ESTIMATION AND CHARACTERIZATION OF THE NATURAL STREAMFLOW OF THE WHITE RIVER NEAR THE NEBRASKA-SOUTH DAKOTA STATE LINE

By Steven K. Sando

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CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
square mile (mi^2)	2.590	square kilometer

Water year in Geological Survey reports dealing with surface-water supply is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends; thus, the year ending September 30, 1990, is called the "1990 water year."

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ABSTRACT

A reconnaissance-level study to estimate and characterize the monthly natural streamflow of the White River at the Nebraska-South Dakota State line was performed by the U.S. Geological Survey in cooperation with the U.S. Bureau of Indian Affairs. The MOVE.1 curve-fitting technique was used to extend 2 years of gaged streamflow records for the gaging station near the State line to a base period of suitable length (water years 1944-89) to estimate long-term streamflow characteristics. Monthly irrigation depletions were estimated using annual irrigated acreage data and mean monthly net crop irrigation requirements. Adjustment factors were developed to use when flow conditions do not permit irrigators to meet the full crop requirements. An estimate of non-beneficial consumptive use also was included in the estimate of irrigation depletions.

The estimated monthly irrigation depletions were added to the gaged and extended historical streamflow records to obtain a record of estimated monthly natural streamflows. Statistical characteristics of estimated monthly natural streamflow were determined and are presented in tabular form. The estimated median annual natural streamflow of the White River at the State line is 35,938 acre-feet, which is about 9,000 acre-feet greater than the median annual streamflow determined from extended and gaged records.

INTRODUCTION

The U.S. Bureau of Indian Affairs is studying the water resources of the White River basin. To aid in determining the amount of water in the White River that is legally available for use on the Pine Ridge Indian Reservation (fig. 1), the Bureau requested that the U.S. Geological Survey make a reconnaissance-level study to estimate and characterize the monthly natural streamflow of the White River at the Nebraska-South Dakota State line.

The term "natural streamflow" generally refers to streamflow that is unaltered by human activities. Some common ways that human activities influence streamflow are by: diversion of water from the stream channel to satisfy domestic, industrial, and agricultural water demands; impoundment and storage of water for many purposes including flood control, power generation, recreation, and domestic, industrial, and agricultural demands; and supplementation of streamflow by reservoir releases or interbasin diversions.

To meet water-management and legal objectives, it is sometimes important to determine the effect of human activities on the records of historical streamflow and subsequently estimate natural streamflow at a given location. To accomplish this, streamflow depletions and accretions caused by human

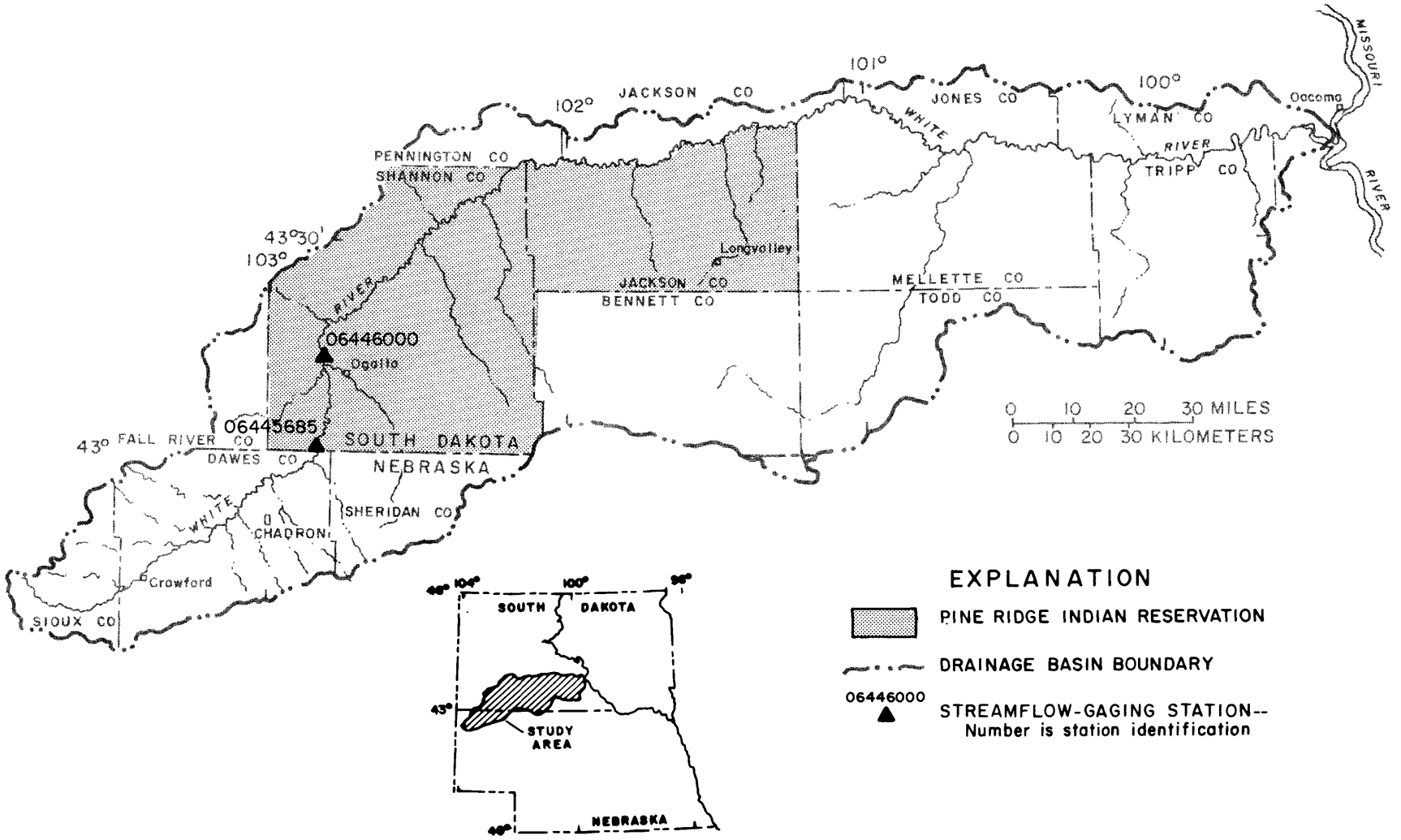

Figure 1.--White River basin.

activities are measured or estimated upstream from a location with streamflow gaging records. Records of historical streamflow from the gaged location are then adjusted by adding depletions and subtracting accretions to obtain an estimate of the natural streamflow.

Purpose and Scope

The purpose of this study was to estimate and characterize the monthly natural streamflow of the White River at the Nebraska-South Dakota State line. Although several factors affect the natural flow of the White River, irrigation accounts for nearly all consumptive use of water in the White River basin upstream from the Nebraska-South Dakota State line. For this reason, irrigation depletions were the only human effects on historical streamflow that were used in estimating natural streamflow. Natural streamflow was determined by estimating irrigation depletions in the basin upstream from the State line and adding these depletions to gaged or extended historical streamflow records for the White River at the State line. This report presents the findings of the study.

Basin Description

The White River flows in a generally northeastward direction from its headwaters in northwestern Nebraska to its confluence with the Missouri River near Oacoma, South Dakota (fig. 1). The White River basin lies in an unglaciated part of the Missouri Plateau and is characterized by undulating uplands, wide flood plains along the larger streams, scattered bluffs and buttes, and areas of badlands (U.S. Geological Survey, 1975). The drainage area of the basin is about 1,440 mi^2 at the State line and about 10,200 mi^2 at the mouth of the river near Oacoma. At Long Valley, South Dakota, which is located in the White River basin, normal annual precipitation is 17 in.; about 75 percent occurs during the growing season (U.S. Department of Commerce, 1988). The elevation of the river at the State line is about 3,030 ft.

ESTIMATION OF NATURAL STREAMFLOW

Estimation of natural streamflow in the White River at the Nebraska-South Dakota State line was performed by: (1) Producing a long-term record of historical streamflow, and (2) estimating irrigation depletions using information about irrigated area, crop irrigation requirements, irrigation operations, and non-beneficial consumptive use. Irrigation depletions were added to historical streamflow records to obtain an estimated record of monthly natural streamflow.

Historical Streamflow

The period of record for the streamflow gaging station no. 06445685, White River near Nebraska-South Dakota State line, is water years 1988-89. Because of climatic and hydrologic variability, such a short period of record probably would result in inaccurate estimates of long-term streamflow characteristics. For this reason, the MOVE.1 monthly streamflow record-extension procedure (Hirsch, 1982; Alley and Burns, 1983) was used to extend the streamflow records of the gaging station.

The MOVE.1 curve-fitting technique (also referred to as the line of organic correlation) is similar to ordinary least squares regression, except that ordinary least squares regression minimizes the sum of the squared vertical deviations of the dependent variable from the regression line whereas the MOVE.1 technique minimizes the sum of the areas of right triangles formed by the horizontal and vertical deviations from the regression line (Hirsch and Gilroy, 1984).

The streamflow gaging station no. 06446000, White River near Oglala, South Dakota, was used as the long-term station (water years 1944-89 base period) to extend the streamflow records of White River near Nebraska-South Dakota State line. During the base period, there were no substantial diversions of flow between the two gaging locations which could have altered the relation in flow at the two sites. Because there were only 2 years of concurrent record between the short-term station (White River near Nebraska-South Dakota State line) and the long-term station (White River near Oglala), development of different extension equations for each month was not possible. Instead, the 24 concurrent monthly streamflows were used to develop a single extension equation, which was used for all months. Gaged and extended monthly streamflows for White River near Nebraska-South Dakota State line are presented in table 1. Values presented for 1988 and 1989 were gaged, but may not exactly equal previously reported values for these years due to rounding performed by the MOVE.1 extension program. Also, it should be noted that values in table 1 are presented as they were output from the MOVE.1 extension program and used in subsequent analyses. The number of significant figures are not, however, indicative of the accuracy of the estimates. Statistical characteristics of gaged and extended monthly streamflows for White River near Nebraska-South Dakota State line are presented in table 2.

Irrigation Depletions

Irrigation depletions account for nearly all of the consumptive use of water in the White River basin upstream from the Nebraska-South Dakota State line. Irrigation depletions were estimated using information about irrigated area, irrigation requirements, tributary operations, and non-beneficial consumptive use.

Irrigated Area

Annual irrigated acreage for the part of the White River basin upstream from the State line was determined using priority dates and irrigated acreages from a water rights listing of 156 irrigation appropriations provided by the Nebraska Department of Water Resources. Irrigated area for main-stem and tributary diversions were determined separately. The area associated with each appropriation was assumed to have been irrigated starting either in the year of the priority date for appropriations with priority dates before July 15 of a specified year, or in the year following the priority date for appropriations with priority dates on or after July 15 of a specified year. Irrigation for each appropriation was assumed to continue until the end of the base period. Some appropriations had been partially cancelled so that the actual irrigated area associated with an appropriation was less than the area recorded on the water rights listing. Areas associated with the partially cancelled appropriations were estimated according to the guideline of 70 acres irrigated for each cubic foot per second of allotted diversion rate. Summary data on irrigated area in the White River basin upstream from the State line for each year of the base period are presented in table 3.

Table 1.--Gaged and extended monthly streamflow, in acre-feet, for White River near Nebraska-South Dakota State line

[Values for water years 1988 and 1989 are gaged streamflow records; values prior to water year 1988 are extended streamflow records]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual[1]
1944	258	726	473	363	489	7858	5254	10441	14001	5288	3659	1095	49905
1945	775	1654	885	658	744	9623	4451	4292	7866	2785	4593	3189	41516
1946	1420	1315	1039	1107	1755	5626	1511	10311	8569	1347	1304	3784	39088
1947	2084	2208	2822	1912	3410	4999	3927	2718	40278	14769	2761	2053	83942
1948	1875	1345	1906	1390	1760	6468	3332	4759	5778	3154	2712	494	34974
1949	578	1726	1254	523	3293	40127	5391	8209	5046	2915	953	1006	71019
1950	799	1107	861	683	1572	4648	3404	4956	1738	1015	922	1345	23048
1951	695	833	947	928	1277	2066	1630	1869	6063	6198	1814	3267	27588
1952	1088	988	769	664	3440	8602	4671	5085	2969	1015	418	280	29988
1953	307	262	264	535	844	9512	2029	5429	2041	996	3271	756	26247
1954	652	315	762	541	1522	1654	1273	4144	2398	928	529	684	15404
1955	277	732	523	480	439	5860	3540	4845	6069	1506	1094	8801	34166
1956	928	369	2226	922	2974	4630	1178	2933	1559	849	879	381	19828
1957	381	1012	1101	603	1972	1857	5058	29102	22344	3517	1224	1131	69299
1958	1187	1398	1224	1291	1594	2355	4058	2423	2249	5724	1334	601	25439
1959	646	780	744	953	1072	2607	1904	2312	1434	1636	301	1291	15679
1960	344	345	437	400	679	11578	1523	4249	1946	904	750	363	23517
1961	633	1095	1033	443	644	1359	756	1549	494	799	596	434	9836
1962	719	482	289	326	822	3572	601	7016	38916	8289	1931	738	63700
1963	1347	869	953	627	2744	7514	2267	1451	9616	2054	357	476	30273
1964	221	292	252	344	535	1248	2178	1070	2696	842	49	0	9727
1965	0	208	86	160	255	787	1178	5374	5105	2619	492	417	16682
1966	775	1261	953	424	561	18864	3362	1771	649	1254	3806	1119	34799
1967	1328	393	443	553	1250	1691	2838	4630	49829	7188	2349	3880	76371
1968	3197	1601	1138	1131	2347	3554	5147	3247	10336	2595	1906	940	37138
1969	658	869	621	652	778	4064	3189	2447	946	15741	892	381	31237
1970	639	845	461	424	1066	1838	8580	2416	2559	381	289	95	19596
1971	209	619	332	49	2549	3659	3029	9217	8045	1470	258	720	30155

Table 1.--Gaged and extended monthly streamflow, in acre-feet, for White River near Nebraska-South Dakota State line--Continued

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual[1]
1972	928	530	510	344	696	2896	1369	4323	1708	1119	344	256	15023
1973	191	262	240	412	1039	5694	3648	4642	1172	892	141	833	19165
1974	461	916	1076	1838	3471	2699	5671	2029	946	264	80	190	19643
1975	221	428	344	215	378	1777	5730	2054	5314	744	1353	30	18588
1976	394	161	289	344	2600	2115	1981	2564	1059	1131	467	226	13332
1977	160	30	160	37	272	1525	5677	2134	1857	535	2054	1422	15861
1978	412	422	461	295	255	20291	3326	4784	3326	2521	2982	714	39791
1979	369	405	332	148	150	3197	1845	2183	1797	4704	6567	619	22314
1980	1709	1232	621	793	2169	7046	4147	1931	4171	775	1101	226	25921
1981	252	262	424	584	939	1101	631	750	238	2226	2183	238	9827
1982	31	387	375	197	905	1359	1059	13269	9158	1660	1217	482	30099
1983	2632	1339	1045	1162	3482	3751	4570	15722	4957	2792	1193	321	42966
1984	547	946	873	1162	3664	3911	4802	8787	2386	1734	320	54	29185
1985	215	345	437	400	700	3210	1363	683	298	0	61	0	7710
1986	197	750	86	541	3043	5823	11437	5233	23665	7667	1697	2928	63066
1987	2896	2737	2693	1808	2299	10527	17530	5626	2463	916	369	488	50353
1988	695	708	676	572	615	4267	3975	9014	2594	935	486	268	24805
1989	455	464	363	467	433	3659	1511	1525	690	61	98	541	10269

[1]Sum of monthly values may not equal annual total because of independent rounding.

Table 2.--Statistical characteristics of gaged and extended streamflow for White River near Nebraska-South Dakota State line

[Percentile denotes exceedance percentile, where the XX percentile refers to that value which is equaled or exceeded XX percent of the time]

Parameter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
Mean	800	825	778	661	1511	5719	3642	5120	7159	2792	1395	1077	31480
Stand. deviation	739	563	611	452	1088	6640	2986	4910	10876	3376	1362	1526	18875
Maximum	3197	2737	2822	1912	3664	40127	17530	29102	49829	15741	6567	8801	83942
Minimum	0	30	86	37	150	787	601	683	238	0	49	0	7710
90 Percentile	195	262	248	186	346	1359	1142	1503	678	489	129	83	10139
80 Percentile	234	345	332	344	545	1802	1426	1970	1277	845	330	245	15752
70 Percentile	347	406	425	401	696	2380	1851	2322	1803	929	469	365	19600
60 Percentile	446	520	461	462	840	3207	2249	2687	2359	1098	719	468	23424
50 Percentile	636	741	621	541	1069	3705	3329	4270	2645	1488	1024	571	26918
40 Percentile	695	869	787	607	1576	4634	3704	4764	4975	2088	1240	724	30179
30 Percentile	797	1009	952	681	2149	5810	4421	5218	6035	2769	1802	999	34956
20 Percentile	1272	1294	1064	1045	2686	7720	5111	7731	8922	4229	2282	1323	42386
10 Percentile	1938	1617	1450	1321	3419	10842	5693	10350	22740	7332	3387	3213	65380

Table 3.--Irrigated area in the White River basin upstream from the State line listed by source and irrigation type for each year of the base period

[Source: Nebraska Department of Water Resources]

Year	Newly irrigated area				Cumulative total irrigated area			
	Main-stem gravity-flow irrigated area (acres)	Main-stem sprinkler irrigated area (acres)	Tributary gravity-flow irrigated area (acres)	Tributary sprinkler irrigated area (acres)	Main-stem gravity-flow irrigated area (acres)	Main-stem sprinkler irrigated area (acres)	Tributary gravity-flow irrigated area (acres)	Tributary sprinkler irrigated area (acres)
1944	0.0	0.0	0.0	0.0	3755.0	229.0	2732.6	261.4
1945	.0	.0	.0	.0	3755.0	229.0	2732.6	261.4
1946	.0	.0	63.0	.0	3755.0	229.0	2795.6	261.4
1947	.0	.0	.0	.0	3755.0	229.0	2795.6	261.4
1948	.0	.0	.0	.0	3755.0	229.0	2795.6	261.4
1949	.0	236.6	.0	.0	3755.0	465.6	2795.6	261.4
1950	.0	149.6	.0	.0	3755.0	615.2	2795.6	261.4
1951	.0	141.4	.0	103.4	3755.0	756.6	2795.6	364.8
1952	.0	146.6	.0	7.0	3755.0	903.2	2795.6	371.8
1953	.0	28.0	.0	619.4	3755.0	931.2	2795.6	991.2
1954	.0	599.0	228.3	127.4	3755.0	1530.2	3023.9	1118.6
1955	.0	.0	.0	42.0	3755.0	1530.2	3023.9	1160.6
1956	.0	77.1	.0	186.1	3755.0	1607.3	3023.9	1346.7
1957	.0	84.0	.0	440.3	3755.0	1691.3	3023.9	1787.0
1958	.0	44.3	.0	.0	3755.0	1735.6	3023.9	1787.0
1959	.0	.0	.0	.0	3755.0	1735.6	3023.9	1787.0
1960	.0	.0	262.0	53.0	3755.0	1735.6	3285.9	1840.0
1961	.0	.0	.0	.0	3755.0	1735.6	3285.9	1840.0
1962	.0	51.1	80.0	106.2	3755.0	1786.7	3365.9	1946.2
1963	7.7	.0	19.1	0.0	3762.7	1786.7	3385.0	1946.2
1964	.0	.0	.0	117.6	3762.7	1786.7	3385.0	2063.8
1965	.0	.0	.0	.0	3762.7	1786.7	3385.0	2063.8
1966	.0	.0	.0	.0	3762.7	1786.7	3385.0	2063.8

Table 3.--Irrigated area in the White River basin upstream from the State line listed by source and irrigation type for each year of the base period--Continued

Year	Newly irrigated area				Cumulative total irrigated area			
	Main-stem gravity-flow irrigated area (acres)	Main-stem sprinkler irrigated area (acres)	Tributary gravity-flow irrigated area (acres)	Tributary sprinkler irrigated area (acres)	Main-stem gravity-flow irrigated area (acres)	Main-stem sprinkler irrigated area (acres)	Tributary gravity-flow irrigated area (acres)	Tributary sprinkler irrigated area (acres)
1967	0.0	0.0	0.0	1.5	3762.7	1786.7	3385.0	2065.3
1968	.0	7.0	.0	3.5	3762.7	1793.7	3385.0	2068.8
1969	.0	.0	.0	21.0	3762.7	1793.7	3385.0	2089.8
1970	.0	.0	.0	.0	3762.7	1793.7	3385.0	2089.8
1971	.0	.0	.0	.0	3762.7	1793.7	3385.0	2089.8
1972	.0	.0	.0	.0	3762.7	1793.7	3385.0	2089.8
1973	.0	.0	.0	12.1	3762.7	1793.7	3385.0	2101.9
1974	.0	.0	.0	13.5	3762.7	1793.7	3385.0	2115.4
1975	175.0	.0	.0	298.0	3937.7	1793.7	3385.0	2413.4
1976	.0	.0	25.9	342.6	3937.7	1793.7	3410.9	2756.0
1977	70.0	.0	.0	247.1	4007.7	1793.7	3410.9	3003.1
1978	.0	4.8	.0	.0	4007.7	1798.5	3410.9	3003.1
1979	12.2	174.0	.0	118.5	4019.9	1972.5	3410.9	3121.6
1980	.0	108.6	.0	.0	4019.9	2081.1	3410.9	3121.6
1981	241.7	531.4	.0	419.4	4261.6	2612.5	3410.9	3541.0
1982	.0	63.7	.0	98.7	4261.6	2676.2	3410.9	3639.7
1983	.0	.0	.0	34.0	4261.6	2676.2	3410.9	3673.7
1984	.0	.0	.0	.0	4261.6	2676.2	3410.9	3673.7
1985	.0	.0	117.9	.0	4261.6	2676.2	3528.8	3673.7
1986	.0	.0	.0	.0	4261.6	2676.2	3528.8	3673.7
1987	.0	.0	.0	.0	4261.6	2676.2	3528.8	3673.7
1988	.0	.0	.0	.0	4261.6	2676.2	3528.8	3673.7
1989	.0	.0	.0	.0	4261.6	2676.2	3528.8	3673.7

Crops and Net Irrigation Requirements

Alfalfa is the primary irrigated crop in the White River basin upstream from the State line, currently comprising approximately 95 percent of the irrigated area (T. Mitchell, Nebraska Department of Water Resources, oral commun., 1990; C. Dickerson, U.S. Soil Conservation Service, oral commun., 1990). Native grasses and corn account for the rest of the irrigated area. A crop distribution of 95 percent alfalfa and 5 percent corn was used for each year of the base period in calculating irrigation depletions.

The U.S. Soil Conservation Service (SCS) has published irrigation guides for many States with substantial irrigated agriculture. Mean monthly irrigation requirements reported in these guides are useful in estimating the amount of water required to satisfy crop water demands. Unfortunately, the SCS irrigation guide for Nebraska does not include mean monthly irrigation requirements for alfalfa in the Nebraska part of the White River basin (U.S. Soil Conservation Service, 1983). For this reason, mean monthly irrigation requirements for corn and alfalfa were estimated using values reported for the South Dakota part of the White River basin in the South Dakota Irrigation Guide (U.S. Soil Conservation Service, 1978) and are presented in table 4. Differences in climatic characteristics between the Nebraska and South Dakota parts of the White River basin are not large and crop water requirements in the two areas probably are very similar.

Table 4.--Mean monthly net irrigation requirements, in inches, for alfalfa and corn in the White River basin in South Dakota

[From U.S. Soil Conservation Service, 1978]

	Monthly net irrigation requirement					
Crop	May	June	July	August	September	October
Alfalfa	1.3	3.4	5.4	4.3	3.2	0.4
Corn	.0	1.1	5.4	4.8	1.0	.0

The mean monthly net irrigation requirements were held constant from year to year for the entire base period. Because actual net irrigation requirements vary from year to year due to climatic variability, the use of constant monthly net irrigation requirements may result in errors during unusually wet or dry years. However, the annual variability in net irrigation requirements probably is not large enough to produce large errors in estimates of long-term characteristics of natural streamflow. For example, the difference between the median and 75-percentile seasonal net irrigation requirement for corn in the Nebraska part of the White River basin is about 5 percent (U.S. Soil Conservation Service, 1983). However, the error may affect estimates of natural streamflow in individual years of extreme moisture conditions.

Tributary Irrigation Operations

Because tributaries in the Nebraska part of the White River basin are ephemeral, water to satisfy irrigation diversions from tributaries generally is available only during the early part of the irrigation season. Irrigation begins when the water temperature is high enough to not retard root growth and continues until water is no longer available.

Tributary irrigation operations are simple. Gravity-flow systems are characterized by simple diversion ditches which convey water to individual fields. Water is flooded onto border systems or nearly level benches. These types of operations commonly are referred to as water-spreading operations. Prior to the early 1950's, water-spreading operations comprised most of the tributary irrigation in the Nebraska part of the White River basin. In the early 1950's, the use of sprinklers became increasingly more common; sprinkler irrigation in 1990 comprised about 60 percent of the area irrigated by tributary diversions. Most tributary sprinkler systems are center pivots, but some side-roll sprinklers also are used.

In order to simulate the ephemeral character of tributary irrigation operations, the following guidelines were developed (T. Mitchell, Nebraska Department of Water Resources, oral commun., 1990): in years of below-normal moisture (annual streamflow less than or equal to the 33.3 percentile), tributary irrigators satisfy mean monthly irrigation requirements through May 31 and then receive no water for the remainder of the irrigation season; in years of near-normal moisture (annual streamflow greater than the 33.3-percentile annual streamflow but less than the 66.7 percentile), tributary irrigators satisfy mean monthly irrigation requirements through June 30 and then receive no water for the remainder of the irrigation season; in years of above-normal moisture (annual streamflow greater than the 66.7 percentile), tributary irrigators satisfy mean monthly net irrigation requirements through July 31 and then receive no water for the remainder of the irrigation season.

Main-Stem Irrigation Operations

The White River in Nebraska generally flows year round, although zero streamflow does occur at some locations in some years. The streamflow of the White River generally is not sufficient to fully satisfy the net irrigation requirement for all appropriators during the later part of the irrigation season (T. Mitchell, Nebraska Department of Water Resources, oral commun., 1990). Conveyance canals that supply water to main-stem gravity-flow irrigation operations typically are larger than those used by tributary irrigators and generally a single canal will convey water to numerous irrigators comprising an irrigation district. Graded borders is the most common gravity-flow field-application method used by main-stem irrigators. Prior to the early 1950's, gravity-flow systems accounted for nearly all of the area irrigated from the main stem of the White River in Nebraska. Since the early 1950's, use of sprinklers has become increasingly more common; sprinkler irrigation in 1990 comprised about 40 percent of the area irrigated from the main stem White River in Nebraska. Sprinkler systems that divert water from the main stem White River in Nebraska are mostly side-roll sprinklers but some center pivots are used.

In order to simulate the partial-supply character of main-stem irrigation operations, the following guidelines were developed (T. Mitchell, Nebraska Department of Water Resources, oral commun., 1990): in years of

below-normal moisture (annual streamflow less than or equal to the 33.3 percentile), main-stem irrigators satisfy mean monthly net irrigation requirements through May 31, then satisfy one-half the mean monthly irrigation requirements from June 1 through August 31, then satisfy one-fifth the mean monthly irrigation requirements for the remainder of the irrigation season; in years of near-normal moisture (annual streamflow greater than the 33.3-percentile annual streamflow but less than the 66.7 percentile), main-stem irrigators satisfy mean monthly irrigation requirements through June 30 and then satisfy one-half the mean monthly irrigation requirements for the remainder of the irrigation season; in years of above-normal moisture (annual streamflow greater than the 66.7 percentile), main-stem irrigators satisfy mean monthly irrigation requirements through August 15, then satisfy three-fourths the mean monthly irrigation requirements for the remainder of the irrigation season.

Non-Beneficial Consumptive Use

In the process of conveying water from the point of diversion to the crop root zone, some water is lost by percolation to ground-water aquifers, storage in canal banks, transpiration by phreatophytes, and soil surface and free-water surface evaporation. The concept of irrigation efficiency is used in considering water loss from irrigation operations. Irrigation efficiency is calculated by dividing the net irrigation requirement by the gross diversion. Estimated irrigation efficiencies for irrigation operations in the Nebraska part of the White River basin are 0.30 for gravity-flow systems and 0.59 for sprinkler systems (C. Dickerson, U.S. Soil Conservation Service, oral commun., 1990).

Much of the water lost from irrigation operations eventually is returned to the stream by ground-water discharge or bank-storage release, but some of the water is irrecoverably lost from the river system and is referred to as non-beneficial consumptive use. Non-beneficial consumptive use for irrigation operations in the Nebraska part of the White River basin was assumed to be 15 percent of the difference between the gross diversion requirement and the net irrigation requirement (R. DeVore, U.S. Bureau of Reclamation, oral commun., 1990).

Calculation of Irrigation Depletions

The total irrigation depletion for the White River basin upstream from the State line was calculated for each month of the base period 1943-89 using the formulas that follow. Estimated monthly irrigation depletions are presented in table 5 and characteristics of monthly irrigation depletions in the White River basin upstream from the State line are presented in table 6.

$$D_C = IR_N * (((A_{MG} + A_{MS}) * C_M) + ((A_{TG} + A_{TS}) * C_T))$$

$$D_{NB} = (IR_N * ((((A_{MG} * C_M) + (A_{TG} * C_T)) / E_G) - ((A_{MG} * C_M) + (A_{TG} * C_T))) * 0.15) + (IR_N * ((((A_{MS} * C_M) + (A_{TS} * C_T)) / E_S) - ((A_{MS} * C_M) + (A_{TS} * C_T))) * 0.15)$$

$$D_{TOT} = D_C + D_{NB}$$

where D_C = streamflow depletion from crop consumptive use, in acre-feet;
IR_N = mean monthly net irrigation requirement, in feet;
A_{MG} = area irrigated from main-stem diversions using gravity-flow systems, in acres;
A_{MS} = area irrigated from main-stem diversion using sprinkler systems, in acres;
C_M = an adjustment factor to account for the partial-supply character of main-stem irrigation operations; in years of below-normal moisture (annual streamflow less than or equal to the 33.3 percentile), C_M equals 1.0 through May 31, 0.5 from June 1 through August 31, and 0.2 for the remainder of the irrigation season; in years of near-normal moisture (annual streamflow greater than the 33.3 percentile but less than the 66.7 percentile), C_M equals 1.0 through June 30 and 0.5 for the remainder of the irrigation season; in years of above-normal moisture (annual streamflow greater than the 66.7 percentile), C_M equals 1.0 through August 15, and 0.75 for the remainder of the irrigation season;
A_{TG} = area irrigated from tributary diversions using gravity-flow systems, in acres;
A_{TS} = area irrigated from tributary diversions using sprinkler systems, in acres;
C_T = an adjustment factor to account for the ephemeral character of tributary irrigation operations; in years of below-normal moisture (annual streamflow less than or equal to the 33.3 percentile), C_T equals 1.0 through May 31 and 0 for the remainder of the irrigation season; in years of near-normal moisture (annual streamflow greater than the 33.3 percentile but less than the 66.7 percentile), C_T equals 1.0 through June 30 and 0 for the remainder of the irrigation season; in years of above-normal moisture (annual streamflow greater than the 66.7 percentile), C_T equals 1.0 through July 31 and 0 for the remainder of the irrigation season;
D_{NB} = streamflow depletion due to non-beneficial consumptive use associated with irrigation operations;
E_G = irrigation efficiency for gravity-flow irrigation operations;
E_S = irrigation efficiency for sprinkler-irrigation operations; and
D_{TOT} = total streamflow depletion due to irrigation.

Results

The irrigation depletions were added to the gaged or extended historical streamflow records to obtain an estimated record of monthly natural streamflow. The estimated monthly natural streamflow for the White River near Nebraska-South Dakota State line is presented in table 7 and statistical characteristics of the natural streamflow at this site are presented in table 8.

Errors associated with using long-term mean values to estimate some of the variables in this study may result in substantial errors in estimates of individual monthly values. Therefore, greater confidence should be placed in the statistical characteristics of the estimated values than in individual monthly values. Comparison of tables 2 and 8 indicate that the median annual natural streamflow of the White River at the State line is about 9,000 acre-ft greater than the median annual historical streamflow determined from extended and gaged records at this location.

Table 5.--Estimated monthly irrigation depletions, in acre feet, in the White River basin upstream from the State line

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual[1]
1944	76	0	0	0	0	0	0	865	2300	3780	1512	926	9457
1945	114	0	0	0	0	0	0	865	2300	3780	1512	926	9495
1946	114	0	0	0	0	0	0	872	2320	3814	1512	926	9558
1947	114	0	0	0	0	0	0	872	2320	3814	1512	926	9558
1948	114	0	0	0	0	0	0	872	2320	3814	1512	926	9558
1949	121	0	0	0	0	0	0	903	2401	3948	1605	983	9961
1950	125	0	0	0	0	0	0	922	2453	1187	951	679	6318
1951	86	0	0	0	0	0	0	954	2537	1227	983	702	6490
1952	89	0	0	0	0	0	0	974	2590	1269	1016	726	6663
1953	90	0	0	0	0	0	0	1057	2812	1277	1022	731	6989
1954	102	0	0	0	0	0	0	1179	879	1446	1158	331	5095
1955	41	0	0	0	0	0	0	1185	3151	5179	2026	1241	12822
1956	155	0	0	0	0	0	0	1219	893	1467	1175	336	5245
1957	42	0	0	0	0	0	0	1286	3421	5624	2090	1280	13743
1958	159	0	0	0	0	0	0	1292	3436	1504	1204	860	8455
1959	106	0	0	0	0	0	0	1292	915	1504	1204	344	5365
1960	42	0	0	0	0	0	0	1331	3541	1504	1204	860	8482
1961	106	0	0	0	0	0	0	1331	915	1504	1204	344	5404
1962	43	0	0	0	0	0	0	1361	3621	5952	2128	1303	14408
1963	160	0	0	0	0	0	0	1365	3630	1520	1218	870	8762
1964	107	0	0	0	0	0	0	1380	925	1520	1218	348	5497
1965	43	0	0	0	0	0	0	1380	925	1520	1218	348	5433
1966	43	0	0	0	0	0	0	1380	3670	6033	2131	1305	14561
1967	160	0	0	0	0	0	0	1380	3671	6034	2131	1305	14680
1968	161	0	0	0	0	0	0	1381	3674	6040	2133	1306	14696
1969	161	0	0	0	0	0	0	1384	3681	1522	1219	871	8838
1970	107	0	0	0	0	0	0	1384	926	1522	1219	348	5507
1971	43	0	0	0	0	0	0	1384	3681	1522	1219	871	8720
1972	107	0	0	0	0	0	0	1384	926	1522	1219	348	5507
1973	43	0	0	0	0	0	0	1386	926	1522	1219	348	5444
1974	43	0	0	0	0	0	0	1387	926	1522	1219	348	5446
1975	44	0	0	0	0	0	0	1447	955	1569	1257	359	5632

Table 5.--Estimated monthly irrigation depletions, in acre feet, in the White River basin upstream from the State line--Continued

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual[1]
1976	44	0	0	0	0	0	0	1495	955	1569	1257	359	5679
1977	45	0	0	0	0	0	0	1535	966	1588	1272	364	5770
1978	45	0	0	0	0	0	0	1536	4086	6716	2228	1364	15975
1979	173	0	0	0	0	0	0	1575	4190	1642	1315	940	9835
1980	118	0	0	0	0	0	0	1589	4227	1673	1340	957	9904
1981	133	0	0	0	0	0	0	1742	1148	1888	1512	432	6855
1982	54	0	0	0	0	0	0	1763	4689	1906	1526	1091	11028
1983	134	0	0	0	0	0	0	1767	4701	7727	2671	1636	18636
1984	201	0	0	0	0	0	0	1767	4701	1906	1526	1091	11192
1985	134	0	0	0	0	0	0	1782	1159	1906	1526	436	6944
1986	54	0	0	0	0	0	0	1782	4739	7791	2671	1636	18673
1987	201	0	0	0	0	0	0	1782	4739	7791	2671	1636	18820
1988	201	0	0	0	0	0	0	1782	4739	1906	1526	1091	11245
1989	134	0	0	0	0	0	0	1782	1159	1906	1526	436	6944

[1]Sum of monthly values may not equal annual total because of independent rounding.

Table 6.--Statistical characteristics of estimated irrigation depletions, in acre feet, in the White River basin upstream from the State line

[Percentile denotes exceedance percentile, where the XX percentile refers to that value which is equaled or exceeded XX percent of the time]

Parameter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
Mean	103	0	0	0	0	0	0	1355	2605	2932	1516	822	9332
Stand. deviation	50	0	0	0	0	0	0	292	1398	2090	457	404	3961
Maximum	201	0	0	0	0	0	0	1782	4739	7791	2671	1636	18820
Minimum	41	0	0	0	0	0	0	865	879	1187	951	331	5095
90 Percentile	43	0	0	0	0	0	0	872	922	1395	1117	347	5424
80 Percentile	43	0	0	0	0	0	0	1007	926	1504	1204	348	5507
70 Percentile	54	0	0	0	0	0	0	1287	1150	1522	1219	433	6336
60 Percentile	90	0	0	0	0	0	0	1355	2316	1522	1219	721	6944
50 Percentile	107	0	0	0	0	0	0	1380	2495	1657	1327	870	8741
40 Percentile	114	0	0	0	0	0	0	1384	3424	1906	1512	926	9558
30 Percentile	132	0	0	0	0	0	0	1490	3666	3811	1526	980	9955
20 Percentile	157	0	0	0	0	0	0	1681	3924	5446	2065	1264	13375
10 Percentile	164	0	0	0	0	0	0	1782	4701	6243	2162	1324	15080

Table 7.--Estimated monthly natural streamflow, in acre feet, for White River near Nebraska-South Dakota State line

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual[1]
1944	334	726	473	363	489	7858	5254	11305	16301	9068	5170	2021	59362
1945	889	1654	885	658	744	9623	4451	5156	10166	6565	6105	4115	51012
1946	1534	1315	1039	1107	1755	5626	1511	11184	10889	5161	2815	4710	48646
1947	2198	2208	2822	1912	3410	4999	3927	3590	42599	18583	4272	2979	93500
1948	1989	1345	1906	1390	1760	6468	3332	5631	8098	6968	4223	1420	44531
1949	699	1726	1254	523	3293	40127	5391	9111	7447	6862	2558	1989	80981
1950	925	1107	861	683	1572	4648	3404	5878	4190	2202	1873	2024	29367
1951	781	833	947	928	1277	2066	1630	2823	8600	7425	2797	3969	34078
1952	1178	988	769	664	3440	8602	4671	6059	5559	2283	1434	1006	36652
1953	397	262	264	535	844	9512	2029	6486	4853	2273	4294	1486	33236
1954	754	315	762	541	1522	1654	1273	5323	3277	2374	1687	1015	20498
1955	317	732	523	480	439	5860	3540	6030	9220	6686	3121	10042	46988
1956	1083	369	2226	922	2974	4630	1178	4151	2452	2316	2055	717	25073
1957	423	1012	1101	603	1972	1857	5058	30388	25765	9141	3314	2410	83042
1958	1345	1398	1224	1291	1594	2355	4058	3715	5686	7228	2539	1461	33894
1959	751	780	744	953	1072	2607	1904	3604	2349	3139	1506	1635	21044
1960	387	345	437	400	679	11578	1523	5580	5486	2408	1954	1223	32000
1961	739	1095	1033	443	644	1359	756	2881	1409	2303	1801	779	15240
1962	762	482	289	326	822	3572	601	8377	42537	14241	4058	2041	78108
1963	1507	869	953	627	2744	7514	2267	2816	13246	3574	1574	1346	39036
1964	328	292	252	344	535	1248	2178	2450	3620	2363	1267	348	15224
1965	43	208	86	160	255	787	1178	6754	6030	4140	1709	764	22115
1966	818	1261	953	424	561	18864	3362	3151	4319	7287	5937	2423	49360
1967	1489	393	443	553	1250	1691	2838	6010	53499	13222	4479	5184	91051
1968	3358	1601	1138	1131	2347	3554	5147	4628	14010	8635	4040	2247	51834
1969	819	869	621	652	778	4064	3189	3831	4628	17263	2111	1252	40076
1970	747	845	461	424	1066	1838	8580	3800	3485	1903	1508	444	25102
1971	252	619	332	49	2549	3659	3029	10601	11726	2992	1477	1591	38876
1972	1036	530	510	344	696	2896	1369	5707	2634	2641	1563	604	20530
1973	233	262	240	412	1039	5694	3648	6028	2098	2414	1361	1181	24609
1974	504	916	1076	1838	3471	2699	5671	3416	1872	1787	1299	539	25089
1975	266	428	344	215	378	1777	5730	3501	6268	2313	2610	389	24220

Table 7.--Estimated monthly natural streamflow, in acre feet, for White River near Nebraska-South Dakota State line--Continued

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual[1]
1976	438	161	289	344	2600	2115	1981	4059	2014	2701	1724	585	19011
1977	205	30	160	37	272	1525	5677	3669	2823	2123	3326	1786	21631
1978	457	422	461	295	255	20291	3326	6320	7412	9237	5210	2078	55765
1979	542	405	332	148	150	3197	1845	3758	5987	6346	7882	1558	32150
1980	1827	1232	621	793	2169	7046	4147	3520	8399	2447	2440	1183	35825
1981	385	262	424	584	939	1101	631	2492	1386	4114	3695	670	16682
1982	84	387	375	197	905	1359	1059	15032	13847	3566	2744	1573	41127
1983	2766	1339	1045	1162	3482	3751	4570	17490	9657	10519	3864	1957	61602
1984	748	946	873	1162	3664	3911	4802	10554	7087	3640	1846	1144	40377
1985	349	345	437	400	700	3210	1363	2464	1457	1906	1588	436	14654
1986	250	750	86	541	3043	5823	11437	7014	28404	15458	4368	4563	81739
1987	3097	2737	2693	1808	2299	10527	17530	7408	7203	8707	3040	2124	69173
1988	896	708	676	572	615	4267	3975	10796	7334	2840	2012	1358	36050
1989	589	464	363	467	433	3659	1511	3307	1850	1967	1625	978	17213

[1]Sum of monthly values may not equal annual total because of independent rounding.

Table 8.--Statistical characteristics of the estimated natural streamflow, in acre feet, for White River near Nebraska-South Dakota State line

[Percentile denotes exceedance percentile, where the XX percentile refers to that value which is equaled or exceeded XX percent of the time]

Parameter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
Mean	903	825	778	661	1511	5719	3642	6475	9765	5725	2910	1899	40812
Stand. deviation	766	563	611	452	1088	6640	2986	4914	11337	4393	1516	1696	21759
Maximum	3358	2737	2822	1912	3664	40127	17530	30388	53499	18583	7882	10042	93500
Minimum	43	30	86	37	150	787	601	2450	1386	1787	1267	348	14654
90 Percentile	245	262	248	186	346	1359	1142	2821	1865	2076	1464	510	17054
80 Percentile	331	345	332	344	545	1802	1426	3450	2525	2307	1580	736	21279
70 Percentile	400	406	425	401	696	2380	1851	3674	3677	2408	1732	1028	25074
60 Percentile	535	520	461	462	840	3207	2249	4013	5360	2813	2001	1246	32120
50 Percentile	747	741	621	541	1069	3705	3329	5452	6149	3607	2548	1474	35938
40 Percentile	788	869	787	607	1576	4634	3704	6014	7419	6390	2860	1665	40136
30 Percentile	922	1009	952	681	2149	5810	4421	6470	9158	7202	3658	2024	48480
20 Percentile	1431	1294	1064	1045	2686	7720	5111	8818	12638	8924	4253	2345	57924
10 Percentile	2052	1617	1450	1321	3419	10842	5693	11220	26557	13527	5182	4250	81208

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