yield, and recharge. For each of the simulations, total appropriations were assumed to be 0. The hydraulic conductivity was varied from 100 ft/d to 200 ft/d while the specific yield and the recharge were held constant at 0.15 and 1 in/year, respectively. Then the specific yield was varied from 0.1 to 0.2 while the hydraulic conductivity and the recharge were held constant at 150 ft/d and 1 in/year, respectively. Finally, the recharge was varied from 1 in/year to 3 in/year with a constant hydraulic conductivity of 150 ft/d and a specific yield of 0.15.

Simulations were then completed while varying the appropriations from 0 to 100 percent of total appropriations to determine the effects of appropriations on each of the systems. Hydraulic conductivity, specific yield, and the recharge values of 150 ft/d, 0.15, and 1 in/year, respectively, were used for the simulations with the appropriations. Because of the regional scale at which the aquifer for each of the subreaches was modeled, it was not practical or meaningful to compare simulated water table configurations. Therefore, the hydrologic budget was used as a means of

comparing the effects of variations in the different parameters and overall effects of ground-water appropriations on the respective aquifer systems.

Model Results

Each of the models was set up similarly and attempts were made to run identical simulations for each of the subreaches. Each of the simulations was set up for a 10-year period with time steps of one year. However, it was necessary to adjust the number of time-steps within the stress periods depending upon the unique conditions within the subreach in order to obtain convergence within the model. In each case, the hydrologic budget terms were compared for the last time-step of the 10th stress-period. The results of these simulations are shown in Appendix 2.

The modeling efforts in each of the five subreaches yielded similar results. Variations in primary aquifer parameters permeability (K), storage (S) and recharge (R), simply changed the amount of water entering or leaving the aquifer through the constant head boundary. Increasing or decreasing K allowed water to move into or out of the aquifer faster or slower. The volume of water in storage was changed by raising or lowering S. Raising or lowering recharge had the effect of increasing or decreasing the amount of water passing through the constant head stream node which would cause a corresponding change in streamflow.

Removing water from the aquifer by increased pumping raised the amount of water entering the aquifer through the constant head boundary which would have the effect of reducing streamflow during the pumping season. Increasing pumping also had the effect of decreasing the amount of water leaving the aquifer through the constant head boundary which would cause reduced seepage to the river, therefore reducing baseflow.

Each of the model runs clearly identified the river as the dominant mechanism controlling the aquifer system. When flow was maintained along the river boundary (i.e. constant head in the river nodes), the hydrologic system could adequately meet the demands of ground-water pumping, even with pumping at 100 percent of total appropriations. Results of the 10-year simulations showed that there was a relatively rapid lowering of the water table when pumping was initiated

followed by a flattening of the decline curve as the river began supplying water to wells, replenishing the aquifer. When flow was not maintained along the river boundary (i.e. river nodes were not defined with constant head), ground-water pumping quickly lowered the water table in the alluvial aquifer to a point that was ineffective for pumping, even with pumping as low as 25 percent of total appropriations.

Conclusions

Maintenance of streamflow is critical to the health of the hydrologic system on the Solomon basin. The model clearly identified the importance of the overall surface water-ground water system. Because of the interaction between the alluvial system and the river, it is apparent that the ground-water appropriations cannot be considered independent of surface appropriations and minimum flows required to meet the demands placed on the system.

The modeling indicates that basically where there is streamflow, in the reaches below Webster and Kirwin, and below Glen Elder, ground-water levels in the aquifer will not decline to any great extent as long as there is streamflow to recharge the aquifer. That is, the ground-water system will fluctuate in the short term of a pumping season but over the long term will remain basically stable as recharge takes place from precipitation and from the river. This is generally true whether all wells pump or only junior or senior pumping is allowed.

In the reach above Webster Reservoir, modeling indicates that ground-water pumping will generally deplete ground water in storage when there is no streamflow to replenish the aquifer. In order to maintain a ground-water balance in this region, pumping should be limited to the natural recharge.

3. Ground-water Recharge Estimations

There are several methods by which estimates of regional ground-water recharge can be made (Meyboom, 1966; Freeze, 1967; Sophocleous, 1981; Sophocleous and McAllister, 1987), such as: (1) actual field measurements at the recharge end of the flow system; (2) interpretation of

streamflow records at the discharge end of the flow system; (3) the use of soil-moisture budgets based on hydrometeorological data; and (4) calculation of quantitative regional flow by analytical or numerical model analysis. In this report, the second and third methods have been employed to estimate ground-water recharge. A more detailed analysis of ground-water recharge estimation for the Solomon basin using the soil-moisture budget methodology is presented in Appendix 3.

The long-term average recharge to the alluvial aquifer was assumed to equal the long-term average ground-water outflow during the early times of the Solomon watershed irrigation development. Such an equilibrium condition existed in the watershed until the early 1960's (Weston, 1979). An examination of the data and soil-moisture budget analysis results for that period indicated that only during the calendar years 1960 and 1961 soil water surplus, and thus potential ground-water recharge, was observed. Therefore, these two years were selected for recharge estimation. During 1960 and 1961, the average amount of ground water appropriated in the ~395,674-acre area drained by the North Fork Solomon above Glade (fig. 1) was 13,860 acre-ft/yr, which amounts to 0.42 in/yr over that subwatershed area (water appropriation data from Division of Water Resources, Kansas State Board of Agriculture). The average annual baseflow during the period 1960–1961, as derived from the streamflow data at Glade, was ~10,200 acre-ft/yr, which amounts to 0.31 inches of water over the same subwatershed area. Thus the total ground-water outflow (baseflow plus pumpage) for 1960–1961 was 0.73 in/yr, which, under the assumption of equilibrium, represents the amount of ground-water recharge. Ground-water outflow through evapotranspiration was presumed negligible and therefore was not considered in the calculations.

The second method for estimating regional ground-water recharge in the Solomon watershed is the moisture-budget technique. The results of this technique apply to any size area characterized by a specified soil-moisture capacity and climatic conditions. Table 2 presents the calculated average monthly moisture surpluses for all the climatic stations in and around the Solomon watershed, and the frequencies at which surpluses occurred during the 1964–1988 period. The table indicates that in the Solomon watershed and for the predominant soil-moisture capacity of 12 inches, moisture surpluses occur 4 percent or less of the time from July to September; 20 percent or less of the time

during June and from October to January, and <60 percent of the time from February to May. The totals in column 3 of table 2 show the total average moisture surplus which constitutes potential ground-water replenishment. Column 4 shows the same amount as a percentage of the average total annual precipitation from 1964 to 1988. In the summary table 3, the precipitation potential and actual evapotranspiration and the moisture surplus for various soil-moisture capacities representative of the Solomon watershed soils are listed for all the climatic stations shown in fig. 1. The soil map (fig. 2) has been interpreted in terms of the percentage of the effective drainage area covered by soils representing each of the soil-moisture capacities (table 1).

If the 25 years of records (1964–1988) for all these stations are at all representative of the average conditions in the Solomon watershed, moisture budgets indicate that the average potential annual ground-water replenishment in this watershed for the predominant 12-inch soil-moisture capacity varies from 0 inches to 3.8 inches (column 3, table 2). Or, in other words, the potential annual recharge in this area lies between 0 percent and 13.7 percent of the average total annual precipitation (column 4, table 2). For the 1960–1961 period, and from the climatic data from the Kirwin Dam station (the closest station to the Glade streamgaging station and centrally located within the entire watershed) and the predominant soil-moisture capacity of 12 inches, precipitation totaled 27.84 inches, Thornthwaite potential evapotranspiration and actual evapotranspiration totaled 27.79 inches and 25.98 inches, respectively, and moisture surplus totaled 1.89 inches, which is above normal compared to the 25-year average of 1.16 inches for the same conditions (table 3). Table 3 shows that as the soil moisture capacity increases, the percentage of the available water that is actually evapotranspired increases at the expense of the moisture surplus. The actual evapotranspiration plus the moisture surplus should equal the precipitation amount; the small discrepancies in table 3 are the result of the averaging of the budgeting procedure.

During the 1960–1961 period, the average total streamflow at Glade was 34,720 acre-ft/yr and the average baseflow was 10,200 acre-ft/yr, resulting in a direct surface runoff (the difference between total streamflow and baseflow) of 24,520 acre-ft/yr (0.74 in/yr). The moisture surplus

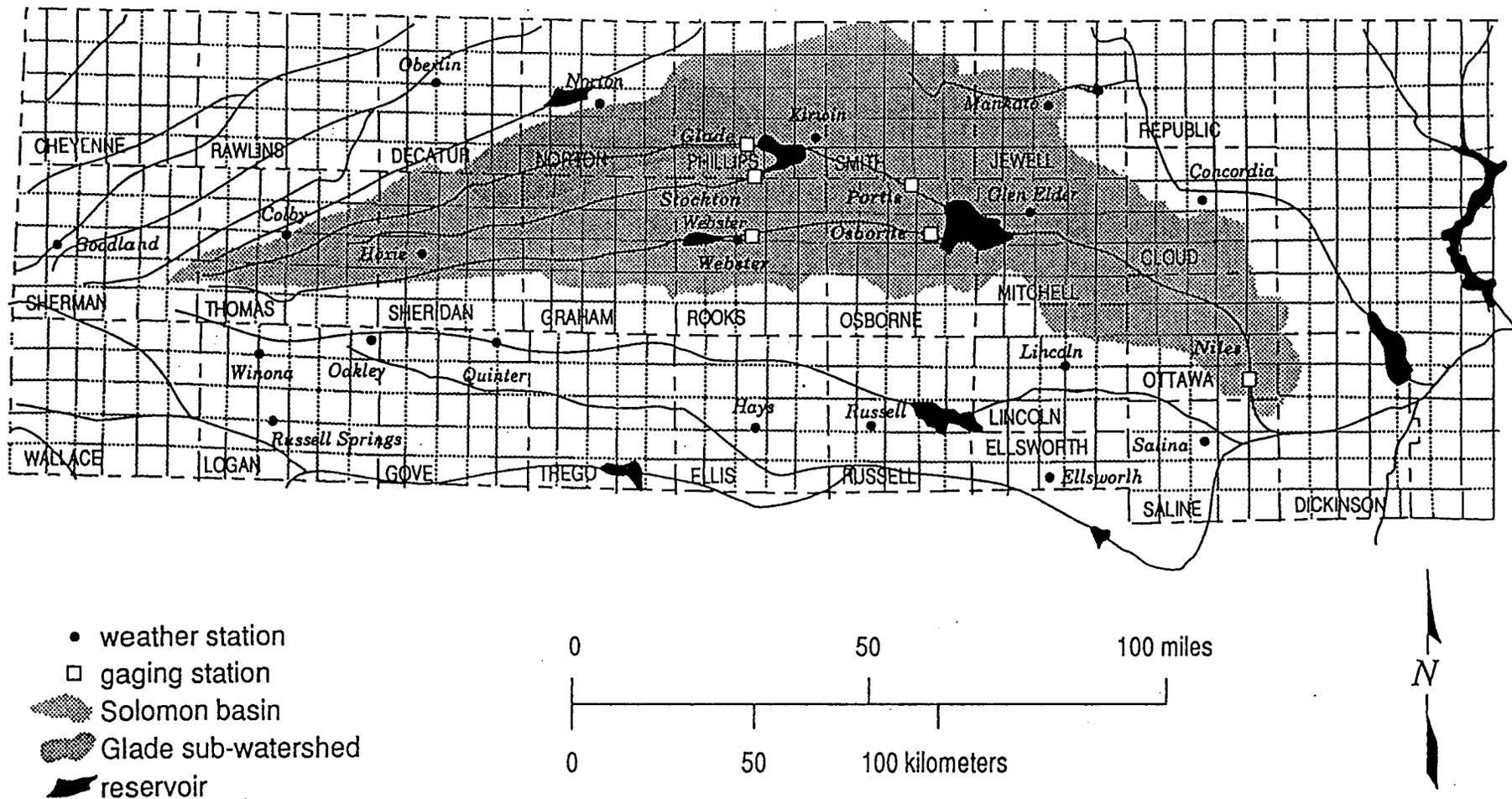


Figure 1: Precipitation and stream flow data stations for the Solomon basin

Table 1. Soil association coverage of the Solomon watershed

Item	Soil association	Area of soils in basin (mi ²)	% of assoc. in basin	% Breakdown of units in generalized soil associations	Weighted ave. soil-moisture capacity (inches) in upper 5 ft of soil
1	Keith-Holdredge-Ulysses	1174.4	17.6	46-43-10	12.0
2	Uly-Holdrege-Wakeen	2219.9	33.2	39-26-15	12.0
3	Uly-Wakeen-Penden	471.0	7.0	38-20-16	12.0
4	Hord-Roxbury-Munjor	697.0	10.4	31-28-17	11.4
5	Harney-Crete-Corinth	1124.5	16.8	52-8-12	10.8
6	Crete-Hastings-Geary	378.9	5.7	40-30-27	10.8
7	Lancaster-Edalgo-Hedville	228.4	3.4	38-26-22	9.0
8	Heizer-Harney-Armo	390.4	5.8	28-27-24	9.0
Total		6685.4			
Soil association item		Soil-moisture capacity (inches)	% Area covered		
1+2+3		12.0	57.8		
4		11.4	10.4		
5+6		10.8	22.5		
7+8		9.0	9.3		

must, however, satisfy the surface runoff and the ground-water recharge. This surface runoff figure, when subtracted from the average 1960–1961 moisture surplus of 1.89 inches, based on the Kirwin station, results in a value for regional ground-water recharge of 1.15 inches. This value is of the same order of magnitude as the recharge value (0.73 in/yr) calculated from baseflow and ground-water pumpage data.

Thus, assuming that the more than 395,000-acre subwatershed above Glade is typical of the entire Solomon watershed, based on the two previously mentioned recharge estimation methods, the average estimated regional ground-water recharge for the Solomon watershed is 0.94 inches, which represents only 4 percent of the average annual precipitation (23.29 in/yr). During 1980–1981, the ground-water appropriations in the Glade sub-watershed, which reached 146,182 acre-ft, compared to 13,860 ac-ft in 1960–1961, amounted to more than 4.7 times the amount of estimated natural ground-water replenishment for that subwatershed.

Table 2. Calculated average monthly moisture surpluses for all 19 stations in and around the Solomon watershed shown in Fig. 1 during the 1964-1988 period^a

SOIL MOISTURE CAPACITY= 12.00 in.

Station	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		Period	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	3	4
Colby	0.00	0	0.00	0	0.00	0	0.02	4	0.16	8	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.18	0.9
Concordia	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Ellsworth	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Glen Elder	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Goodland	0.00	0	0.00	0	0.00	0	0.00	0	0.22	4	0.01	4	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.23	1.3
Hays	0.00	0	0.00	0	0.17	12	0.13	12	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.30	1.4
Hoxie	0.00	0	0.00	0	0.00	0	0.14	8	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.14	0.7
Kirwin	0.01	4	0.01	8	0.43	20	0.15	24	0.38	24	0.05	4	0.00	0	0.00	0	0.00	0	0.04	4	0.05	8	0.05	8	1.16	5.0
Lincoln	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Mankato	0.16	20	0.22	28	0.93	40	0.60	60	0.95	52	0.21	12	0.00	0	0.00	0	0.08	4	0.17	8	0.19	12	0.27	16	3.78	13.7
Norton	0.06	12	0.09	12	0.22	20	0.43	32	0.30	20	0.12	8	0.00	0	0.00	0	0.00	0	0.09	4	0.02	8	0.06	8	1.39	5.9
Oakley	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Oberlin	0.02	4	0.02	4	0.05	8	0.12	8	0.16	12	0.18	4	0.00	4	0.00	0	0.02	4	0.04	4	0.00	0	0.00	0	0.60	2.7
Quinter	0.00	0	0.03	8	0.09	12	0.30	16	0.08	16	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.50	2.2
Russell FAA	0.01	4	0.00	0	0.62	32	0.49	44	0.32	20	0.04	8	0.00	0	0.24	4	0.12	4	0.00	0	0.00	0	0.08	4	1.92	7.3
Russell Springs	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Salina	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Webster	0.01	4	0.00	0	0.36	20	0.27	16	0.21	8	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.06	4	0.91	4.1
Winona	0.00	0	0.00	0	0.00	0	0.00	4	0.06	4	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.06	0.3

^aExplanation of columns: 1, average monthly moisture surplus (in.) for the period 1964-1988; 2, percentage of years during the period 1964-1988 in which moisture surplus occurred during the month indicated; 3, total average moisture surplus from Jan to Dec (in.); 4, total average moisture surplus from Jan. to Dec. expressed as percentage of average total annual precipitation 1964-1988.

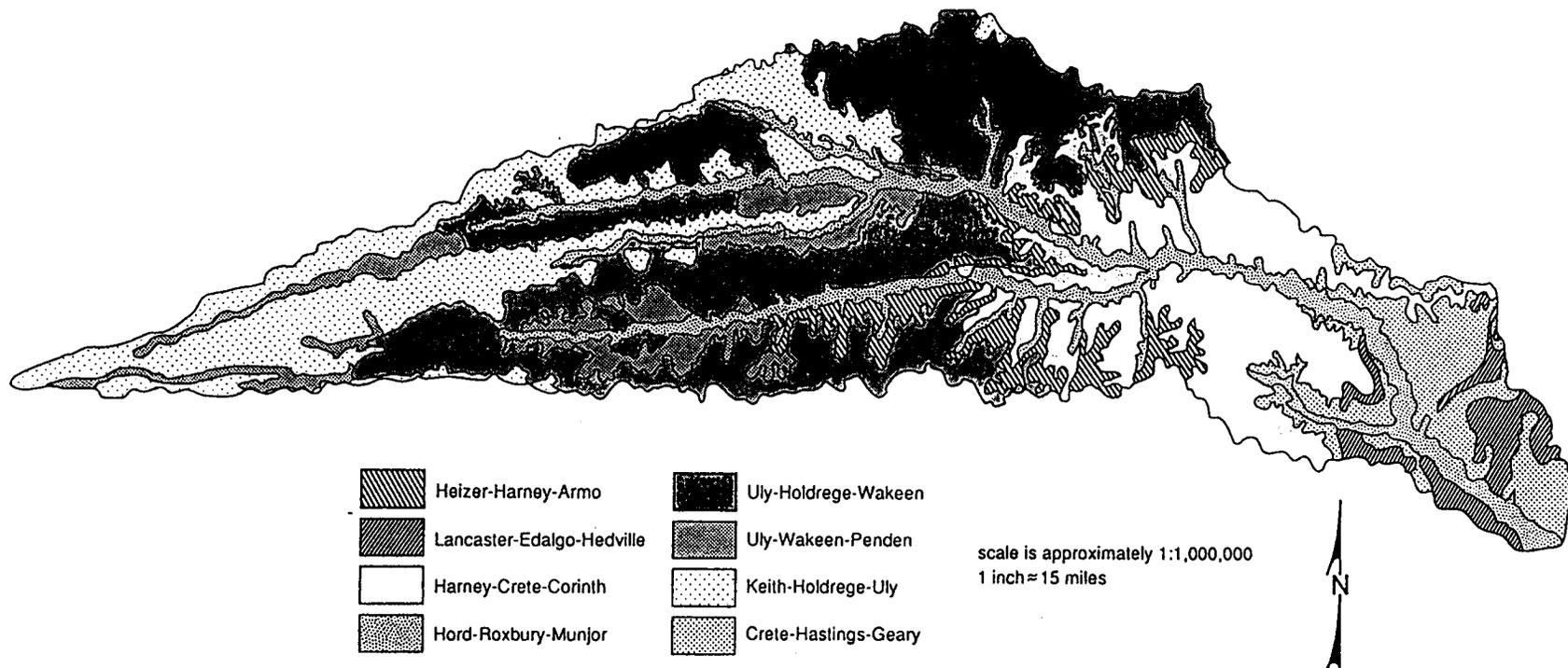


Figure 2. Generalized soil associations of the Solomon basin

Table 3. Holmes and Robertson soil-moisture budget for all 19 stations in and around the Solomon watershed shown in fig. 1 during the 1964–1988 period

Station	Precip. (inches)	Thornthwaite potential ET (inches)	Actual evapotranspiration (inches) for various soil-moisture capacities				Moisture surplus (inches) for various soil-moisture capacities			
			9.0	10.8	11.4	12.0	9.0	10.8	11.4	12.0
Colby	19.05	26.43	-	-	-	19.15	-	-	-	0.18
Concordia	29.01	29.23	25.34	25.60	25.69	-	3.95	3.70	3.63	-
Ellsworth	27.89	30.48	25.45	25.74	25.82	-	2.72	2.45	2.38	-
Glen Elder	24.92	28.29	23.18	23.47	23.55	-	2.01	1.73	1.66	-
Goodland	18.18	26.62	-	-	-	18.19	-	-	-	0.23
Hays	21.68	28.85	21.43	-	21.67	21.72	0.55	-	0.34	0.30
Hoxie	19.97	29.08	-	-	-	20.20	-	-	-	0.14
Kirwin	23.31	27.78	-	-	22.32	22.39	-	-	1.23	1.16
Lincoln	27.39	30.06	24.86	25.23	25.33	-	2.82	2.50	2.41	-
Mankato	27.56	27.04	23.65	23.91	23.99	24.07	4.17	3.92	3.85	3.78
Norton	23.71	25.67	-	-	22.38	22.45	-	-	1.46	1.39
Oakley	18.96	28.12	-	-	-	19.29	-	-	-	-
Oberlin	22.63	28.23	-	-	22.17	22.22	-	-	0.65	0.60
Quinter	22.73	27.78	-	-	-	22.52	-	-	-	0.50
Russell FAA	26.36	29.73	24.18	24.56	24.68	24.78	2.48	2.13	2.02	1.92
Russell Springs	18.23	27.55	-	-	-	18.62	-	-	-	-
Salina	29.99	30.82	25.75	26.10	26.20	-	4.52	4.19	4.09	-
Webster	22.44	28.30	21.51	-	21.77	21.82	1.20	-	0.96	0.91
Winona	18.52	27.12	-	-	-	18.74	-	-	-	0.06

4. Baseflow Characteristics of Basin Streams

Baseflow is that portion of streamflow derived from ground-water seepage. Under natural conditions in the Solomon basin baseflow comes from the local alluvial aquifers and the Dakota Formation and can be thought of as a gauge of the hydrologic health of the basin. Over the long term (tens of years), baseflow fluctuates around an average value with increases during wet periods and decreases in dry periods. A long-term increase or decrease in the average indicates something is affecting the amount of water in the local aquifer from which baseflow is derived.

Calculating baseflow volumes has generally been done in the past by graphic methods such as baseflow recession methods (Olmsted and Hely, 1962; Riggs, 1963; Rorabaugh, 1963) and fitting a curve under a streamflow hydrograph (Linsley et al., 1982). The difficulty with these methods is that they sometimes seem to be more art than science and the results are difficult to reproduce with different investigators.

Pettyjohn (1979) derived a computerized method to calculate baseflow which makes hydrograph separation a relatively rapid, easy and reproducible effort. A similar computer program is also used by White and Sloto (1990) to calculate baseflows of Pennsylvania streams. Both authors use three slightly different techniques called fixed-interval, sliding-interval and local-minimum. All three techniques were used to calculate baseflows for Solomon basin streamflow stations and results were found to be very similar. Generally, the local-minimum technique was the slightly more conservative of the three, estimating slightly less baseflow and it was used for calculating baseflows for the five stream-gaging stations at the lower ends of the subreaches designated for water-budget studies. Surface water data for the stations were obtained from the U.S. Geological Survey data base for Kansas:

06876900	Solomon River at Niles
06874000	South Fork Solomon River at Osborne
06872500	North Fork Solomon River at Portis
06871000	North Fork Solomon River at Glade
06873000	South Fork Solomon River above Webster Reservoir

Annual streamflow from 1970-1991 for each station is characterized in four graphs for this discussion, however, later in the report the discussion will include the seasonal variation in the four categories:

1. Annual streamflow which includes runoff and baseflow.
2. Annual baseflow.
3. Baseflow as a percent of annual streamflow.
4. Annual runoff.

Appendix A tabulates the results of streamflow separation into baseflow and surface runoff for the Solomon River for the 1970-1991 period of record, whereas Appendix B tabulates available streamflows for all streams for the period of record

Solomon River at Niles

Annual streamflow (fig. 3), which is influenced by Waconda Reservoir 150 miles upstream, varies from about 70,000 acre-ft to slightly over one million acre-ft. The regression line indicates little change in flow during the 1970-1991 time period. Annual baseflow (fig. 4) fluctuates from 20K to about 600K with wide variations similar to streamflow. The general trend, however, is for slightly increasing baseflow which might be explained by increasing discharge from the Dakota and alluvial aquifers. The average annual conductance (fig. 5) is also increasing

Figure 3

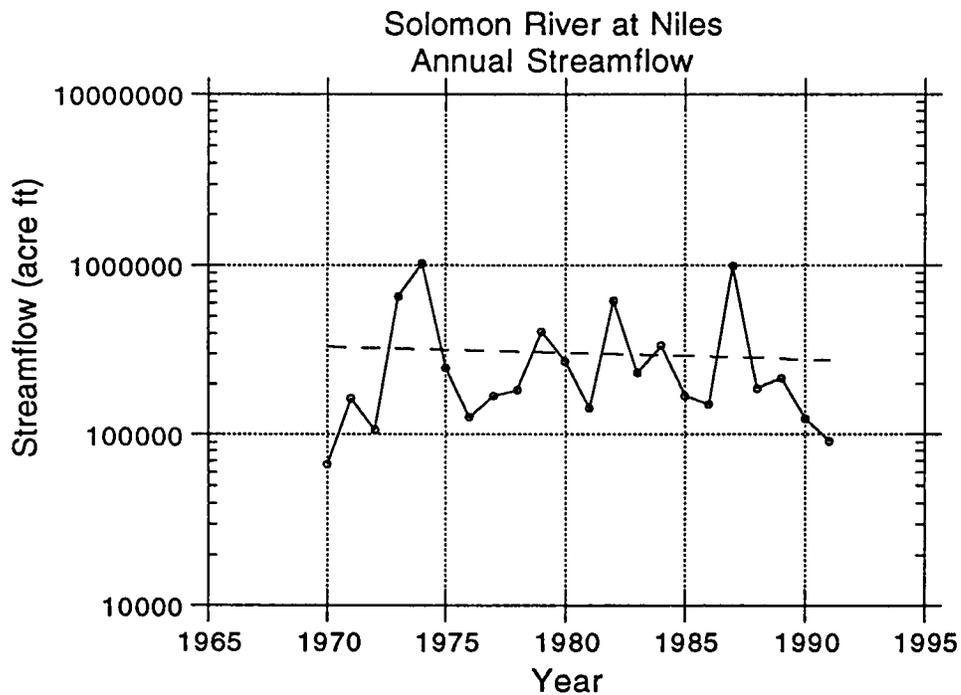


Figure 4

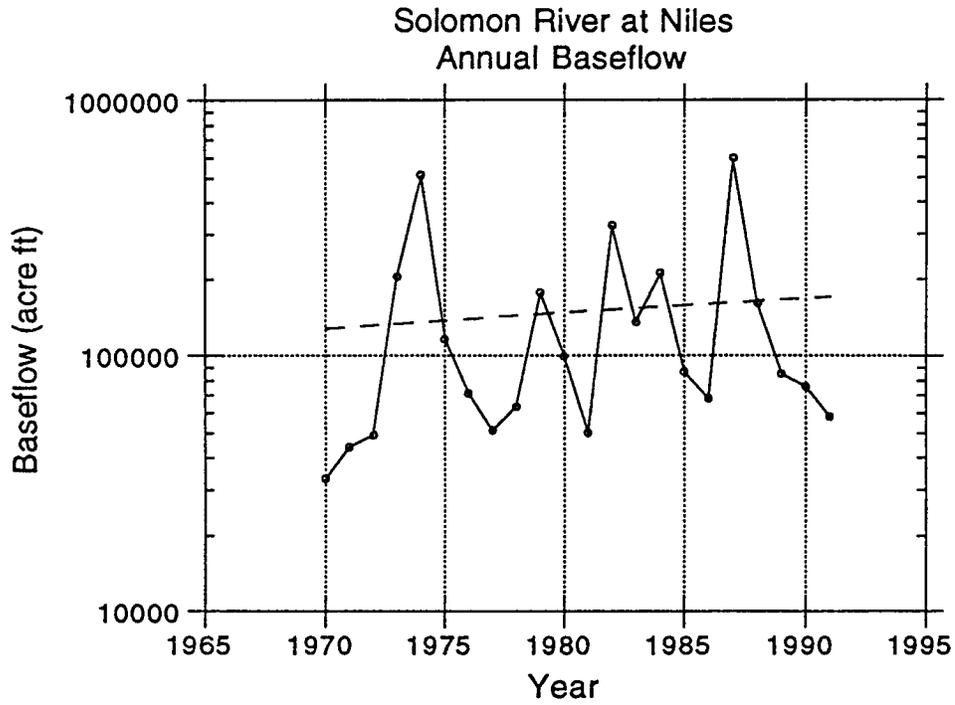
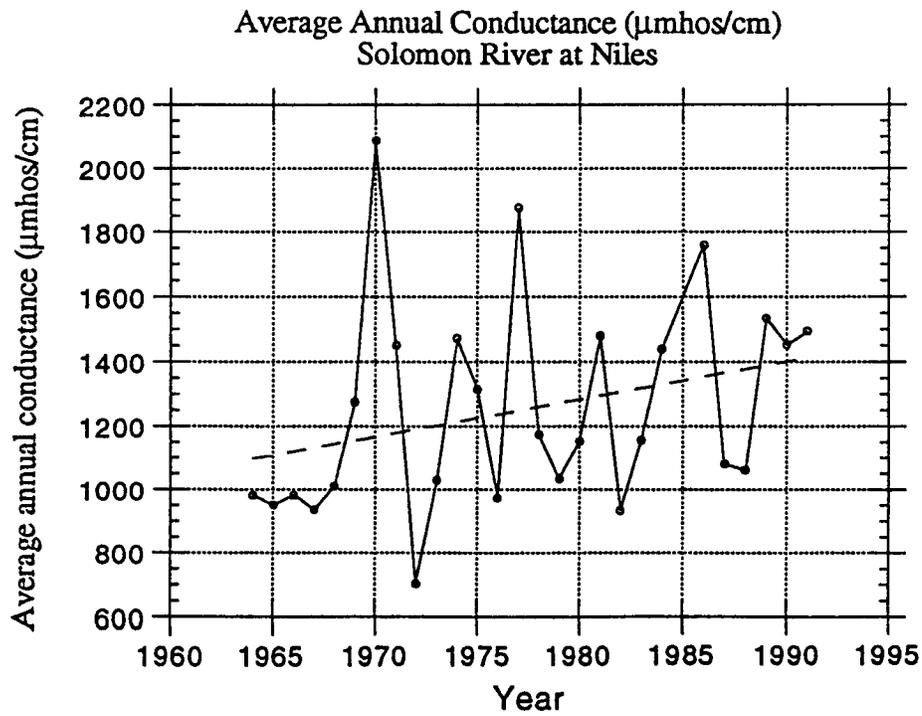


Figure 5



which could indicate an increase in discharge of the more mineralized water from the Dakota; however, the Osborne (fig. 6) and Portis (fig. 7) water quality stations also show increasing conductance so determining what part of the increase is due to the Dakota would be difficult with the data available. Baseflow as a percent of annual streamflow (fig. 8) ranges from about 25 to 85 percent but the long term average, as indicated by the regression line, clearly increases from 35 to about 60 percent. The companion graph to fig. 8 is fig. 9 which shows the annual runoff at Niles. Runoff is decreasing, causing baseflow to become a greater percent of the annual flow. Decreasing runoff over the long term has been observed in a number of other Kansas streams (U.S. Bureau of Reclamation, 1984; Kansas Biological Survey and Kansas Geological Survey, 1987) and is generally thought to be caused by water conservation methods such as ponds, terraces, and tillage methods. Precipitation records have been examined (U.S. Bureau of Reclamation, 1984) and long-term precipitation amounts have remained at or close to normal.

Figure 6

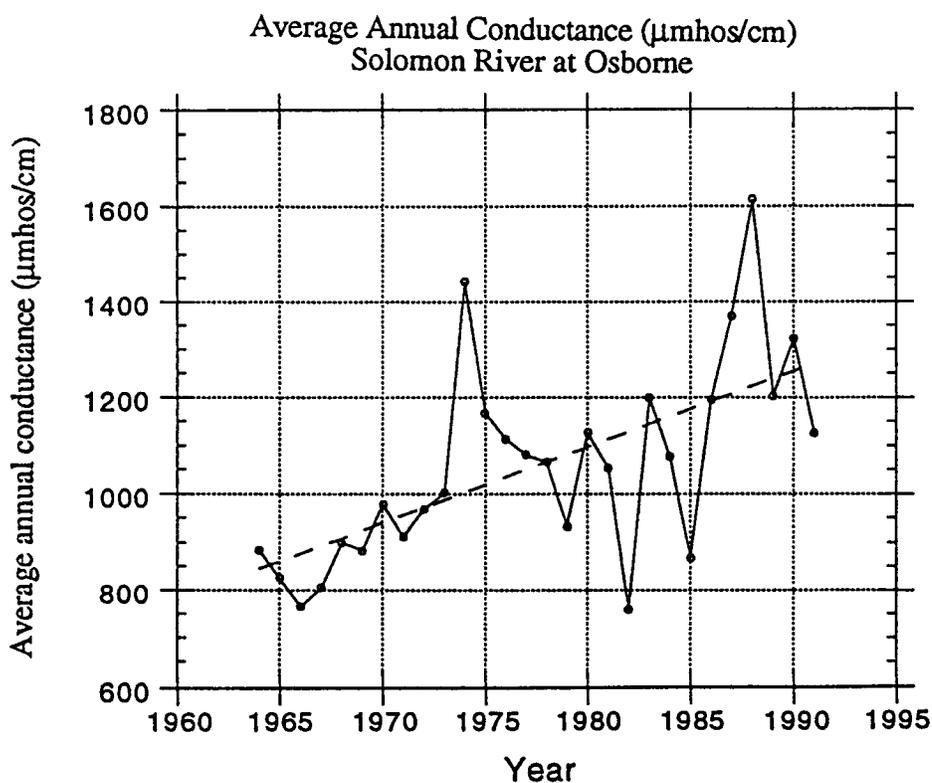


Figure 7

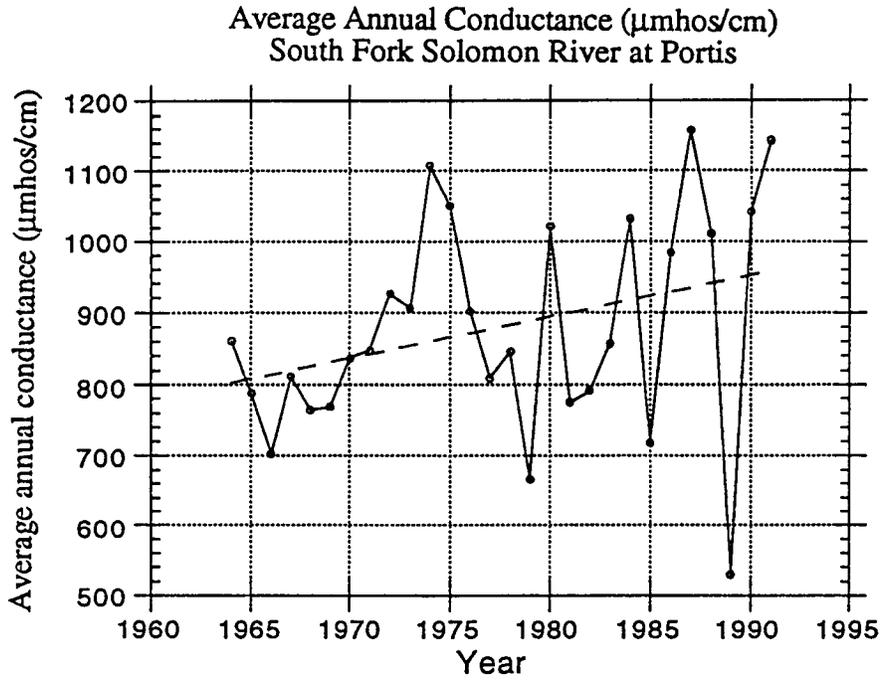


Figure 8

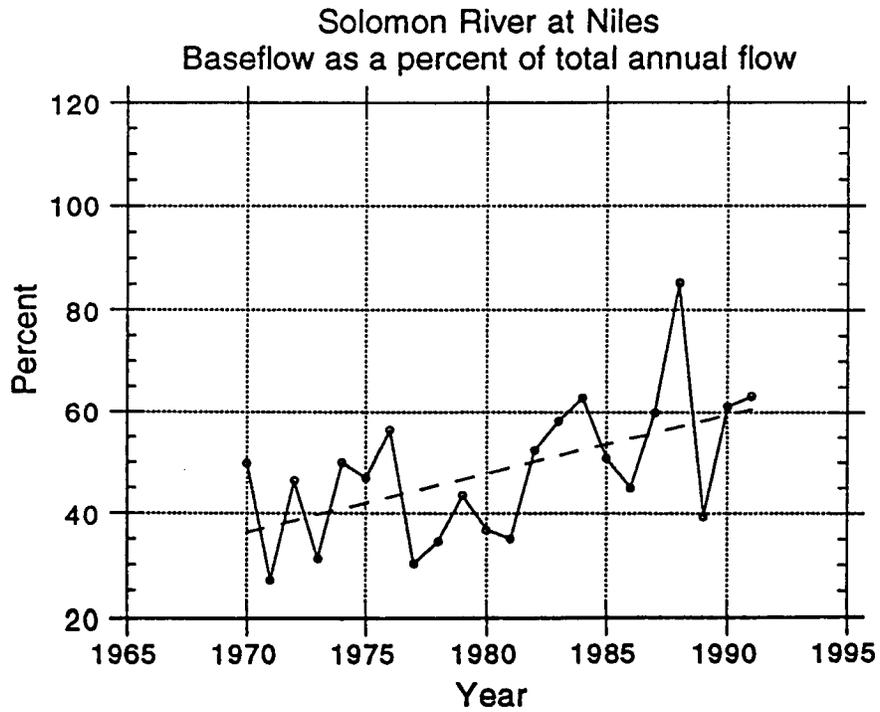
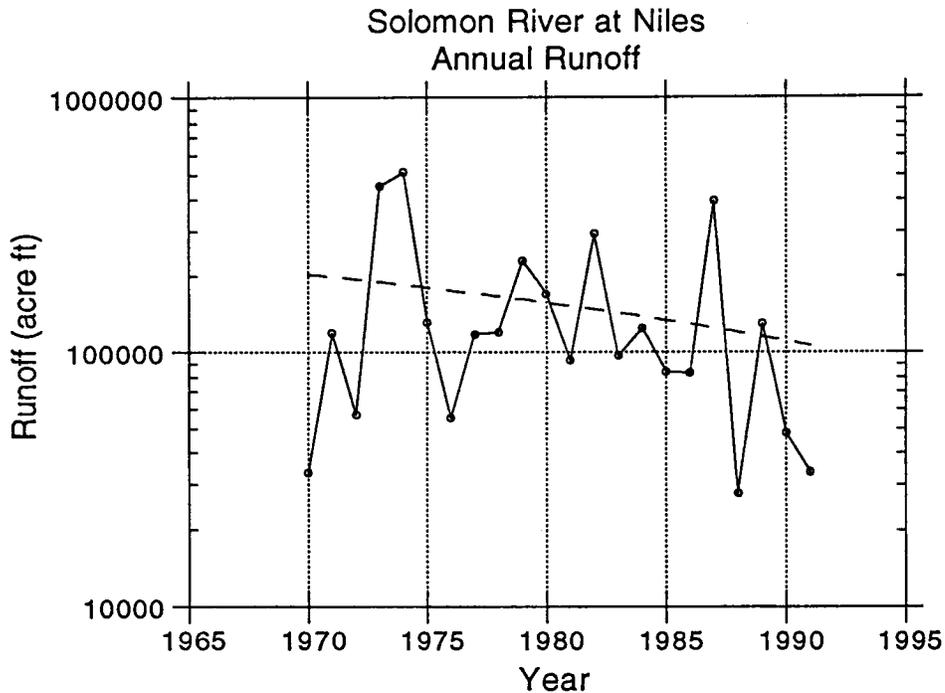


Figure 9



South Fork Solomon River at Osborne

Streamflow at Osborne (fig.10) is influenced by releases from Webster Reservoir 65 miles upstream as well as a number of surface and ground-water diversions. Streamflow variation in the 1970-1991 period ranges from about 7,000–200,000 acre/ft with a generally constant trend for this time period except for the 1981–1991 period which shows a steady decline. Baseflow (fig. 11) also varies widely but shows a stable trend. Baseflow as a percent of annual flow (fig. 13) and annual runoff (fig. 12) also show variations but general stability over the 1970–1991 time period.

North Fork Solomon River at Portis

Annual streamflow at Portis (fig. 14), influenced by Kirwin Reservoir 41 miles upstream and a number of surface and ground water diversions, declined slightly on the long-term average from about 50,000–30,000 acre/ft during the 1970–1991 time period. Baseflow (fig. 15) and annual runoff (fig. 16) both appear to be declining slightly also, but at approximately the same rate

so that baseflow as a percent of annual flow (fig. 17) remains about constant at 50 percent of annual flow.

North Fork Solomon River at Glade

Annual streamflow at Glade (fig. 18) has decreased on the average from slightly over 10,000 acre/ft to about 6,000 acre/ft per year during the 1970–1991 period. This decrease is a result of the slight declines in annual baseflow (fig. 19) and annual runoff (fig. 20). Runoff is decreasing at a more rapid rate than baseflow, therefore baseflow as a percent of annual flow (fig. 21) has generally increased from about 40 to 50 percent.

South Fork Solomon River above Webster Reservoir

Similar to streamflow values at the other stations reviewed, annual streamflow (fig. 22) above Webster has generally decreased during 1970–1991 from 20,000 acre/ft to about 8,000

Figure 10

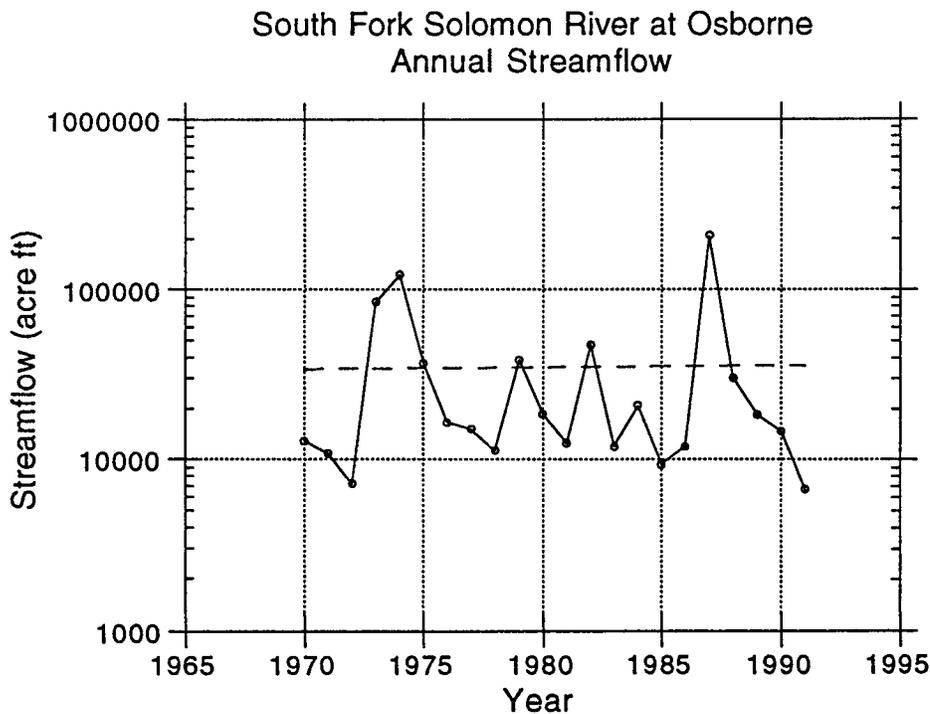


Figure 11

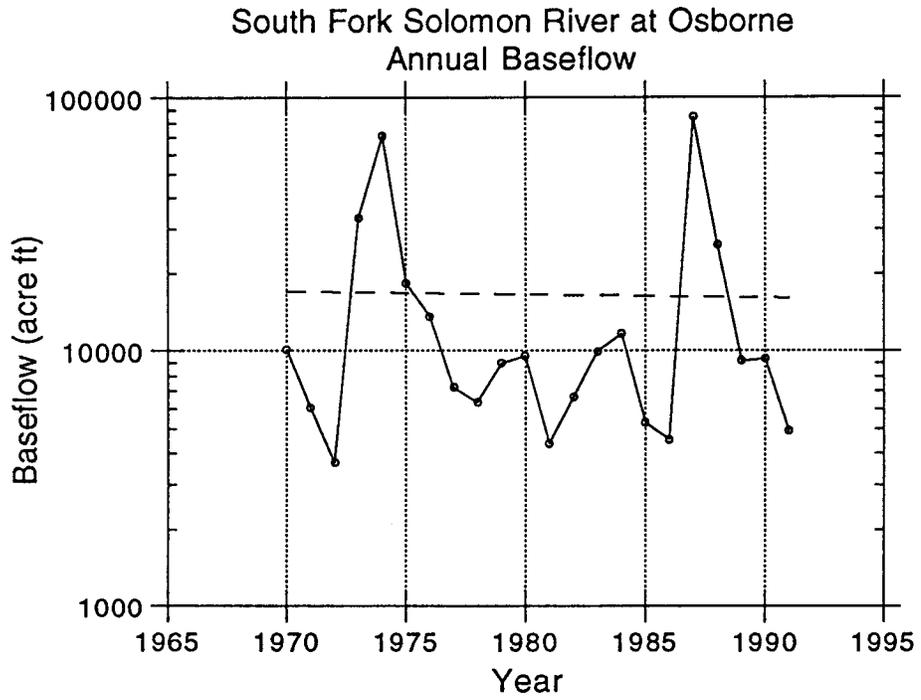


Figure 12

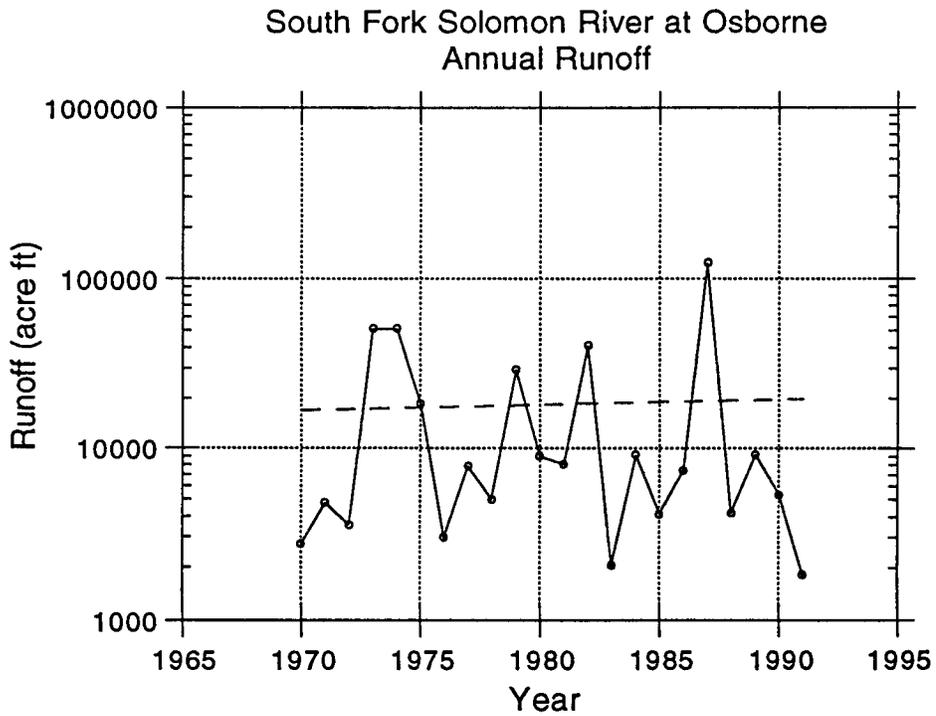


Figure 13

South Fork Solomon River At Osborne
Baseflow as a Percent of Total Annual Flow

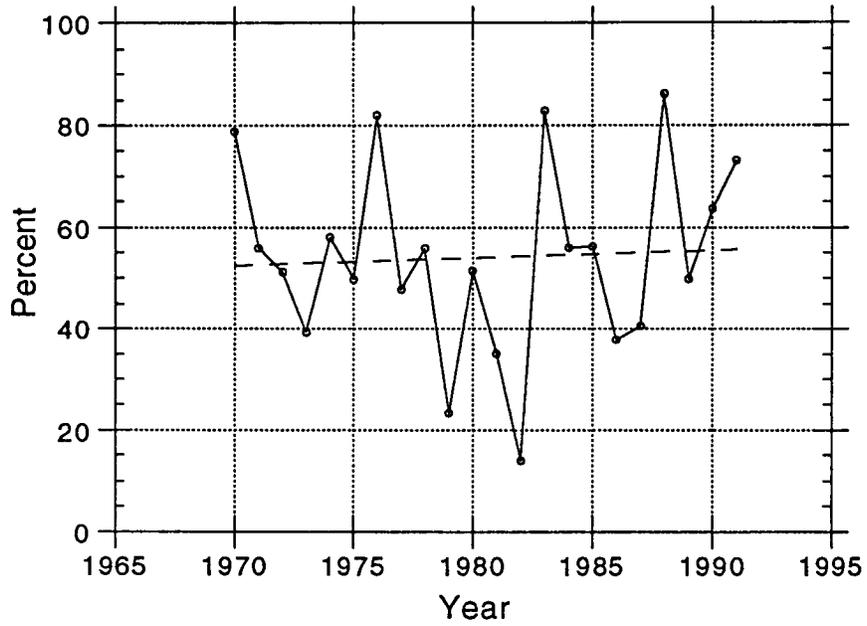


Figure 14

North Fork Solomon River at Portis
Annual Streamflow

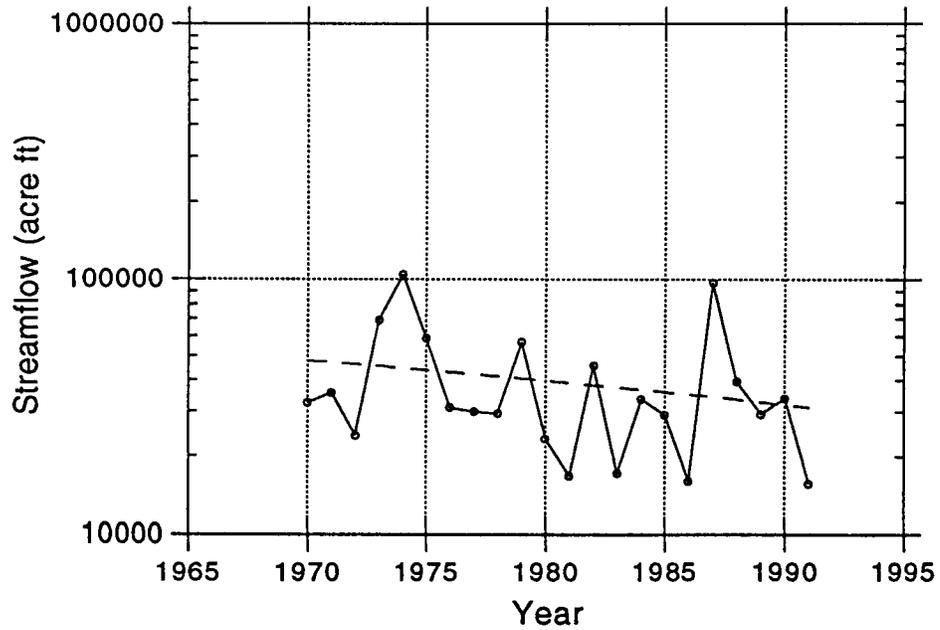


Figure 15

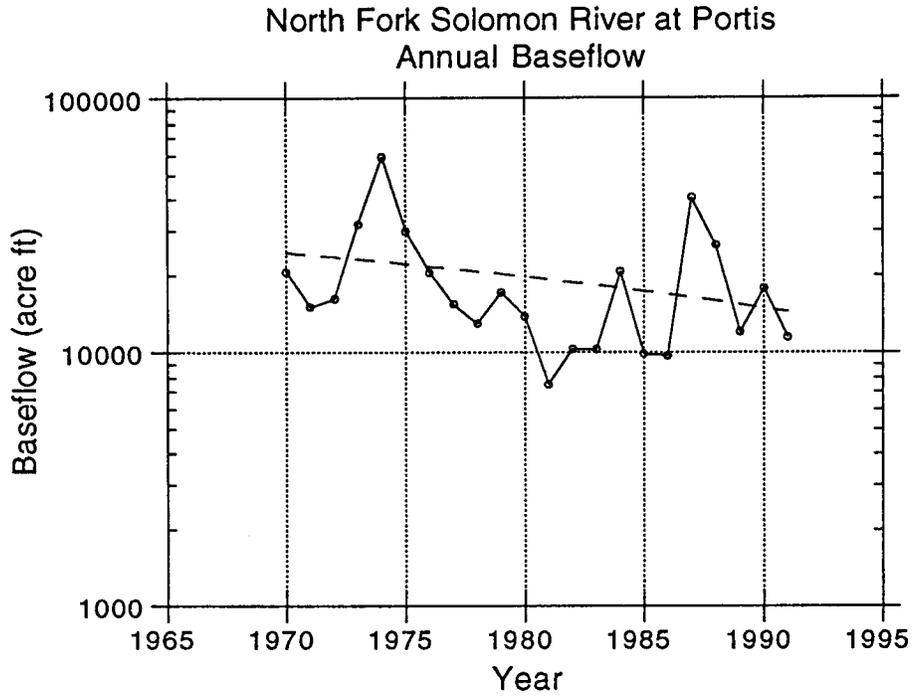


Figure 16

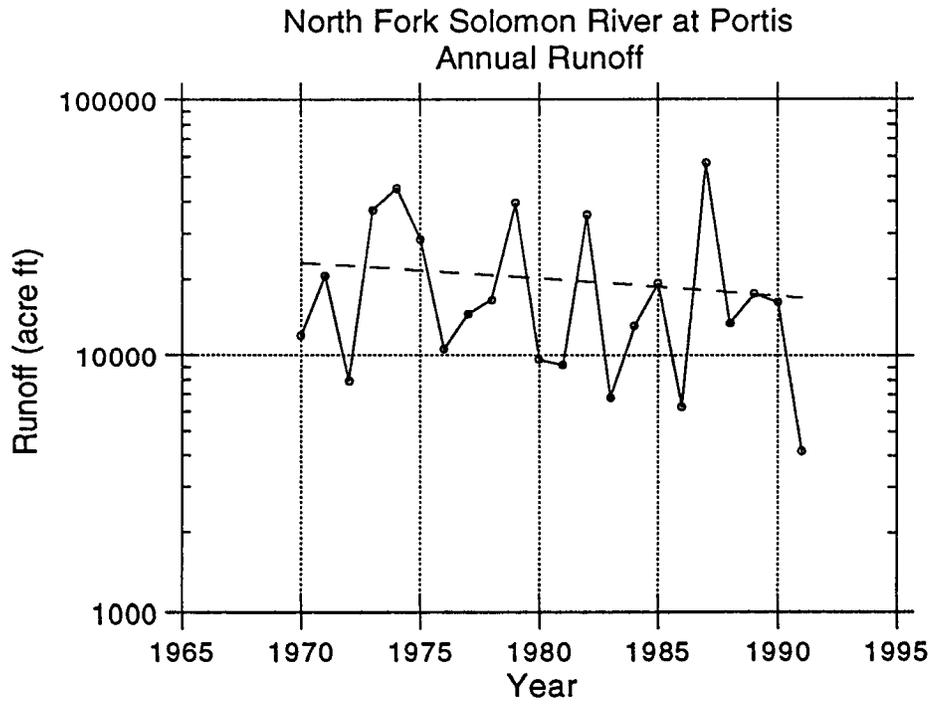


Figure 17

North Fork Solomon River at Portis
Baseflow as a percent of total annual flow

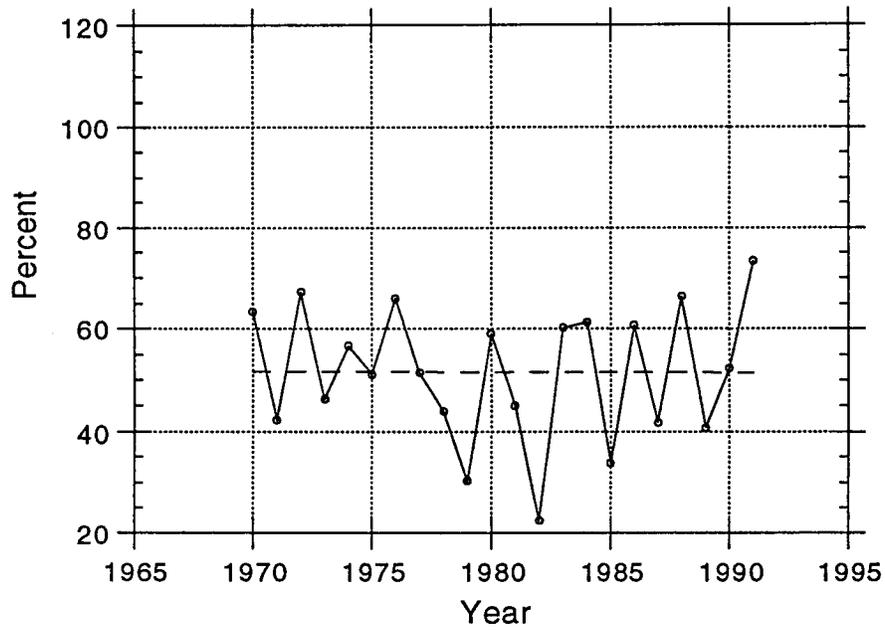


Figure 18

North Fork Solomon River at Glade
Annual Streamflow

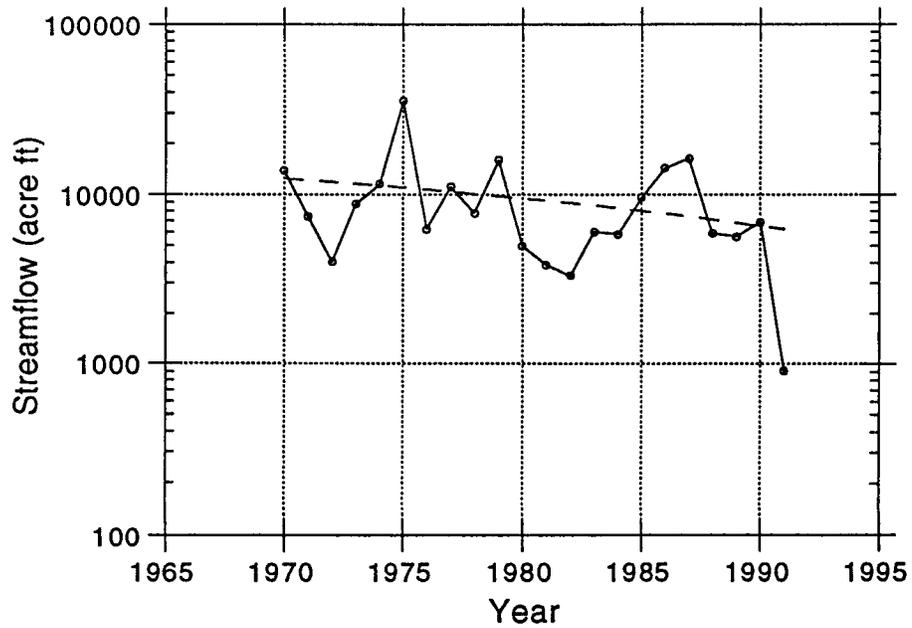


Figure 19

North Fork Solomon River at Glade
Annual Baseflow

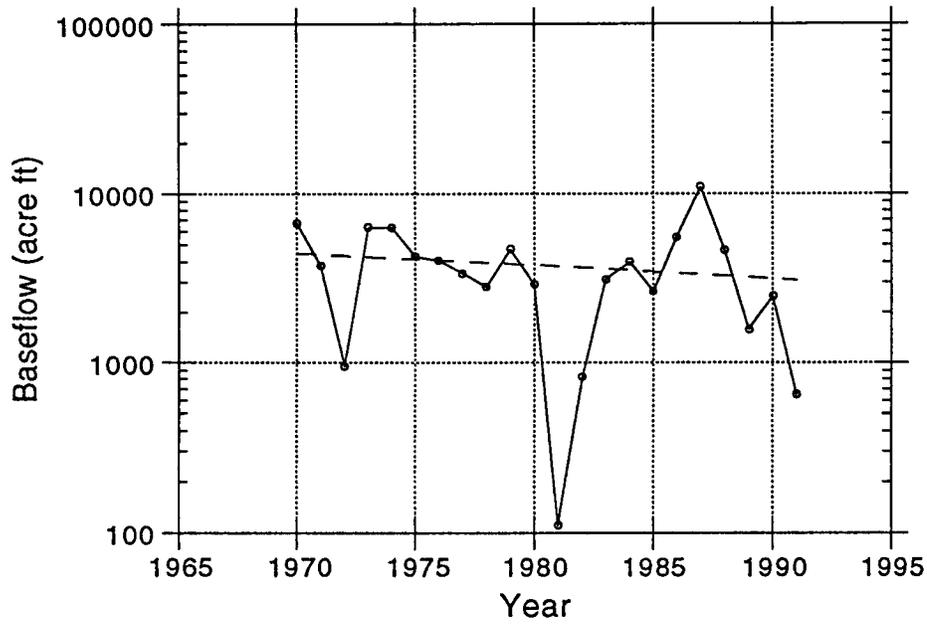


Figure 20

North Fork Solomon River at Glade
Annual Runoff

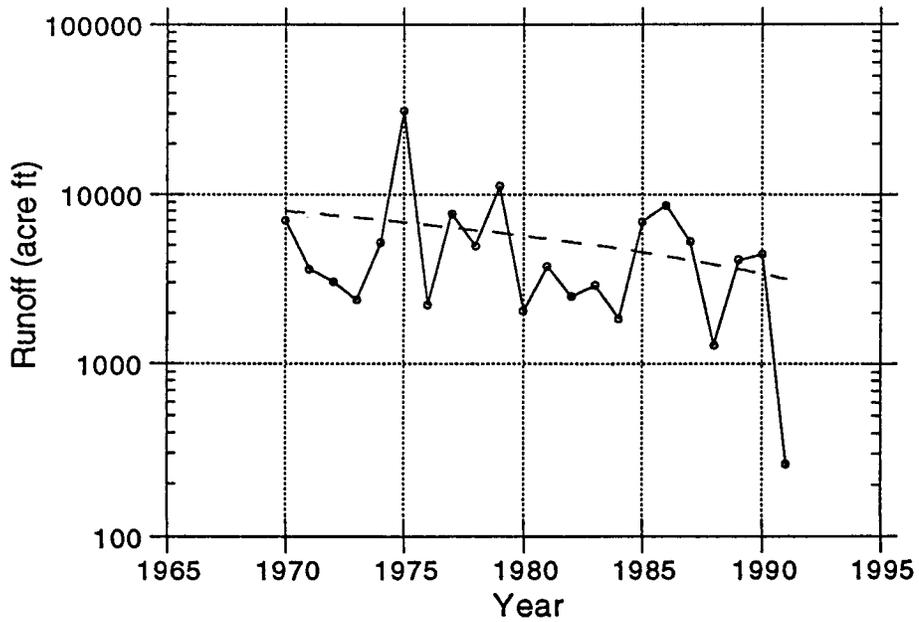


Figure 21

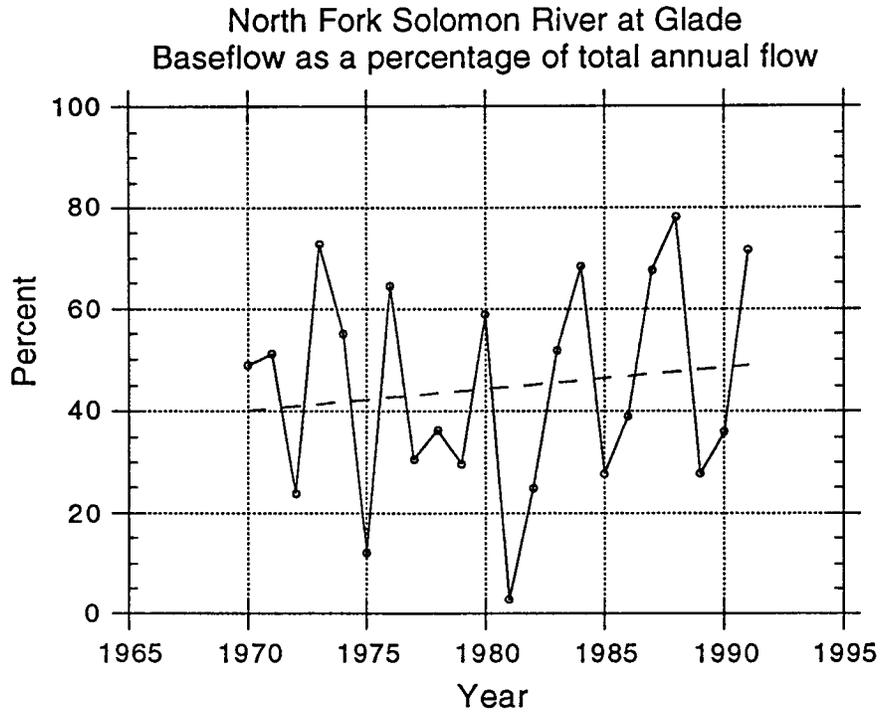
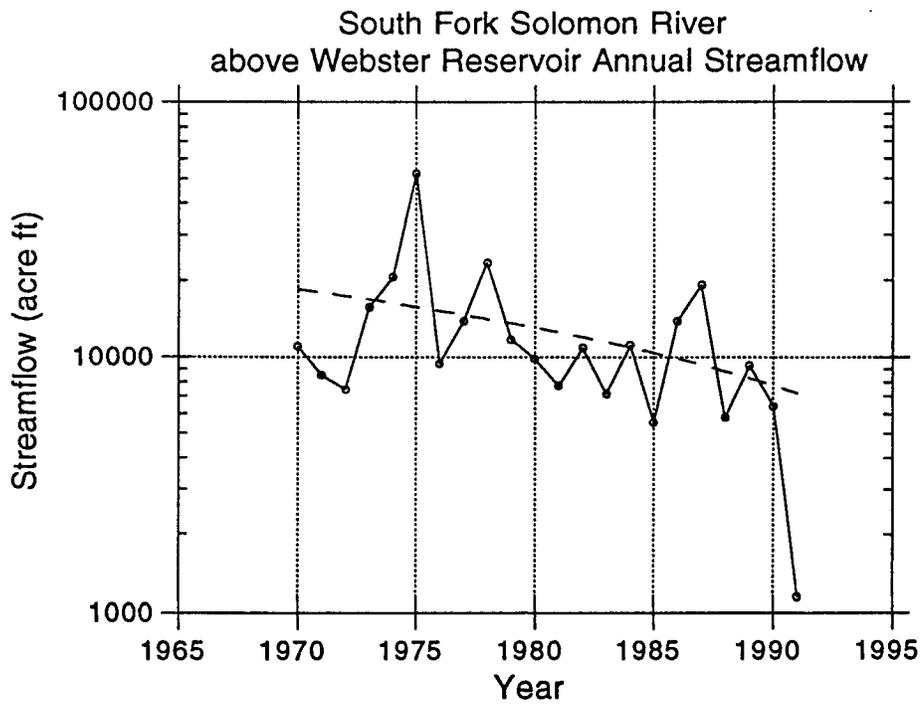


Figure 22



acre/ft. Both annual baseflow (fig. 23) and runoff (fig. 24) have decreased, but runoff at a faster rate so that baseflow as a percent of annual flow (fig. 25) has slightly increased.

Discussion

Based on the observed data the two basic components of streamflow (baseflow and runoff) are increasing, stable, or decreasing depending on the reach of the Solomon River. At the upper end of the basin (above Webster and Kirwin reservoirs) where precipitation is less, ground water is the predominant source for water supply, and land treatment is considered to be a cause for the decline in runoff, both runoff and baseflow are declining. Again, at both these locations baseflow is becoming a larger portion of annual streamflow.

Data at Osborne and Portis gages in the central portion of the basin are affected by Webster and Kirwin reservoirs, respectively, as well as ground-water pumping and surface-water diversions in the reaches above the gages. Both baseflow and runoff appear to be declining at Portis with the percentages of the two remaining about constant at 50 percent. Osborne differs

Figure 23

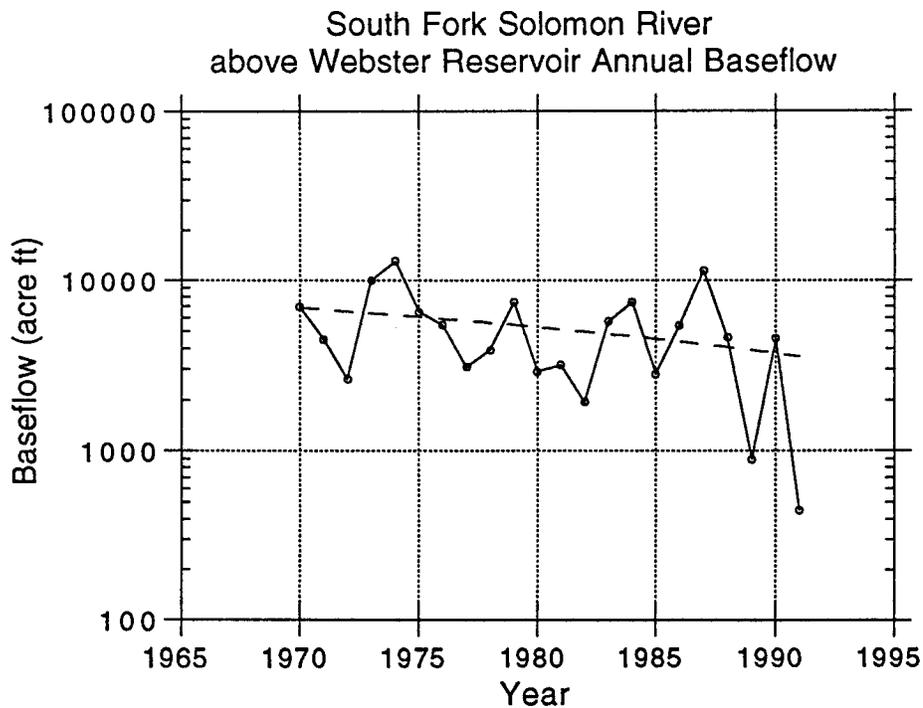


Figure 24

South Fork Solomon River
above Webster Reservoir Annual Runoff

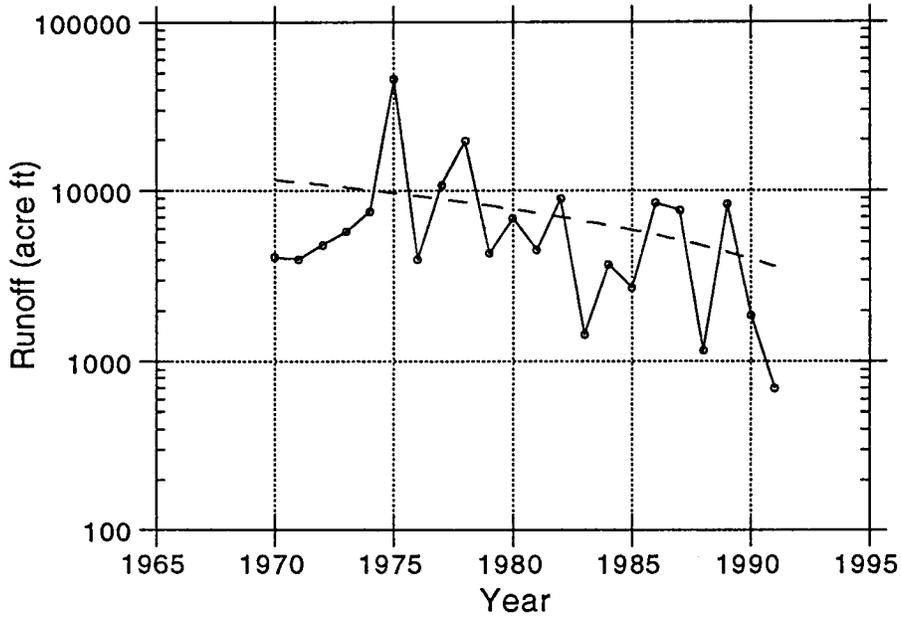
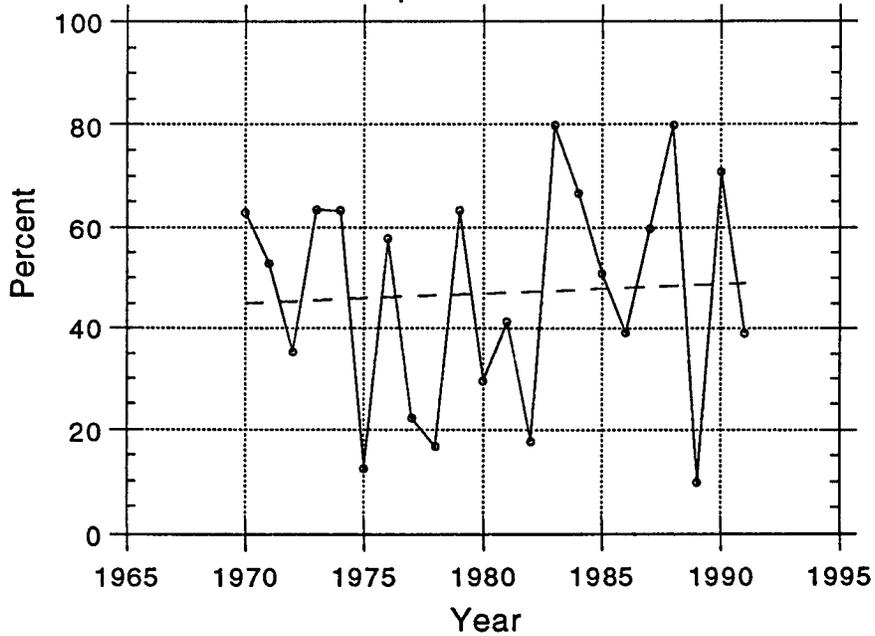


Figure 25

South Fork Solomon River
above Webster Reservoir
Baseflow as a percent of total annual flow



from the rest of the sites in that trend for both baseflow and runoff have remained about constant for the 1970-1991 period.

Data from the Niles gage differs from the other gages in that runoff has declined but baseflow appears to have increased, resulting in a significant increase in baseflow as a percent of annual flow.

5. Water Use and Water Rights

Reported ground-water use values for irrigation in the Solomon basin were obtained from KWO and DWR (1989, 1990) and compared with ground-water appropriations on file with the Division of Water Resources. These data were summed to legal township and listed in Appendix C of this report. A summary of the data by reach is listed in table 4.

Table 4. Comparison of reported water use for irrigation and ground-water appropriations.

Reach	Irrigation (acre-ft) Reported 1989	Irrigation (acre-ft) Reported 1990	Estimated Appropriations (acre-ft)
1	3292	4437	9101.3
2	6489	6671	10861.7
3	none	none	9697.3
4	none	none	3906
5	2267	2639	9907.5
Totals	10248	13747	43473.8

Several points need to be made in order to understand table 4. First, 1989 and 1990 water-use values are reported for irrigation use only and the estimated appropriations are for all ground-water rights, including municipal, industrial, and recreation which make up a relatively minor amount of the total. The appropriations are estimated because of the difficulty in understanding the appropriation records. Second, water use is not reported by township in the annual publication if there are less than 640 acres irrigated in the township. There may be small amounts of water being pumped which were not in the final totals for each township. Consistently, less water is being

reported pumped than is appropriated. It is interesting to note that for Reach 3 and Reach 4 no water has been reported used for irrigation in 1989 and 1990, yet there are estimated 9697.3 and 3906 acre-ft appropriated, respectively.

6. Water Quality in the Solomon River Basin

Ground- and surface-water quality in the Solomon River basin vary widely from place to place. Generally, the water quality reflects solution of the geologic material through or over which the water flows.

Ground Water Regions

The various geologic formations and their water-bearing characteristics in the Solomon River basin can be grouped as follows.

1. Ogallala Formation.
2. Upper Cretaceous rock formations consisting of the Pierre Shale, Niobrara Chalk, Carlile Shale, Greenhorn Limestone, and the Graneros Shale.
3. Lower Cretaceous rock formations consisting of the Dakota Formation (both upper and lower Cretaceous), Kiowa Formation, and the Cheyenne Sandstone.
4. Alluvium of the Solomon River and its tributaries.

Plate 2 (in pocket) displays the principal aquifers in the region.

Ogallala Formation

The Ogallala Formation is found in about the western one-third of the Solomon basin. Water quality in the Ogallala is generally suitable for all purposes although it contains high enough calcium and magnesium concentrations to make the water hard. The Pierre Shale and Niobrara Chalk occur beneath the Ogallala but they seem to have little effect on the water quality in the portions of the aquifer where the saturated thickness is generally greater than 40 feet. Where the saturated thickness is thin, mineralization of the water becomes greater, generally from increased sulfate content.

Upper Cretaceous Rocks

Upper Cretaceous rock units include the Pierre Shale, Niobrara Chalk, Carlile Shale, Greenhorn Limestone, and Graneros Shale. The Pierre underlies the Ogallala as does the Niobrara. The Niobrara, however, crops out at the land surface in the west-central part of the basin. None of these units is a major aquifer, yielding only small amounts of sometimes highly mineralized water to domestic and stock wells. Some of these units contain gypsum which contributes high calcium and sulfate concentrations to the general mineralization of the ground water.

Lower Cretaceous Rock Formations

The Dakota Formation, Cheyenne Sandstone, and the Kiowa Formation generally act as one hydrologic unit (usually termed the Dakota aquifer) over much of western Kansas and in the Solomon basin. The Dakota Formation straddles the upper and lower Cretaceous Series boundary. The rock units crop out at the surface in the eastern quarter of the basin and in the subsurface in the remainder of the basin. Water quality is highly variable in these rock units ranging from good quality for most uses in the outcrop area to poor quality in the subsurface. The salinity increases as the rocks get deeper in the subsurface so that generally west of Osborne County the water is too mineralized for most purposes. Macfarlane et al. (1991) have described in some detail the water quality and stratigraphy for the Dakota aquifer. Flow directions for the water in the Dakota are generally from west to east so that poor quality water seeps into the alluvial aquifers where they are in close hydraulic connection with the Dakota. This occurs in the alluvium of the Solomon River approximately between Beloit and Bennington and in Rattlesnake Creek, a tributary to Salt Creek in Ottawa County. This more highly mineralized water moves out of the alluvium becoming base flow for Salt Creek.

Alluvium

Ground-water quality in the alluvium of the Solomon River varies widely much like the water quality in the other aquifers in the basin. In general, it is somewhat more mineralized than the Ogallala aquifer because the alluvium is in direct contact with and receives constituents dissolved from minerals in the upper and lower Cretaceous rocks directly beneath it. The water is usable for most purposes in the alluvium of the North and South Forks. The water in the Solomon Valley below Beloit becomes more mineralized as poor quality water from the Dakota seeps into the alluvium and eventually into the stream as baseflow. The deterioration of water quality is not as pronounced in the Solomon as in Salt Creek probably because there is greater dilution in the Solomon.

Surface-water Quality

Streamflow samples for surface-water quality are taken at U.S. Geological Survey gaging stations (op. cit.) along the North Fork Solomon (Portis), South Fork Solomon (Osborne) and main stem (Niles) of the Solomon River. Data from these station were used to characterize inorganic water quality, particularly the specific conductance which can be used as an overall indicator of total-dissolved solids (TDS) and chloride concentrations which can come from either natural or anthropogenic sources. The values for both chloride and conductance were derived by averaging the total number of annual samples which ranged from 4 to about 30 in any given year.

Osborne

A previous study by the U.S. Bureau of Reclamation (USBR, 1984) briefly discussed the surface-water quality and compared chloride concentrations from 1962-67 to 1972-77 at Osborne. The Bureau reported increases in chlorides between the sampling periods. Table 5 lists these chloride concentrations and more recent data from the same locations. The 1982-87 values fit the periodicity of the earlier 5-yr averages taken 5 years apart. The 1988-1991 values were included to provide an indication of recent trends.

The 60 percent increase between 1962-67 and 1972-77 seems to have leveled off by 1982-87. However, the 1988-1991 data show another increase of 32 percent.

The average annual conductance at Osborne from 1964 to 1992 is illustrated in fig. 6. Average annual conductance has increased from about 850 $\mu\text{mhos/cm}$ (553 mg/L TDS) in 1964 to 1250 $\mu\text{mhos/cm}$ (813 mg/L TDS) in 1992. The TDS values are estimates based on multiplying the conductance by 0.65. There are no rock formations along the South Fork which yield substantial quantities of natural saltwater to streamflow. The chloride contents of the stream water are a combination of small amounts from natural geologic sources with added concentrations from agricultural activities and municipal wastewater.

Table 5. Chloride concentrations, South Fork Solomon River at Osborne

Year	Average Annual Concentration (mg/L)
1962-67	56.6
1972-77	90.7
1982-87	90.1
1988-91	118.8

Portis

Average chloride concentrations at Portis (table 6) have increased although not as much as at Osborne. There is a 40 percent increase between 1962-67 and 1972-77 and a 15 percent increase by 1982-87. The 1988-1991 average shows a continued increase of 13 percent. The average annual conductance for Portis is shown in fig. 7 and indicates a long-term average increase in the conductance from about 800 μmhos (520 TDS) to about 950 μmhos (618 TDS). As in the South Fork Solomon, the chloride content probably is a mixture of small amounts of natural and anthropogenic sources.

Niles

Water quality at Niles is reflected in table 7 which shows the chloride data from 1962-67 and 1972-77. Chloride concentration increased 96 percent between the two time periods. However, chloride measurements were discontinued in 1983 by the USGS so the 1982-87 comparison cannot be made. Figure 5, showing the average annual conductance of streamflow at Niles from 1964 to 1992, indicates the increasing salinity of the streamflow. Again, long-term average streamflow appears to be slightly increasing (fig. 3) with baseflow becoming an appreciably larger percent of the total annual flow (fig. 8). Water quality at Niles, unlike Portis and Osborne, is affected by substantial amounts of poor quality ground-water inflows from the Dakota Formation which subcrops beneath the alluvium downstream from Beloit. The increased concentrations of dissolved solids could be due to both natural and anthropogenic causes, but are probably mainly related to the increased baseflows which contain saline ground-water inflow.

Table 6. Chloride concentrations, Solomon River at Portis

Year	Average Annual Concentration (mg/L)
1962-67	32.9
1972-77	46.2
1982-87	52.6
1988-91	59.4

Table 7. Chloride concentrations, Solomon River at Niles

Year	Average Annual Concentration (mg/L)
1962-67	125
1972-77	245

7. Phreatophytes

One of the concerns regarding water supply in the Solomon Basin is the effect of vegetation located along the stream corridor. This vegetation (riparian) consists of woody plants and trees which are located in areas of shallow water table and have their roots in the water table, thereby removing ground water directly from the alluvial system. A significant amount of research has been done in order to try to quantify water use by plants; however, practical values of annual phreatophyte water use are difficult to find. The attached appendix on phreatophyte water use was compiled as a guide. Several hydrologic studies have been done in the Solomon basin area which provide some indication of these water-use values.

A 1972 study by the Kansas Fish and Game commission (quoted in U.S. Bureau of Reclamation, 1984) indicated 126 river miles of the South Fork of the Solomon River above Webster Reservoir. Trees commonly noted in the riparian corridor are cottonwood, elm, salt cedar, hackberry, willow, ash, and box elder. No calculations of areal coverage of each type were noted. Remote sensing data indicated about 7600 acres of riparian vegetation in this reach, or an average of 60.3 acres per mile which, using a value of 30 acres on each side of the stream, gives a corridor of riparian vegetation approximately 250 ft by 5280 ft long wide on each side of the stream. Consumptive use estimates for phreatophytes in the Solomon basin were estimated at approximately 4 acre-feet per acre per year (U.S. Bureau of Reclamation, 1984, p. 67). Using these values, consumptive use by phreatophytes along the South Fork above Webster Reservoir was estimated to be over 30,000 acre-feet per year. Similar estimates for the North Fork (assumed above Kirwin Reservoir) indicated an average annual water use of over 16,000 acre-feet per year.

Another study by the U.S. Bureau of Reclamation (Weston, 1979) calculates a ground-water budget for the South Fork of the Solomon River above Webster Reservoir and states "some ground-water discharge is obviously occurring through phreatophyte consumption along the river, but the changes in this quantity throughout the study period are assumed to be negligible in the overall budget computation" (p. 22).

Phillips (1980) in a study similar to that of Weston, calculated a ground-water budget for the North Fork Solomon River basin above Kirwin Reservoir and estimated phreatophyte water use at 7000 acre-feet per year. The 7000 acre-feet value was derived by subtracting the growing season (April-September) mean baseflow from the non-growing season (April-September) mean baseflow for the years 1919-1955. Acreage of riparian habitat is not calculated in Phillips' work.

Stullken (1984) conducted a study of the Prairie Dog Creek alluvial aquifer, the next basin northwest of the Solomon, and used a value of 1.5 cfs (1086 acre-ft-yr) for evapotranspiration for the length of the Prairie Dog from the Woodruff gage (Kansas-Nebraska state line) to Norton dam, a distance of 47.5 river miles. The 1.5 cfs was estimated by analyzing baseflow hydrographs at the Woodruff gage. If one assumes a riparian corridor of approximately 250 feet on each side of the stream, then total riparian vegetation is estimated at 2864 acres. Dividing 2864 acres into 1086 acre-ft/yr yields a value of .38 acre-ft/acre/yr for riparian evapotranspiration.

Jorgensen and Stullken (1981) modeled the Kirwin Dam to Waconda Lake reach of the North Fork of the Solomon and calculated a value of riparian evapotranspiration of 3.5 cfs (2500 acre-ft/yr) using baseflow calculations. The modeled reach is approximately 57.4 river miles. Using the estimate of corridors about 250 feet wide on each side of the stream, a riparian acreage of 3461 acres can be calculated. The acreage of riparian vegetation (3461 divided into 2500 acre-ft) yields a value of 0.72 acre-ft/acre/yr for an evapotranspiration value.

Clearly, calculating or estimating an annual value for riparian evapotranspiration is a difficult process and answers can vary widely depending on the data available and process used. The studies on the Prairie Dog and the North Fork Solomon yield riparian evapotranspiration values ranging from 48 percent to 18 percent, respectively, of annual baseflow and appear to be reasonable estimates. If an average value of 0.5 acre-ft/acre/yr was used (based on the two previously mentioned studies) for the Solomon area, then riparian evapotranspiration for the following Solomon reaches could be estimated in table 8.

Table 8. Estimates of riparian evapotranspiration for various reaches of the Solomon River

	River miles	Acres of vegetation	Acre-ft/ year	Acre-ft/ acre/year	Source
Waconda to Niles gage	150.8	9093	4500	0.5	average
Waconda to Kirwin	47.5	2864	1086	0.72	KGS/USGS
Waconda to Webster	82.4	4968	2484	0.5	average
Above Kirwin	NA	NA	7000	?	Phillips
	?	?	16,000	?	KF&GC
Above Webster	NA	NA	30,000	4	KF&GC

It would be easy to assume that considerable amounts of ground water could be used for other purposes if it were not being transpired by plants. Riparian ecosystems are very complex and delicate, not only supporting wildlife but providing water-quality benefits such as filtration of pollutants and lowering stream temperatures by reducing incoming solar radiation. Any attempt to significantly change the streamside vegetation would need to be studied very carefully for environmental impact.

8. Summary

Hydrogeologically, the Solomon River basin consists of three major aquifers: (1) the Ogallala formation; (2) the alluvial aquifer along the North and South forks and the main stem of the Solomon River; and (3) the Dakota Formation. This study concentrated on the alluvial aquifer. The Solomon maintains significant streamflow unlike other western Kansas rivers. As might be expected, computer modeling of the alluvial aquifer indicates that streamflow and ground-water levels in the aquifer are closely linked. So long as there is streamflow, ground water removed by pumping will be replaced by surface water.

A study of the upper end of the basin above the gaging station at Glade indicates that ground-water recharge in this part of the basin is about 0.94 inches or 4 percent of the average annual precipitation of 23.29 inches/yr. During the 1980-81 water year, ground water appropriated was almost five times the amount of estimated recharge. Actual pumpage was assumed to be less than appropriations.

Long-term trends of basin runoff and stream baseflow vary depending on whether they are measured in the upper, middle, or lower portions of the basin. Streamflow in the middle (Portis

and Osborne Gages) and lower (Niles) portions of the basin is affected by basin reservoirs (Kirwin, Webster, and Waconda, respectively).

Streamflow below Waconda Reservoir appears steady over the long term with baseflow increasing slightly and runoff decreasing. This increase could be explained by increasing discharge from the Dakota and alluvial aquifers. The average annual conductance of streamflow is increasing which could reflect a greater amount of more mineralized water from the Dakota aquifer contributing to streamflow.

Streamflow in the South Fork Solomon at Osborne appeared steady during the study period with both runoff and baseflow relatively unchanging.

Streamflow in the North Fork Solomon at Portis declined slightly during the study period with both baseflow and runoff decreasing but remaining about the same proportion of total flow.

Streamflow at Glade on the North Fork of the Solomon declined slightly during the study period, with baseflow remaining almost constant but runoff declining. Baseflow generally increased as a percent of the total annual flow.

Streamflow in the South Fork of the Solomon above Webster Reservoir generally decreased with both baseflow and runoff decreasing. Runoff declined slightly faster causing baseflow to become an increasingly larger portion of total flow.

Reported water use in the alluvial aquifer of the Solomon River basin appears to be considerably less than appropriations. This difference is common in other areas of Kansas. If all ground water that was appropriated was pumped, there would be much more significant declines in streamflow and baseflow and ground-water levels would probably decline.

Ground- and surface-water quality in the basin is highly variable depending on the source of the water and the geologic material with which it has come into contact. Ground water in the Ogallala formation is generally good quality although hard. Water from the upper Cretaceous rocks of the Pierre, Niobrara, Carlile, Greenhorn, and Graneros units yield small amounts of sometimes highly mineralized water to wells with calcium sulfate being a common constituent. The lower Cretaceous units of the Dakota, Cheyenne, and Kiowa formations have highly variable water quality ranging from good quality in the outcrop areas to poor in the subsurface. West of Osborne County the water in the Dakota Formation is too mineralized for most purposes.

Ground-water quality in the alluvium varies widely, like the water in other aquifers in the basin. Since there is seepage from some of the bedrock formations over which it flows, some parts of the aquifer contain more highly mineralized water, for example, the part of the valley below Beloit where more mineralized water from the Dakota seeps into the alluvium.

Surface-water quality is generally good in the basin; however, long-term trends at the Osborne, Portis and Niles gages show chlorides increasing. Sources of this mineralization are

probably ground-water inflow from lower aquifers such as the Dakota as well as agricultural sources and municipal wastewater.

Several studies have attempted to estimate water use by phreatophyte vegetation along the alluvial stream corridor. Estimation of transpiration by plants vary from 0.5 to 4 acre-ft per acre in the alluvial aquifer part of the basin.

9. Recommendations

1. Continue measurement of ground-water levels in wells in the alluvial aquifer and Ogallala and establish an observation well system in the Dakota Formation. The Dakota contributes important baseflow in the lower end of the basin.
2. Continue to analyze and track the baseflow/runoff characteristics at the gaging stations.
3. More closely examine the reported water-use numbers for the alluvial aquifer to determine the appropriated/pumped ratio. If the amount of pumping increases there will be a point where streamflow in the Solomon River will become seriously depleted like Walnut Creek, Pawnee River, Arkansas River, and the Smoky Hill River.
4. Continue to track the surface-water quality. At some point the increases in dissolved solids could begin to impair agricultural or municipal uses.
5. Conduct a systematic inventory of the riparian vegetation in the alluvial aquifer. Results of this should provide a more reliable estimate of riparian water use in the water budget for the basin.
6. If the Solomon basin is to remain with viable streamflow, runoff and baseflow need to be stabilized. It will be easier to slow down pumpage than to control land-use treatment.

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Appendix 1

Solomon Basin Coverage and Map Composition Documentation

(KGS Open-File Report 91-11 by R. Bassler)

Coverage Name: AQFRS (Aquifers of the Solomon Basin)
 Source Accuracy: 0.001" (digitizer)
 Source Scale: 1:24000
 Source Projection: 7.5' USGS Topographic Quadrangles
 Coverage Type: Polygon/Arc
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
AQUIFER	10	10	C	-
AQ_ABBR	5	5	C	-

AQUIFER - Four types of aquifers were designated:

Ogallala - also known as the High Plains Aquifer

Dakota - Outcrop/Subcrop of the stratigraphic units that comprise the Dakota aquifers (Dakota Formation, Kiowa Formation, and Cheyenne Sandstone)

Alluvial - Alluvial aquifers of the Solomon Basin

Other - Discontinuous minor aquifers - Cretaceous Niobrara Chalk, Carlile Shale, Greenhorn Limestone, Graneros Shale, and Permian Sumner Group

AQ_ABBR - Each aquifer has a unique abbreviation (except for the discontinuous aquifers):

Qal = Alluvial
 To = Ogallala
 Kd = Dakota

This coverage's limits extend to four miles beyond the basin boundary. A clip coverage was made by buffering the basin boundary to four miles and the aquifers coverage was then clipped to this size.

The following commands were used to create the plot files for the water table map. The prompt will be shown with each command. (OF 91-11C)

```
)ARC
Arc: ARCPLOT
Arcplot: PAGESI 38 18
Arcplot: MAPE 2 14 38 31
Arcplot: MAP SOL.WATTAB
Arcplot: MAPSCALE 1.0
Arcplot: TEXTSET ROD.TXT
Arcplot: MAPPO CEN CEN
Arcplot: LINECOLOR 14
Arcplot: ARCS LEG.GRID
Arcplot: LINECOLOR 12
Arcplot: ARCS BORDER
Arcplot: LINECOLOR 6
Arcplot: ARCS NEATLINE
Arcplot: LINECOLOR 4
Arcplot: ARCS SCALE
Arcplot: ARCS LOCATOR
Arcplot: RESEL LEG.ANNO2 LINE TYPE = 'BASIN_BND'
Arcplot: LINECOLOR 818
Arcplot: ARCS LEG.ANNO2
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO2 LINE TYPE = 'STREAM'
Arcplot: LINECOLOR 449
Arcplot: ARCS LEG.ANNO2
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO2 LINE TYPE = 'TOWN_BND'
Arcplot: LINECOLOR 3
Arcplot: ARCS LEG.ANNO2
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO2 LINE TYPE = 'COUNTY_BND'
Arcplot: LINECOLOR 7
Arcplot: ARCS LEG.ANNO2
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO2 LINE TYPE = 'STATE_BND'
Arcplot: LINECOLOR 15
Arcplot: ARCS LEG.ANNO2
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO2 LINE TYPE = '
Arcplot: LINECOLOR 4
Arcplot: ARCS LEG.ANNO2
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO2 LINE TYPE = 'CONTOUR'
Arcplot: LINECOLOR 219
Arcplot: ARCS LEG.ANNO2
Arcplot: MSEL 6 7 8 9 10 11 12
Arcplot: MGROUP
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL LOCATOR POLY NAME = 'SOLOMON'
Arcplot: POLYGONSH LOCATOR 24
Arcplot: RESEL SCALE POLY SCALEFILL = 'FILL'
Arcplot: POLYGONSH SCALE 24
```

Arcplot: POLYGONSH SCALE 24
Arcplot: ANNOTEXT TITLES.3
Arcplot: ANNOTEXT LEG.ANNO3
Arcplot: LINECOLOR 4
Arcplot: ARCS KGS
Arcplot: ANNOTEXT KGS
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL KGS POLY POLYFILL = 'BLACK'
Arcplot: POLYGONSH KGS 24
Arcplot: CLEARSEL
Arcplot: RESEL KGS POLY POLYFILL = 'GRAY'
Arcplot: POLYGONSH KGS 12
Arcplot: MSEL 11 12 13 14
Arcplot: MGROUP
Arcplot: MSCALE .284
Arcplot: MMOVE * (move the symbol to the corner of the map)
Arcplot: WEEDDRAW OFF
Arcplot: MAPE TR.PJTD
Arcplot: MAPU FEET
Arcplot: MAPSCALE 500000
Arcplot: LINECOLOR 3
Arcplot: ARCS TR.PJTD
Arcplot: LINECOLOR 7
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 15
Arcplot: RESEL COUNTIES.PJTD LINE KCD# = 4310
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 818
Arcplot: ARCS BASIN.PJTD
Arcplot: LINECOLOR 449
Arcplot: ARCS HYDRO.PJTD
Arcplot: SHADESET PLOTTER.SHD
Arcplot: POLYGONSH LAKES.PJTD 684
Arcplot: MARKERSET PLOTTER
Arcplot: MARKERSYM 1
Arcplot: MARKERCOLOR 1
Arcplot: MARKERSI .025
Arcplot: POINTS WLDEC.PT.PJTD
Arcplot: MARKER * (place the well symbol in the legend)
Arcplot: LINECOLOR 219
Arcplot: ARCS WLDEC.CONT.PJTD
Arcplot: ANNOTEXT WLDEC.CONT.PJTD
Arcplot: ANNOTEXT TR.PJTD
Arcplot: ANNOTEXT COUNTIES.PJTD
Arcplot: ANNOTEXT HYDRO.PJTD
Arcplot: MSEL 12 13 14 15 16 17 18 20 21 22 23 24
Arcplot: MROTATE .70
Arcplot: MMOVE .705 5 .650 5
Arcplot: MSEL 1
Arcplot: MDELETE
Arcplot: MAP END
Arcplot: RESET (create a new map with only 1 plot file)
Arcplot: PAGESI 38 18
Arcplot: MAP SOL.WLDECGRP

Arcplot: RESET (create a new map to compress all plots into 1 plot file)
Arcplot: PAGESI 38 18
Arcplot: MAP SOL.SATHICKGRP
Arcplot: MBEGIN
Arcplot: PLOT SOL.SATHICK
Arcplot: MEND
Arcplot: MAP END
Arcplot: QUIT
Arc: COLOR SOL.SATHICKGRP:E0001.PLT CAL.SOLSATHICK .19685 BANNER
Arc: QUIT
)BY

Coverage Name: BASIN (Basin Boundary for the Solomon)
 Coverage Type: Polygon/Arc
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Description:

The basin boundary was obtained from the Soil Conservation Service. Sub-basin boundaries were removed to leave only the exterior basin boundary for the Solomon River. The following specifications as described by the SCS accompanied the original coverage received by the Kansas Geological Survey:

DESCRIPTION	= KANSAS HYDROLOGIC UNIT BOUNDARIES AT THE 11-DIGIT LEVEL
AGENCY-RESP	= USGS-WRD FOR 8-DIGIT LEVEL & USDA-SCS FOR 11-DIGIT LEVEL
COVER-PROJECTION	= LAMBERT CONFORMAL CONIC
PROJECTION-PARMS	= 1st STD PARALLEL:33 2nd STD PARALLEL:45 CEN MER:-98 15' 00"
COVER-UNITS	= METERS
COVER-TYPE	= POLY, ARC
COVER-DATE	= 6/10/90
COVER-RMSE	= DIGITIZING < 0.003
DATA-TYPE	= PRIMARY
MANUSCRIPT	= COMPOSITES OF HYDROLOGY AND COUNTY & 8-DIGIT HUC BOUNDARIES
MANUS-SOURCE	= COMPOSITE PLOTS BY KWO OF USGS-WRD & KGS DATA + TOPO MAPS
MANUS-PROJECTION	= LAMBERT CONFORMAL CONIC
MANUS-SCALE	= 1:100000
MANUS-MATERIAL	= MYLAR
MANUS-DATE	= 1990
PROJECT-NAME	= MANAGEMENT & PROTECTION OF WATER RESOURCES IN KANSAS
REMARKS	= 11-DIGIT BOUNDARIES COMPILED BY SCS & DIGITIZED BY KWO
DISCLAIMER	= INTENDED FOR STATE & BASIN LEVEL USE NOT LESS THAN 1:100000

Coverage Name: COUNTIES
 Source Accuracy: 0.001" (digitizer)
 Source Scale: 1:24000
 Source Projection: 7.5' USGS Topographic Quadrangles
 Coverage Type: Polygon/Arc
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
NAME	15	15	C	-
FIPS	4	4	I	0

NAME - The name of the county.

FIPS - The FIPS code for the county.

.AAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
KCD#	4	4	I	0
DLG#	4	4	I	0

KCD# - The Kansas Cartographic Database attribute code for arc features. Codes used in this coverage are:

- 4310 - State Boundary (Political Areas)
- 4320 - County Boundary (Political Areas)

DLG# - The Digital Line Graph attribute code for arc features. See the DLG 1:2,000,000 data users guide for a complete description. Codes used in this coverage are:

- 6005 - State/Provincial (Land) (Political Boundaries)
- 6006 - State/Provincial (Water) (Political Boundaries)
- 6009 - County (Land) (Political Boundaries)
- 6010 - County (Water) (Political Boundaries)

Coverage Name: **BEDROCK (Bedrock elevations)**
 Source Accuracy: N/A
 Source Scale: N/A
 Source Projection: N/A
 Coverage Type: Point
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
TWNRNG	15	15	C	-
LANDELEV	8	8	F	1
D2BEDROCK	8	8	F	1
WELLDEPTH	8	8	F	1
BEDELEV	8	8	F	1

TWNRNG - Township and range location of the well data point

LANDELEV - Land surface elevation of the well data point

D2BEDROCK - Depth to bedrock from the land surface

WELLDEPTH - Well depth of the well data point

BEDELEV - Bedrock elevation of the well data point

Coverage Name: CITIES
 Source Accuracy: N/A
 Source Scale: N/A
 Source Projection: N/A
 Coverage Type: Point
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
COUNTY	14	14	C	-
CITY	19	19	C	-
TYPE	11	11	C	-
LC_CITY	19	19	C	-

COUNTY - The name of the county where the city is located

CITY - The name of the city

TYPE - Designates if the city is a county seat

LC_CITY - Lower case city - Column used purely for cartographic production - County seats were to be in all uppercase and all others to be in mixed upper/lower case.

Coverage Name: HWY (Highways)
 Source Accuracy: 0.001" (digitizer)
 Source Scale: 1:24000
 Source Projection: 7.5' USGS Topographic Quadrangles
 Coverage Type: Arc/Point
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
TYPE	10	10	C	-
HWY_NO.	4	4	C	-

TYPE - Three types of labels were designated: Interstate, Federal, and State

HWY_NO. - Allowed the placing of the proper highway number in the marker symbol on the map

.AAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
TYPE	10	10	C	-

TYPE - Three types of arcs were designated: Interstate, Federal and State highways

Coverage Name: HYDRO (Hydrology for the Solomon Basin)
 Source Accuracy: 0.001" (digitizer)
 Source Scale: 1:24000
 Source Projection: 7.5' USGS Topographic Quadrangles
 Coverage Type: Arc
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.AAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
KCD#	4	5	I	0
TYPE	20	20	C	-

KCD# - The Kansas Cartographic Database attribute code for arc features. Codes used in this coverage are:

- 2411 - Primary Perennial Stream
- 2421 - Primary Intermittent Stream

TYPE - Character item designating whether a stream is primary perennial or primary intermittent

Coverage Name: SATHICK (Saturated Thickness)
 also: SATHICK.CLIP (clipped with CLIPCOV)
 Source Accuracy: N/A
 Source Scale: N/A
 Source Projection: N/A
 Coverage Type: Point
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
TWNRNG	15	15	C	-
BEDELEV	8	8	F	1
WATTAB	8	8	F	1
SATHICK	8	8	F	1

TWNRNG - Township and range location of the well data point

BEDELEV - Bedrock elevation for the well data point

WATTAB - Modern water table elevation for the well data point

SATHICK - Saturated thickness for the well data point

Coverage Name: TR (Township/Range)
 Source Accuracy: 0.001" (digitizer)
 Source Scale: 1:24000
 Source Projection: 7.5' USGS Topographic Quadrangles
 Coverage Type: Polygon/Arc
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
TWNRNG	15	15	C	-
TOWN	2	2	I	0
RANGE	2	2	I	0
DIR	1	1	C	-

- TWNRNG - The township and range location of the polygons Ex. T10S R40W
- TOWN - The individual township number for that polygon
- RANGE - The individual range number for that polygon
- DIR - Designates the direction of the range - either "W" for West or "E" for East

Coverage Name: SATHICK.CONT (Saturated Thickness Contours)
Source Accuracy: 0.001"
Source Scale: 1:250000
Source Projection: Geometric (Longitude/Latitude)
Coverage Type: Arc
Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.AAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
CONTOUR	4	4	I	0
TOPOGRAPHY	10	10	C	-

CONTOUR - The value of the contour line in feet

TOPOGRAPHY - Designates if the contour line represents a DEPRESSION.

Due to inaccuracies of contours derived from automated mapping, the contours in this coverage were hand-drawn and approved by Tom McClain. The contours were then digitized in the Geohydrology Section.

Coverage Name: TICCOV (Master Tic Coverage)
 Source Accuracy: N/A
 Source Scale: N/A
 Source Projection: N/A
 Coverage Type: Point
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
TICID	10	10	I	0
LONGITUDE	10	10	C	-
LATTITUDE	10	10	C	-

TICID - Tic ID's are created using the degrees and minutes of the longitude and latitude at the point each tic is located. The negative on the longitude is dropped and the degrees and minutes from each are appended, longitude first and latitude second, to create the Tic ID.

Ex: Longitude: -102 47' 21"
 Latitude: 39 11' 39"
 Tic ID: 102473911

LONGITUDE - The longitude of the point.

LATTITUDE - The latitude of the point.

Use of the Master Tic Coverage:

This coverage is intended to be used as the common tic reference in the Geohydrology Section. The Tic ID's correspond to the corners of every 7.5' USGS topographic quad with in the ranges of longitude -91 to -107 and latitude 35 to 42. This facilitates the location of control points when digitizing as the corners of every USGS map will fall on tics that are identified by their long/lat coordinates.

Coverage Name: WATTAB (Water Table Elevation)
 also: WATTAB.CLIP (clipped with CLIPCOV)
 Source Accuracy: N/A
 Source Scale: N/A
 Source Projection: N/A
 Coverage Type: Point
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
TWNRNG	15	15	C	-
LANDELEV	8	8	F	1
BEDELEV	8	8	F	1
WATTAB	8	8	F	1

TWNRNG - Township and range location of the well data point

LANDELEV - Land surface elevation of the well data point

BEDELEV - Bedrock elevation for the well data point

WATTAB - Modern water table (1989) elevation for the well data point

Coverage Name: WATTAB.CONT (Water Table Contours)
 Coverage Name: WLDEC.CONT (Water Level Decline Contours)
 Source Accuracy: 0.001"
 Source Scale: 1:250000
 Source Projection: Geometric (Longitude/Latitude)
 Coverage Type: Arc
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.AAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
CONTOUR	4	4	I	0

CONTOUR - The value of the contour line in feet

Due to inaccuracies of contours derived from automated mapping, the contours in these coverages were hand-drawn and approved by Tom McClain. The contours were then digitized in the Geohydrology Section.

Coverage Name: WLDEC (Water Level Decline)
 also: WLDEC.CLIP (clipped with CLIPCOV)
 Source Accuracy: N/A
 Source Scale: N/A
 Source Projection: N/A
 Coverage Type: Point
 Storage Projection: Geometric (Longitude/Latitude)

Attributes Descriptions:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
LANDELEV	8	8	F	1
BEDELEV	8	8	F	1
HIST-WATTAB	8	8	F	1
MOD-WATTAB	8	8	F	1
WLDEC	8	8	F	1

LANDELEV - Land surface elevation of the well data point

BEDELEV - Bedrock elevation for the well data point

HIST-WATTAB - Historical (pre-development to 1950) water table elevation for the well data point.

MOD-WATTAB - Modern (1989) water table elevation for the well data point

WLDEC - Water level decline between the historical and modern water table records

Coverage Name: SECTIONS (Section Corners)
Source Accuracy: 0.001" (digitizer)
Source Scale: 1:24000
Source Projection: 7.5' USGS Topographic Quadrangle
Coverage Type: Point
Storage Projection: Geometric (Longitude/Latitude)

Attributes: None - The section coverage was used exclusively for cartographic production and it was deemed unnecessary to attribute.

Coverage Name: RR (Railroads)
Source Accuracy: 0.001" (digitizer)
Source Scale: 1:24000
Source Projection: 7.5' USGS Topographic Quadrangle
Coverage Type: Arc
Storage Projection: Geometric (Longitude/Latitude)

Attributes: None - The railroad coverage was used exclusively for cartographic production and it was deemed unnecessary to attribute this coverage.

Coverage Name: LAKES (Solomon Basin Lakes)
Source Accuracy: 0.001" (digitizer)
Source Scale: 1:24000
Source Projection: 7.5' USGS Topographic Quadrangle
Coverage Type: Polygon/Arc
Storage Projection: Geometric (Longitude/Latitude)

Attributes: None - The lakes coverage was used exclusively for cartographic production and it was deemed unnecessary to attribute this coverage. It was derived from the hydrology coverage.

Coverage Name: CLIPCOV (Clip coverage for the Solomon)
Coverage Type: Polygon
Storage Projection: Geometric (Longitude / Latitude)

Attributes: None - The clip coverage was used to clip all coverages for map production and was created interactively using ARCEDIT.

Coverage Name: LOCATOR (Locator map for main maps)
Coverage Type: Polygon
Storage Units: Inches

Attributes: The .PAT contains a NAME (SOLOMON) for the polygon showing the Solomon Basin. This coverage was intended solely for cartographic purposes.

Coverage Name: SCALE (Scale for 1:500000 maps)
 Coverage Type: Polygon
 Storage Units: Inches

Attributes Description:

.PAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
POLYFILL	4	4	C	-

This coverage was created to produce the scale on the basin maps. It was built as a polygon coverage so that the appropriate polys in the scale could be shaded.

Coverage Name: LEG.ANNOx (Legend annotation for the five maps:
 LEG.ANNO0, LEG.ANNO1, LEG.ANNO2,
 LEG.ANNO3, LEG.ANNO4)

Coverage Type: Arc
 Storage Units: Inches

LEG.ANNO0 = Legend annotation for the basemap
 LEG.ANNO1 = Legend annotation for the sathick map
 LEG.ANNO2 = Legend annotation for the wattab map
 LEG.ANNO3 = Legend annotation for the wldec map
 LEG.ANNO4 = Legend annotation for the aquifers map

Attributes Description:

.AAT

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
TYPE	15	15	C	-

TYPE - This was used to define the different types of arcs in the basin such as the symbol used for highways, county boundaries, north arrow, and streams. By doing this each arc could have the same attributes (color, thickness, etc.) as the arcs in the corresponding coverage.

.PAT (either polygon or point attributes - not in all LEG.ANNOx coverages)

<u>Item Name</u>	<u>Width</u>	<u>Output</u>	<u>Type</u>	<u># Decimals</u>
HWY_NO.	4	4	I	0
POLY_COLOR	4	4	I	0

HWY_NO. - This was used to assign the proper marker symbols in the legend as well as a sample highway number to the shield symbols.

POLY_COLOR - This was used to assign the color to the polygon symbols in the legend for the aquifer map.

Coverage Name: LEG.GRID (Legend grid)
Coverage Type: Arc
Storage Units: Inches

Attributes: None - This coverage is a grid of lines that was used to line up the text in the annotation coverages so that everything would be properly spaced and laid out. This coverage was intended solely for cartographic purposes.

Coverage Name: BORDER (Map border)
Coverage Type: Arc
Storage Units: Inches

Attributes: None - This coverage is the map border. It was intended solely for cartographic purposes.

Coverage Name: NEATLINE (Map neatline)
Coverage Type: Arc
Storage Units: Inches

Attributes: None - This coverage is the map neatline. It was intended solely for cartographic purposes.

Coverage Name: TITLES.x (TITLES.0, TITLES.1, TITLES.2, TITLES.3, TITLES.4)
Coverage Type: Arc
Storage Units: Inches

TITLES.0 = titles for the basemap
TITLES.1 = titles for the sathick map
TITLES.2 = titles for the wattab map
TITLES.3 = titles for the wldec map
TITLES.4 = titles for the aquifers map

Attributes: None - These coverages were originally created separately because of plotter problems. They could now be merged with the legend annotation coverages. These coverages were intended solely for cartographic purposes.

The following coverages are projected using this projection file with these parameters (these are based on the Kansas Cartographic Database's Standard State Projection):

```
INPUT
PROJECTION GEOGRAPHIC
UNITS DD
PARAMETERS
OUTPUT
PROJECTION LAMBERT
UNITS FEET
PARAMETERS
34 00 00
44 00 00
-98 18 45
36 52 30
0.0
0.0
END
```

They were projected so that annotation could be added to the coverages in units (feet) that could be easily calculated based on the desired (inch) sizes to be displayed on the final maps. Another factor is that ARCPLOT did not seem to want to project the map annotations if the coverages were not already projected. They are essentially the same coverages as the unprojected coverages described up to this point, except that they have the annotation needed for creation of the final maps. These coverages are probably of little use to anyone except those people who wish to produce maps with the above parameters. The above projection file is called 'PROJLAMBERT.STATE.F'.

```
AQFRS.PJTD
BASIN.PJTD
BEDROCK.PJTD
CITIES.PJTD
COUNTIES.PJTD
HWY.PJTD
HYDRO.PJTD
LAKES.PJTD
RR.PJTD
SATHICK.CONT.PJTD          (contour lines)
SATHICK.PT.PJTD           (points from clipped cover)
SECTIONS.PJTD
TR.PJTD
WATTAB.CONT.PJTD          (contour lines)
WATTAB.PT.PJTD           (points from clipped cover)
WLDEC.CONT.PJTD           (contour lines)
WLDEC.PT.PJTD            (points from clipped cover)
```

The following commands were used to create the plot files for the Solomon River basemap. The map appears very cluttered, but it is intended to show the basic geographic features available in the Kansas Cartographic Database. The prompt for each command will also be shown. (OF 91-11A)

```
)ARC
Arc: ARCPLOT
Arcplot: PAGESI 38 18
Arcplot: MAPE 2 14 38 31
Arcplot: MAP SOL.BASEMAP
Arcplot: MAPSCALE 1.0
Arcplot: TEXTSET ROD.TXT
Arcplot: MAPPO CEN CEN
Arcplot: LINECOLOR 14
Arcplot: ARCS LEG.GRID
Arcplot: LINECOLOR 12
Arcplot: ARCS BORDER
Arcplot: LINECOLOR 6
Arcplot: ARCS NEATLINE
Arcplot: LINECOLOR 4
Arcplot: ARCS SCALE
Arcplot: ARCS LOCATOR
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'BASIN_BND'
Arcplot: LINECOLOR 818
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'STREAM'
Arcplot: LINECOLOR 449
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'TOWN_BND'
Arcplot: LINECOLOR 3
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'COUNTY_BND'
Arcplot: LINECOLOR 7
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'STATE_BND'
Arcplot: LINECOLOR 15
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'INTERSTATE'
Arcplot: LINECOLOR 870
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'FEDERAL'
Arcplot: LINECOLOR 548
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'STATE'
Arcplot: LINECOLOR 226
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
```

Arcplot: RESEL LEG.ANNO0 POINT HWY_NO. > 0
Arcplot: TEXTSYM 33
Arcplot: TEXTSI .05
Arcplot: POINTTEXT LEG.ANNO0 HWY_NO. # CC
Arcplot: RESEL LEG.ANNO0 POINT HWY_NO. = 70
Arcplot: MARKERSET HWY.MRK
Arcplot: MARKERSYM 1
Arcplot: POINTMARKER LEG.ANNO0 1
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 POINT HWY_NO. = 40
Arcplot: POINTMARKER LEG.ANNO0 2
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 POINT HWY_NO. = 25
Arcplot: POINTMARKER LEG.ANNO0 3
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = ' '
Arcplot: LINECOLOR 4
Arcplot: ARCS LEG.ANNO0
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO0 LINE TYPE = 'RAILROAD'
Arcplot: LINESET PLOTTER.LIN
Arcplot: LINESYM 85
Arcplot: LINECOLOR 6
Arcplot: ARCS LEG.ANNO0
Arcplot: LINESET PLOTTER
Arcplot: LINESYM 1
Arcplot: MSEL 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Arcplot: MGROUP
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL LOCATOR POLY NAME = 'SOLOMON'
Arcplot: POLYGONSH LOCATOR 24
Arcplot: RESEL SCALE POLY SCALEFILL = 'FILL'
Arcplot: POLYGONSH SCALE 24
Arcplot: ANNOTEXT TITLES.0
Arcplot: ANNOTEXT LEG.ANNO0
Arcplot: LINECOLOR 4
Arcplot: ARCS KGS
Arcplot: ANNOTEXT KGS
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL KGS POLY POLYFILL = 'BLACK'
Arcplot: POLYGONSHADES KGS 24
Arcplot: CLEARSEL
Arcplot: RESEL KGS POLY POLYFILL = 'GRAY'
Arcplot: POLYGONSH KGS 12
Arcplot: MSEL 11 12 13 14
Arcplot: MGROUP
Arcplot: MSCALE .284
Arcplot: MMOVE * (move symbol to the corner of the map)
Arcplot: WEEDDRAW OFF
Arcplot: MAPE TR.PJTD
Arcplot: MAPU FEET
Arcplot: MAPSCALE 500000
Arcplot: MARKERSET PLOTTER
Arcplot: MARKERSYM 1

Arcplot: MARKERCOLOR 1
Arcplot: MARKERSI .025
Arcplot: POINTS SECTIONS.PJTD
Arcplot: MARKER * (place the section corner symbol in the legend)
Arcplot: LINECOLOR 3
Arcplot: ARCS TR.PJTD
Arcplot: LINECOLOR 7
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 15
Arcplot: RESEL COUNTIES.PJTD LINE KCD# = 4310
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 818
Arcplot: ARCS BASIN.PJTD
Arcplot: LINECOLOR 449
Arcplot: ARCS HYDRO.PJTD
Arcplot: SHADESET PLOTTER.SHD
Arcplot: POLYGONSH LAKES.PJTD 684
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD LINE TYPE = 'STATE'
Arcplot: LINECOLOR 226
Arcplot: ARCS HWY.PJTD
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD LINE TYPE = 'FEDERAL'
Arcplot: LINECOLOR 548
Arcplot: ARCS HWY.PJTD
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD LINE TYPE = 'INTERSTATE'
Arcplot: LINECOLOR 870
Arcplot: ARCS HWY.PJTD
Arcplot: LINESET PLOTTER.LIN
Arcplot: LINESYM 85
Arcplot: LINECOLOR 6
Arcplot: ARCS RR.PJTD
Arcplot: LINESET PLOTTER
Arcplot: LINESYM 1
Arcplot: LINECOLOR 1
Arcplot: ANNOTEXT TR.PJTD
Arcplot: ANNOTEXT COUNTIES.PJTD
Arcplot: ANNOTEXT HYDRO.PJTD
Arcplot: ANNOTEXT CITIES.PJTD
Arcplot: TEXTSYM 33
Arcplot: TEXTSI .05
Arcplot: POINTTEXT HWY.PJTD HWY_NO. # CC
Arcplot: MARKERSET MUNICIPAL.MRK
Arcplot: MARKERSYM 111
Arcplot: MARKERSI .07
Arcplot: POINTS CITIES.PJTD
Arcplot: MARKER * (place the city symbol in the legend)
Arcplot: MARKERSET HWY.MRK
Arcplot: MARKERSYM 1
Arcplot: MARKERSI .10
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD POINT TYPE = 'INTERSTATE'
Arcplot: POINTMARKERS HWY.PJTD 1000

Arcplot: ANNOTEXT TITLES.1
Arcplot: ANNOTEXT LEG.ANNO1
Arcplot: LINECOLOR 4
Arcplot: ARCS KGS
Arcplot: ANNOTEXT KGS
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL KGS POLY POLYFILL = 'BLACK'
Arcplot: POLYGONSH KGS 24
Arcplot: CLEARSEL
Arcplot: RESEL KGS POLY POLYFILL = 'GRAY'
Arcplot: POLYGONSH KGS 12
Arcplot: MSEL 11 12 13 14
Arcplot: MGROUP
Arcplot: MSCALE .284
Arcplot: MMOVE * (move the symbol to the corner of the map)
Arcplot: WEEDDRAW OFF
Arcplot: MAPE TR.PJTD
Arcplot: MAPU FEET
Arcplot: MAPSCALE 500000
Arcplot: LINECOLOR 3
Arcplot: ARCS TR.PJTD
Arcplot: LINECOLOR 7
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 15
Arcplot: RESEL COUNTIES.PJTD LINE KCD# = 4310
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 818
Arcplot: ARCS BASIN.PJTD
Arcplot: LINECOLOR 449
Arcplot: ARCS HYDRO.PJTD
Arcplot: SHADESET PLOTTER.SHD
Arcplot: POLYGONSH LAKES.PJTD 684
Arcplot: MARKERSET PLOTTER
Arcplot: MARKERSYM 1
Arcplot: MARKERCOLOR 1
Arcplot: MARKERSI .025
Arcplot: POINTS SATHICK.PT.PJTD
Arcplot: MARKER * (place the marker symbol in the legend for the well point)
Arcplot: LINECOLOR 219
Arcplot: ARCS SATHICK.CONT.PJTD
Arcplot: LINESYM 90
Arcplot: LINECOLOR 219
Arcplot: RESEL SATHICK.CONT.PJTD LINE TOPOGRAPHY = 'DEPRESSION'
Arcplot: ARCS SATHICK.CONT.PJTD
Arcplot: ANNOTEXT SATHICK.CONT.PJTD
Arcplot: ANNOTEXT TR.PJTD
Arcplot: ANNOTEXT COUNTIES.PJTD
Arcplot: ANNOTEXT HYDRO.PJTD
Arcplot: MSEL 12 13 14 15 16 17 18 20 21 22 23 24 25
Arcplot: MROTATE .70
Arcplot: MMOVE .705 5 .650 5
Arcplot: MSEL 1
Arcplot: MDELETE
Arcplot: MAP END

Arcplot: MARKERSYM 2
Arcplot: MARKERSI .10
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD POINT TYPE = 'FEDERAL'
Arcplot: POINTMARKERS HWY.PJTD 1000
Arcplot: MARKERSYM 3
Arcplot: MARKERSI .16
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD POINT TYPE = 'STATE'
Arcplot: POINTMARKERS HWY.PJTD 1000
Arcplot: MSEL 11 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 30 31 32
Arcplot: MROTATE .70
Arcplot: MMOVE .705 5 .650 5
Arcplot: MSEL 1
Arcplot: MDELETE
Arcplot: MAP END
Arcplot: RESET (create a new map with only 1 plotfile)
Arcplot: PAGESI 38 18
Arcplot: MAP SOL.BASEGRP
Arcplot: MBEGIN
Arcplot: PLOT SOL.BASEMAP
Arcplot: MEND
Arcplot: MAP END
Arcplot: QUIT
Arc: COLOR SOL.BASEGRP:E0001.PLT CAL.SOLBASEMAP .19685 BANNER
Arc: QUIT
)BY

The following commands were used to create the plot files for the saturated thickness map.
The prompt will be shown with each command. (OF 91-11B)

```
)ARC
Arc: ARCPLOT
Arcplot: PAGESI 38 18
Arcplot: MAPE 2 14 38 31
Arcplot: MAP SOL.SATHICK
Arcplot: MAPSCALE 1.0
Arcplot: TEXTSET ROD.TXT
Arcplot: MAPPO CEN CEN
Arcplot: LINECOLOR 14
Arcplot: ARCS LEG.GRID
Arcplot: LINECOLOR 12
Arcplot: ARCS BORDER
Arcplot: LINECOLOR 6
Arcplot: ARCS NEATLINE
Arcplot: LINECOLOR 4
Arcplot: ARCS SCALE
Arcplot: ARCS LOCATOR
Arcplot: RESEL LEG.ANNO1 LINE TYPE = 'BASIN_BND'
Arcplot: LINECOLOR 818
Arcplot: ARCS LEG.ANNO1
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO1 LINE TYPE = 'STREAM'
Arcplot: LINECOLOR 449
Arcplot: ARCS LEG.ANNO1
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO1 LINE TYPE = 'TOWN_BND'
Arcplot: LINECOLOR 3
Arcplot: ARCS LEG.ANNO1
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO1 LINE TYPE = 'COUNTY_BND'
Arcplot: LINECOLOR 7
Arcplot: ARCS LEG.ANNO1
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO1 LINE TYPE = 'STATE_BND'
Arcplot: LINECOLOR 15
Arcplot: ARCS LEG.ANNO1
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO1 LINE TYPE = '
Arcplot: LINECOLOR 4
Arcplot: ARCS LEG.ANNO1
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO1 LINE TYPE = 'CONTOUR'
Arcplot: LINECOLOR 219
Arcplot: ARCS LEG.ANNO1
Arcplot: MSEL 6 7 8 9 10 11 12
Arcplot: MGROUP
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL LOCATOR POLY NAME = 'SOLOMON'
Arcplot: POLYGONSH LOCATOR 24
Arcplot: RESEL SCALE POLY SCALEFILL = 'FILL'
Arcplot: POLYGONSH SCALE 24
```

Arcplot: ANNOTEXT TITLES.2
Arcplot: ANNOTEXT LEG.ANNO2
Arcplot: LINECOLOR 4
Arcplot: ARCS KGS
Arcplot: ANNOTEXT KGS
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL KGS POLY POLYFILL = 'BLACK'
Arcplot: POLYGONSH KGS 24
Arcplot: CLEARSEL
Arcplot: RESEL KGS POLY POLYFILL = 'GRAY'
Arcplot: POLYGONSH KGS 12
Arcplot: MSEL 11 12 13 14
Arcplot: MGROUP
Arcplot: MSCALE .284
Arcplot: MMOVE * (move the symbol to the corner of the map)
Arcplot: WEEDDRAW OFF
Arcplot: MAPE TR.PJTD
Arcplot: MAPU FEET
Arcplot: MAPSCALE 500000
Arcplot: LINECOLOR 3
Arcplot: ARCS TR.PJTD
Arcplot: LINECOLOR 7
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 15
Arcplot: RESEL COUNTIES.PJTD LINE KCD# = 4310
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 818
Arcplot: ARCS BASIN.PJTD
Arcplot: LINECOLOR 449
Arcplot: ARCS HYDRO.PJTD
Arcplot: SHADESET PLOTTER.SHD
Arcplot: POLYGONSH LAKES.PJTD 684
Arcplot: MARKERSET PLOTTER
Arcplot: MARKERSYM 1
Arcplot: MARKERCOLOR 1
Arcplot: MARKERSI .025
Arcplot: POINTS WATTAB.PT.PJTD
Arcplot: MARKER * (move the well symbol to the legend of the map)
Arcplot: LINECOLOR 219
Arcplot: ARCS WATTAB.CONT.PJTD
Arcplot: ANNOTEXT WATTAB.CONT.PJTD
Arcplot: ANNOTEXT TR.PJTD
Arcplot: ANNOTEXT COUNTIES.PJTD
Arcplot: ANNOTEXT HYDRO.PJTD
Arcplot: MSEL 12 13 14 15 16 17 18 20 21 22 23 24
Arcplot: MROTATE .70
Arcplot: MMOVE .705 5 .650 5
Arcplot: MSEL 1
Arcplot: MDELETE
Arcplot: MAP END
Arcplot: RESET (create a new map with only 1 plot file)
Arcplot: PAGESI 38 18
Arcplot: MAP SOL.WATTABGRP
Arcplot: MBEGIN

Arcplot: PLOT SOL.WATTAB

Arcplot: MEND

Arcplot: MAP END

Arcplot: QUIT

Arc: COLOR SOL.WATTABGRP:E0001.PLT CAL.SOLWATTAB .19685 BANNER

Arc: QUIT

)BY

The following commands were used to create the plot files for the water level change map.
The prompt. The prompt will be shown with each command. (OF 91-11D)

```
)ARC
Arc: ARC PLOT
Arcplot: PAGESI 38 18
Arcplot: MAPE 2 14 38 31
Arcplot: MAP SOL.WLDEC
Arcplot: MAPSCALE 1.0
Arcplot: TEXTSET ROD.TXT
Arcplot: MAPPO CEN CEN
Arcplot: LINECOLOR 14
Arcplot: ARCS LEG.GRID
Arcplot: LINECOLOR 12
Arcplot: ARCS BORDER
Arcplot: LINECOLOR 6
Arcplot: ARCS NEATLINE
Arcplot: LINECOLOR 4
Arcplot: ARCS SCALE
Arcplot: ARCS LOCATOR
Arcplot: RESEL LEG.ANNO3 LINE TYPE = 'BASIN_BND'
Arcplot: LINECOLOR 818
Arcplot: ARCS LEG.ANNO3
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO3 LINE TYPE = 'STREAM'
Arcplot: LINECOLOR 449
Arcplot: ARCS LEG.ANNO3
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO3 LINE TYPE = 'TOWN_BND'
Arcplot: LINECOLOR 3
Arcplot: ARCS LEG.ANNO3
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO3 LINE TYPE = 'COUNTY_BND'
Arcplot: LINECOLOR 7
Arcplot: ARCS LEG.ANNO3
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO3 LINE TYPE = 'STATE_BND'
Arcplot: LINECOLOR 15
Arcplot: ARCS LEG.ANNO3
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO3 LINE TYPE = '
Arcplot: LINECOLOR 4
Arcplot: ARCS LEG.ANNO3
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO3 LINE TYPE = 'CONTOUR'
Arcplot: LINECOLOR 219
Arcplot: ARCS LEG.ANNO3
Arcplot: MSEL 6 7 8 9 10 11 12
Arcplot: MGROUP
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL LOCATOR POLY NAME = 'SOLOMON'
Arcplot: POLYGONSH LOCATOR 24
Arcplot: RESEL SCALE POLY SCALEFILL = 'FILL'
```

Arcplot: MBEGIN
Arcplot: PLOT SOL.WLDEC
Arcplot: MEND
Arcplot: MAP END
Arcplot: QUIT
Arc: COLOR SOL.WLDECGRP:E0001.PLT CAL.SOLWLDEC .19685 BANNER
Arc: QUIT
) BY

The following commands were used to create the plot files for the aquifers map. The prompt for each command will be shown. (OF 91-11E)

```
)ARC
Arc: ARCPLOT
Arcplot: PAGESI 38 18
Arcplot: MAPE 2 14 38 31
Arcplot: MAP SOL.AQUIFERS
Arcplot: MAPSCALE 1.0
Arcplot: TEXTSET ROD.TXT
Arcplot: MAPPO CEN CEN
Arcplot: LINECOLOR 14
Arcplot: ARCS LEG.GRID
Arcplot: LINECOLOR 12
Arcplot: ARCS BORDER
Arcplot: LINECOLOR 6
Arcplot: ARCS NEATLINE
Arcplot: LINECOLOR 4
Arcplot: ARCS SCALE
Arcplot: ARCS LOCATOR
Arcplot: RESEL LEG.ANNO4 LINE TYPE = 'BASIN_BND'
Arcplot: LINECOLOR 818
Arcplot: ARCS LEG.ANNO4
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 LINE TYPE = 'STREAM'
Arcplot: LINECOLOR 449
Arcplot: ARCS LEG.ANNO4
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 LINE TYPE = 'TOWN_BND'
Arcplot: LINECOLOR 3
Arcplot: ARCS LEG.ANNO4
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 LINE TYPE = 'COUNTY_BND'
Arcplot: LINECOLOR 7
Arcplot: ARCS LEG.ANNO4
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 LINE TYPE = 'STATE_BND'
Arcplot: LINECOLOR 15
Arcplot: ARCS LEG.ANNO4
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 LINE TYPE = 'INTERSTATE'
Arcplot: LINECOLOR 870
Arcplot: ARCS LEG.ANNO4
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 LINE TYPE = 'FEDERAL'
Arcplot: LINECOLOR 548
Arcplot: ARCS LEG.ANNO4
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 LINE TYPE = 'STATE'
Arcplot: LINECOLOR 226
Arcplot: ARCS LEG.ANNO4
Arcplot: RESEL LEG.ANNO4 LINE TYPE = '
Arcplot: LINECOLOR 4
Arcplot: ARCS LEG.ANNO4
```

Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 POLY HWY_NO. > 0
Arcplot: TEXTSYM 33
Arcplot: TEXTSI .05
Arcplot: POLYGONTEXT LEG.ANNO4 HWY_NO.
Arcplot: RESEL LEG.ANNO4 POLY HWY_NO. = 70
Arcplot: MARKERSET HWY.MRK
Arcplot: MARKERSYM 1
Arcplot: LABELMARKER LEG.ANNO4 1
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 POLY HWY_NO. = 40
Arcplot: LABELMARKER LEG.ANNO4 2
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 POLY HWY_NO. = 25
Arcplot: LABELMARKER LEG.ANNO4 3
Arcplot: SHADESET PLOTTER.SHD
Arcplot: CLEARSEL
Arcplot: RESEL LEG.ANNO4 POLY POLY_COLOR > 12
Arcplot: POLYGONSH LEG.ANNO4 POLY_COLOR
Arcplot: CLEARSEL
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL LEG.ANNO4 POLY POLY_COLOR = 12
Arcplot: POLYGONSH LEG.ANNO4 POLY_COLOR
Arcplot: MSEL 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Arcplot: MGROUP
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL LOCATOR POLY NAME = 'SOLOMON'
Arcplot: POLYGONSH LOCATOR 24
Arcplot: RESEL SCALE POLY SCALEFILL = 'FILL'
Arcplot: POLYGONSH SCALE 24
Arcplot: ANNOTEXT TITLES.4
Arcplot: ANNOTEXT LEG.ANNO4
Arcplot: LINECOLOR 4
Arcplot: ARCS KGS
Arcplot: ANNOTEXT KGS
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL KGS POLY POLYFILL = 'BLACK'
Arcplot: POLYGONSH KGS 24
Arcplot: CLEARSEL
Arcplot: RESEL KGS POLY POLYFILL = 'GRAY'
Arcplot: POLYGONSH KGS 12
Arcplot: MSEL 11 12 13 14
Arcplot: MGROUP
Arcplot: MSCALE .284
Arcplot: MMOVE * (move the symbol to the corner position)
Arcplot: WEEDDRAW OFF
Arcplot: MAPE TR.PJTD
Arcplot: MAPU FEET
Arcplot: MAPSCALE 500000
Arcplot: LINECOLOR 3
Arcplot: ARCS TR.PJTD
Arcplot: LINECOLOR 7
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 15

Arcplot: RESEL COUNTIES.PJTD LINE KCD# = 4310
Arcplot: ARCS COUNTIES.PJTD
Arcplot: LINECOLOR 818
Arcplot: ARCS BASIN.PJTD
Arcplot: LINECOLOR 449
Arcplot: ARCS HYDRO.PJTD
Arcplot: SHADESET PLOTTER.SHD
Arcplot: POLYGONSH LAKES.PJTD 684
Arcplot: WEEDDRAW ON
Arcplot: RESEL AQFRS.PJTD POLY AQUIFER = 'Ogallala'
Arcplot: POLYGONSH AQFRS.PJTD 54
Arcplot: CLEARSEL
Arcplot: RESEL AQFRS.PJTD POLY AQUIFER = 'Dakota'
Arcplot: POLYGONSH AQFRS.PJTD 720
Arcplot: CLEARSEL
Arcplot: RESEL AQFRS.PJTD POLY AQUIFER = 'Alluvial'
Arcplot: POLYGONSH AQFRS.PJTD 20
Arcplot: CLEARSEL
Arcplot: SHADESET PLOTTER2.SHD
Arcplot: RESEL AQFRS.PJTD POLY AQUIFER = 'Other'
Arcplot: POLYGONSH AQFRS.PJTD 12
Arcplot: LINECOLOR 1
Arcplot: ARCS AQFRS.PJTD
Arcplot: WEEDDRAW OFF
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD LINE TYPE = 'STATE'
Arcplot: LINECOLOR 226
Arcplot: ARCS HWY.PJTD
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD LINE TYPE = 'FEDERAL'
Arcplot: LINECOLOR 548
Arcplot: ARCS HWY.PJTD
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD LINE TYPE = 'INTERSTATE'
Arcplot: LINECOLOR 870
Arcplot: ARCS HWY.PJTD
Arcplot: ANNOTEXT TR.PJTD
Arcplot: ANNOTEXT COUNTIES.PJTD
Arcplot: ANNOTEXT HYDRO.PJTD
Arcplot: ANNOTEXT CITIES.PJTD
Arcplot: TEXTSYM 33
Arcplot: TEXTSI .05
Arcplot: POINTTEXT HWY.PJTD HWY_NO. # CC
Arcplot: MARKERSET MUNICIPAL.MRK
Arcplot: MARKERSYM 111
Arcplot: MARKERSI .07
Arcplot: POINTS CITIES.PJTD
Arcplot: MARKER * (put symbol in legend for city)
Arcplot: MARKERSET HWY.MRK
Arcplot: MARKERSYM 1
Arcplot: MARKERSI .10
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD POINT TYPE = 'INTERSTATE'
Arcplot: POINTMARKERS HWY.PJTD 1000

Arcplot: MARKERSYM 2
Arcplot: MARKERSI .10
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD POINT TYPE = 'FEDERAL'
Arcplot: POINTMARKERS HWY.PJTD 1000
Arcplot: MARKERSYM 3
Arcplot: MARKERSI .16
Arcplot: CLEARSEL
Arcplot: RESEL HWY.PJTD POINT TYPE = 'STATE'
Arcplot: POINTMARKERS HWY.PJTD 1000
Arcplot: MSEL 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 33 34 35
Arcplot: MROTATE .70
Arcplot: MMOVE .705 5 .650 5
Arcplot: MSEL 1
Arcplot: MDELETE
Arcplot: MAP END
Arcplot: RESET (make a new map with only 1 plot file)
Arcplot: PAGESI 38 18
Arcplot: MAP SOL.AQUIFERSGRP
Arcplot: MBEGIN
Arcplot: PLOT SOL.AQUIFERS
Arcplot: MEND
Arcplot: MAP END
Arcplot: QUIT
Arc: COLOR SOL.AQUIFERSGRP:E0001.PLT CAL.SOLAQUIFERS .19685 BANNER
Arc: QUIT
) BY

Appendix 2

Solomon Basin Modeling Data Bases and Model Results

Solomon Basin Modeling Data Bases and Model Results

The Solomon basin was subdivided into five different Subreaches. Subreach 1 includes the area downstream from Waconda Reservoir. Subreach 2 includes the North Fork of the Solomon between Waconda Reservoir and Kirwin Reservoir. Subreach 3 includes the South Fork of the Solomon between Waconda Reservoir and Webster Reservoir. Subreaches 4 and 5 represent the area above the Kirwin and Webster reservoirs, respectively.

The upper two subreaches were modeled somewhat differently than the lower three subreaches. However, a similar approach was used for the development of the input data for the models in each of the five subreaches. In each case, the model input was developed within ARC/INFO. The following provides a description of the steps involved with the preparation of the ARC/INFO data sets which were used as model input for each of the subreaches. ARC/INFO coverages which were used to construct the Grid coverage attributes were generated by the Geohydrology Section from the Kansas Cartographic Data Base. These coverages include alluvial aquifer boundaries, township boundaries, hydrography, and bedrock elevation. Water-table coverages were constructed from the KGS water-level database.

- 1.) A Grid coverage was generated using the ARC GENERATE command. For each of the coverages the Grid was aligned with the township and range.

Grid Resolution

Subreach 1	5280 ft (X) by 2640 ft (Y)
Subreach 2	5280 ft (X) by 2640 ft (Y)
Subreach 3	5280 ft (X) by 2640 ft (Y)
Subreach 4	2640 ft (X) by 1320 ft (Y)
Subreach 5	2640 ft (X) by 1320 ft (Y)

- 2.) Each of the Grid coverages had additional attributes added which are listed below:

Item	Input Width	Output Width	Type	# of Decimals
Row	4	5	B	0
Col	4	5	B	0
Cell	4	5	B	0
Model	4	5	B	0
Wattab	4	12	F	1
Bedelev	4	12	F	1
Approp	4	12	F	1

- 3.) Row, Col, and Cell were used to provide a means of cell identification between the ARC/INFO coverage and the MODFLO Input/Output. Row and Col were arbitrarily assigned from an origin in the upper left corner which is consistent with MODFLO's Row, Col format. i.e.

	Col	1	2	3	.	.	m
Row	1						
	2						
	3						
	.						
	.						
	n						

Cell was arbitrarily assigned the value of the GRID_ID. Cell is used to flag each record to provide a means of attaching model output back to the Grid coverage using the unique Cell ID with the JOINITEM command.

- 4.) Model was used to identify the type of node, and model was arbitrarily defined based upon the aquifer boundary and the location of the river.
- Model = 0 Identifies Cells with no flow
 - Model = 1 Identifies active flow Cells
 - Model = -1 Identifies Cells with constant head
- 5.) Watab was used to record initial water table for each Cell. The Watab value for each Cell represents an average water-table elevation over the Cell area. The water table was contoured with ARCTIN and TINCONTOUR using default parameters. The resulting water-table coverages were then edited to insure accurate representation of the water-table configuration.

Once the edited water table coverage was completed, ARCTIN was used to obtain a TIN which included the edited water table. The TINLATTICE command was then used to generate a lattice of the TIN. In each case, the resolution of the lattice was selected to include at least three points along the X direction and two points along the Y direction of each cell to insure a representative estimate of the Cell value. The lattice was then converted to a point coverage using the VIP command using 100 percent selection to insure that all of the points from the lattice were included in the resulting point coverage.

The point coverage was intersected with the Grid coverage using the INTERSECT command with the join option invoked. The resulting coverage contained individual point values for water-table elevation with all of the associated Grid Cell attributes attached. An average water-table value for each Cell was obtained by running the STATISTICS command on the intersected point coverage. The Cell field was used as the case item for the STATISTICS command and the mean was generated which created a statistics output file with the Cell Id and the average water-table value within the Cell. This statistics file was then attached to the GRID.PAT file using the JOINITEM command with Cell as the relate item.

The following provides a list of the commands used to generate the Watab field in the order in which they would need to be run.

```
Arc:      ARCTIN <Point Coverage> WatTIN POINT Watab # #
Arc:      TINCONTOUR WatTIN WatCON <interval> {base contour} Watab SMOOTH
Arc:      ARCEDIT {proceed with appropriate edit commands to edit contours}
Arcedit:  Save
Arcedit:  QUIT
Arc:      ARCTIN WatCON WatCONTIN LINE Watab # #
Arc:      TINLATTICE WatCONTIN WatLat SMOOTH
           Enter # of points in X and Y direction:      [Appropriate]
           Enter lattice origin (xmin, ymin):           [Use default]
           Enter distance between points in X and Y direction:
Arc:      VIP WatLat WatPnts 100%
Arc:      INTERSECT WatPnts Grid WatPntGrd POINT # JOIN
Arc:      STATISTICS:WatPntGrd.PAT WatStat-1 Cell
           Statistics:      Mean Watab
Arc:      JOINITEM Grid.PAT WatStat-1 Grid.PAT Cell # LINEAR
Arc:      INFO
INFO:     SELECT GRID.PAT
INFO:     CALCULATE WATTAB = MEAN-SPOT
```

```

INFO:    Q STOP
Arc:     DROPITEM Grid.PAT Grid.PAT Frequency
Arc:     DROPITEM Grid.PAT Grid.PAT Mean-Spot

```

- 6.) Bedelev was used to record the bedrock elevation for each cell. The value for the bedrock elevation was generated in much the same manner that the Watab value was generated. The discussion of the methods would be identical to that described for the Watab field above. The following provides a summary list of the ARC/INFO commands used to generate the bedrock elevation for the Bedelev field.

```

Arc:     ARCTIN <Point Coverage> BedTIN POINT Watab # #
Arc:     TINCONTOUR BedTIN BedCON <interv.> {base contour} Bedelev SMOOTH
Arc:     ARCEDIT {proceed with appropriate edit commands to edit contours}
Arcedit: Save
Arcedit: QUIT
Arc:     ARCTIN BedCON BedCONTIN LINE Bedelev # #
Arc:     TINLATTICE BedCONTIN BedLat SMOOTH
          Enter # of points in X and Y direction:      [Appropriate]
          Enter lattice origin (xmin, ymin):           [Use default]
          Enter distance between points in X and Y direction:
Arc:     VIP BedLat BedPnts 100%
Arc:     INTERSECT BedPnts Grid BedPntGrd POINT # JOIN
Arc:     STATISTICS: BedPntGrd.PAT BedStat-1 Cell
          Statistics:      Mean Bedelev
Arc:     JOINITEM Grid.PAT BedStat-1 Grid.PAT Cell # LINEAR
Arc:     INFO
INFO:    SELECT GRID.PAT
INFO:    CALCULATE BEDELEV = MEAN-SPOT
INFO:    Q STOP
Arc:     DROPITEM Grid.PAT Grid.PAT Frequency
Arc:     DROPITEM Grid.PAT Grid.PAT Mean-Spot

```

- 7.) Approp was used to record the total ground-water appropriations within each Cell. The appropriation data was obtained from the Kansas State Board of Agriculture, and the data was placed into an ARC/INFO coverage by the Geohydrology Section of the Kansas Geological Survey. The ground-water appropriations were summed for each of the Cells in the Grid coverage, and the Approp field was derived using an approach similar to that used to derive the Watab and the Bedelev fields.

The coverage containing the appropriation values included all appropriations within the basin. Therefore, the surface-water appropriations were deleted from the coverage prior to totaling the appropriations within each Cell. The following summarizes the ARC/INFO commands used to sum the appropriations for each Cell of the model Grid.

```

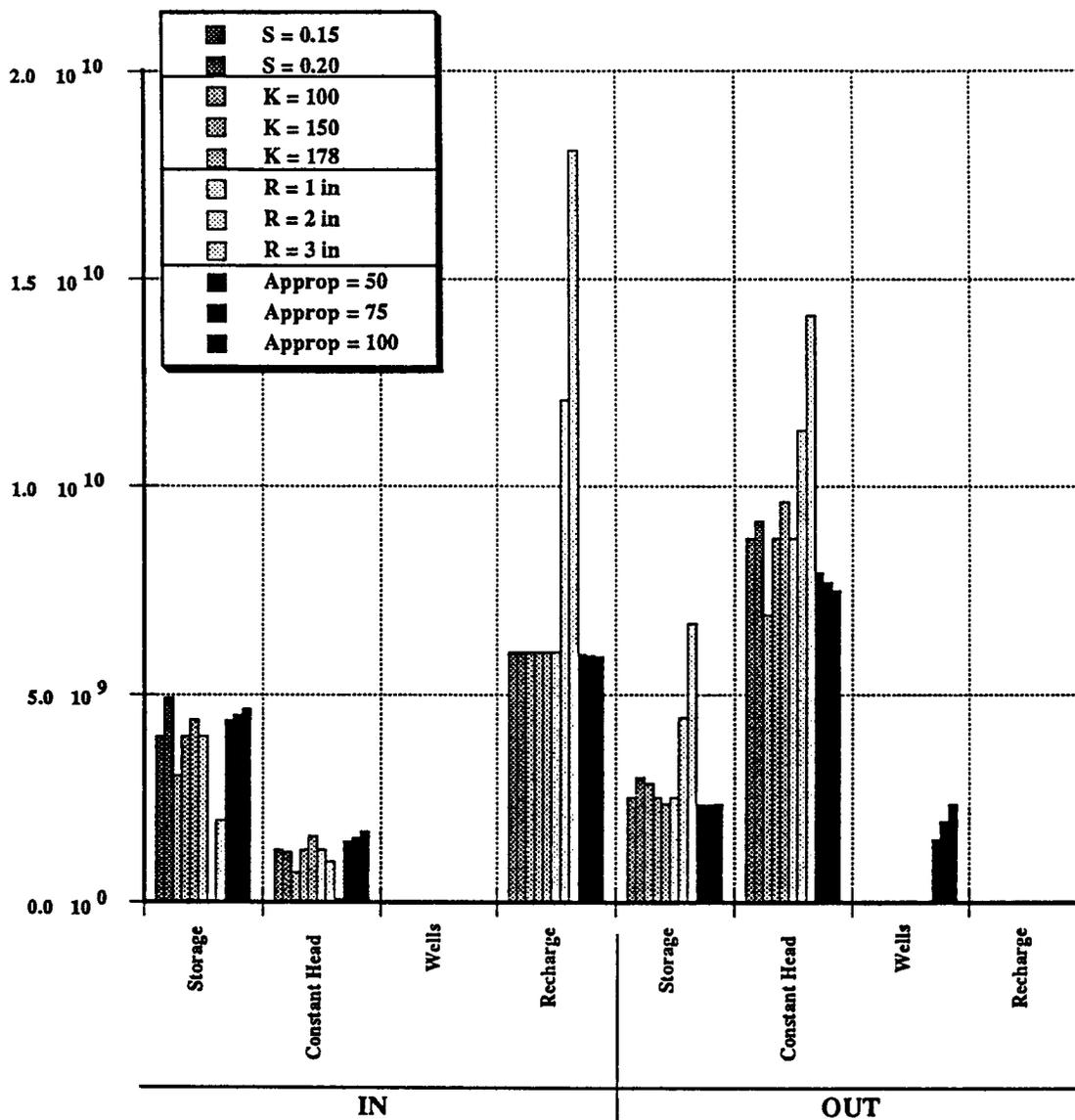
Arc:     INTERSECT WtRights Grid WRPntGrd POINT # JOIN
Arc:     STATISTICS:WRPntGrd.PAT WRst-1 Cell
          Statistics:      Sum Approp
Arc:     JOINITEM Grid.PAT WRst-1 Grid.PAT Cell # LINEAR
Arc:     INFO
INFO:    SELECT GRID.PAT
INFO:    CALCULATE WATAB = SUM-SPOT
INFO:    Q STOP
Arc:     DROPITEM Grid.PAT Grid.PAT Frequency
Arc:     DROPITEM Grid.PAT Grid.PAT Sum-Spot

```

- 8.) The Grid attribute data was exported through INFO. A copy of the Grid.PAT was sorted by Row and Col to insure the appropriate order for MODFLO. The INFO REPORT command was used to generate a report for the individual attributes associated with the Grid.PAT. The output from the REPORT command was re-directed using the OUTPUT command. Once the individual data attributes were exported from ARC/INFO, the data was formatted for MODFLO. A FORTRAN program was used to re-format the appropriation data for input into MODFLO.

Model Results

Hydrologic Budget for Subreach 1



Variation in Hydraulic Conductivity (K)

K = 100; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	3.03E+09	2.83E+09
Constant Head	7.01E+08	6.91E+09
Wells	0.00E+00	0.00E+00
Recharge	6.03E+09	0.00E+00
Total	9.75E+09	9.74E+09
In - Out	1.03E+07	
Percent Difference	0.11	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	3.99E+09	2.49E+09
Constant Head	1.24E+09	8.76E+09
Wells	0.00E+00	0.00E+00
Recharge	6.03E+09	0.00E+00
Total	1.12E+10	1.12E+10
In - Out	1.03E+07	
Percent Difference	0.09	

K = 178; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	4.39E+09	2.36E+09
Constant Head	1.58E+09	9.63E+09
Wells	0.00E+00	0.00E+00
Recharge	6.03E+09	0.00E+00
Total	1.20E+10	1.19E+10
In - Out	1.05E+07	
Percent Difference	0.09	

* The model would not converge with K = 200.

Variation in Specific Yield (S)

The model would not converge with a specific yield of 0.1. Therefore, output from this run was not included.

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	3.99E+09	2.49E+09
Constant Head	1.24E+09	8.76E+09
Wells	0.00E+00	0.00E+00
Recharge	6.03E+09	0.00E+00
Total	1.12E+10	1.12E+10
In - Out	1.03E+07	
Percent Difference	0.09	

K = 150; S = 0.2; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	4.93E+09	2.98E+09
Constant Head	1.19E+09	9.16E+09
Wells	0.00E+00	0.00E+00
Recharge	6.03E+09	0.00E+00
Total	1.21E+10	1.21E+10
In - Out	1.03E+07	
Percent Difference	0.08	

Variation in recharge (R)

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	3.99E+09	2.49E+09
Constant Head	1.24E+09	8.76E+09
Wells	0.00E+00	0.00E+00
Recharge	6.03E+09	0.00E+00
Total	1.12E+10	1.12E+10
In - Out	1.03E+07	
Percent Difference	0.09	

K = 150; S = 0.15; R = 2 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	2.77E+09	4.44E+09
Constant Head	9.66E+08	1.13E+10
Wells	0.00E+00	0.00E+00
Recharge	1.20E+10	0.00E+00
Total	1.57E+10	1.57E+10
In - Out	6.11E+06	
Percent Difference	0.04	

K = 150; S = 0.15; R = 3 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	1.94E+09	6.72E+09
Constant Head	7.91E+08	1.41E+10
Wells	0.00E+00	0.00E+00
Recharge	1.81E+10	0.00E+00
Total	2.08E+10	2.08E+10
In - Out	-5.59E+06	
Percent Difference	-0.03	

Variation in Appropriations

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
 Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	3.99E+09	2.49E+09
Constant Head	1.24E+09	8.76E+09
Wells	0.00E+00	0.00E+00
Recharge	6.03E+09	0.00E+00
Total	1.12E+10	1.12E+10
In - Out	1.03E+07	
Percent Difference	0.09	

K = 150; S = 0.15; R = 1 inch; Appropriations = 50% of total appropriations
 Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	4.37E+09	2.34E+09
Constant Head	1.45E+09	7.95E+09
Wells	0.00E+00	1.50E+09
Recharge	5.98E+09	0.00E+00
Total	1.18E+10	1.17E+10
In - Out	1.05E+07	
Percent Difference	0.09	

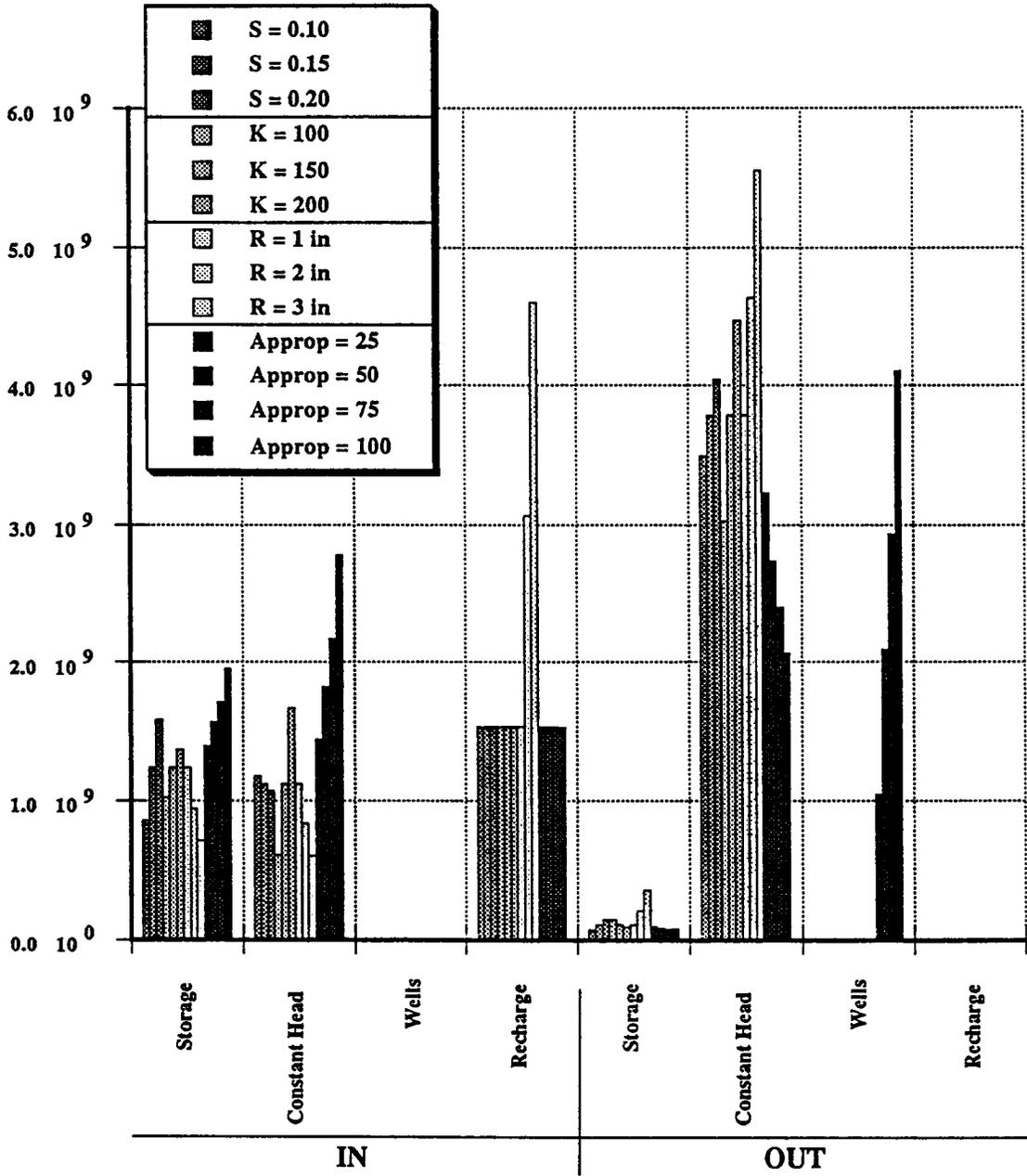
K = 150; S = 0.15; R = 1 inch; Appropriations = 75% of total appropriations
 Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	4.52E+09	2.35E+09
Constant Head	1.54E+09	7.71E+09
Wells	0.00E+00	1.94E+09
Recharge	5.95E+09	0.00E+00
Total	1.20E+10	1.20E+10
In - Out	1.04E+07	
Percent Difference	0.09	

K = 150; S = 0.15; R = 1 inch; Appropriations = 100% of total appropriations
 Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	4.64E+09	2.36E+09
Constant Head	1.69E+09	7.53E+09
Wells	0.00E+00	2.35E+09
Recharge	5.92E+09	0.00E+00
Total	1.22E+10	1.22E+10
In - Out	1.02E+07	
Percent Difference	0.08	

Hydrologic Budget for Subreach 2



Variation in Hydraulic Conductivity (K)

K = 100; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.02E+09	1.50E+08
Constant Head	6.13E+08	3.03E+09
Wells	0.00E+00	0.00E+00
Recharge	1.53E+09	0.00E+00
Total	3.17E+09	3.17E+09
In - Out	-6.00E+04	
Percent Difference	0.00	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.24E+09	1.13E+08
Constant Head	1.12E+09	3.79E+09
Wells	0.00E+00	0.00E+00
Recharge	1.53E+09	0.00E+00
Total	3.90E+09	3.90E+09
In - Out	-9.00E+04	
Percent Difference	0.00	

K = 200; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.37E+09	9.53E+07
Constant Head	1.66E+09	4.48E+09
Wells	0.00E+00	0.00E+00
Recharge	1.53E+09	0.00E+00
Total	4.57E+09	4.57E+09
In - Out	-1.38E+05	
Percent Difference	0.00	

Variation in Specific Yield (S)

K = 150; S = 0.10; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	8.60E+08	7.60E+07
Constant Head	1.18E+09	3.50E+09
Wells	0.00E+00	0.00E+00
Recharge	1.53E+09	0.00E+00
Total	3.57E+09	3.57E+09
In - Out	-1.01E+05	
Percent Difference	0.00	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.24E+09	1.13E+08
Constant Head	1.12E+09	3.79E+09
Wells	0.00E+00	0.00E+00
Recharge	1.53E+09	0.00E+00
Total	3.90E+09	3.90E+09
In - Out	-9.00E+04	
Percent Difference	0.00	

K = 150; S = 0.2; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.58E+09	1.49E+08
Constant Head	1.07E+09	4.04E+09
Wells	0.00E+00	0.00E+00
Recharge	1.53E+09	0.00E+00
Total	4.19E+09	4.19E+09
In - Out	-7.00E+04	
Percent Difference	0.00	

Variation in recharge (R)

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.24E+09	1.13E+08
Constant Head	1.12E+09	3.79E+09
Wells	0.00E+00	0.00E+00
Recharge	1.53E+09	0.00E+00
Total	3.90E+09	3.90E+09
In - Out	-9.00E+04	
Percent Difference	0.00	

K = 150; S = 0.15; R = 2 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	9.45E+08	2.14E+08
Constant Head	8.37E+08	4.63E+09
Wells	0.00E+00	0.00E+00
Recharge	3.07E+09	0.00E+00
Total	4.85E+09	4.85E+09
In - Out	2.40E+05	
Percent Difference	0.00	

K = 150; S = 0.15; R = 3 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	7.14E+08	3.62E+08
Constant Head	6.06E+08	5.56E+09
Wells	0.00E+00	0.00E+00
Recharge	4.60E+09	0.00E+00
Total	5.92E+09	5.92E+09
In - Out	9.00E+04	
Percent Difference	0.00	

Variation in Appropriations

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.24E+09	1.13E+08
Constant Head	1.12E+09	3.79E+09
Wells	0.00E+00	0.00E+00
Recharge	1.53E+09	0.00E+00
Total	3.90E+09	3.90E+09
In - Out	-9.00E+04	
Percent Difference	0.00	

K = 150; S = 0.15; R = 1 inch; Appropriations = 25% of total appropriations
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.39E+09	9.86E+07
Constant Head	1.44E+09	3.23E+09
Wells	0.00E+00	1.04E+09
Recharge	1.53E+09	0.00E+00
Total	4.37E+09	4.37E+09
In - Out	-1.40E+04	
Percent Difference	0.00	

K = 150; S = 0.15; R = 1 inch; Appropriations = 50% of total appropriations
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.56E+09	8.73E+07
Constant Head	1.82E+09	2.74E+09
Wells	0.00E+00	2.09E+09
Recharge	1.53E+09	0.00E+00
Total	4.92E+09	4.92E+09
In - Out	-9.30E+04	
Percent Difference	0.00	

K = 150; S = 0.15; R = 1 inch; Appropriations = 75% of total appropriations
Volumetric Budget at the end of Time Step 4 of Stress Period 10

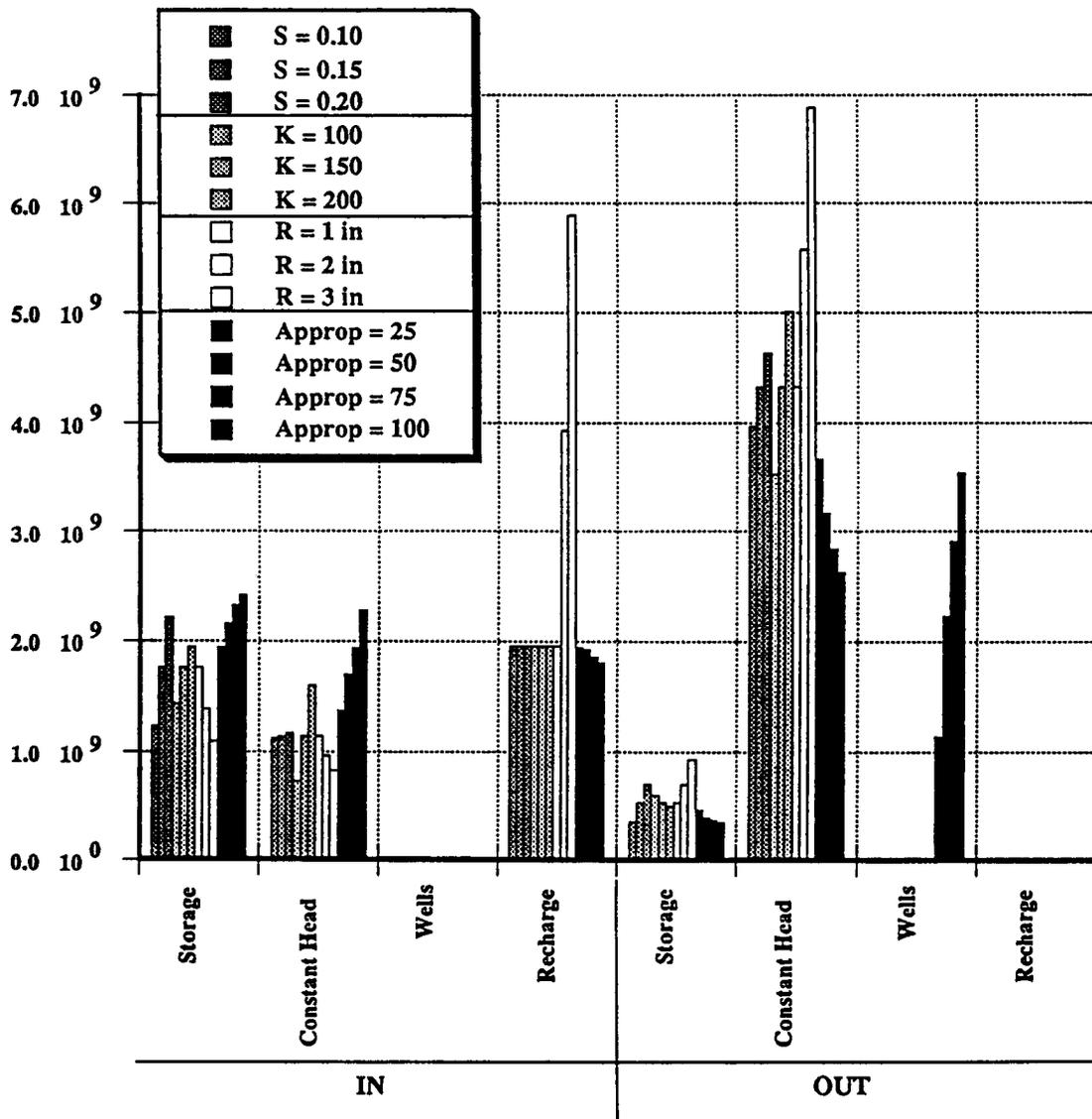
	IN	OUT
Storage	1.71E+09	8.08E+07
Constant Head	2.18E+09	2.41E+09
Wells	0.00E+00	2.93E+09
Recharge	1.53E+09	0.00E+00
Total	5.42E+09	5.42E+09
In - Out	-1.39E+05	
Percent Difference	0.00	

Volumetric Budget at the end of Time Step 4 of Stress Period 10

K = 150; S = 0.15; R = 1 inch; Appropriations = 100% of total appropriations

	IN	OUT
Storage	1.94E+09	8.21E+07
Constant Head	2.78E+09	2.06E+09
Wells	0.00E+00	4.11E+09
Recharge	1.52E+09	0.00E+00
Total	6.26E+09	6.26E+09
In - Out	-1.38E+05	
Percent Difference	0.00	

Hydrologic Budget for Subreach 3



Variation in Hydraulic Conductivity (K)

K = 100; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	1.43E+09	5.98E+08
Constant Head	7.30E+08	3.53E+09
Wells	0.00E+00	0.00E+00
Recharge	1.96E+09	0.00E+00
<u>Total</u>	<u>4.13E+09</u>	<u>4.13E+09</u>
In - Out	3.19E+06	
Percent Difference	0.08	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	1.76E+09	5.31E+08
Constant Head	1.14E+09	4.33E+09
Wells	0.00E+00	0.00E+00
Recharge	1.96E+09	0.00E+00
<u>Total</u>	<u>4.86E+09</u>	<u>4.86E+09</u>
In - Out	3.22E+06	
Percent Difference	0.07	

K = 200; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	1.95E+09	4.96E+08
Constant Head	1.60E+09	5.01E+09
Wells	0.00E+00	0.00E+00
Recharge	1.96E+09	0.00E+00
<u>Total</u>	<u>5.51E+09</u>	<u>5.51E+09</u>
In - Out	3.32E+06	
Percent Difference	0.06	

Variation in Specific Yield (S)

K = 150; S = 0.10; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	1.23E+09	3.53E+08
Constant Head	1.12E+09	3.97E+09
Wells	0.00E+00	0.00E+00
Recharge	1.96E+09	0.00E+00
<u>Total</u>	<u>4.33E+09</u>	<u>4.32E+09</u>
In - Out	3.32E+06	
Percent Difference	0.08	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	1.76E+09	5.31E+08
Constant Head	1.14E+09	4.33E+09
Wells	0.00E+00	0.00E+00
Recharge	1.96E+09	0.00E+00
<u>Total</u>	<u>4.86E+09</u>	<u>4.86E+09</u>
In - Out	3.22E+06	
Percent Difference	0.07	

K = 150; S = 0.2; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	2.21E+09	7.04E+08
Constant Head	1.16E+09	4.63E+09
Wells	0.00E+00	0.00E+00
Recharge	1.96E+09	0.00E+00
<u>Total</u>	<u>5.34E+09</u>	<u>5.33E+09</u>
In - Out	3.33E+06	
Percent Difference	0.06	

Variation in recharge (R)

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	1.76E+09	5.31E+08
Constant Head	1.14E+09	4.33E+09
Wells	0.00E+00	0.00E+00
Recharge	1.96E+09	0.00E+00
Total	4.86E+09	4.86E+09
In - Out	3.22E+06	
Percent Difference	0.07	

K = 150; S = 0.15; R = 2 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	1.38E+09	7.00E+08
Constant Head	9.62E+08	5.57E+09
Wells	0.00E+00	0.00E+00
Recharge	3.93E+09	0.00E+00
Total	6.28E+09	6.27E+09
In - Out	2.18E+06	
Percent Difference	0.03	

K = 150; S = 0.15; R = 3 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	1.09E+09	9.27E+08
Constant Head	8.28E+08	6.89E+09
Wells	0.00E+00	0.00E+00
Recharge	5.89E+09	0.00E+00
Total	7.82E+09	7.82E+09
In - Out	-1.59E+06	
Percent Difference	-0.02	

Variation in Appropriations

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	1.76E+09	5.31E+08
Constant Head	1.14E+09	4.33E+09
Wells	0.00E+00	0.00E+00
Recharge	1.96E+09	0.00E+00
Total	4.86E+09	4.86E+09
In - Out	3.22E+06	
Percent Difference	0.07	

K = 150; S = 0.15; R = 1 inch; Appropriations = 25% of total appropriations
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	1.94E+09	4.61E+08
Constant Head	1.38E+09	3.66E+09
Wells	0.00E+00	1.14E+09
Recharge	1.94E+09	0.00E+00
Total	5.27E+09	5.27E+09
In - Out	3.42E+06	
Percent Difference	0.06	

K = 150; S = 0.15; R = 1 inch; Appropriations = 50% of total appropriations
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	2.16E+09	3.97E+08
Constant Head	1.70E+09	3.17E+09
Wells	0.00E+00	2.23E+09
Recharge	1.92E+09	0.00E+00
Total	5.80E+09	5.80E+09
In - Out	3.29E+06	
Percent Difference	0.06	

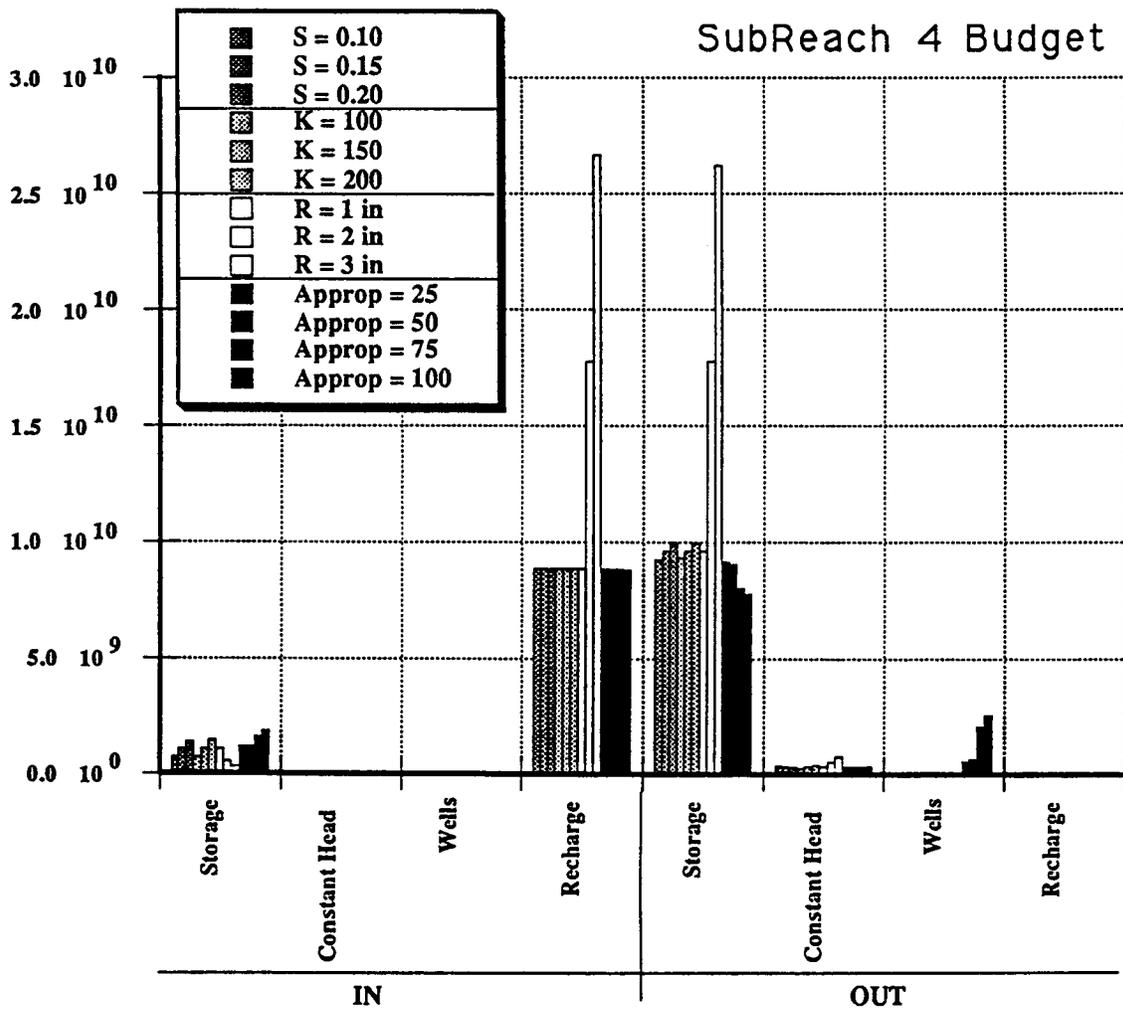
K = 150; S = 0.15; R = 1 inch; Appropriations = 75% of total appropriations
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	2.32E+09	3.71E+08
Constant Head	1.94E+09	2.84E+09
Wells	0.00E+00	2.91E+09
Recharge	1.86E+09	0.00E+00
Total	6.12E+09	6.12E+09
In - Out	3.08E+06	
Percent Difference	0.05	

K = 150; S = 0.15; R = 1 inch; Appropriations = 100% of total appropriations
 Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	2.42E+09	3.44E+08
Constant Head	2.28E+09	2.62E+09
Wells	0.00E+00	3.53E+09
Recharge	1.81E+09	0.00E+00
Total	6.50E+09	6.50E+09
In - Out	3.10E+06	
Percent Difference	0.05	

Hydrologic Budget for Subreach 4



Variation in Appropriations

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.09E+09	9.63E+09
Constant Head	1.99E+07	3.39E+08
Wells	0.00E+00	0.00E+00
Recharge	8.88E+09	0.00E+00
Total	9.99E+09	9.97E+09

In - Out 1.55E+07
Percent Difference 0.15

K = 150; S = 0.15; R = 1 inch; Appropriations = 25% of total appropriations
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.21E+09	9.18E+09
Constant Head	1.98E+07	3.39E+08
Wells	0.00E+00	5.79E+08
Recharge	8.88E+09	0.00E+00
Total	1.01E+10	1.01E+10

In - Out 1.55E+07
Percent Difference 0.15

K = 150; S = 0.15; R = 1 inch; Appropriations = 50% of total appropriations
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.22E+09	9.07E+09
Constant Head	1.99E+07	3.38E+08
Wells	0.00E+00	7.03E+08
Recharge	8.88E+09	0.00E+00
Total	1.01E+10	1.01E+10

In - Out 1.54E+07
Percent Difference 0.15

K = 150; S = 0.15; R = 1 inch; Appropriations = 75% of total appropriations
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.62E+09	8.08E+09
Constant Head	1.99E+07	3.36E+08
Wells	0.00E+00	2.09E+09
Recharge	8.88E+09	0.00E+00
Total	1.05E+10	1.05E+10

In - Out 1.54E+07
Percent Difference 0.15

Variation in Hydraulic Conductivity (K)

K = 100; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	7.36E+08	9.35E+09
Constant Head	8.98E+06	2.66E+08
Wells	0.00E+00	0.00E+00
Recharge	8.88E+09	0.00E+00
Total	9.63E+09	9.61E+09
In - Out	1.55E+07	
Percent Difference	0.16	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.09E+09	9.63E+09
Constant Head	1.99E+07	3.39E+08
Wells	0.00E+00	0.00E+00
Recharge	8.88E+09	0.00E+00
Total	9.99E+09	9.97E+09
In - Out	1.55E+07	
Percent Difference	0.15	

K = 200; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.46E+09	9.95E+09
Constant Head	3.69E+07	4.11E+08
Wells	0.00E+00	0.00E+00
Recharge	8.88E+09	0.00E+00
Total	1.04E+10	1.04E+10
In - Out	1.55E+07	
Percent Difference	0.15	

Variation in Specific Yield (S)

K = 150; S = 0.10; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	7.53E+08	9.27E+09
Constant Head	2.06E+07	3.76E+08
Wells	0.00E+00	0.00E+00
Recharge	8.88E+09	0.00E+00
Total	9.66E+09	9.64E+09
In - Out	1.54E+07	
Percent Difference	0.16	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.09E+09	9.63E+09
Constant Head	1.99E+07	3.39E+08
Wells	0.00E+00	0.00E+00
Recharge	8.88E+09	0.00E+00
Total	9.99E+09	9.97E+09
In - Out	1.55E+07	
Percent Difference	0.15	

K = 150; S = 0.2; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.39E+09	9.96E+09
Constant Head	1.92E+07	3.18E+08
Wells	0.00E+00	0.00E+00
Recharge	8.88E+09	0.00E+00
Total	1.03E+10	1.03E+10
In - Out	1.57E+07	
Percent Difference	0.15	

Variation in recharge (R)

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.09E+09	9.63E+09
Constant Head	1.99E+07	3.39E+08
Wells	0.00E+00	0.00E+00
Recharge	8.88E+09	0.00E+00
Total	9.99E+09	9.97E+09
In - Out	1.55E+07	
Percent Difference	0.15	

K = 150; S = 0.15; R = 2 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	5.57E+08	1.78E+10
Constant Head	1.23E+07	5.61E+08
Wells	0.00E+00	0.00E+00
Recharge	1.78E+10	0.00E+00
Total	1.83E+10	1.83E+10
In - Out	9.57E+06	
Percent Difference	0.05	

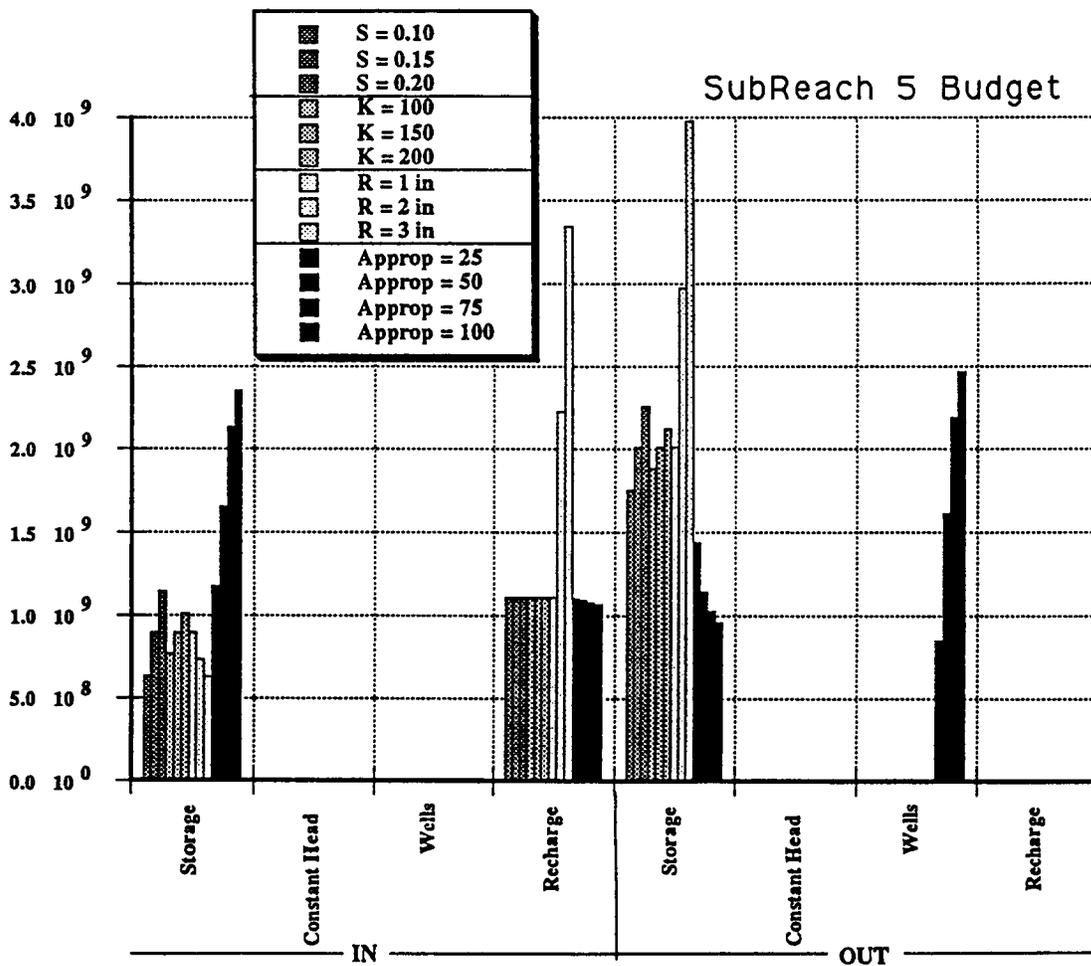
K = 150; S = 0.15; R = 3 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	3.31E+08	2.62E+10
Constant Head	1.04E+07	7.95E+08
Wells	0.00E+00	0.00E+00
Recharge	2.67E+10	0.00E+00
Total	2.70E+10	2.70E+10
In - Out	-7.60E+06	
Percent Difference	-0.03	

K = 150; S = 0.15; R = 1 inch; Appropriations = 100% of total appropriations
 Volumetric Budget at the end of Time Step 4 of Stress Period 10

	IN	OUT
Storage	1.88E+09	7.83E+09
Constant Head	1.99E+07	3.35E+08
Wells	0.00E+00	2.58E+09
Recharge	8.86E+09	0.00E+00
Total	1.08E+10	1.07E+10
In - Out	1.54E+07	
Percent Difference	0.14	

Hydrologic Budget for Subreach 5



Variation in Hydraulic Conductivity (K)

K = 100; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	7.69E+08	1.89E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	1.11E+09	0.00E+00
Total	1.88E+09	1.89E+09
In - Out	-1.99E+06	
Percent Difference	-0.11	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	8.97E+08	2.01E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	1.11E+09	0.00E+00
Total	2.01E+09	2.01E+09
In - Out	-2.03E+06	
Percent Difference	-0.10	

K = 200; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	<u>IN</u>	<u>OUT</u>
Storage	1.01E+09	2.13E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	1.11E+09	0.00E+00
Total	2.13E+09	2.13E+09
In - Out	-2.10E+06	
Percent Difference	-0.10	

Variation in Specific Yield (S)

K = 150; S = 0.10; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	6.38E+08	1.75E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	1.11E+09	0.00E+00
Total	1.75E+09	1.75E+09
In - Out	-2.01E+06	
Percent Difference	-0.11	

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	8.97E+08	2.01E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	1.11E+09	0.00E+00
Total	2.01E+09	2.01E+09
In - Out	-2.03E+06	
Percent Difference	-0.10	

K = 150; S = 0.2; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	1.15E+09	2.26E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	1.11E+09	0.00E+00
Total	2.26E+09	2.26E+09
In - Out	-2.00E+06	
Percent Difference	-0.09	

Variation in recharge (R)

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	8.97E+08	2.01E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	1.11E+09	0.00E+00
Total	2.01E+09	2.01E+09
In - Out	-2.03E+06	
Percent Difference	-0.10	

K = 150; S = 0.15; R = 2 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	7.38E+08	2.97E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	2.23E+09	0.00E+00
Total	2.97E+09	2.97E+09
In - Out	-2.66E+06	
Percent Difference	-0.09	

K = 150; S = 0.15; R = 3 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	6.32E+08	3.98E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	3.35E+09	0.00E+00
Total	3.98E+09	3.98E+09
In - Out	-4.86E+06	
Percent Difference	-0.12	

Variation in Appropriations

K = 150; S = 0.15; R = 1 inch; Appropriations = 0 acre-feet.
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	8.97E+08	2.01E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	0.00E+00
Recharge	1.11E+09	0.00E+00
Total	2.01E+09	2.01E+09
In - Out	-2.03E+06	
Percent Difference	-0.10	

K = 150; S = 0.15; R = 1 inch; Appropriations = 25% of total appropriations
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	1.18E+09	1.43E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	8.48E+08
Recharge	1.10E+09	0.00E+00
Total	2.28E+09	2.28E+09
In - Out	-1.94E+06	
Percent Difference	-0.09	

K = 150; S = 0.15; R = 1 inch; Appropriations = 50% of total appropriations
Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	1.66E+09	1.15E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	1.61E+09
Recharge	1.10E+09	0.00E+00
Total	2.75E+09	2.76E+09
In - Out	-2.00E+06	
Percent Difference	-0.07	

K = 150; S = 0.15; R = 1 inch; Appropriations = 75% of total appropriations
 Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	2.14E+09	1.03E+09
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	2.19E+09
Recharge	1.08E+09	0.00E+00
Total	3.22E+09	3.22E+09
In - Out	-2.10E+06	
Percent Difference	-0.07	

K = 150; S = 0.15; R = 1 inch; Appropriations = 100% of total appropriations
 Volumetric Budget at the end of Time Step 8 of Stress Period 10

	IN	OUT
Storage	2.36E+09	9.60E+08
Constant Head	0.00E+00	0.00E+00
Wells	0.00E+00	2.47E+09
Recharge	1.07E+09	0.00E+00
Total	3.43E+09	3.43E+09
In - Out	-2.06E+06	
Percent Difference	-0.06	

Appendix 3

Soil-Moisture Budget Analysis and Regional Groundwater Recharge Estimation for the Solomon Basin, Kansas

Appendix 5

Soil-Moisture Budget Analysis and Regional Groundwater Recharge Estimation for the Solomon Watershed, Kansas

Marios Sophocleous, Rod Bassler, and Tom McClain
August 1990/Revised May 1991

Abstract

For the Solomon watershed the mean annual precipitation during the 1964–1988 period was 23.29 in., whereas the mean annual potential evapotranspiration (ET) for a typical meteorological station, such as Kirwin, was 27.8 in. Average streamflow and baseflow at the stream gaging stations of the watershed have been declining over time, but precipitation patterns have not changed. Thus at the Glade station average streamflow was approximately 30,000 acft/yr and baseflow approximately 7,000 acft/yr during the 1950's and 1960's, whereas during the 1970's and 1980's they were approximately 10,000 and 5,000 ac-ft/yr, respectively. Water-balance diagrams for the area show that precipitation increases during the warm months, as do potential and actual ET. At the western portion of the watershed, potential ET is always greater than precipitation. As one moves eastward, precipitation occasionally exceeds potential ET, and at the eastern end of the watershed precipitation almost equals potential ET. Two methods were employed to estimate regional groundwater recharge for the watershed. One is based on streamflow record analysis and the other on soil-moisture budget analysis. Assuming that the long term average recharge equals the long term average groundwater outflow under equilibrium conditions, such as what existed in the early 1960's in the area, it is estimated that 0.73 in. per year (in./yr) of recharge occurred. Based on the soil-moisture budget analysis for the same period, the estimated recharge was 1.15 in./yr. Thus the average recharge based on the two estimation methods is estimated to be 0.94 in./yr, which represents only 4% of the average annual precipitation. During the early 1980's, groundwater appropriations at the Glade subwatershed amounted to 4.7 times the estimated recharge.

Components of the water balance in the Solomon watershed

Precipitation and temperature

There are 19 meteorologic stations in or near the Solomon watershed that have precipitation records of sufficient length and completeness for analysis (National Oceanic and Atmospheric Administration, various years). The locations of these stations are shown in fig. 1. All stations measure precipitation and temperature; in addition, the Kirwin, Webster and Glen Elder stations measure pan evaporation. However, these data are not complete (numerous missing values).

The mean annual precipitation over the entire watershed for 1964–1988 ranges from 18.5 in. at the west end of the watershed to 30 in. at the east end. The mean annual precipitation during the 1964–1988 period was 23.29 in. The monthly precipitation and temperature records for the last 25 years (1964–1988) for which data are available for all 19 stations are shown in tables 1 and 2, respectively (National Weather Service data tapes).

Evapotranspiration

Evapotranspiration is the combined process of evaporation from free water and bare soil surfaces and transpiration by plants. Potential evapotranspiration is defined as the evapotranspiration that would occur from a vegetation-covered soil surface that is never short of water. Because moisture is never restricted, potential evapotranspiration is limited solely by available energy, primarily solar energy. If there is a shortage of moisture, actual evapotranspiration will fall short of potential evapotranspiration.

No direct measurements of evaporation or evapotranspiration are available in the Solomon watershed. As an approach to the problem of estimating potential evapotranspiration, the empirical method of Thornthwaite (1948) was applied to the data of all 19 stations shown in fig. 1. The minimum amount of meteorologic data required for this method and the method's simplicity were the factors considered in choosing this method, although the results are only a rough approximation of evapotranspiration.

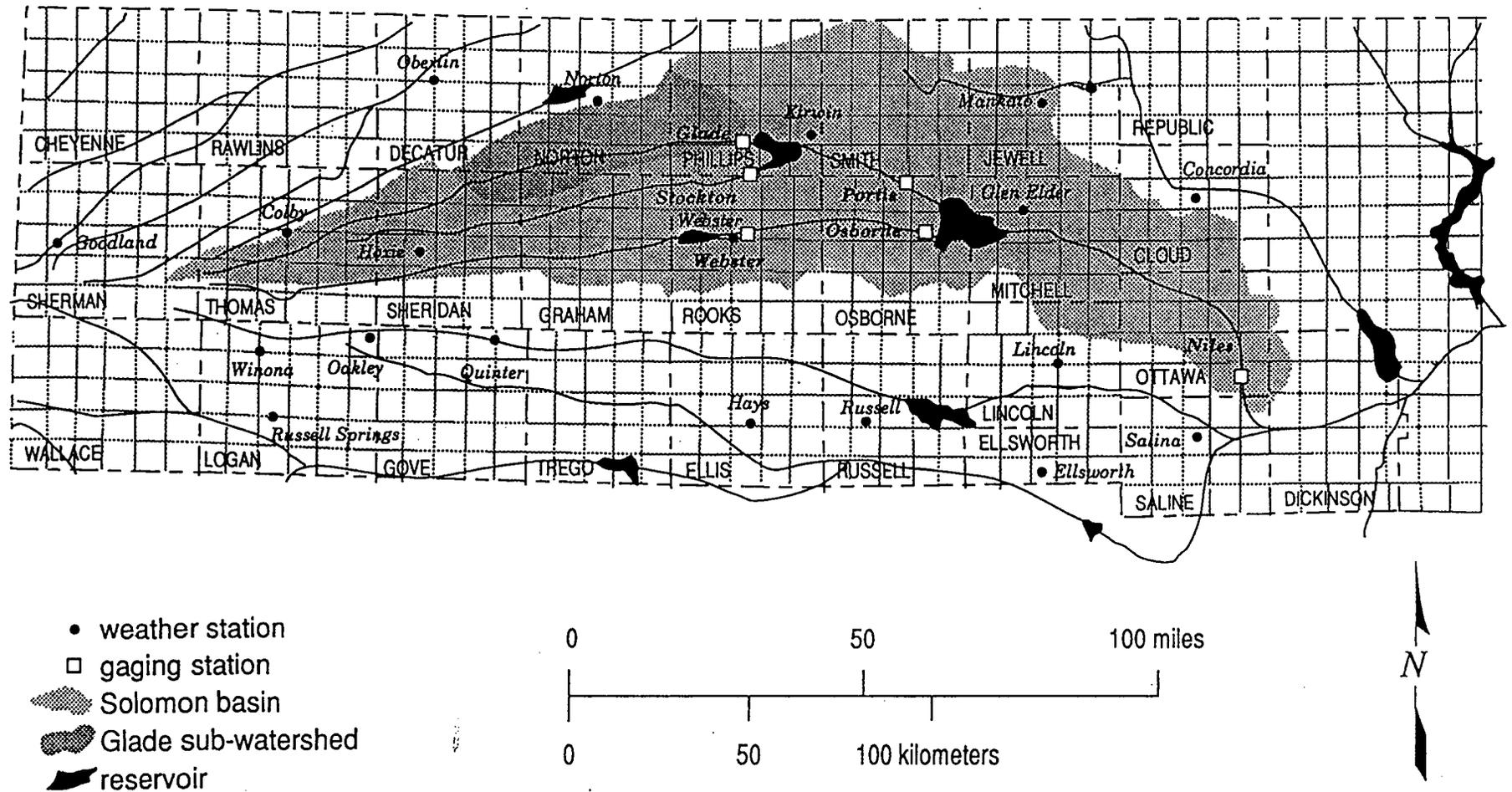


Figure 1: Precipitation and stream flow data stations for the Solomon basin

The formula developed by Thornthwaite for determining potential evapotranspiration from temperature data is:

$$E = 1.62 (10T / I)^a, \quad (1)$$

where E is the monthly evapotranspiration in centimeters, T is the mean monthly temperature in degrees centigrade, I is the heat index determined by adding for the expression $(T/5)^{1.514}$ 12 months, and

$$a = 67.5 \times 10^{-8}I^3 - 77.1 \times 10^{-6}I^2 + 0.0179I + 0.492.$$

The computed potential evapotranspiration is adjusted for day length, which is determined by the latitude of the data-collecting station.

The average monthly and yearly values determined by the Thornthwaite approach for the centrally-located Kirwin station are listed in Table 3. The average (1964–1988) annual potential evapotranspiration from this station is approximately 27.8 in.

Table 1. Average monthly and yearly precipitation records in inches for the 25-year period (1964–1988) for all 19 stations in and around the Solomon watershed shown in Figure. 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly Total
Colby	0.30	0.37	1.15	1.72	3.61	3.08	3.08	2.01	1.62	1.13	0.62	0.37	19.05
Concordia	0.59	0.80	2.16	2.52	4.17	4.42	3.82	3.60	2.85	1.99	1.20	0.90	29.01
Ellsworth	0.60	0.80	2.19	2.54	4.11	3.92	2.86	3.35	3.18	2.35	1.11	0.86	27.89
Glen Elder	0.50	0.62	1.90	2.48	3.64	3.57	2.94	2.70	2.88	2.03	1.06	0.61	24.92
Goodland	0.42	0.43	1.18	1.43	3.53	2.96	2.86	1.74	1.50	1.00	0.70	0.44	18.18
Hays	0.35	0.58	1.84	2.09	2.72	3.37	3.22	2.54	1.86	1.54	0.99	0.58	21.68
Hoxie	0.38	0.52	1.42	2.14	3.36	2.74	2.80	2.41	1.60	1.27	0.85	0.48	19.97
Kirwin	0.34	0.60	1.90	2.35	4.01	3.20	2.71	2.46	2.56	1.74	0.97	0.47	23.31
Lincoln	0.67	0.84	2.23	2.50	4.16	3.21	3.11	3.34	2.88	2.23	1.35	0.88	27.39
Mankato	0.59	0.79	1.88	2.70	3.99	3.77	3.06	3.44	3.10	2.04	1.28	0.92	27.56
Norton	0.29	0.42	1.44	2.52	3.98	3.78	3.17	2.85	2.18	1.74	0.95	0.39	23.71
Oakley	0.39	0.48	1.09	1.78	3.23	2.70	3.02	2.29	1.57	1.10	0.82	0.48	18.96
Oberlin	0.42	0.54	1.57	2.23	3.59	3.84	3.58	2.14	1.98	1.33	0.88	0.53	22.63
Quinter	0.45	0.73	1.51	2.08	3.84	2.90	3.19	3.00	1.87	1.50	1.03	0.64	22.73
Russell FAA	0.57	0.74	2.17	2.95	3.46	3.19	3.07	3.75	2.73	1.77	1.13	0.83	26.36
Russell Springs	0.39	0.37	1.21	1.54	3.14	2.81	2.61	2.20	1.72	1.11	0.75	0.37	18.23
Salina	0.72	0.94	2.43	3.15	4.24	4.20	2.95	3.36	2.94	2.60	1.47	0.99	29.99
Webster	0.41	0.63	1.67	2.28	3.71	2.66	2.92	2.81	2.14	1.64	0.97	0.59	22.44
Winona	0.34	0.37	1.12	1.41	3.31	2.86	2.74	2.40	1.51	1.37	0.63	0.45	18.52
Average yearly total													23.29

Table 2. Average monthly air temperature records in degrees Fahrenheit for the 25-year period (1964–1988) for all 19 stations in and around the Solomon watershed shown in Figure 1.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Colby	25	29	36	48	58	69	75	72	62	50	36	27
Concordia	24	30	40	52	62	72	78	75	66	54	40	29
Ellsworth	26	32	42	54	64	74	79	77	68	56	41	31
Glen Elder	22	28	39	51	60	71	78	75	65	53	39	28
Goodland	27	31	37	48	58	68	75	72	63	50	37	29
Hays	25	30	40	52	61	72	78	75	66	53	40	29
Hoxie	28	33	41	53	61	72	78	75	66	54	39	30
Kirwin	23	28	38	51	59	70	77	74	64	51	38	26
Lincoln	26	32	43	54	63	74	80	78	69	56	41	31
Mankato	21	27	37	49	60	69	75	73	63	52	36	26
Norton	21	27	35	49	58	68	74	69	60	48	35	26
Oakley	28	33	40	51	59	70	77	73	64	53	38	31
Oberlin	26	32	40	51	61	70	77	75	65	52	38	29
Quinter	26	31	37	49	60	70	77	74	65	52	39	29
Russell FAA	26	32	41	52	62	73	79	76	66	55	40	30
Russell Springs	27	31	38	49	59	69	77	73	63	52	38	29
Salina	26	32	42	54	63	73	80	77	68	56	42	31
Webster	24	29	39	51	61	72	77	74	65	52	39	28
Winona	27	31	38	48	57	69	76	72	64	52	38	29

Table 3. Thornthwaite potential evapotranspiration calculation (inches per month)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1964	0.00	0.00	0.14	1.76	4.08	5.07	7.26	5.34	3.59	1.74	0.47	0.00	29.46
1965	0.00	0.00	0.00	2.10	4.16	4.96	6.20	5.30	2.72	2.04	0.67	0.08	28.23
1966	0.00	0.00	0.69	1.39	3.48	5.37	7.35	5.11	3.49	1.72	0.29	0.99	28.88
1967	0.00	0.00	0.82	2.17	2.98	4.64	5.63	4.96	3.22	1.88	0.47	0.00	26.76
1968	0.00	0.00	0.87	1.79	2.76	5.48	6.30	5.55	3.31	1.87	0.34	0.00	28.26
1969	0.00	0.00	0.00	2.08	3.65	4.40	6.40	5.49	3.69	1.27	0.58	0.00	27.56
1970	0.00	0.00	0.00	1.28	4.11	5.06	6.49	6.16	3.14	1.36	0.23	0.00	27.83
1971	0.00	0.00	0.28	1.88	2.87	5.76	5.67	5.40	3.21	2.13	0.53	0.00	27.73
1972	0.00	0.00	0.92	1.79	3.36	5.26	5.87	5.25	3.44	1.45	0.18	0.00	27.50
1973	0.00	0.00	0.90	1.47	2.96	5.24	6.04	5.74	3.08	1.91	0.40	0.00	27.72
1974	0.00	0.03	0.73	1.86	3.68	4.76	6.31	4.77	2.78	2.05	0.48	0.00	27.45
1975	0.00	0.00	0.07	1.66	3.48	4.70	6.15	5.59	3.01	1.80	0.32	0.00	26.78
1976	0.00	0.48	0.50	2.11	2.98	5.00	6.22	5.58	3.30	1.19	0.12	0.00	27.49
1977	0.00	0.16	0.77	2.23	4.22	5.60	6.76	4.89	3.42	1.65	0.39	0.00	30.07
1978	0.00	0.00	0.30	2.16	3.20	5.30	6.39	5.30	3.80	1.65	0.22	0.00	28.31
1979	0.00	0.00	0.52	1.82	3.17	4.98	6.03	5.23	3.68	2.12	0.17	0.11	27.83
1980	0.00	0.00	0.10	1.49	3.15	5.27	7.05	5.71	3.69	1.88	0.52	0.00	28.86
1981	0.00	0.00	0.81	2.75	2.83	5.48	6.20	5.21	3.51	0.00	0.62	0.00	28.40
1982	0.00	0.00	0.54	1.68	3.82	3.39	6.33	5.60	3.23	1.77	0.17	0.00	26.52
1983	0.00	0.01	0.39	1.16	2.70	4.54	6.76	6.69	3.60	1.71	0.38	0.00	27.93
1984	0.00	0.25	0.09	1.23	3.24	5.19	6.14	6.00	3.06	1.47	0.35	0.00	27.02
1985	0.00	0.00	0.78	2.25	3.75	4.49	5.98	4.73	3.24	1.31	0.00	0.00	26.54
1986	0.04	0.00	0.96	1.84	3.21	5.81	6.66	5.18	3.82	1.64	0.08	0.00	29.24
1987	0.00	0.19	0.52	1.90	0.79	5.62	6.50	5.19	3.67	1.54	0.62	0.00	26.53
1988	0.00	0.00	0.45	1.52	3.82	5.18	5.76	5.24	2.98	0.11	0.44	0.00	25.51
Average yearly total													27.78

Streamflow and baseflow

The runoff from the Solomon watershed is measured at several stream gaging stations (fig. 1). However, only the Glade station had complete streamflow and baseflow data. The streamflow records for the Glade station have been analyzed for 1955–1976 (Phillips, 1980; U.S. Geological Survey, various years). The average streamflow over this period was 23,454 ac-ft/yr. Figure 2 shows the total annual streamflow and baseflow (the groundwater contribution to streamflow) data for that period of record, together with the mean precipitation over the area. Baseflow data were obtained from streamflow data following the separation procedures outlined by Busby and Armentrout (1965). To distinguish the data trend more clearly, we applied a seven-year moving-average time-trend analysis (Davis, 1973) to the data, also as shown in fig. 2. The moving-average analysis indicates how the major or long-term features of the record are emphasized at the expense of shorter variations. A streamflow decline is evident from the data, although average areal precipitation over the same period of record does not decrease (fig. 2). This indicates that a growing increase in groundwater use is probably one major cause of this streamflow decline.

To estimate the average yearly declines in streamflow and baseflow, we performed a linear regression on the log-transformed data, with the resulting straight lines on the semilog paper plotted in fig. 3. Projection to the future is possible by extrapolation. Correlation coefficients of 93.5% for the streamflow and 82.3% for baseflow are calculated, indicating that the straight line on the semi-log plot adequately approximates the flow data. From figs. 2 and 3 it can be seen that, during the 1950's and 1960's, the long-term average streamflow was approximately 30,000 ac-ft/yr and the baseflow was ~7,000 ac-ft/yr, whereas during the 1970's and 1980's they were approximately 10,000 ac-ft/yr and 5,000 ac-ft/yr, respectively.

Solomon watershed soils

The soils of the Solomon watershed formed mainly from deposits of loess, outwash material, and alluvium. Figure 4 is a generalized soil associations map of the Solomon watershed.

Glade Streamflow & Baseflow (Data Smoothed, 7 terms)

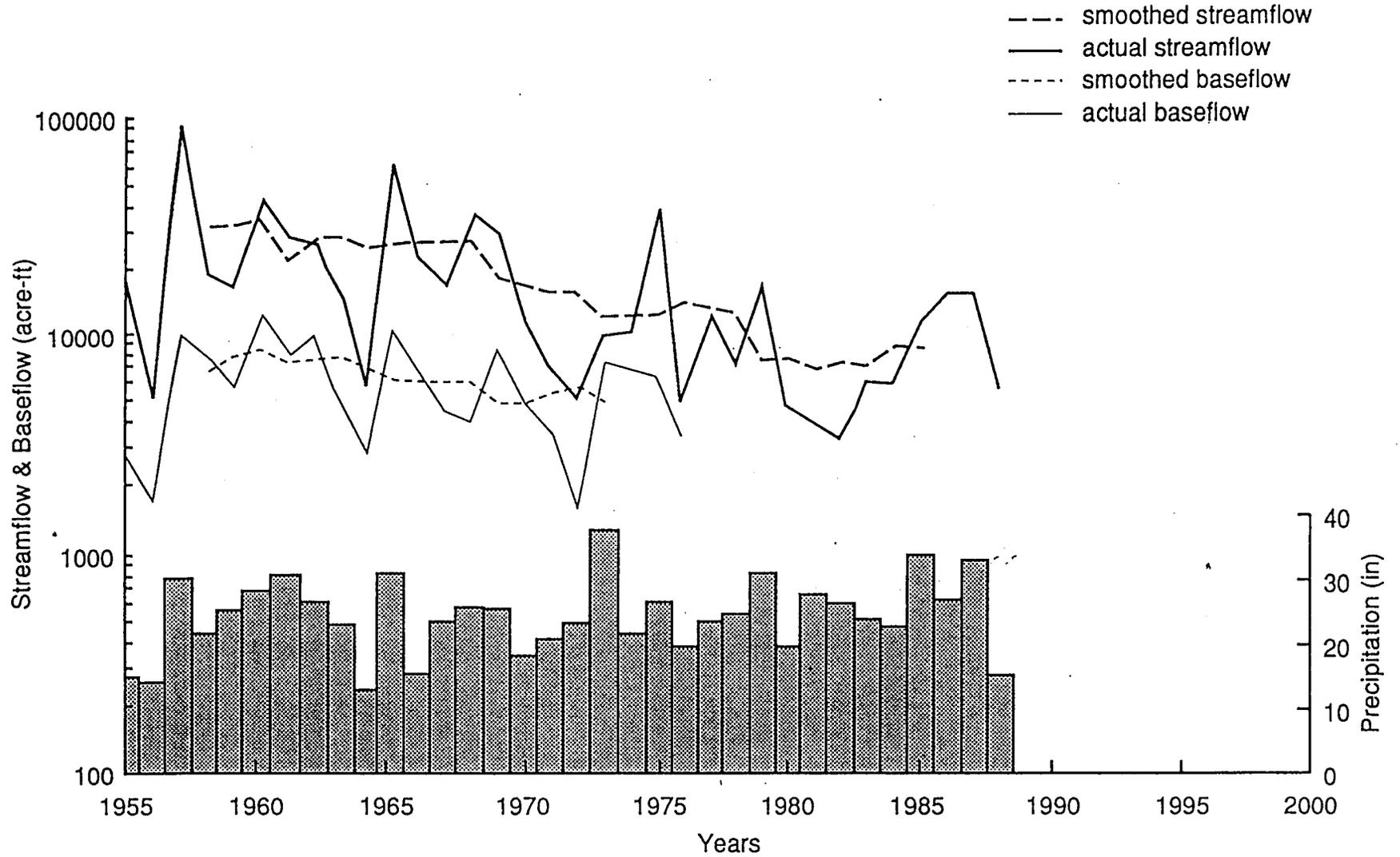


Figure 2: Annual streamflow, baseflow, and precipitation data for the Glade station. Dash lines indicate seven-year moving-average trend for streamflow and baseflow.

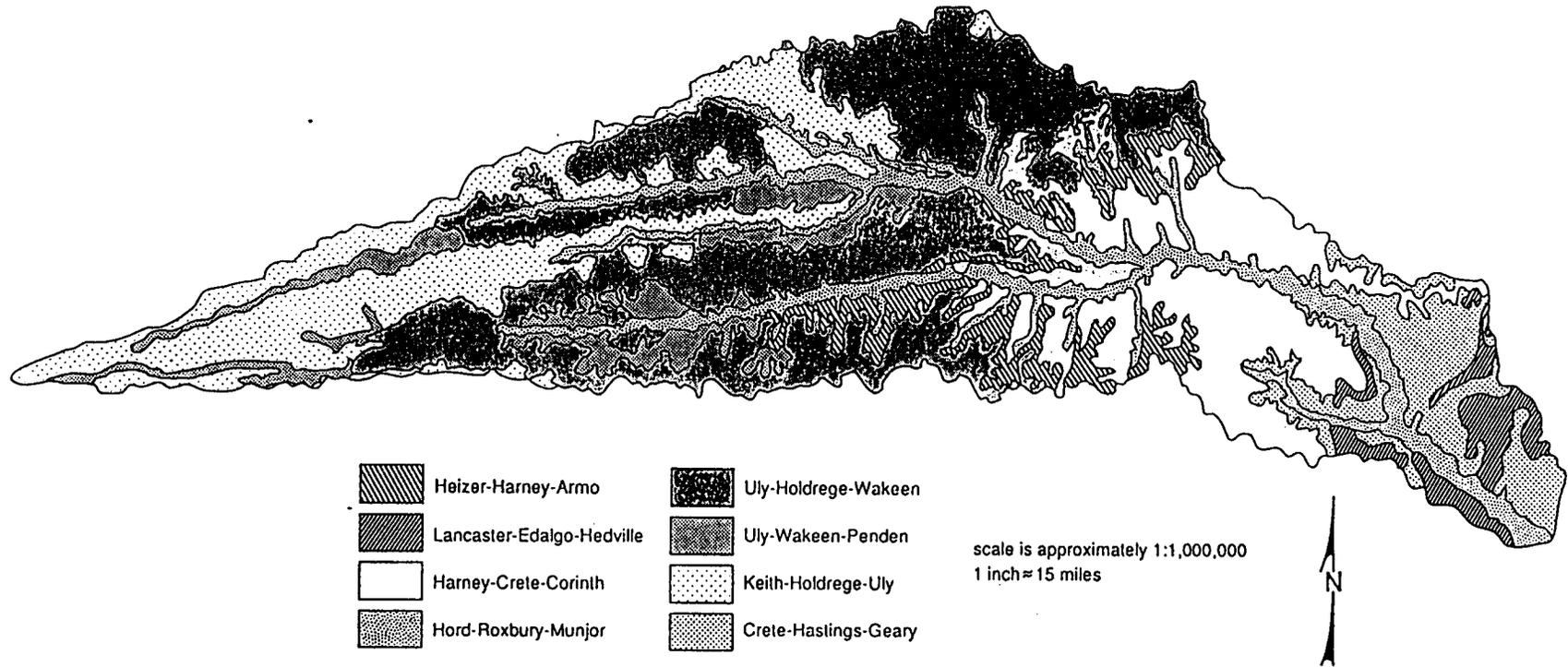


Figure 4: Generalized soil associations of the Solomon basin

Glade Streamflow & Baseflow (Data Smoothed, 7 Terms)

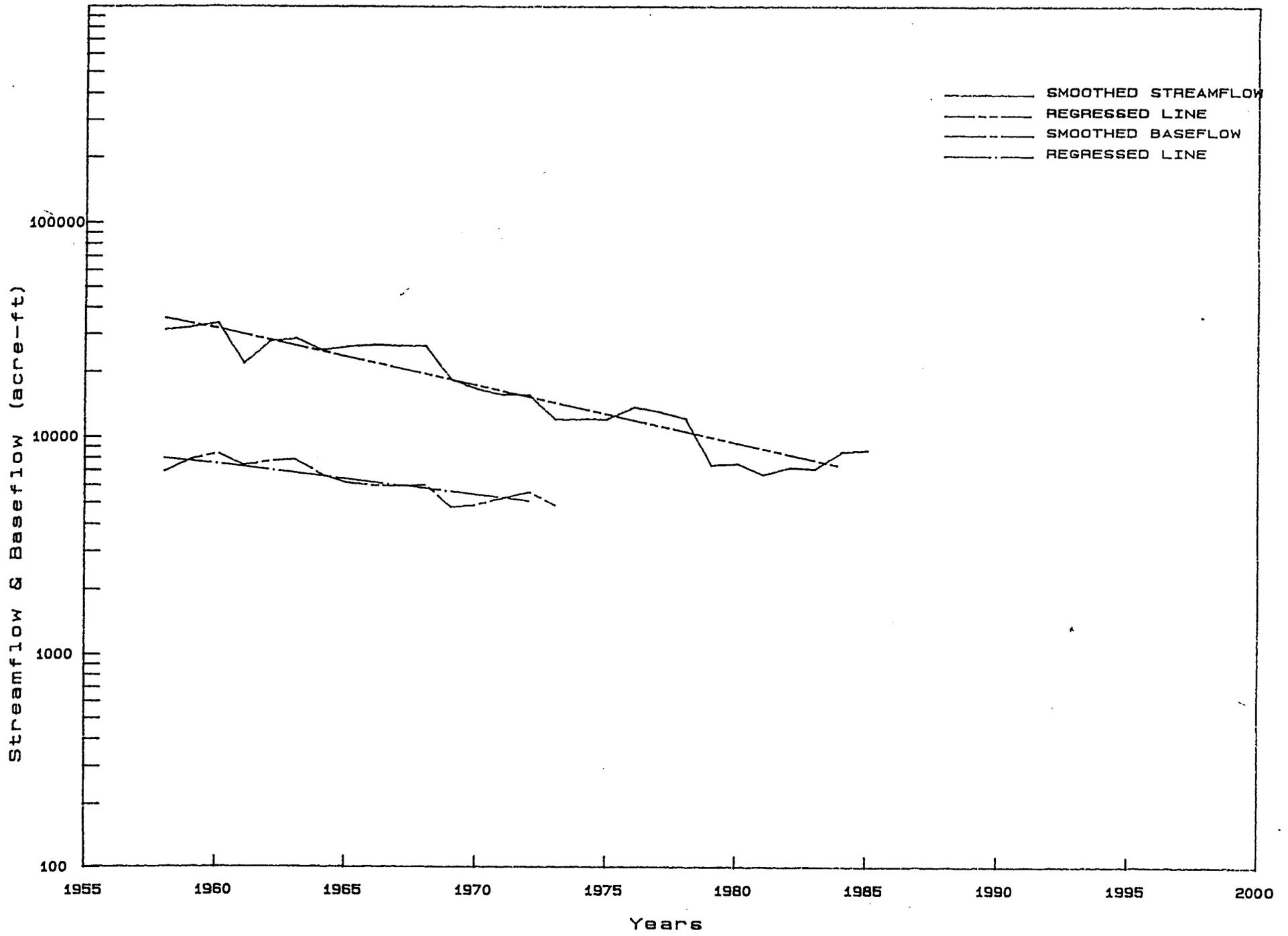


Figure 3: Linear regression lines superimposed on the seven-year moving average streamflow and baseflow data plotted on semilogarithmic paper.

Construction of this map involved some grouping of various soil associations presented in the county soil maps (Angell et al., 1973, 1984; Atkinson, 1976; Atkinson and Grimwood, 1980; Barker et al., 1980; Barker and Hamilton, 1985; Cline et al., 1959; Fleming, 1977; Hamilton, 1978, 1980, 1984; Hamilton et al., 1989; Jantz and Saffry, 1980; Jantz et al., 1982; Palmer, 1982; Palmer and Hamilton, 1987; Watts et al., 1986) and some regrouping of soil associations used in those reports to better reflect the pattern of soils in the natural landscapes for the multi-county area. Table 4 indicates the major soil associations, their areal extent, the percentage of watershed covered by the associations, and their water-holding properties.

Soil-moisture budget

To estimate actual evapotranspiration, we followed the soil-moisture budget approach. The measured precipitation and the calculated potential evapotranspiration values have been used together with the Holmes and Robertson (1959) moisture budget technique to determine the monthly and annual actual evapotranspiration and the moisture surplus available for runoff and groundwater recharge. This method takes into account soil texture, expansion of plant roots during the growing season, and the decreasing withdrawal of moisture from the root zone with increasing moisture stress. With the aid of the computer program POTEV (Freeze, 1967), the analysis was carried out for four different soil-moisture capacities varying from 9 to 12 in. These soil-moisture capacity values cover the range of values observed in the watershed area (table 4). A brief discussion on the basic concepts of soil-moisture budget analysis are presented in what follows.

A soil is saturated with water if all its interstices are filled. When the soil is permitted to drain freely, some water will be removed. This amount, expressed as a volume ratio, is called the specific yield of the soil. After gravitational water has drained out, the soil is said to be at field capacity. The moisture tension at field capacity is normally between 0.1 and 0.3 atmospheres (atm). Field capacity is the upper limit of moisture available to plant life; the lower limit is reached at the wilting point, which corresponds to a moisture tension of about 15 atm. The actual amount

Table 4. Soil association coverage of the Solomon watershed

Item	Soil association	Area of soils in basin (mi ²)	% of assoc. in basin	% Breakdown of units in generalized soil associations	Weighted ave. soil-moisture capacity (in.) in upper 5 ft of soil
1	Keith-Holdredge-Ulysses	1174.4	17.6	46-43-10	12.0
2	Uly-Holdrege-Wakeen	2219.9	33.2	39-26-15	12.0
3	Uly-Wakeen-Pender	471.0	7.0	38-20-16	12.0
4	Hord-Roxbury-Munjor	697.0	10.4	31-28-17	11.4
5	Harney-Crete-Corinth	1124.5	16.8	52-8-12	10.8
6	Crete-Hastings-Geary	378.9	5.7	40-30-27	10.8
7	Lancaster-Edalgo-Hedville	228.4	3.4	38-26-22	9.0
8	Heizer-Harney-Armo	390.4	5.8	28-27-24	9.0
Total		6685.4			
	Soil association item	Soil-moisture capacity (in.)	% Area covered		
	1 + 2 + 3	12.0	57.8		
	4	11.4	10.4		
	5 + 6	10.8	22.5		
	7 + 8	9.0	9.3		

of moisture stored in the root zone between moisture tensions of 0.1 and 15 atm depends mainly on the soil texture and is called the available storage capacity or soil-moisture capacity.

Soil-moisture deficit is the amount of moisture that has to be added to the root zone (here considered 5 ft deep) to bring it to field capacity. A soil-moisture surplus exists when more moisture has been added to the root zone than the amount required to satisfy the transpiration demands of the vegetation and to bring the soil to field capacity. Thus rain infiltrating the ground first meets the vegetation demands; only excess water can pass below the root zone and eventually to the water table if the soil in the root zone is at field capacity. It is therefore possible to determine whether percolation will take place or whether it has taken place by knowing the relationship among precipitation, actual and potential evapotranspiration, and antecedent soil-moisture conditions. This relation, which is generally presented in the form of a soil-moisture budget, can be calculated from meteorologic records.

There are several techniques for calculating soil-moisture budgets. The technique used here is the Thornthwaite method for calculating potential evapotranspiration in conjunction with the

modulated soil-moisture technique devised by Holmes and Robertson (1959) to obtain the actual evapotranspiration and moisture surplus or deficit. If more detailed climatic data are available, the Penman method (Penman, 1948), which is generally considered superior to the Thornthwaite method, can be employed. Figure 5 shows the flow diagram for the computer program POTEV for calculating potential evapotranspiration and the Holmes and Robertson moisture budget. The data processing steps for running this program are outlined in fig. 6.

An accurate visual representation of wet and dry seasons of an area is usually represented by a water-balance diagram. A complete water-balance diagram consists of comparing potential and actual evapotranspiration with the amount of precipitation, usually on a monthly basis. This comparison then gives information on the amount of deficit or surplus water available during different seasons. When the evapotranspiration rate is higher than the precipitation rate, the soil moisture is used until depleted and a moisture deficiency occurs. When the precipitation rate exceeds the evapotranspiration rate, soil moisture recharge occurs. In addition to variations in location, the appearance of the water balance can vary considerably in one location from year to year.

Water-balance diagrams resulting from the moisture budget analysis based on 25-year means (1964–1988) for the Hoxie, Webster, Kirwin, Glen Elder, and Salina stations (fig. 1) are shown in figs. 7 through 11. These diagrams are based on the most prominent soil-moisture capacity of the Solomon watershed soils. In all these figures, part (a) displays the entire 25-year water balance of the station on an annual basis, part (b) displays the 25-year average water balance on a monthly basis, and parts (c) and (d) display the monthly water balance of a particularly wet and dry year, respectively. As can be seen from these diagrams, precipitation increases during the warm months, as do potential and actual evapotranspiration. A mild bimodal precipitation distribution occurs, with peaks in May and August–September. A bimodal characteristic is prevalent in a large portion of the central United States (Eagleman, 1975). This reflects the influence of frontal systems in the spring and fall with slightly less precipitation from air-mass thunderstorms in midsummer. Agricultural practices and crop distributions can be related directly

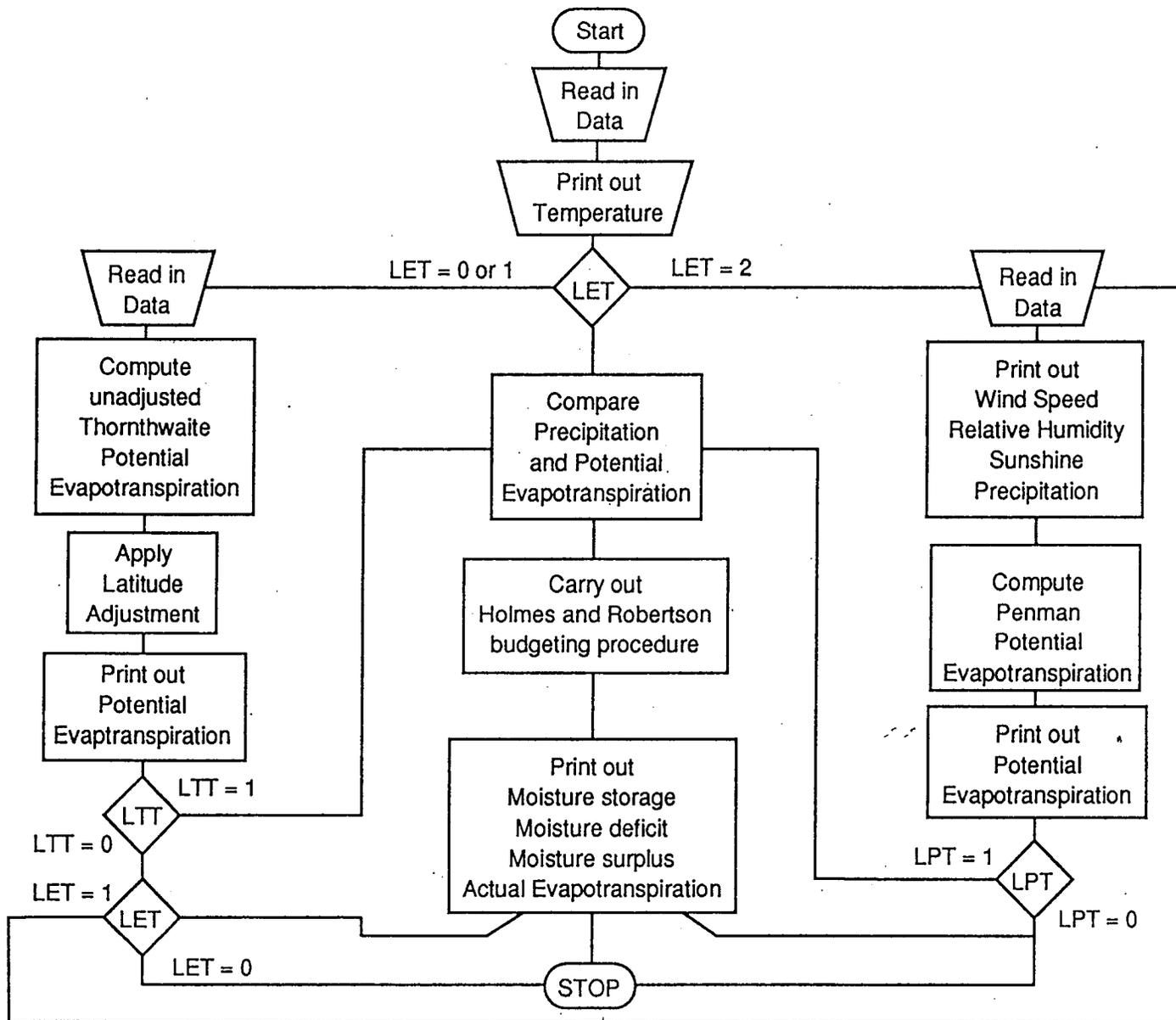
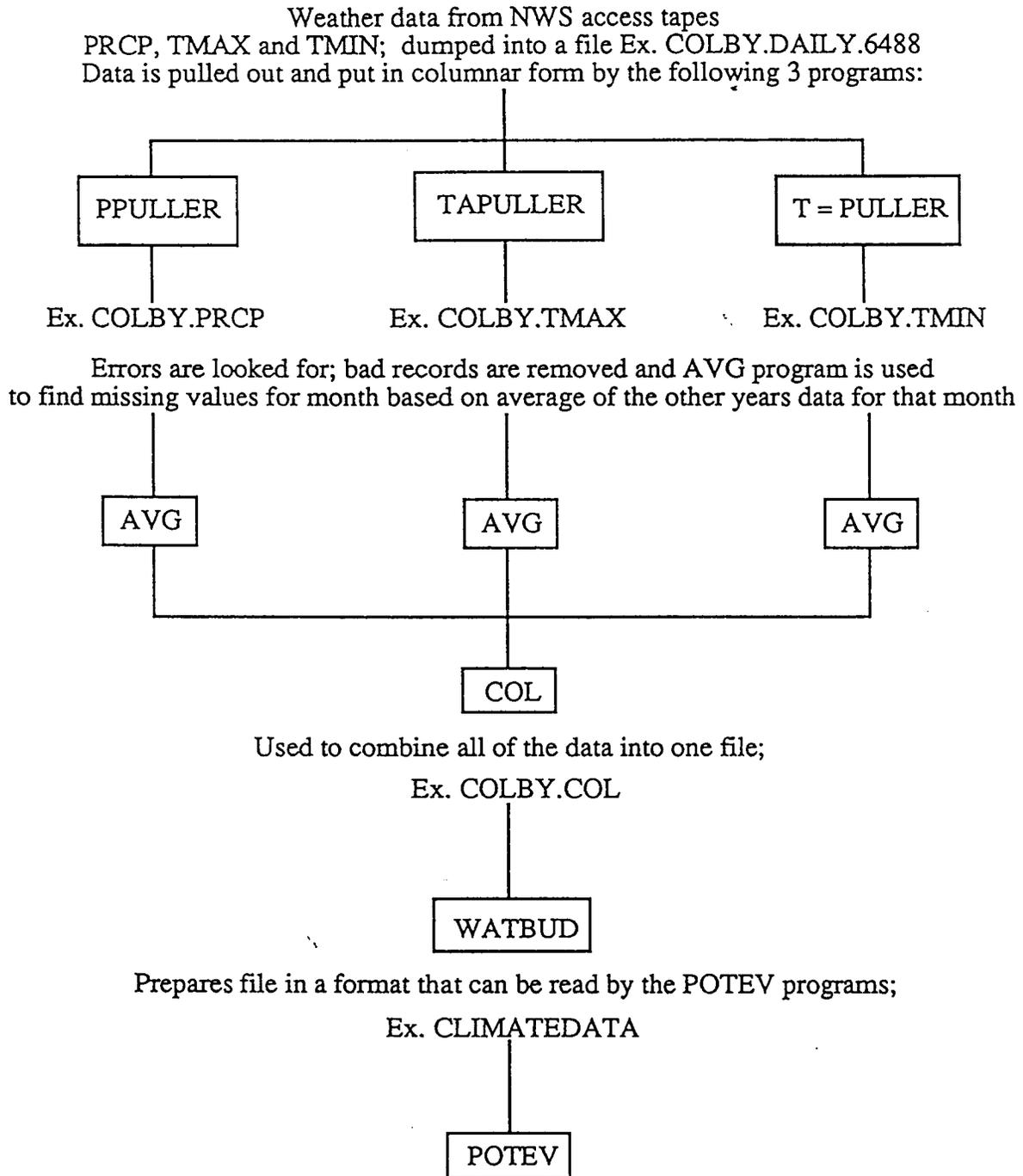


Figure 5: Flow diagram for the potential evapotranspiration and soil-moisture budget calculations using the program POTEV.

Figure 6. Data processing steps



*Boxed titles are FORTRAN77 programs.

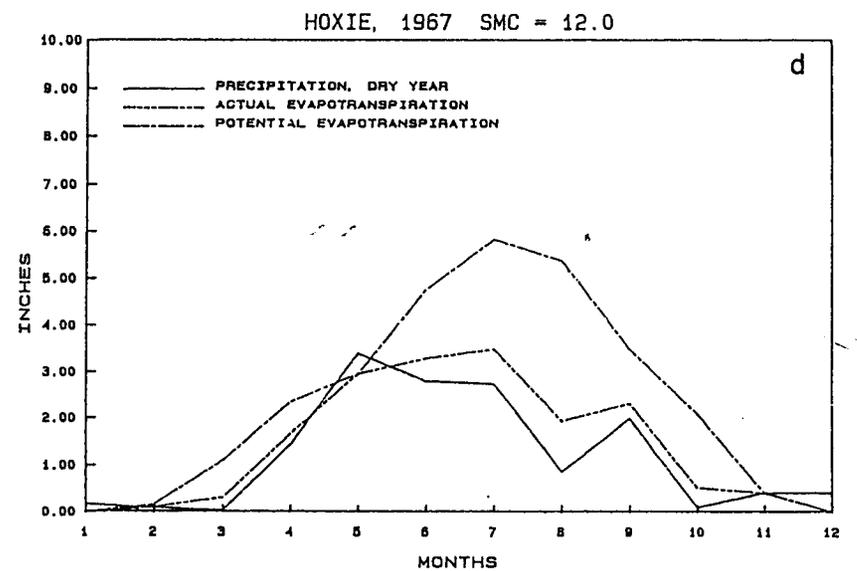
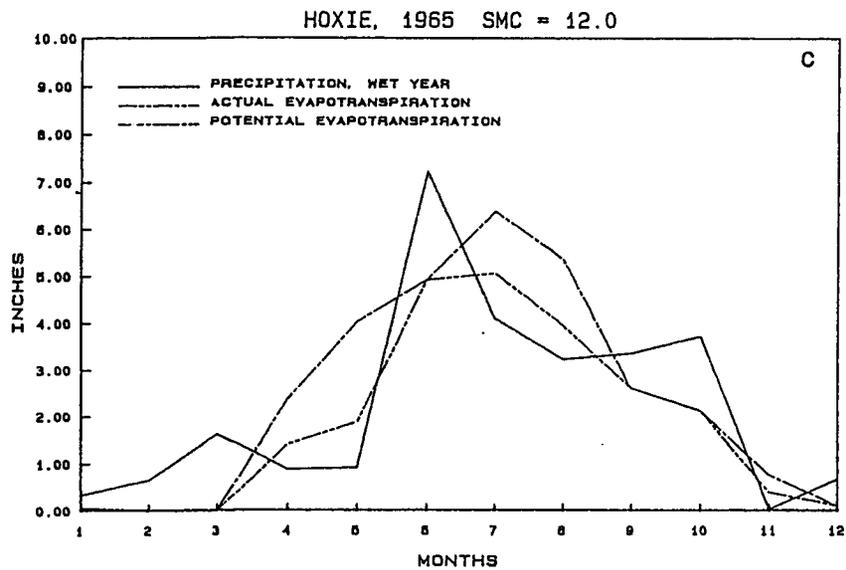
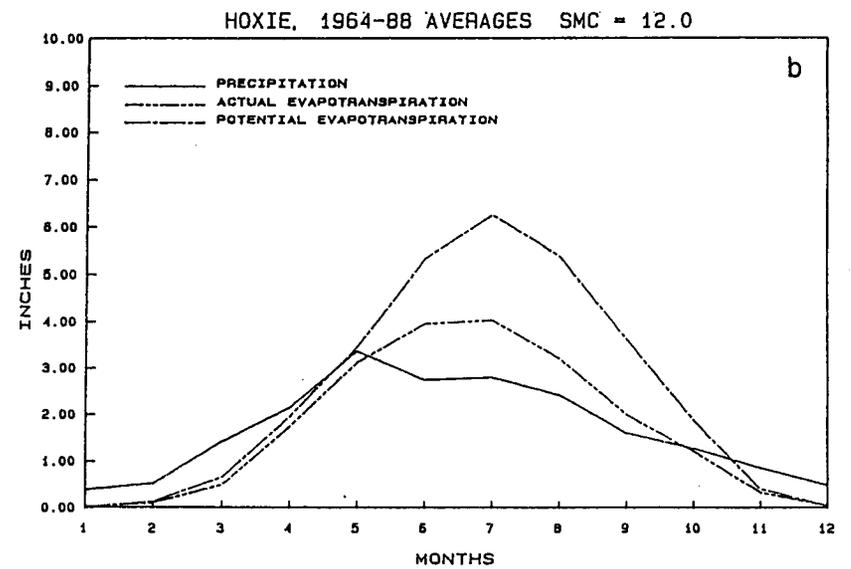
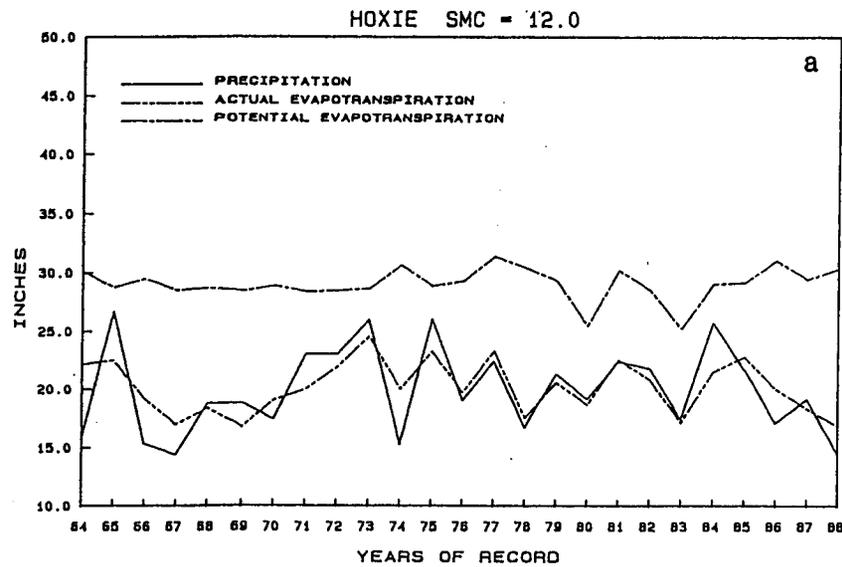


Figure 7: Water balance diagrams for the Hoxie station: (a) yearly water balance for the 1964–1988 period of record; (b) 1964–1988 average monthly water balance; (c) wet year water balance; (d) dry year water balance.

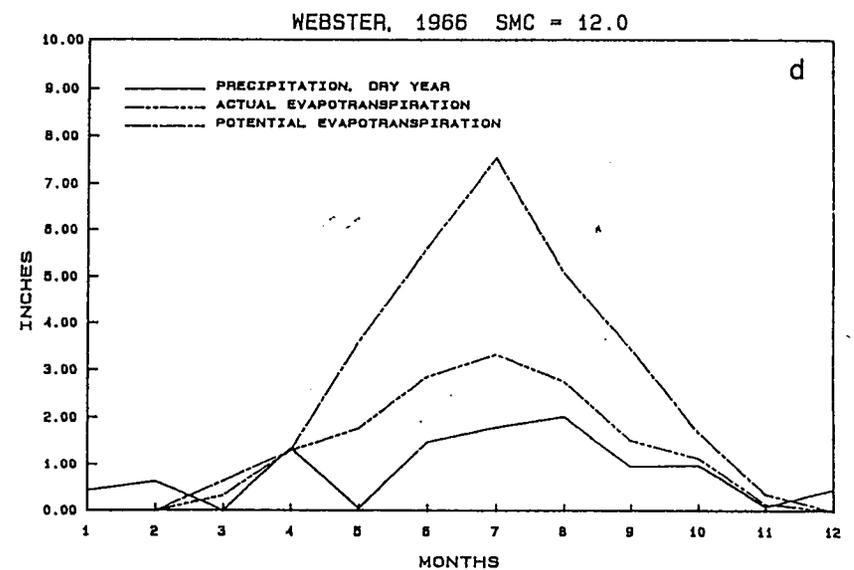
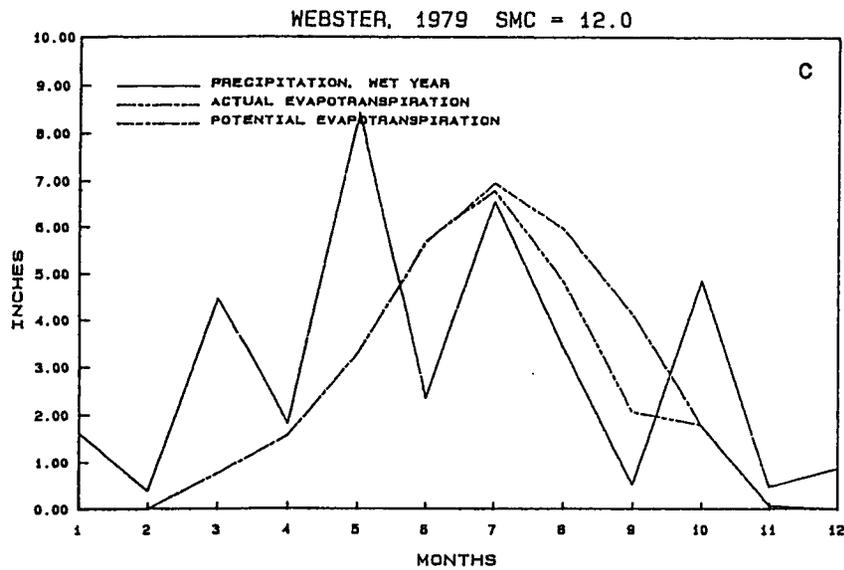
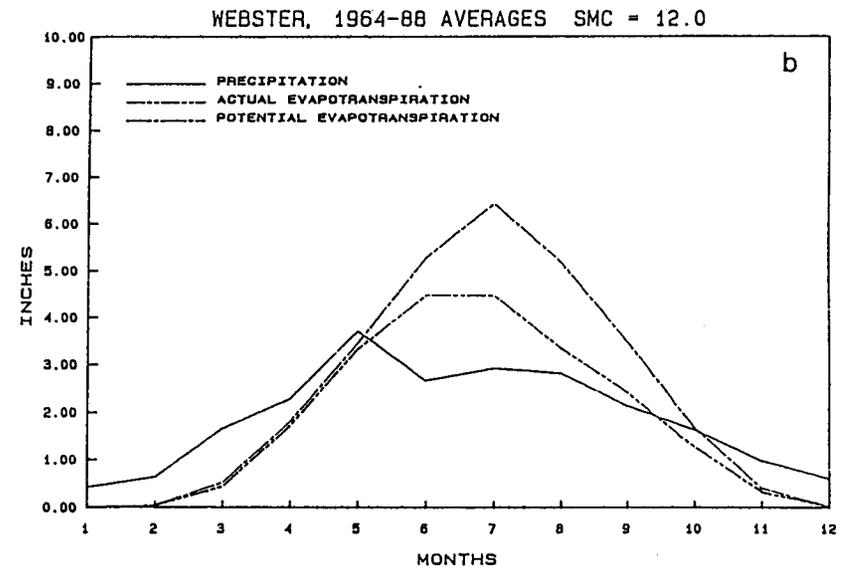
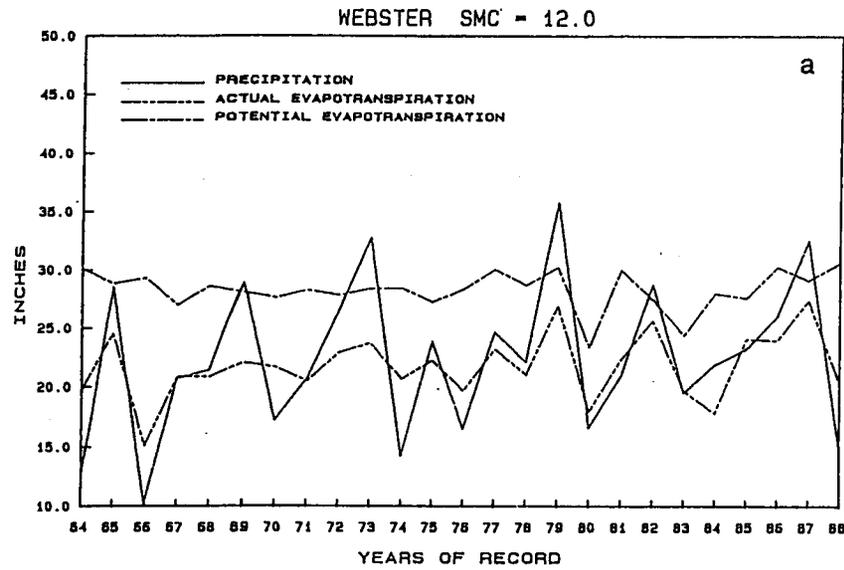


Figure 8: Water balance diagrams for the Webster station: (a) yearly water balance for the 1964–1988 period of record; (b) 1964–1988 average monthly water balance; (c) wet year water balance; (d) dry year water balance.

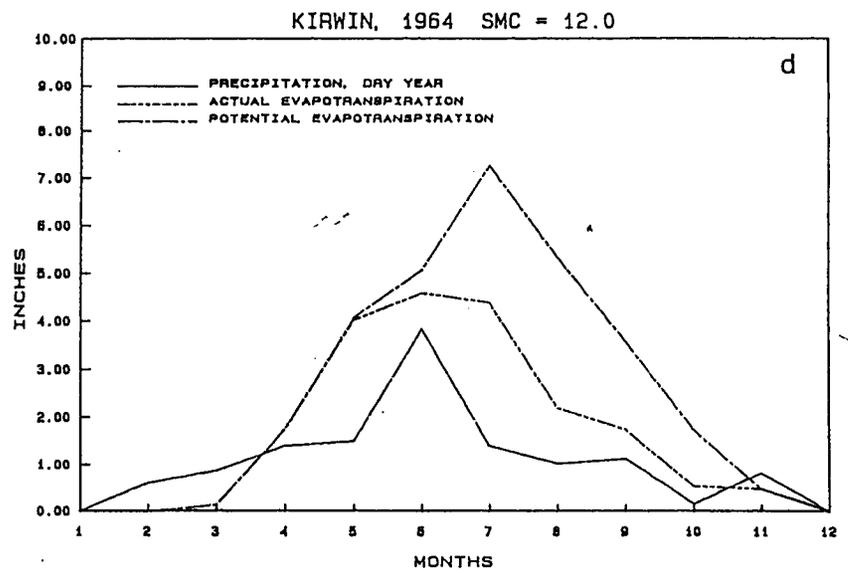
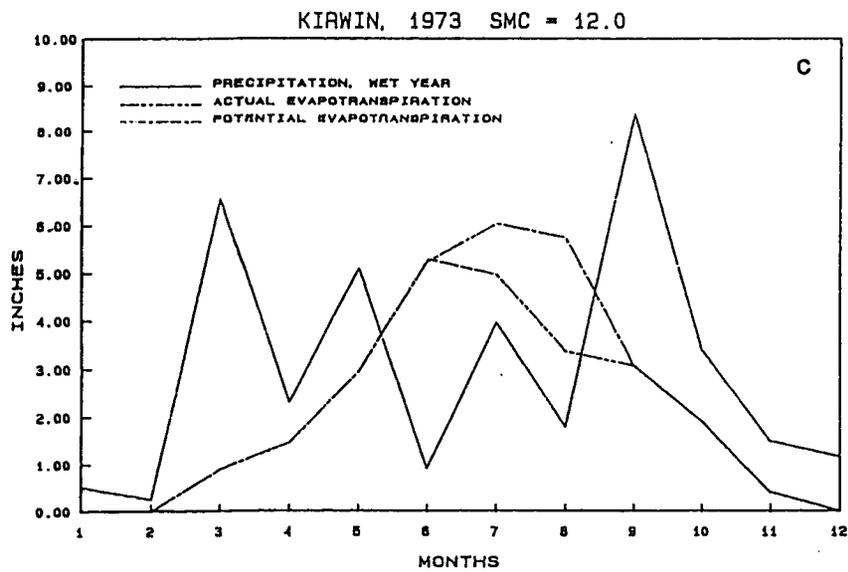
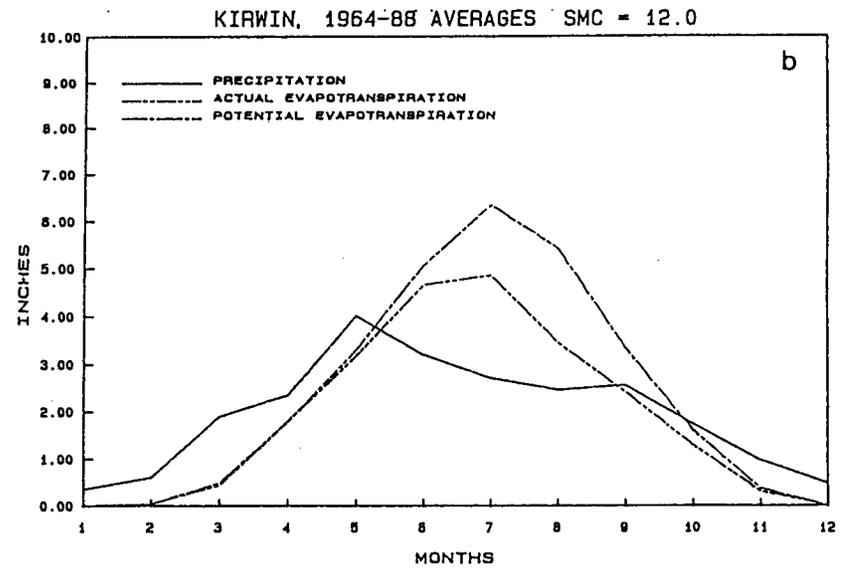
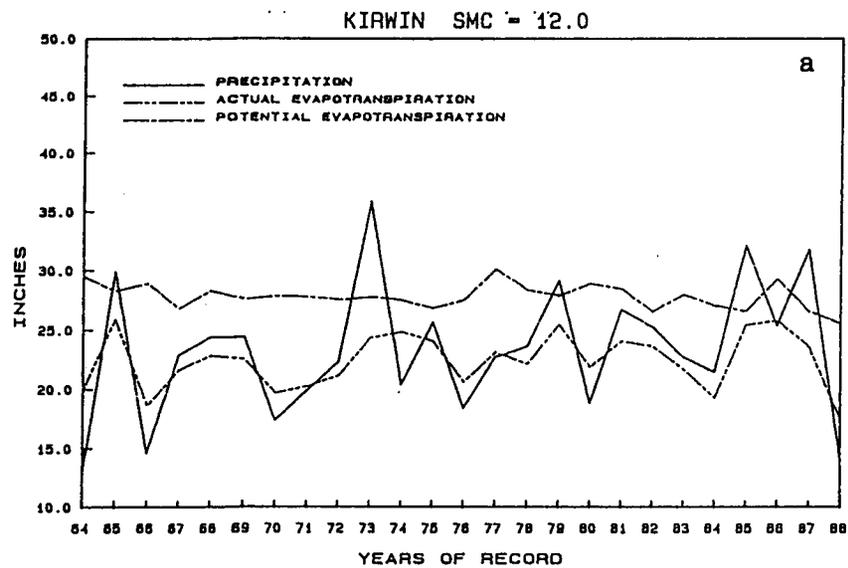


Figure 9: Water balance diagrams for the Kirwin station: (a) yearly water balance for the 1964–1988 period of record; (b) 1964–1988 average monthly water balance; (c) wet year water balance; (d) dry year water balance.

Table 2. Calculated average monthly moisture surpluses for all 19 stations in and around the Solomon watershed shown in fig. 1 during the 1964–1988 period^a

SOIL MOISTURE CAPACITY= 12.00 in.

Station	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		Period	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	3	4
Colby	0.00	0	0.00	0	0.00	0	0.02	4	0.16	8	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.18	0.9
Concordia	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Ellsworth	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Glen Elder	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Goodland	0.00	0	0.00	0	0.00	0	0.00	0	0.22	4	0.01	4	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.23	1.3
Hays	0.00	0	0.00	0	0.17	12	0.13	12	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.30	1.4
Hoxie	0.00	0	0.00	0	0.00	0	0.14	8	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.14	0.7
Kirwin	0.01	4	0.01	8	0.43	20	0.15	24	0.38	24	0.05	4	0.00	0	0.00	0	0.00	0	0.04	4	0.05	8	0.05	8	1.16	5.0
Lincoln	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Mankato	0.16	20	0.22	28	0.93	40	0.60	60	0.95	52	0.21	12	0.00	0	0.00	0	0.08	4	0.17	8	0.19	12	0.27	16	3.78	13.7
Norton	0.06	12	0.09	12	0.22	20	0.43	32	0.30	20	0.12	8	0.00	0	0.00	0	0.00	0	0.09	4	0.02	8	0.06	8	1.39	5.9
Oakley	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Oberlin	0.02	4	0.02	4	0.05	8	0.12	8	0.16	12	0.18	4	0.00	4	0.00	0	0.02	4	0.04	4	0.00	0	0.00	0	0.60	2.7
Quinter	0.00	0	0.03	8	0.09	12	0.30	16	0.08	16	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.50	2.2
Russell FAA	0.01	4	0.00	0	0.62	32	0.49	44	0.32	20	0.04	8	0.00	0	0.24	4	0.12	4	0.00	0	0.00	0	0.08	4	1.92	7.3
Russell Springs	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Salina	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.0
Webster	0.01	4	0.00	0	0.36	20	0.27	16	0.21	8	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.06	4	0.91	4.1
Winona	0.00	0	0.00	0	0.00	0	0.00	4	0.06	4	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.06	0.3

^aExplanation of columns: 1, average monthly moisture surplus (in.) for the period 1964–1988; 2, percentage of years during the period 1964–1988 in which moisture surplus occurred during the month indicated; 3, total average moisture surplus from Jan to Dec (in.); 4, total average moisture surplus from Jan. to Dec. expressed as percentage of average total annual precipitation 1964–1988.

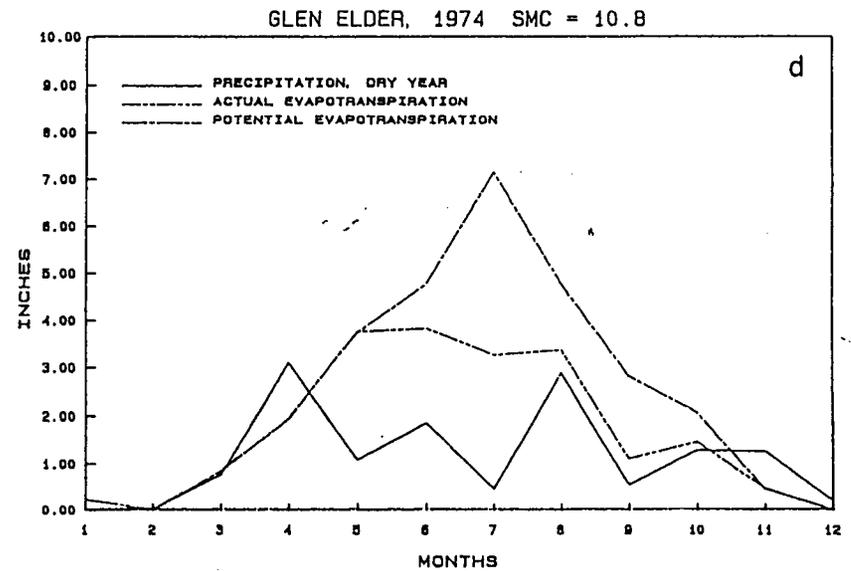
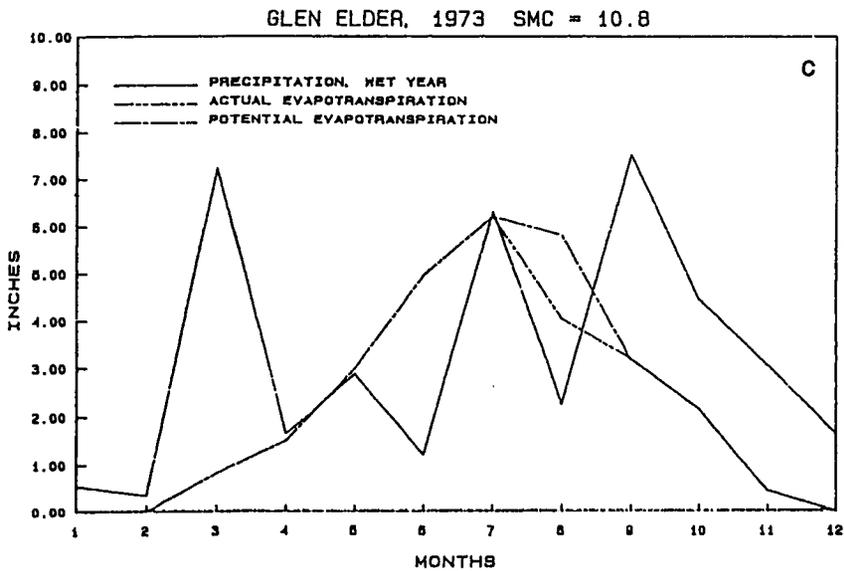
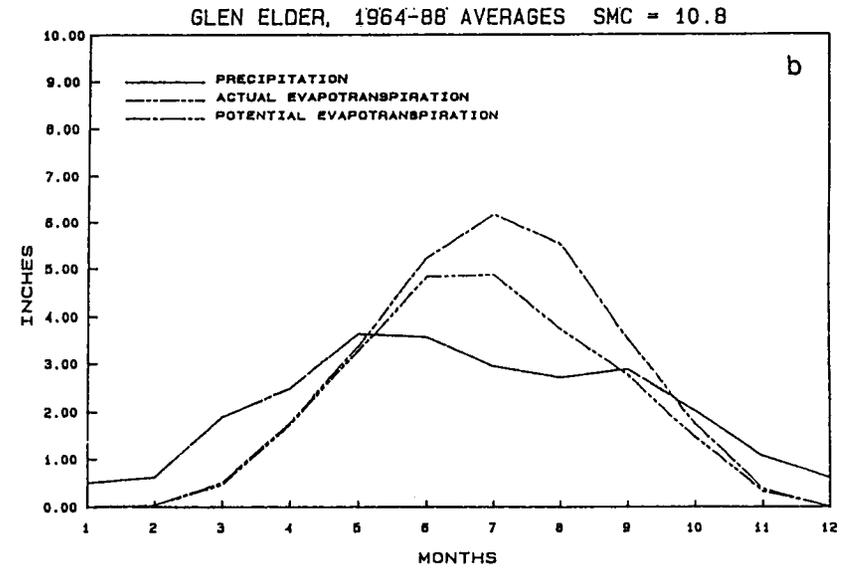
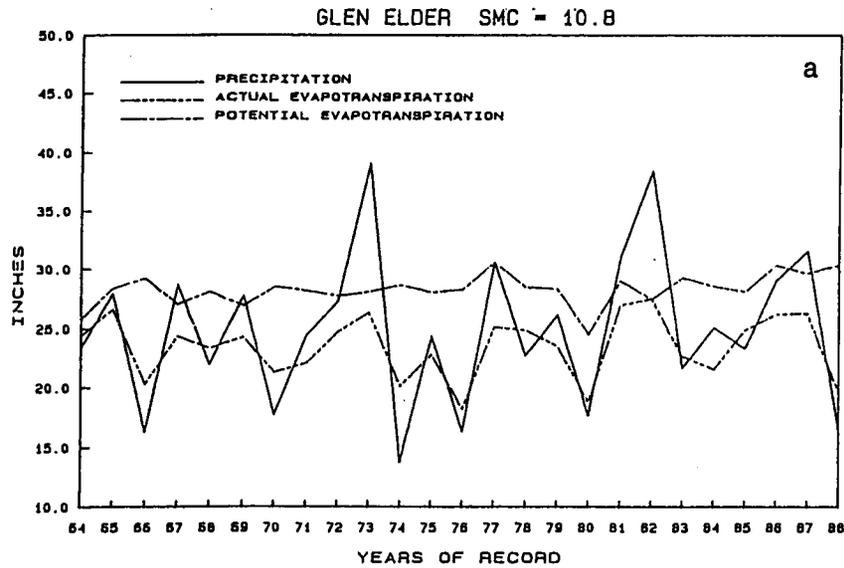


Figure 10: Water balance diagrams for the Glen Elder station: (a) yearly water balance for the 1964-1988 period of record; (b) 1964-1988 average monthly water balance; (c) wet year water balance; (d) dry year water balance.

to the water balance. As can be seen from these diagrams, in the Solomon watershed adequate moisture occurs during November through April. This is the period when water is needed for growing wheat, the major crop of the area. At Hoxie potential evapotranspiration is always greater than precipitation. As one moves eastward, precipitation occasionally exceeds potential evapotranspiration, whereas at Salina it often exceeds it (Figs. 7a, 8a, 9a, 10a, and 11a).

Information on many aspects of the water relations at any place can be obtained from the water-balance diagrams (Mather, 1974). The difference between the potential and the actual evapotranspiration provides a measure of the moisture deficit of a place (i.e., the amount by which the available moisture fails to satisfy the demand for water). Knowledge of the moisture deficit is basic to any understanding of the economic feasibility of irrigation, for it provides information on the total volume of water needed at any time and gives a definitive measure of drought. Information on the water surplus, the amount by which precipitation exceeds the water needs when the soil is at field capacity, is fundamental in hydrologic studies that deal with the recharge of groundwater or with the runoff of water in streams and rivers.

IV. Estimates of regional groundwater recharge

There are several methods by which estimates of regional groundwater recharge can be made (Meyboom, 1966; Freeze, 1967; Sophocleous, 1981; Sophocleous and McAllister, 1987), such as: (1) actual field measurements at the recharge end of the flow system, (2) interpretation of streamflow records at the discharge end of the flow system, (3) the use of soil-moisture budgets based on hydrometeorological data, and (4) calculation of quantitative regional flow by analytical or numerical model analysis. In this report, the second and third methods have been employed to estimate groundwater recharge.

The long-term average recharge to the alluvial aquifer was assumed to equal the long-term average groundwater outflow during the early times of the Solomon watershed irrigation development. Such an equilibrium condition existed in the watershed until the early 1960's (Weston, 1979). An examination of the data and soil-moisture budget analysis results for that

period indicated that only during the calendar years 1960 and 1961 soil water surplus, and thus potential groundwater recharge, was observed. Therefore, these two years were selected for recharge estimation. During 1960 and 1961, the average amount of groundwater appropriated in the ~395,674-acre area drained by the North Fork Solomon above Glade (fig. 1) was 13,860 ac-ft/yr, which amounts to 0.42 in./yr over that subwatershed area (water appropriation data from Division of Water Resources, Kansas State Board of Agriculture). The average annual baseflow during the period 1960–1961, as derived from the streamflow data at Glade, was ~10,200 ac-ft/yr, which amounts to 0.31 in. of water over the same subwatershed area. Thus the total groundwater outflow (baseflow plus pumpage) for 1960–1961 was 0.73 in./yr, which, under the assumption of equilibrium, represents the amount of groundwater recharge. Groundwater outflow through evapotranspiration was presumed negligible and therefore was not considered in the calculations.

The second method for estimating regional groundwater recharge in the Solomon watershed is the moisture-budget technique. The results of this technique apply to any size area characterized by a specified soil moisture capacity and climatic conditions. Table 5 presents the calculated average monthly moisture surpluses for all the climatic stations in and around the Solomon watershed, and the frequencies at which surpluses occurred during the 1964–1988 period. The table indicates that in the Solomon watershed and for the predominant soil-moisture capacity of 12 in., moisture surpluses occur 4% or less of the time from July to September; 20% or less of the time during June and from October to January, and <60% of the time from February to May. The column labeled "3" in Table 5 shows the total average moisture surplus, which constitutes potential groundwater replenishment. The column labeled "4" shows the same amount as a percentage of the average total annual precipitation from 1964 to 1988. In the summary table 6, the precipitation potential and actual evapotranspiration and the moisture surplus for various soil-moisture capacities representative of the Solomon watershed soils are listed for all the climatic stations shown in fig. 1. The soil map (fig. 4) has been interpreted in terms of the percentage of the effective drainage area covered by soils representing each of the soil-moisture capacities (table 4).

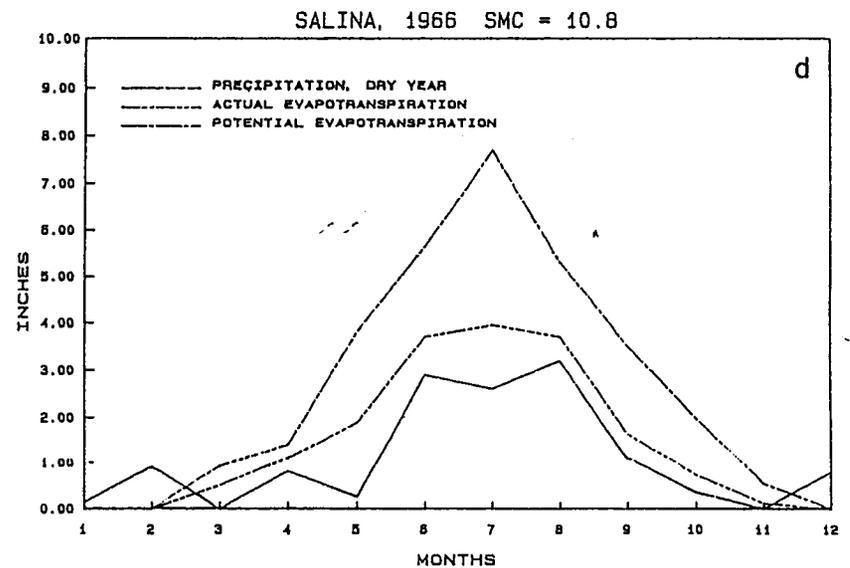
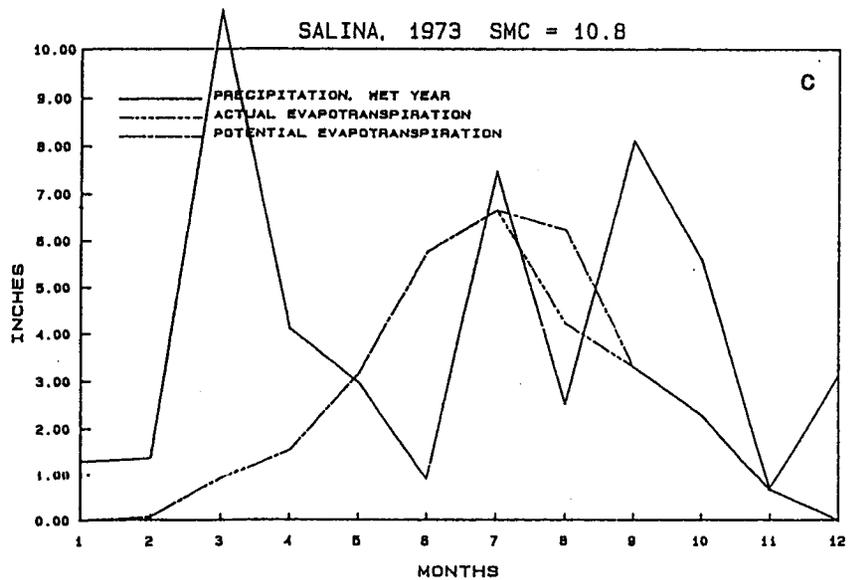
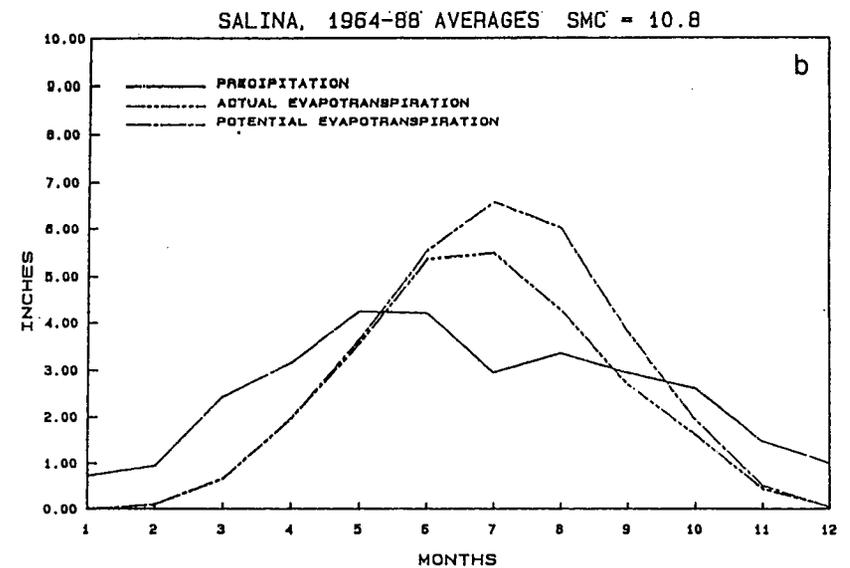
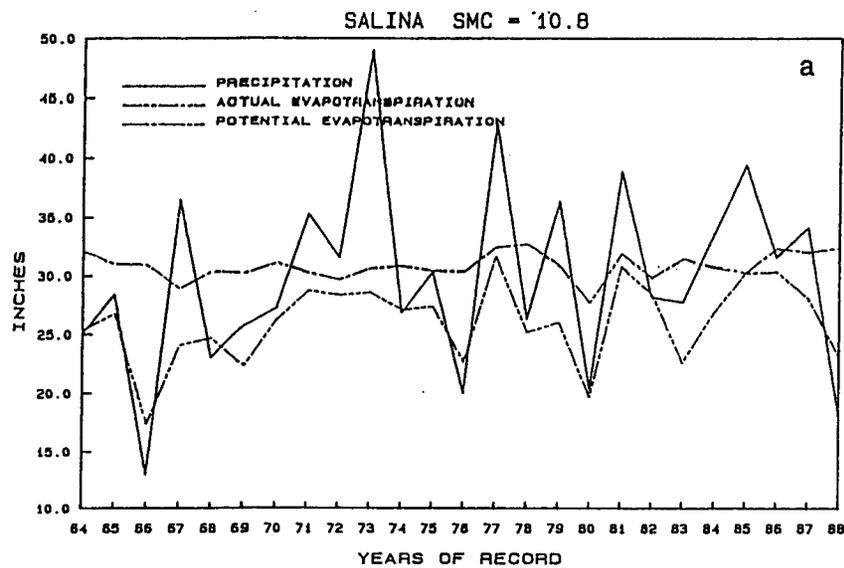


Figure 11: Water balance diagrams for the Salina station: (a) yearly water balance for the 1964-1988 period of record; (b) 1964-1988 average monthly water balance; (c) wet year water balance; (d) dry year water balance.

Table 6. Holmes and Robertson soil-moisture budget for all 19 stations in and around the Solomon watershed shown in Fig. 1 during the 1964–1988 period

Station	Precip. (in.)	Thornwt. Potent. ET (in.)	Actual ET (in.) for various soil-moisture capacities				Moisture surplus (in.) for various soil-moisture capacities			
			9.0	10.8	11.4	12.0	-9.0	10.8	11.4	12.0
Colby	19.05	26.43	–	–	–	19.15	–	–	–	0.18
Concordia	29.01	29.23	25.34	25.60	25.69	–	3.95	3.70	3.63	–
Ellsworth	27.89	30.48	25.45	25.74	25.82	–	2.72	2.45	2.38	–
Glen Elder	24.92	28.29	23.18	23.47	23.55	–	2.01	1.73	1.66	–
Goodland	18.18	26.62	–	–	–	18.19	–	–	–	0.23
Hays	21.68	28.85	21.43	–	21.67	21.72	0.55	–	0.34	0.30
Hoxie	19.97	29.08	–	–	–	20.20	–	–	–	0.14
Kirwin	23.31	27.78	–	–	22.32	22.39	–	–	1.23	1.16
Lincoln	27.39	30.06	24.86	25.23	25.33	–	2.82	2.50	2.41	–
Mankato	27.56	27.04	23.65	23.91	23.99	24.07	4.17	3.92	3.85	3.78
Norton	23.71	25.67	–	–	22.38	22.45	–	–	1.46	1.39
Oakley	18.96	28.12	–	–	–	19.29	–	–	–	–
Oberlin	22.63	28.23	–	–	22.17	22.22	–	–	0.65	0.60
Quinter	22.73	27.78	–	–	–	22.52	–	–	–	0.50
Russell FAA	26.36	29.73	24.18	24.56	24.68	24.78	2.48	2.13	2.02	1.92
Russell Springs	18.23	27.55	–	–	–	18.62	–	–	–	–
Salina	29.99	30.82	25.75	26.10	26.20	–	4.52	4.19	4.09	–
Webster	22.44	28.30	21.51	–	21.77	21.82	1.20	–	0.96	0.91
Winona	18.52	27.12	–	–	–	18.74	–	–	–	0.06

If the 25 years of records (1964–1988) for all these stations are at all representative of the average conditions in the Solomon watershed, moisture budgets indicate that the average potential annual groundwater replenishment in this watershed for the predominant 12-in. soil-moisture capacity varies from 0 in. to 3.8 in (column 3, Table 5). Or, in other words, the potential annual recharge in this area lies between 0% and 13.7% of the average total annual precipitation (table 5). For the 1960–1961 period and from the climatic data from the Kirwin Dam station (the closest station to the Glade streamgaging station and centrally located within the entire watershed) and the predominant soil-moisture capacity of 12 in., precipitation totaled 27.84 in., Thornthwaite potential

evapotranspiration and actual evapotranspiration totaled 27.79 in. and 25.98 in., respectively, and moisture surplus totalled 1.89 in., which is above normal compared to the 25-year average of 1.16 in for the same conditions (Table 6). Table 6 shows that as the soil moisture capacity increases, the percentage of the available water that is actually evapotranspired increases at the expense of the moisture surplus. The actual evapotranspiration plus the moisture surplus should equal the precipitation amount; the small discrepancies in table 6 are the result of the averaging of the budgeting procedure.

During the 1960–1961 period, the average total streamflow at Glade was 34,720 ac-ft/yr and the average baseflow was 10,200 ac-ft/yr, resulting in a direct surface runoff (the difference between total streamflow and baseflow) of 24,520 ac-ft/yr (0.74 in/yr). The moisture surplus must, however, satisfy the surface runoff and the groundwater recharge. This surface runoff figure, when subtracted from the average 1960–1961 moisture surplus of 1.89 in. based on the Kirwin station, results in a value for regional groundwater recharge of 1.15 in. This value is of the same order of magnitude as the recharge value (0.73 in./yr) calculated from baseflow and groundwater pumpage data.

Thus, assuming that the more than 395,000-acre subwatershed above Glade is typical of the entire Solomon watershed based on the two previously mentioned recharge estimation methods, the average estimated regional groundwater recharge for the Solomon watershed is 0.94 in., which represents only 4% of the average annual precipitation (23.29 in./yr). During 1980–1981, the groundwater appropriations in the Glade subwatershed, which reached 146,182 ac-ft, compared to 13,860 ac-ft in 1960–1961, amounted to more than 4.7 times the amount of estimated natural groundwater replenishment for that subwatershed.

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Appendix A

Appendix A. HYSEP files

Appendix A. HYSEP files

Year	Streamflow (acre ft.)	Baseflow (acre ft.)	Baseflow as percent of streamflow	Runoff (acre ft.)
<u>South Fork Solomon River above Webster Reservoir</u>				
1970	11048	6954	62.95	4094
1971	8504	4497	52.88	4007
1972	7471	2639	35.33	4832
1973	15770	10004	63.44	5766
1974	20657	13069	63.27	7587
1975	52480	6514	12.41	45966
1976	9450	5461	57.79	3989
1977	13874	3088	22.26	10786
1978	23483	3898	16.60	19585
1979	11760	7446	63.31	4314
1980	9863	2919	29.60	6944
1981	7709	3185	41.31	4524
1982	10932	1940	17.75	8991
1983	7171	5724	79.82	1447
1984	11186	7455	66.65	3731
1985	5541	2819	50.87	2722
1986	13907	5449	39.18	8459
1987	19174	11456	59.75	7718
1988	5782	4617	79.86	1165
1989	9289	900	9.69	8388
1990	6429	4558	70.90	1871
1991	1151	450	39.07	701
<u>North Fork Solomon River at Glade</u>				
1970	13785	6744	48.92	7042
1971	7409	3790	51.15	3620
1972	4020	958	23.83	3063
1973	8775	6385	72.77	2390
1974	11508	6332	55.02	5176
1975	35648	4294	12.05	31354
1976	6286	4053	64.47	2233
1977	11139	3412	30.63	7726
1978	7807	2836	36.32	4972
1979	15923	4730	29.70	11194
1980	4986	2936	58.88	2051
1981	3867	111	2.86	3756
1982	3325	826	24.86	2499
1983	6047	3134	51.83	2913
1984	5837	3992	68.40	1844
1985	9606	2667	27.77	6939
1986	14271	5576	39.07	8695
1987	16293	11020	67.63	5273
1988	5937	4646	78.26	1291
1989	5680	1582	27.85	4098
1990	6921	2496	36.06	4426
1991	915	655	71.54	261

Appendix A (cont). HYSEP Files

Year	Streamflow (acre ft.)	Baseflow (acre ft.)	Baseflow as percent of streamflow	Runoff (acre ft.)
<u>Solomon River at Niles</u>				
1970	66835	33304	49.83	33531
1971	163874	44256	27.01	119618
1972	106149	49210	46.36	56940
1973	656632	204904	31.21	451728
1974	1027571	513700	49.99	513871
1975	247964	116340	46.92	131624
1976	126403	71322	56.42	55081
1977	169787	51336	30.24	118451
1978	183511	63436	34.57	120074
1979	408343	177698	43.52	230645
1980	270375	99558	36.82	170817
1981	143250	50195	35.04	93055
1982	620636	325274	52.41	295362
1983	232284	135315	58.25	96970
1984	336456	211452	62.85	125004
1985	170102	86453	50.82	83650
1986	150891	67915	45.01	82975
1987	992079	595499	60.03	396579
1988	188019	160188	85.20	27831
1989	215060	84823	39.44	130237
1990	123864	75816	61.21	48048
1991	91569	57873	63.20	33696
<u>South Fork Solomon River at Osborne</u>				
1970	12878	10142	78.76	2736
1971	10809	6039	55.87	4769
1972	7212	3688	51.13	3525
1973	84623	33308	39.36	51315
1974	122394	71063	58.06	51331
1975	36877	18350	49.76	18526
1976	16593	13608	82.01	2985
1977	15124	7235	47.84	7889
1978	11330	6328	55.85	5003
1979	38589	8967	23.24	29622
1980	18610	9578	51.46	9033
1981	12504	4375	34.99	8129
1982	47518	6638	13.97	40880
1983	11994	9943	82.90	2051
1984	20860	11678	55.98	9182
1985	9402	5292	56.29	4110
1986	11977	4537	37.88	7440
1987	208422	84541	40.56	123881
1988	30321	26146	86.23	4175
1989	18417	9171	49.80	9246
1990	14690	9346	63.62	5345
1991	6712	4912	73.18	1800

Appendix A (cont). HYSEP files

Year	Streamflow (acre ft.)	Baseflow (acre ft.)	Baseflow as percent of streamflow	Runoff (acre ft.)
<u>North Fork Solomon River at Portis</u>				
1970	32611	20676	63.40	11936
1971	35766	15098	42.21	20668
1972	24167	16240	67.20	7926
1973	69344	32066	46.24	37278
1974	104261	59097	56.68	45164
1975	58566	29968	51.17	28598
1976	31127	20544	66.00	10582
1977	30067	15489	51.52	14577
1978	29579	13009	43.98	16570
1979	56795	17190	30.27	39605
1980	23451	13842	59.02	9610
1981	16691	7516	45.03	9174
1982	45937	10316	22.46	35621
1983	17096	10294	60.22	6801
1984	33810	20721	61.29	13090
1985	29190	9865	33.80	19324
1986	15982	9702	60.71	6279
1987	97202	40586	41.75	56616
1988	39763	26369	66.31	13394
1989	29520	12015	40.70	17505
1990	34062	17828	52.34	16234
1991	15693	11504	73.31	4189

Appendix B

Solomon River Flow Data.

Appendix B. Solomon River Flow Data.

Year	Solomon River at Niles	Bow Creek Stock	Solomon River at Beloit	South Fork Solomon River at Webster	North Fork Solomon River at Portis	North Fork Solomon River at Kirwin	South Fork Solomon River at Osborne	Salt Creek near Ada
1918	268.1	-	-	-	-	-	-	-
1919	705.6	-	-	-	-	-	-	-
1920	443.4	-	-	-	-	-	-	-
1921	243.5	-	-	-	-	-	-	-
1922	122.2	-	-	-	-	-	-	-
1923	604.2	-	-	-	-	-	-	-
1924	134.4	-	-	-	-	-	-	-
1925	134.4	-	-	-	-	-	-	-
1926	295.1	-	-	-	-	-	-	-
1927	1122	-	-	-	-	-	-	-
1928	950.9	-	-	-	-	-	-	-
1929	568.5	-	-	-	-	60.9	-	-
1930	328.3	-	180.9	-	-	54.7	-	-
1931	311.8	-	267.5	-	-	55.1	-	-
1932	270	-	151.5	-	-	-	-	-
1933	143.7	-	100.4	-	-	-	-	-
1934	142.8	-	129.7	-	-	-	-	-
1935	947.1	-	718.5	-	-	-	-	-
1936	183.8	-	139.1	-	-	-	-	-
1937	304.3	-	205.6	-	-	-	-	-
1938	371.9	-	261.2	-	-	-	-	-
1939	281.5	-	180	-	-	-	-	-
1940	119.7	-	82.1	-	-	-	-	-
1941	712.8	-	681.5	-	-	-	-	-
1942	1228	-	548.2	-	-	-	-	-
1943	614.2	-	377.2	-	-	53.5	-	-
1944	843.1	-	584.5	-	-	143.5	-	-
1945	817.4	-	377.2	-	-	48.4	-	-
1946	673.8	-	427.9	-	154	39	-	-
1947	955.4	-	668.2	-	284.8	156	161.6	-
1948	666.9	-	241.1	-	68.9	32	70.4	-
1949	857.6	-	683.7	-	310.9	92.5	151.9	-
1950	1263	-	1011	-	308.8	145.6	251.8	-
1951	4113	-	2667	-	855	385.4	994.4	-
1952	735.8	14.5	413.4	-	158	80.6	130.8	-
1953	221.6	8.04	127.6	-	62.1	48.4	41.1	-
1954	253.2	19	200.7	-	100.2	70.7	74.9	-
1955	156.4	7.47	115.8	-	80.5	22.3	17.3	-
1956	108.6	3.89	78.4	-	25.5	0.895	24.6	-
1957	711.3	43.3	577.2	73.4	231.8	14	242.1	-

Appendix B (cont). Solomon River Flow Data.

Year	Solomon River at Niles	Bow Creek Stock	Solomon River at Beloit	South Fork Solomon River at Webster	North Fork Solomon River at Portis	North Fork Solomon River at Kirwin	South Fork Solomon River at Osborne	Salt Creek near Ada
1958	566.3	13.1	356.3	65.4	60.5	0.248	170.6	-
1959	313.4	7.08	172.6	57.1	36.5	0.033	77.2	-
1960	851.6	29.2	555.5	111.4	166.5	45.2	193.8	101.3
1961	1271	22.5	902.4	117.2	197.4	28.5	331.2	115.4
1962	977.4	15.8	717.9	128.6	159.3	21.6	269.9	58.6
1963	379.2	10.5	298.2	65.8	103	4.98	87.3	7.25
1964	178.1	4.72	113.3	40.4	38.6	0.205	25.5	4.26
1965	371.5	22.2	229.5	23.7	112.5	0.093	35.7	32.7
1966	201.2	18.3	-	69.6	81.8	44.3	45.1	3.81
1967	503.6	7.33	-	21.4	87.7	0.041	37.3	56.3
1968	200.1	19.7	-	23	77.8	0.109	27.3	5.78
1969	382.2	29.2	-	25.9	150	37.6	42.1	32.8
1970	92.3	8.43	-	32.1	45	8.82	17.8	6.01
1971	226.4	5.43	-	17.3	49.4	0.146	14.9	43.5
1972	146.5	5.15	-	0.657	33.4	0.18	9.97	34.1
1973	907	10.4	-	18.3	95.8	0.101	116.9	249.2
1974	1419	13.3	-	25.9	144	0.492	169.1	156.6
1975	342.5	31.4	-	26.2	80.9	0.173	50.9	30.5
1976	174.4	5.11	-	37.9	43	0.123	22.9	26.8
1977	234.5	7	-	21.5	41.5	0.177	20.9	37.3
1978	253.5	9.12	-	0	40.9	0.08	15.7	46.0
1979	564	13.5	-	23.4	78.4	0.006	53.3	84.2
1980	373.5	5.35	-	27.1	32.4	0.018	25.7	69.4
1981	197.9	1.73	-	0.003	23.1	0.015	17.3	28.4
1982	857.3	8.95	-	0.011	63.5	0.028	65.6	156.4
1983	320.8	4.47	-	19	23.6	0.004	16.6	47.2
1984	463.9	12.4	-	0	46.7	0.008	28.8	41.2
1985	235	10.9	-	0	40.3	0	13	56.5
1986	208.4	11	-	13.6	22.1	0.018	16.5	32.6
1987	1370	20.5	-	3.17	134.3	0.022	287.9	180.2

Appendix C

Water Rights by River Reach

Appendix C. Water Rights by River Reach

Subreach 1

	1989 Reported Water Use	1990 Reported Water Use	Division of Water Resources Appropriations
T 6-8	0	0	169
T 6-9	0	669	130.5
T 7-6	543	624	1244.2
T 7-7	1162	1345	1678.2
T 7-8	1349	1500	690.9
T 7-9	0	0	6
T 8-4	0	0	674
T 8-5	0	0	165.9
T 8-6	0	0	15.9
T 9-4	0	0	501.6
T 9-5	0	0	0
T 10-4	0	0	489
T 11-3	0	0	1491.5
T 12-2	238	299	1626.6
T 12-3	0	0	42
T 13-1	<u>0</u>	<u>0</u>	<u>176</u>
Totals	3292	4437	9101.3

Subreach 2

	1989 Reported Water Use	1990 Reported Water Use	Division of Water Resources Appropriations
T 4-14	561		662.7
T 4-15	0	519	1189
T 4-16	1817	2219	1190.4
T 5-12	0	0	556
T 5-13	1620	1295	2186
T 5-14	679	670	1184.2
T 5-15	0	0	497.7
T 5-16	0	0	1.7
T 6-11	641	801	1142.2
T 6-12	1171	1167	1918.8
T 6-13	<u>0</u>	<u>0</u>	<u>333</u>
Totals	6489	6671	10861.7

Appendix C (cont.). Water Rights by River Reach

Subreach 3

	1989 Reported Water Use	1990 Reported Water Use	Division of Water Resources Appropriations
T 7-11	0	0	412
T 7-12	0	0	695.5
T 7-13	0	0	1556
T 7-14	0	0	1029.6
T 7-15	0	0	1415.9
T 7-16	0	0	1309.1
T 7-17	0	0	396.5
T 7-18	0	0	2491.7
T 7-19	<u>0</u>	<u>0</u>	<u>391</u>
Totals	0	0	9697.3

Subreach 4

	1989 Reported Water Use	1990 Reported Water Use	Division of Water Resources Appropriations
T 4-17	0	0	965
T 4-18	0	0	366.2
T 4-19	0	0	2.3
T 4-20	0	0	38.3
T 5-20	0	0	0
T 5-21	0	0	463.2
T 5-22	0	0	898
T 5-23	<u>0</u>	<u>0</u>	<u>1173</u>
Totals	0	0	3906

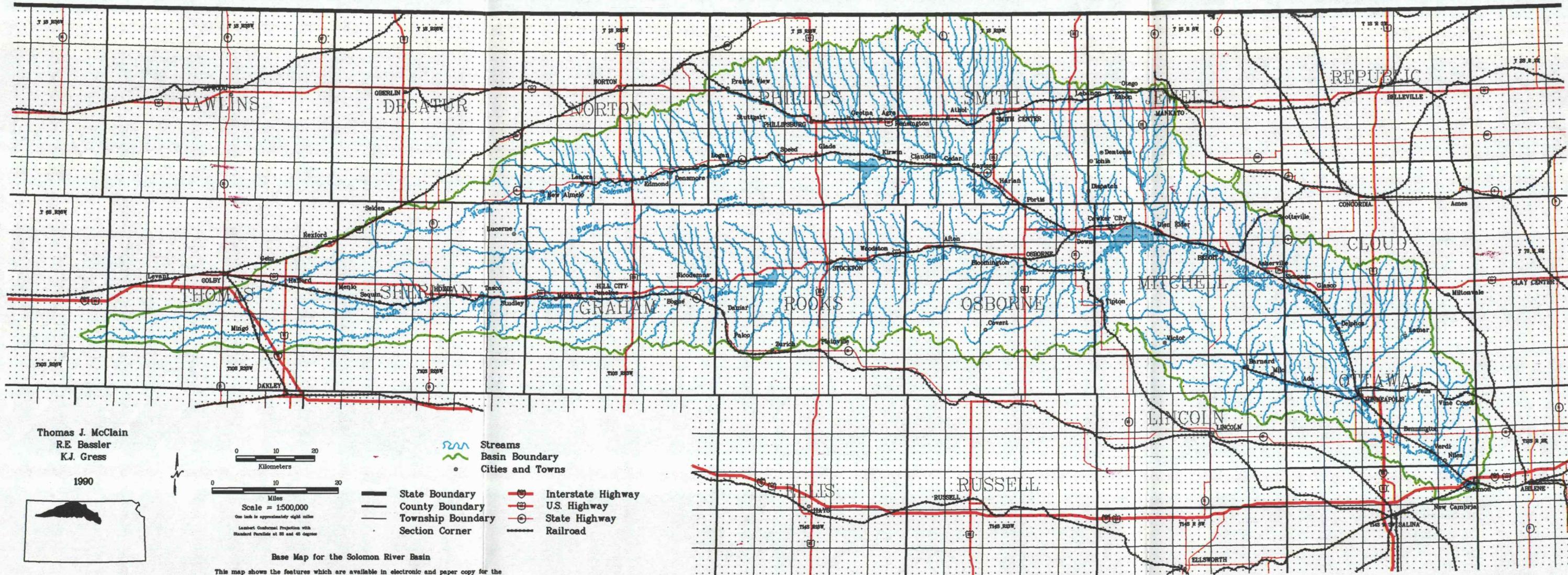
Subreach 5

	1989 Reported Water Use	1990 Reported Water Use	Division of Water Resources Appropriations
T 8-20	0	0	919.9
T 8-21	1136	1322	1518.2
T 8-22	0	0	548
T 8-23	0	0	1396.2
T 8-24	1131	1317	1817
T 8-25	0	0	1618.4
T 8-26	0	0	1298.6
T 8-27	<u>0</u>	<u>0</u>	<u>791.2</u>
Totals	2267	2639	9907.5

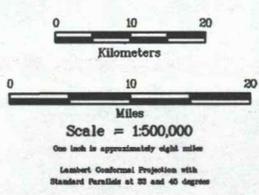
Solomon Basin Plates

The original Plates (maps)
were reduced by 50%
for ease of handling;
therefore the ratio scale indicated
on the maps is not true, but
the bar scale is still valid.

Solomon River Basin



Thomas J. McClain
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K.J. Gress
1990



- Streams
- Basin Boundary
- Cities and Towns
- State Boundary
- County Boundary
- Township Boundary
- Section Corner
- Interstate Highway
- U.S. Highway
- State Highway
- Railroad

Base Map for the Solomon River Basin

This map shows the features which are available in electronic and paper copy for the Solomon Basin. Except for the basin boundary, the data has been digitized from 7.5 minute topographic maps by the Kansas Geological Survey and resides in the Kansas Cartographic Database. Those data are available in electronic and paper copy from the Kansas Geological Survey.

Prepared in cooperation with the Kansas Water Office.

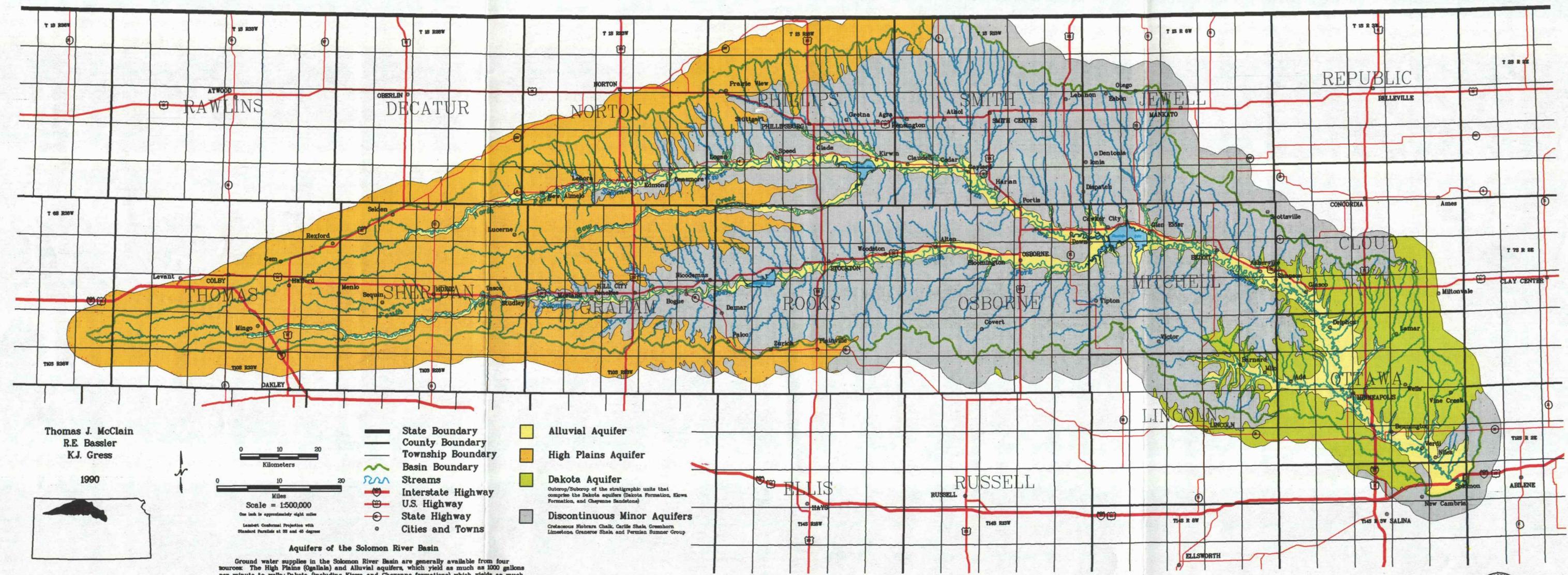
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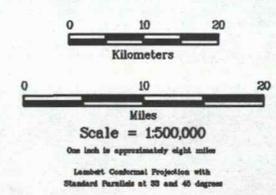
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Solomon River Basin

Principle Aquifers



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1930



- State Boundary
- County Boundary
- Township Boundary
- Basin Boundary
- Streams
- Interstate Highway
- U.S. Highway
- State Highway
- Cities and Towns

- Alluvial Aquifer
 - High Plains Aquifer
 - Dakota Aquifer
 - Discontinuous Minor Aquifers
- Outcrop/Subcrop of the stratigraphic units that comprise the Dakota aquifer (Dakota Formation, Kiowa Formation, and Cheyenne Sandstone)
- Cretaceous Niobrara Chalk, Carlile Shale, Gresham Limestone, Graneros Shale and Permian Sumner Group

Aquifers of the Solomon River Basin

Ground water supplies in the Solomon River Basin are generally available from four sources: The High Plains (Ogallala) and Alluvial aquifers, which yield as much as 1000 gallons per minute to wells; Dakota (including Kiowa and Cheyenne formations) which yields as much as 500 gallons per minute, and discontinuous minor aquifers which yield 1 to 10 gallons per minute.

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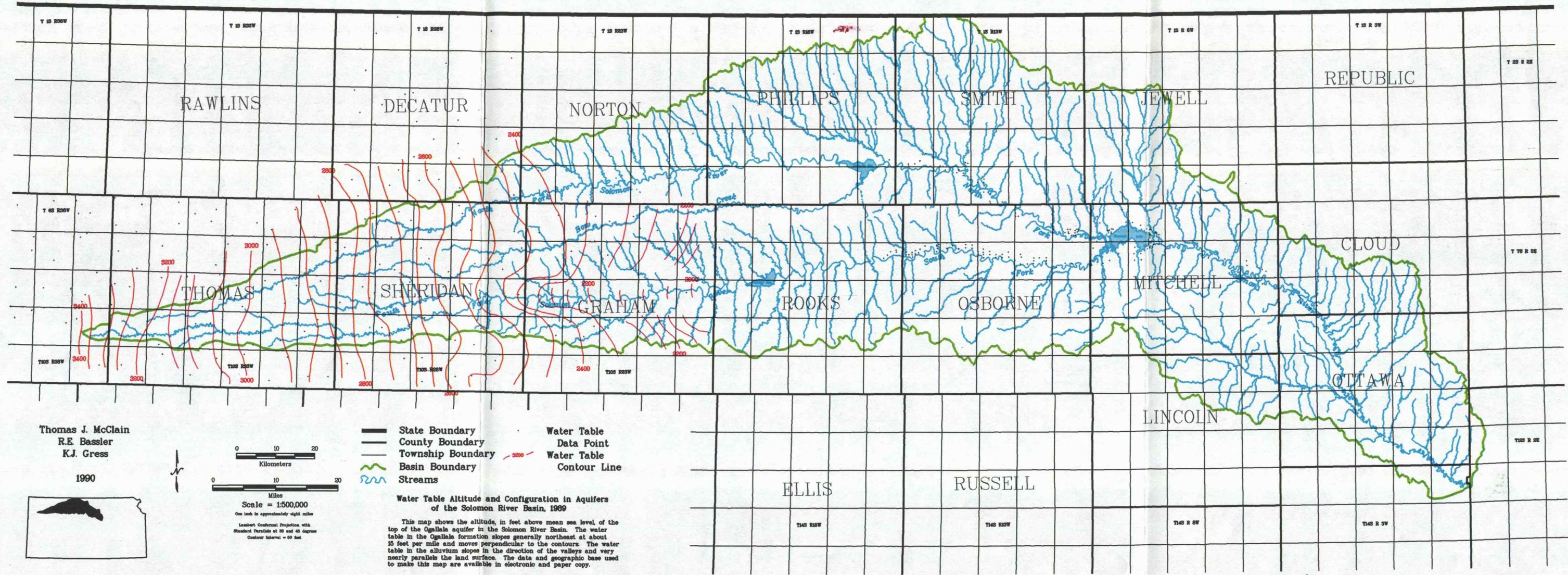
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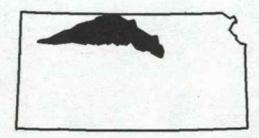
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Solomon River Basin

Water Table Altitude and Configuration



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1990



0 10 20
Kilometers

0 10 20
Miles

Scale = 1:500,000
One inch is approximately eight miles

Lambert Conformal Projection with
Standard Parallels at 35 and 45 degrees
Contour Interval = 50 feet

- State Boundary
- County Boundary
- Township Boundary
- Basin Boundary
- Streams
- Water Table Data Point
- Water Table Contour Line

Water Table Altitude and Configuration in Aquifers of the Solomon River Basin, 1989

This map shows the altitude, in feet above mean sea level, of the top of the Ogallala aquifer in the Solomon River Basin. The water table in the Ogallala formation slopes generally northeast at about 15 feet per mile and moves perpendicular to the contours. The water table in the alluvium slopes in the direction of the valleys and very nearly parallels the land surface. The data and geographic base used to make this map are available in electronic and paper copy.

Prepared in cooperation with the Kansas Water Office.

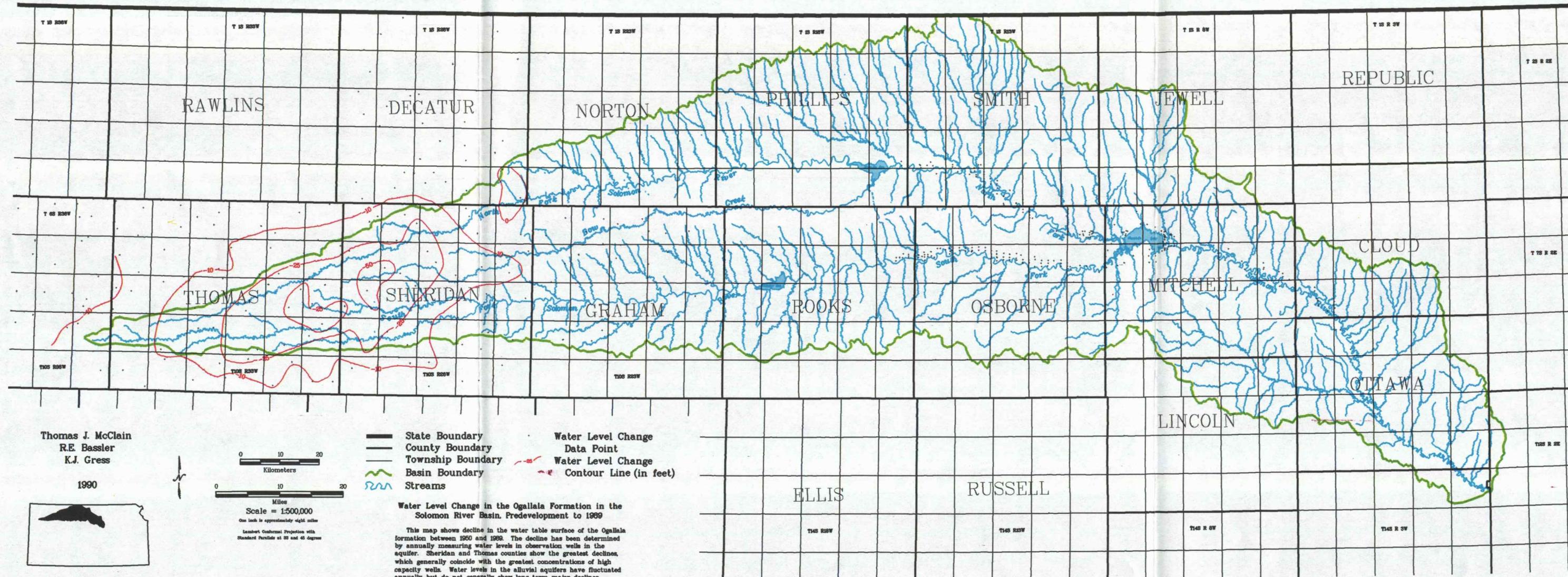
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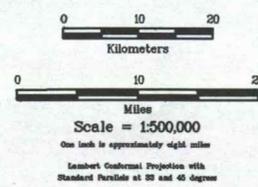
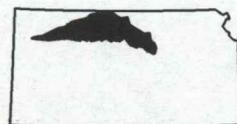
Solomon River Basin

Water Level Change 1950-1989



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1990



- State Boundary
- County Boundary
- Township Boundary
- Basin Boundary
- Streams
- Water Level Change Data Point
- Water Level Change Contour Line (in feet)

Water Level Change in the Ogallala Formation in the Solomon River Basin, Predevelopment to 1989

This map shows decline in the water table surface of the Ogallala formation between 1950 and 1989. The decline has been determined by annually measuring water levels in observation wells in the aquifer. Sheridan and Thomas counties show the greatest declines, which generally coincide with the greatest concentrations of high capacity wells. Water levels in the alluvial aquifers have fluctuated annually but do not generally show long term major declines.

Prepared in cooperation with the Kansas Water Office.

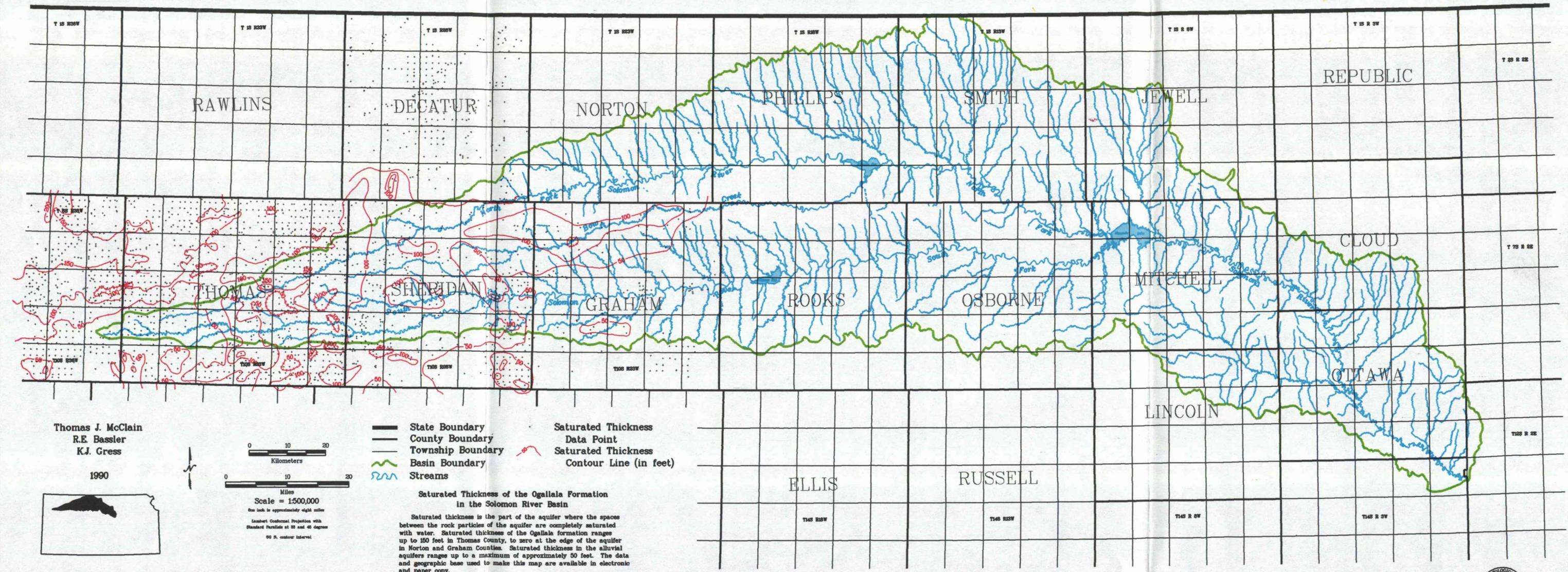
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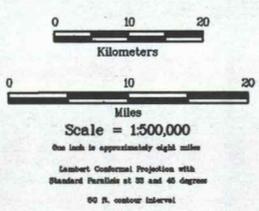
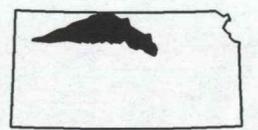
Solomon River Basin

Saturated Thickness of the Ogallala Formation



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- State Boundary
- County Boundary
- Township Boundary
- Basin Boundary
- Streams
- Saturated Thickness Data Point
- Saturated Thickness Contour Line (in feet)

Saturated Thickness of the Ogallala Formation in the Solomon River Basin

Saturated thickness is the part of the aquifer where the spaces between the rock particles of the aquifer are completely saturated with water. Saturated thickness of the Ogallala formation ranges up to 150 feet in Thomas County, to zero at the edge of the aquifer in Norton and Graham Counties. Saturated thickness in the alluvial aquifers ranges up to a maximum of approximately 50 feet. The data and geographic base used to make this map are available in electronic and paper copy.

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