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Analysis of Variation of River Flow and Water Quality in the White River Basin

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ANALYSIS OF VARIATION OF RIVER FLOW
AND WATER QUALITY IN THE
WHITE RIVER BASIN

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Presently agencies of the state of South Dakota are implementing plans to establish current water resource usage, to develop future water resources, and to promote economic prosperity within the state. These plans will offer guidance to the people of South Dakota to better solve water resource problems within the state.

The South Dakota Water Resources Commission (SDWRC) is in the process of developing a State Water Plan. The State Water Plan will inventory the present and future water and related land resources and offer guidance in their management (1-1). The most important goal of the plan seems to stress the development and management of the water resources within the state of South Dakota (1-4). The State Water Plan emphasizes improved economic security for the people (2-4). In order to facilitate planning, the SDWRC has designated 16 major hydrologic drainage areas in South Dakota. Two of the basins do not contribute to streamflows directly but have unique features that set them apart from their neighboring basins (2-8).

The South Dakota Committee on Water Pollution, through the staff of the Division of Sanitary Engineering and Environmental Protection, State Department of Health, has the responsibility for establishing a Water Quality Management Plan (2-4). This plan appears to be oriented in a somewhat different direction. Water Quality Management Planning (3), a guideline from the Environmental Protection Agency, sets forth the requirements for communities or agencies which are working to achieve construction grants for their waste water treatment

facilities, through the Environmental Protection Agency (EPA) (3). The prime objective of this EPA assisted plan appears to be the improvement and maintainance of water quality in other states as well as in the state of South Dakota. In contrast to the State Water Plan, the South Dakota Committee on Water Pollution has divided the state into only seven hydrologic basins for development of their plan. The water quality plan will investigate resources management on the basin level and in the various metropolitan-regional areas within the seven basins (2-3).

The development of the State Water Plan (1) and the Water Quality Management Plan (3) for the state of South Dakota will have to be coordinated to prevent duplication of efforts. It is anticipated that the compatibility and implementation of the two plans will help provide extensive benefits for South Dakota (2-9).

In 1970, Kerwin Rakness (4) conducted a streamflow variation study for the Big Sioux River in South Dakota. He investigated the probable effects of increased water resources usage in such areas as irrigation and domestic waste water. Rakness also studied the adequacy of the length of flow records at streamflow gaging stations along the Big Sioux River. His investigation dealt primarily with low flows and future water resources development (4-4).

At the request of personnel from the South Dakota Water Resources Commission, the Civil Engineering Department at South Dakota State University processed streamflow data for 75 gaging stations within the state. These streamflow data were later to be used in determining

available streamflows during specific time periods throughout the year and was to be included as part of the State Water Plan for South Dakota.

For this investigation, the White River Basin in southwest South Dakota, was selected for a streamflow variations study similar to that of Rakness. This basin is one of the 16 hydrologic drainage areas designated by the South Dakota Water Resources Commission.

The main objectives of this White River Basin study were to analyze flow variation records, to investigate existing river water quality data as compared with the designated beneficial uses for the basin and to consider the influence of present and future irrigation development. Data were collected from a number of sources and brought together for interpretation with respect to these objectives. The streamflow study utilizes the streamflow records from 10 gaging stations in the White River Basin.

It is expected that the results of this investigation may be of assistance to the South Dakota Water Resources Commission and the South Dakota Committee on Water Pollution in developing their state-wide plans.

INFORMATION ON THE WHITE RIVER BASIN

History of the Area

The White River Basin was a part of the vast area of land purchased in 1803 called the Louisiana Purchase. At that time, Indian tribes occupied the river basin area. The Missouri River territory was explored in 1743 by the Verendrye brothers. Trappers and traders hunted the area for over a century before the start of the territory development by the settlers (5-8).

The Sioux tribes resisted most aggressively the advancement of settlers. All the Indian tribes were gradually pushed west. In 1869, two large reservations were established which covered about 75 percent of the White River Basin in what is presently southwestern South Dakota. The reservations have since been reduced to three counties, the Rosebud Reservation in Todd County and the Pine Ridge Reservation in Shannon and Washabaugh Counties. Indian names for geographical locations and features are prevalent in the basin area (5-8).

Cattle ranches spread over the area in the 1880's. After the Messiah War in 1889, a portion of the Indian reservation lands was opened to homesteaders. Much of the land became public domain for the private ownership of settlers and railroads began to traverse the area in 1885 and continued to be built in the basin until 1929 (5-8).

In the year 1908, large numbers of farmers started to break the sod for farming. The great drought in the 1930's reduced the number of people actively making a living by agricultural activities in the White River Basin. Since then the farming tendency has been towards

larger farm units with mechanized equipment and larger sized ranches and grazing herds (5-9).

Location

The White River Basin, with an area of about 10,200 square miles, is located in the minor western tributaries area of the Missouri River in the Great Plains. The White River Basin lies along the South Dakota-Nebraska border, with about 8,500 square miles in South Dakota and 1,700 square miles in Nebraska (see Figure 1). The average width of the basin is 50 miles, with a total east-west length of 245 miles (5-4).

The principal stream in the basin is the White River, which is approximately 507 miles in length. The Little White River (south fork White River) is the only major tributary to the White River. The high plains area in Nebraska is the origin of the main river. Generally, the river flows northeasterly into South Dakota and then easterly to empty into the Missouri River 10 miles south of Chamberlain, South Dakota, at the Fort Randall Reservoir (5-4). The Little White River flows east in southeastern Shannon County and then northeast to the mainstem (White River) about 14 miles northeast of the town of White River (5-4).

Physical Features

Unlike some areas of South Dakota the topography of the White River Basin is quite varied. The topography ranges from the sandhills of Nebraska, through areas of scattered buttes and tablelands (5-5). The far northern tributaries of the White River are bounded by rough

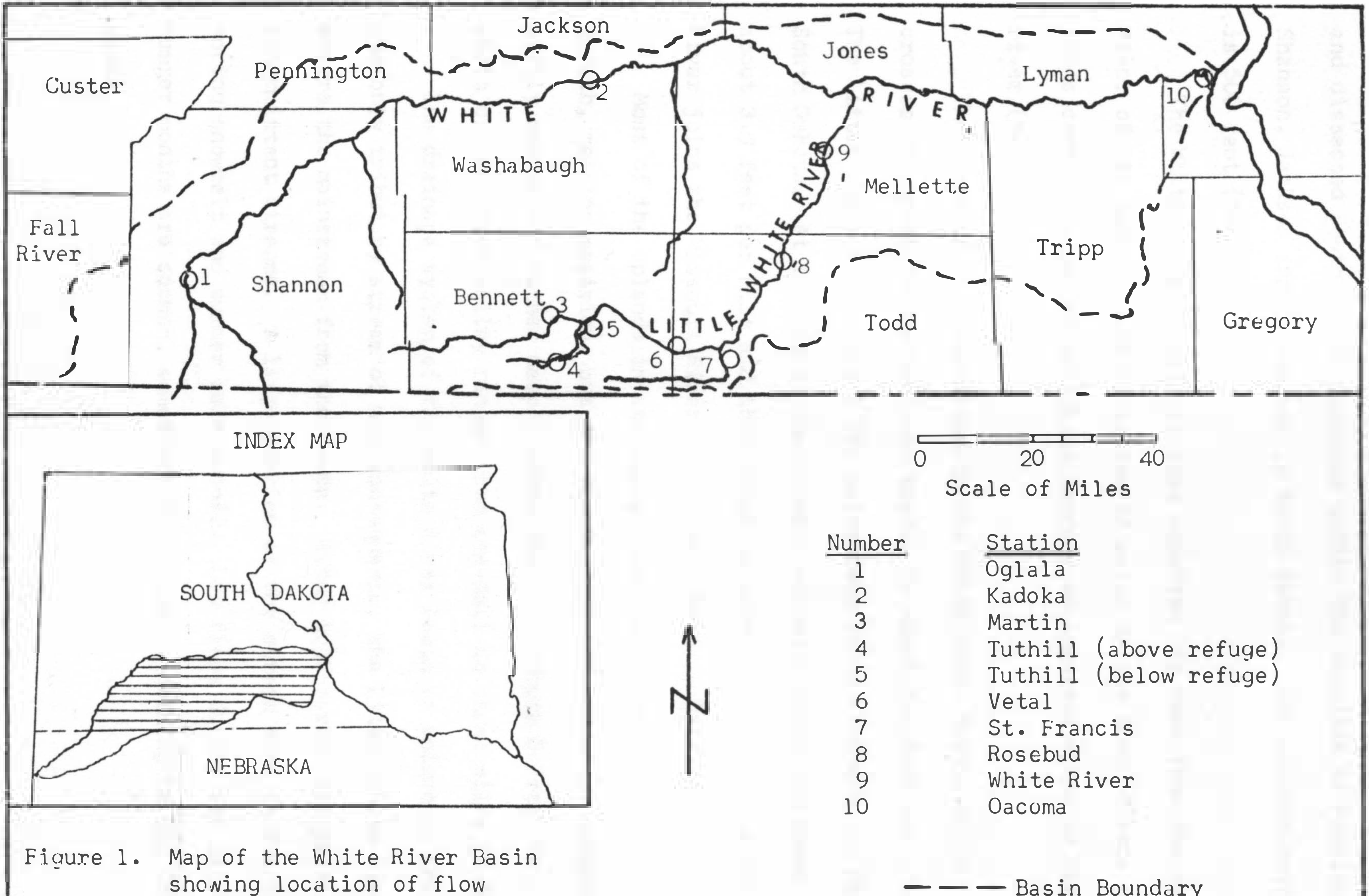

Figure 1. Map of the White River Basin showing location of flow gaging stations.

and dissected South Dakota Badlands within the counties of Pennington, Shannon, Jackson and Washabaugh in South Dakota. The maximum relief is 500 feet (5-5).

The White River is said to have acquired its name from the milky color of its water. Erosive action of water on the South Dakota Badlands carries suspended solids to produce an apparent color in the river (5-1).

The slope of the mainstream in the White River Basin, as it crosses the South Dakota-Nebraska border is about 5.2 feet per mile. The Little White River enters the mainstream river southeast of Murdo, South Dakota. At this point the river's mainstem slope decreases at about 3.9 feet per mile and this slope is maintained until the White River joins the Missouri River at the Fort Randall Reservoir (5-5).

Most of the uplands in the White River Basin are relatively smooth, rolling prairies, but the immediate river valley is comparatively narrow and rather deeply entrenched. In South Dakota the width of the river valley ranges from one-half to three miles (5-6).

The drainage system of the White River Basin is unique in that the only tributary stream of any consequence, the Little White River, enters the mainstream from the south. Other tributaries are primarily intermittent streams. A large portion of the stream flow is due to spring snowmelt and summer rain runoff. Low flows during the late summer months are common, sometimes dwindling to nothing in the dry years (5-6).

Sources of Streamflow Data

The United States Geological Survey (USGS) has streamflow recording stations in many locations in the rivers of South Dakota and other states. The flow records are collected and computed by the Water Resources Division of the USGS (6-1). Each gaging station has been assigned a USGS station number and stations are numbered in the downstream direction along the mainstream. Stations of tributaries are numbered between those of the mainstream according to their points of entry. Numbers are skipped to allow for the future numbering of new stations (6-4).

In the White River Basin in South Dakota, the USGS presently maintains a total of 13 flow gaging stations. In this study, records from 10 of the flow gaging stations were used to evaluate flow variation. These 10 stations were selected because they had flow records of approximately 10 years or more, while the other three stations had flow records for a lesser number of years.

The flow data for the White River Basin were obtained from the USGS, which had stored all the flow information on magnetic computer tapes (7). The South Dakota State University computer center processed the data on an IBM 360 computer.

Since the streamflow gaging stations were placed in operation on different dates, the period of streamflow record may vary with each station. Information about each of the 10 stream gaging stations in the White River Basin, selected for this study is given in Table 1.

Table 1. Information About the White River Basin Stream-gaging Stations (6).

Gaging Station	USGS Station Number	Approximate Location	Period of Records, Used			Total Drainage Area	Non-Contributing Drainage Area	Total Contributing Drainage Area
			Begin (mo/yr)	End (mo/yr)	Number of Months	(sq. mi.)	(sq. mi.)	(sq. mi.)
WHITE RIVER								
Oglala	06/4460.00	7 miles northwest of Oglala	6/1943	9/1970	328	2200	0	2200
Kadoka	06/4470.00	5.8 miles south of Kadoka	7/1942	9/1970	339	5000	0	5000
Oacoma	06/4520.00	8.8 miles southwest of Oacoma	9/1928	9/1970	505	10200	0	10200
LITTLE WHITE RIVER								
Martin	06/4475.00	5.4 miles east of Martin	3/1938 8/1962	9/1940 9/1970	31 98	310	80	230
Rosebud	06/4495.00	6.4 miles north of Rosebud	6/1943	9/1970	328	1020	260	760

Table 1. (continued)

Gaging Station	USGS Station Number	Approximate Location	Period of Records, Used			Total Drainage Area	Non-Contributing Drainage Area	Total Contributing Drainage Area
			Begin (mo/yr)	End (mo/yr)	Number of Months	(sq. mi.)	(sq. mi.)	(sq. mi.)
White River	06/4505.00	2.0 miles north of the town, White River	10/1949	9/1970	252	1570	260	1310
Vetal	06/4491.00	10.8 miles southeast of Vetal	8/1959	9/1970	134	590	175	415
SPRING CREEK								
Tuthill (above refuge)	06/4480.00	7.5 miles southwest of Tuthill	3/1938 8/1962	9/1940 9/1970	31 98	58	35	23
Tuthill (below refuge)	06/4490.00	1.2 miles southwest of Tuthill	8/1962	9/1970	98	120	60	60
LAKE CREEK								
St. Francis	06/4492.50	8.0 miles southwest of St. Francis	10/1959	9/1970	132	57	47	10

Only three of the 10 gaging stations are located on the mainstream of the White River. The three are located at Oglala, Kadoka, and Oacoma (see Figure 1) (6). Gaging stations are located on the Little White River and its tributaries, Lake Creek and Spring Creek. The stations near Martin, Vetal, Rosebud and White River are located on the Little White River. The two Tuthill stations are on Spring Creek, while the St. Francis station is on Lake Creek.

SEASONAL STREAMFLOW RELATIONSHIPS FOR

THE WHITE RIVER BASIN

The first published literature relating to flow duration curves of a stream, is believed to have been written about 1878 (8-1249). Since the year 1915, duration curves have been in general use by engineers studying hydrology (9-1213). In flow duration analysis work, the duration curve has become a very useful engineering tool. The flow duration curve may be defined as a curve, the abscissa of which at any point shows the number of time units or the percentage of time that various flows plotted on the ordinate are equalled or exceeded (10-1242).

The flow duration curve usually combines statistically the mean daily or mean monthly flows occurring throughout the year, although other time periods can be used. The area under a duration curve represents the total flow regardless of whether the time unit is the hour, day, month, or 10-day period.

Kerwin Rakness, in his study (4), developed tables which could provide information for the construction of flow-duration graphs for 36 time periods throughout the year (4). He divided each month into three, 10-day streamflow periods, as separated at the end of the tenth and twentieth day. Rakness determined the percent of time that each specific mean daily flow was equalled or exceeded during each of the 36 time periods throughout the year. Because of the great amount

of flow information, only specific percentages of time that the mean daily river flow was equalled or exceeded were included in the flow-duration tables (4-21).

In this investigation the flow-duration relationships were constructed in the same manner as developed by Rakness. The flows that were equalled or exceeded in the White River and Little White River (and its tributaries), were depicted for specific percentages of time throughout the year. Tables 2, 3, 4 and 5 show the flow-duration relationships for the stations near Oglala, Kadoka, White River and Oacoma in the White River Basin, for indicated periods of the year. Flow-duration tables for each of the other six gaging stations in the basin are located in Appendix A. The maximum and mean flows were also included in the tables for the 36 indicated periods of the year.

The USGS streamflow gaging station at Oglala is the furthest station upstream in the White River in South Dakota. The streamflow data at the stations near Kadoka, White River and Oacoma were used extensively in this investigation in later sections dealing with water quality and irrigation development. At the present time, the furthest gaging station downstream in the White River Basin is located near Oacoma.

Figures 2 and 3 graphically illustrate percentages of time that specific flows are equalled or exceeded near Oglala and Oacoma. Thus, these figures were prepared directly from the information in Tables 2 and 5. The figures show percentages of time of flow for the 36 indicated periods during the year. Interpolations may be used for flows

TABLE 2 FLOW DURATION AND MEAN FLOW FOR THE WHITE RIVER FOR INDICATED PERIODS OF THE YEAR

Station: Oglala
Period of Record: 6/1943-9/1970
USGS Station No.: 64460

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record — Percent of Time: 100% *	90%	80%	70%	60%	50%	25%	10%	MAX	MEAN FLOW(cfs)
January										
1-10	2.0	5.0	7.0	9.0	10.0	12.0	17.0	25.0	45.0	13.8
11-20	2.0	5.0	7.0	8.0	9.0	10.0	17.0	25.0	40.0	13.2
21-31	0.0	3.5	7.0	9.0	10.0	11.0	20.0	30.0	50.0	14.7
February										
1-10	2.5	6.0	10.0	12.0	16.0	22.0	33.0	40.0	130.0	25.2
11-20	2.0	7.0	12.0	16.0	20.0	25.0	38.0	55.0	180.0	30.3
31-28/29	3.0	10.0	15.0	18.0	25.0	30.0	50.0	85.0	280.0	41.0
March										
1-10	4.0	14.0	20.0	25.0	30.0	35.0	75.0	123.0	2490.0	116.8
11-20	11.0	24.0	30.0	35.0	44.0	60.0	150.0	273.0	1720.0	130.8
21-31	8.0	26.0	35.0	47.0	61.0	72.0	154.0	321.0	1140.0	137.4
April										
1-10	8.0	21.0	31.0	38.0	42.0	49.0	86.0	125.0	478.0	66.0
11-20	6.1	17.0	23.0	30.0	37.0	44.0	76.0	123.0	417.0	62.3
21-30	3.1	15.0	22.0	26.0	31.0	43.0	67.0	104.0	710.0	62.9
May										
1-10	2.2	14.0	24.0	35.0	43.0	52.0	82.0	128.0	1010.0	76.0
11-20	1.5	16.0	25.0	31.0	40.0	45.0	80.0	142.0	1290.0	79.0
25-30	5.7	23.0	27.0	32.0	39.0	49.0	122.0	357.0	1960.0	147.0
June										
1-10	3.3	16.0	28.0	34.0	43.0	63.0	116.0	231.0	1060.0	110.0
11-20	5.9	16.0	28.0	36.0	48.0	76.0	245.0	747.0	2950.0	265.0
21-30	2.2	11.0	19.0	26.0	38.0	53.0	136.0	363.0	3870.0	189.0
July										
1-10	0.9	8.0	11.0	16.0	23.0	34.0	80.0	200.0	1550.0	83.0
11-20	0.4	8.0	13.0	16.0	24.0	34.0	69.0	133.0	1110.0	73.8
21-31	0.0	7.0	12.0	15.0	24.0	29.0	53.0	110.0	1280.0	61.8
August										
1-10	0.0	3.9	7.0	9.6	16.0	23.0	40.0	78.0	528.0	36.7
11-20	0.0	4.6	6.0	8.5	14.0	19.0	33.0	62.0	320.0	30.5
21-31	0.0	1.5	4.8	7.0	10.0	12.0	27.0	45.0	272.0	23.8
September										
1-10	0.0	1.1	6.0	7.3	10.0	11.0	25.0	54.0	571.0	25.2
11-20	0.0	3.0	5.1	6.8	8.0	13.0	21.0	52.0	340.0	23.3
21-30	0.0	0.8	5.0	8.0	11.0	14.0	23.0	68.0	1730.0	38.1
October										
1-10	0.0	2.7	6.0	7.0	9.6	13.0	27.0	41.0	92.0	18.9
11-20	0.0	2.5	5.0	7.0	9.0	10.0	19.0	40.0	155.0	17.4
21-31	0.0	2.8	7.0	9.0	12.0	17.0	22.0	28.0	53.0	16.0
November										
1-10	0.0	4.4	7.7	11.0	13.0	16.0	25.0	34.0	141.0	18.5
11-20	1.0	5.4	7.0	13.0	16.0	18.0	26.0	26.0	51.0	19.4
21-30	0.1	7.0	8.1	10.0	15.0	18.0	25.0	31.0	104.0	18.8
December										
1-10	0.5	8.0	9.0	10.0	12.0	16.0	25.0	36.0	118.0	19.0
11-20	0.5	4.5	8.3	9.5	12.0	14.0	20.0	28.0	51.0	15.6
21-31	2.0	5.0	8.0	9.5	12.0	14.0	19.0	30.0	344.0	18.9

* Equivalent to the minimum flow recorded

TABLE 3 FLOW DURATION AND MEAN FLOW FOR THE WHITE RIVER FOR INDICATED PERIODS OF THE YEAR

Station: Kadoka
Period of Record: 7/1942-9/1970
USGS Station No.: 64470

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record — Percent of Time: 100% *	90%	80%	70%	60%	50%	25%	10%	MAX	MEAN FLOW(cfs)
January										
1-10	0.0	1.0	4.0	8.0	13.0	16.0	30.0	50.0	300.0	27.1
11-20	0.0	0.0	5.0	9.0	12.0	16.0	35.0	55.0	550.0	29.2
21-31	0.0	2.0	5.0	8.0	10.0	16.0	40.0	80.0	500.0	33.0
February										
1-10	0.0	5.0	10.0	15.0	22.0	30.0	65.0	200.0	2,040.0	90.7
11-20	0.0	8.0	20.0	30.0	40.0	50.0	100.0	250.0	2,000.0	98.1
21-28/29	0.0	18.0	34.0	50.0	60.0	95.0	180.0	300.0	1,500.0	156.5
March										
1-10	1.0	25.0	50.0	80.0	110.0	140.0	250.0	600.0	6,130.0	368.5
11-20	7.0	35.0	90.0	112.0	175.0	270.0	828.0	1,930.0	7,270.0	786.9
21-31	14.0	68.0	163.0	223.0	300.0	368.0	875.0	1,750.0	7,340.0	737.6
April										
1-10	8.0	73.0	108.0	128.0	161.0	191.0	403.0	980.0	2,510.0	363.3
11-20	11.0	53.0	68.0	92.0	128.0	167.0	316.0	662.0	2,880.0	280.4
21-30	19.0	49.0	61.0	93.0	118.0	133.0	291.0	1,220.0	6,170.0	447.4
May										
1-10	12.0	47.0	85.0	109.0	134.0	163.0	441.0	1,290.0	9,800.0	551.0
11-20	8.0	58.0	105.0	128.0	155.0	186.0	396.0	1,160.0	1,340.0	478.0
21-31	18.0	64.0	80.0	98.0	120.0	155.0	577.0	2,150.0	10,300.0	752.0
June										
1-10	7.0	35.0	66.0	115.0	157.0	260.0	616.0	132.0	1,260.0	626.0
11-20	17.0	46.0	100.0	176.0	253.0	370.0	1,550.0	3,690.0	16,500.0	1,413.0
21-30	7.0	39.0	76.0	105.0	134.0	224.0	702.0	2,520.0	14,500.0	880.0
July										
1-10	4.2	33.0	51.0	79.0	98.0	127.0	264.0	625.0	5,190.0	276.0
11-20	0.0	13.0	44.0	66.0	87.0	119.0	300.0	800.0	4,870.0	340.0
21-31	0.0	13.0	29.0	47.0	98.0	127.0	282.0	785.0	10,200.0	322.0
August										
1-10	0.0	1.6	9.0	27.0	53.0	86.0	200.0	500.0	4,220.0	207.0
11-20	0.0	1.6	6.4	19.0	30.0	51.0	148.0	390.0	3,100.0	169.0
21-31	0.0	0.6	6.0	13.0	22.0	35.0	94.0	330.0	2,720.0	112.0
September										
1-10	0.0	0.0	1.2	3.8	12.0	20.0	56.0	128.0	3,150.0	88.9
11-20	0.0	0.0	0.5	3.6	7.8	13.0	60.0	340.0	8,370.0	151.0
21-30	0.0	0.0	1.0	3.2	5.1	11.0	64.0	250.0	11,400.0	153.0
October										
1-10	0.0	0.0	1.0	3.0	11.0	18.0	56.0	166.0	2,420.0	81.8
11-20	0.0	0.0	3.4	7.0	11.0	21.0	71.0	235.0	1,340.0	85.9
21-31	0.0	1.2	8.0	11.0	15.0	26.0	49.0	160.0	1,470.0	73.1
November										
1-10	0.0	10.0	14.0	19.0	25.0	28.0	64.0	160.0	2,120.0	74.8
11-20	0.2	7.8	17.0	21.0	26.0	34.0	56.0	96.0	828.0	55.2
21-30	1.0	8.0	12.0	20.0	26.0	33.0	57.0	90.0	462.0	47.8
December										
1-10	2.0	5.0	10.0	15.0	20.0	27.0	55.0	70.0	120.0	35.2
11-20	0.0	4.0	9.0	14.0	18.0	22.0	45.0	70.0	120.0	31.6
21-31	0.0	4.0	9.0	12.0	15.0	20.0	45.0	70.0	1,200.0	40.3

* Equivalent to the minimum flow recorded

TABLE 4 FLOW DURATION AND MEAN FLOW FOR THE LITTLE WHITE RIVER FOR INDICATED PERIODS OF THE YEAR

Station: White River
Period of Record: 10/1949-9/1970
USGS Station No.: 64505

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record — Percent of Time: 100%	90%*	80%	70%	60%	50%	25%	10%	MAX	MEAN FLOW(cfs)
January										
1-10	10.0	30.0	55.0	70.0	75.0	80.0	95.0	110.0	132.0	78.3
11-20	10.0	35.0	60.0	65.0	75.0	80.0	100.0	110.0	120.0	77.8
21-31	20.0	45.0	60.0	70.0	75.0	75.0	90.0	100.0	150.0	76.9
February										
1-10	30.0	60.0	70.0	75.0	85.0	90.0	100.0	130.0	170.0	90.5
11-20	25.0	70.0	75.0	80.0	90.0	95.0	115.0	150.0	370.0	101.4
21-28/29	25.0	80.0	95.0	100.0	100.0	110.0	130.0	160.0	280.0	115.8
March										
1-10	40.0	80.0	90.0	110.0	125.0	140.0	170.0	200.0	1,100.0	146.7
11-20	70.0	90.0	115.0	127.0	145.0	158.0	221.0	550.0	2,710.0	274.9
21-31	38.0	107.0	148.0	168.0	192.0	204.0	380.0	690.0	5,220.0	395.3
April										
1-10	82.0	120.0	146.0	162.0	182.0	207.0	294.0	394.0	1,470.0	262.5
11-20	71.0	103.0	117.0	138.0	156.0	171.0	220.0	280.0	608.0	185.0
21-30	68.0	92.0	113.0	126.0	143.0	162.0	230.0	341.0	2,130.0	200.6
May										
1-10	62.0	91.0	112.0	127.0	147.0	170.0	213.0	263.0	2,440.0	221.0
11-20	54.0	106.0	122.0	130.0	139.0	150.0	200.0	259.0	1,300.0	180.0
21-31	62.0	90.0	100.0	109.0	118.0	130.0	217.0	330.0	2,430.0	190.0
June										
1-10	53.0	75.0	85.0	96.0	110.0	120.0	166.0	251.0	7,470.0	235.0
11-20	61.0	73.0	84.0	103.0	110.0	127.0	244.0	422.0	7,590.0	281.0
21-30	44.0	57.0	80.0	98.0	110.0	131.0	188.0	326.0	3,630.0	210.0
July										
1-10	38.0	54.0	67.0	80.0	87.0	96.0	147.0	218.0	854.0	123.0
11-20	29.0	46.0	52.0	59.0	67.0	78.0	112.0	190.0	4,040.0	146.0
21-31	7.0	38.0	46.0	50.0	59.0	66.0	122.0	214.0	382.0	96.6
August										
1-10	25.0	38.0	48.0	54.0	58.0	62.0	86.0	136.0	621.0	81.0
11-20	27.0	40.0	47.0	58.0	64.0	68.0	87.0	127.0	686.0	83.6
21-31	7.0	37.0	49.0	54.0	58.0	62.0	77.0	105.0	272.0	68.0
September										
1-10	7.0	33.0	42.0	47.0	51.0	57.0	71.0	85.0	416.0	61.6
11-20	20.0	41.0	48.0	53.0	57.0	63.0	79.0	99.0	639.0	70.9
21-30	20.0	44.0	49.0	52.0	55.0	59.0	74.0	86.0	196.0	63.9
October										
1-10	28.0	48.0	52.0	57.0	61.0	64.0	75.0	87.0	491.0	71.1
11-20	48.0	58.0	62.0	64.0	68.0	71.0	84.0	103.0	268.0	77.1
21-31	29.0	61.0	66.0	70.0	75.0	78.0	91.0	106.0	139.0	81.0
November										
1-10	36.0	56.0	64.0	68.0	73.0	76.0	90.0	100.0	148.0	78.8
11-20	22.0	51.0	66.0	69.0	76.0	81.0	93.0	109.0	152.0	81.0
21-30	35.0	50.0	66.0	70.0	79.0	86.0	101.0	117.0	162.0	85.2
December										
1-10	17.0	48.0	55.0	65.0	70.0	79.0	95.0	110.0	164.0	79.1
11-20	20.0	45.0	55.0	63.0	70.0	80.0	100.0	115.0	158.0	79.4
21-31	20.0	50.0	60.0	65.0	70.0	75.0	90.0	104.0	156.0	76.7

* Equivalent to the minimum flow recorded

TABLE 5 FLOW DURATION AND MEAN FLOW FOR THE WHITE RIVER FOR INDICATED PERIODS OF THE YEAR

Station: Oacoma
Period of Record: 9/1928-9/1970
USGS Station No.: 64520

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record — Percent of Time: 100% *	90%	80%	70%	60%	50%	25%	10%	MAX	MEAN FLOW(cfs)
January										
1-10	4.5	14.0	22.0	40.0	50.0	60.0	80.0	130.0	250.0	64.1
11-20	5.0	11.0	23.0	35.0	45.0	53.0	70.0	110.0	200.0	58.4
21-31	5.0	15.0	30.0	40.0	45.0	50.0	85.0	150.0	320.0	70.0
February										
1-10	4.8	20.0	30.0	44.0	50.0	55.0	120.0	238.0	1,600.0	107.7
11-21	6.0	24.0	45.0	55.0	70.0	90.0	160.0	484.0	3,600.0	199.0
21-28/29	10.0	34.0	60.0	78.0	100.0	150.0	300.0	600.0	4,000.0	306.0
March										
1-10	11.0	90.0	100.0	155.0	230.0	312.0	700.0	2,000.0	10,200.0	792.4
11-20	40.0	120.0	210.0	290.0	400.0	515.0	1,030.0	2,800.0	18,300.0	1,369.6
21-31	50.0	215.0	318.0	456.0	600.0	786.0	1,740.0	3,450.0	44,000.0	1,774.3
April										
1-10	52.0	208.0	298.0	402.0	488.0	586.0	1,280.0	2,400.0	26,200.0	1,214.4
11-20	108.0	219.0	276.0	355.0	420.0	512.0	934.0	1,650.0	5,940.0	782.0
21-30	108.0	190.0	236.0	276.0	332.0	436.0	872.0	2,040.0	11,700.0	912.0
May										
1-10	84.0	175.0	216.0	293.0	355.0	424.0	972.0	2,120.0	30,700.0	1,454.0
11-20	46.0	137.0	218.0	304.0	376.0	429.0	833.0	2,240.0	26,300.0	1,253.0
21-30	24.0	105.0	200.0	252.0	324.0	405.0	1,060.0	2,780.0	11,400.0	1,050.0
June										
1-10	21.0	156.0	210.0	320.0	411.0	604.0	1,200.0	2,190.0	20,800.0	1,155.0
11-20	34.0	116.0	185.0	300.0	431.0	623.0	1,800.0	4,080.0	18,100.0	1,686.0
21-30	70.0	123.0	200.0	246.0	302.0	418.0	1,190.0	4,000.0	12,000.0	1,238.0
July										
1-10	0.5	52.0	111.0	170.0	234.0	295.0	755.0	1,330.0	10,000.0	614.0
11-20	0.7	56.0	122.0	160.0	190.0	229.0	478.0	883.0	19,900.0	527.0
21-31	0.5	41.0	75.0	104.0	140.0	197.0	390.0	864.0	4,830.0	381.0
August										
1-10	0.5	32.0	55.0	76.0	123.0	154.0	308.0	648.0	5,360.0	307.0
11-20	0.6	20.0	39.0	59.0	90.0	131.0	295.0	725.0	6,980.0	302.0
21-31	0.6	13.0	42.0	68.0	93.0	116.0	254.0	540.0	7,900.0	265.0
September										
1-10	0.8	19.0	37.0	52.0	69.0	86.0	168.0	383.0	4,180.0	191.0
11-20	1.5	21.0	36.0	46.0	56.0	66.0	107.0	323.0	3,700.0	161.0
21-30	6.0	20.0	31.0	40.0	53.0	65.0	176.0	497.0	7,040.0	229.0
October										
1-10	9.0	24.0	32.0	46.0	57.0	67.0	163.0	335.0	4,980.0	168.0
11-20	18.0	34.0	41.0	56.0	65.0	82.0	160.0	388.0	2,630.0	176.0
21-31	26.0	45.0	57.0	69.0	80.0	95.0	167.0	247.0	2,070.0	148.0
November										
1-10	14.0	47.0	66.0	74.0	88.0	99.0	141.0	248.0	1,660.0	148.0
11-20	9.0	35.0	60.0	75.0	92.0	101.0	152.0	250.0	1,420.0	138.0
21-30	5.0	23.0	40.0	60.0	80.0	90.0	134.0	200.0	598.0	108.0
December										
1-10	5.0	23.0	35.0	46.0	60.0	70.0	100.0	160.0	608.0	85.3
11-20	2.0	14.0	23.0	40.0	50.0	60.0	95.0	160.0	320.0	75.0
21-31	2.0	15.0	20.0	40.0	50.0	60.0	95.0	150.0	320.0	72.6

* Equivalent to the minimum flow recorded

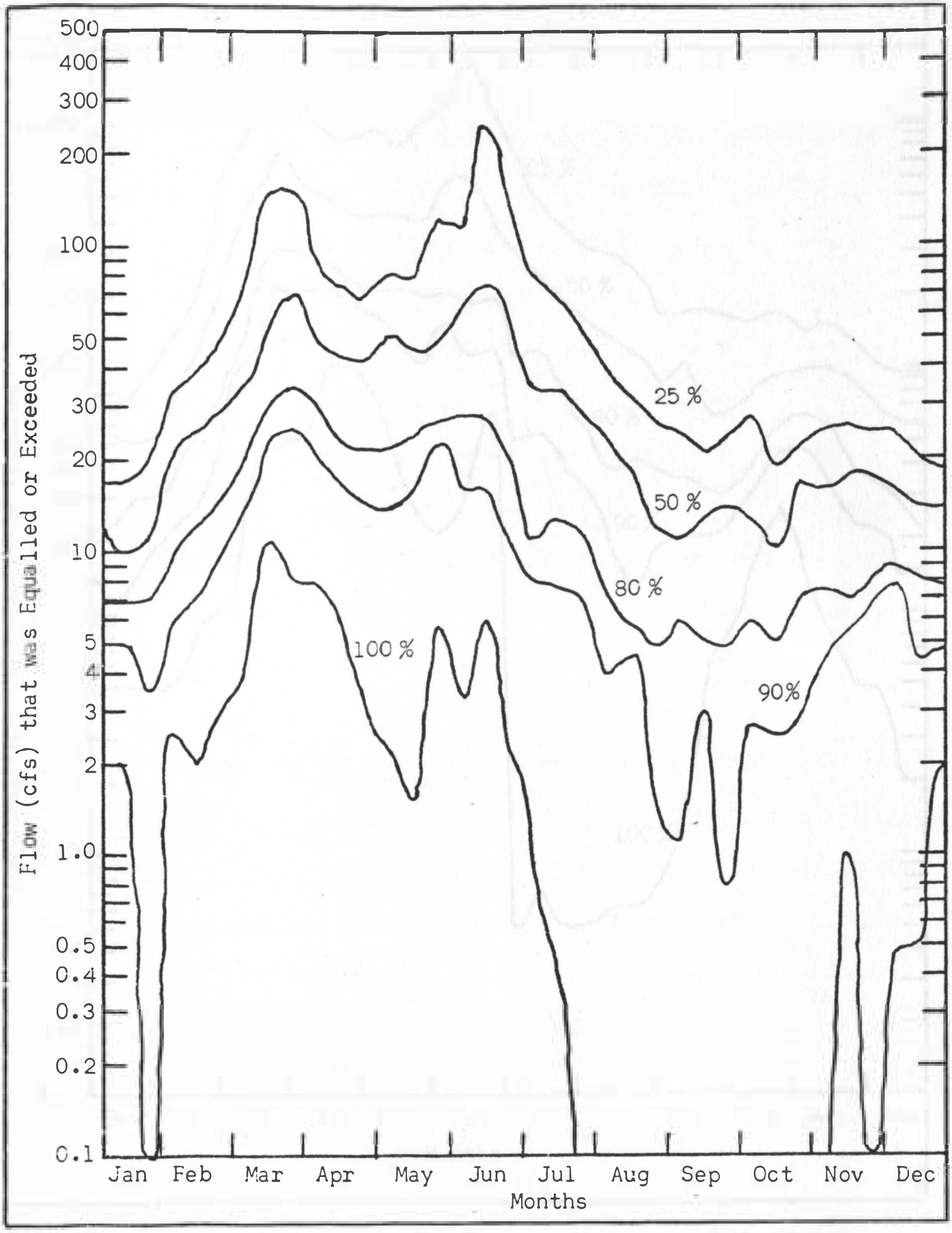

Figure 2. Seasonal flow-duration relationships for the White River at Oglala, South Dakota.

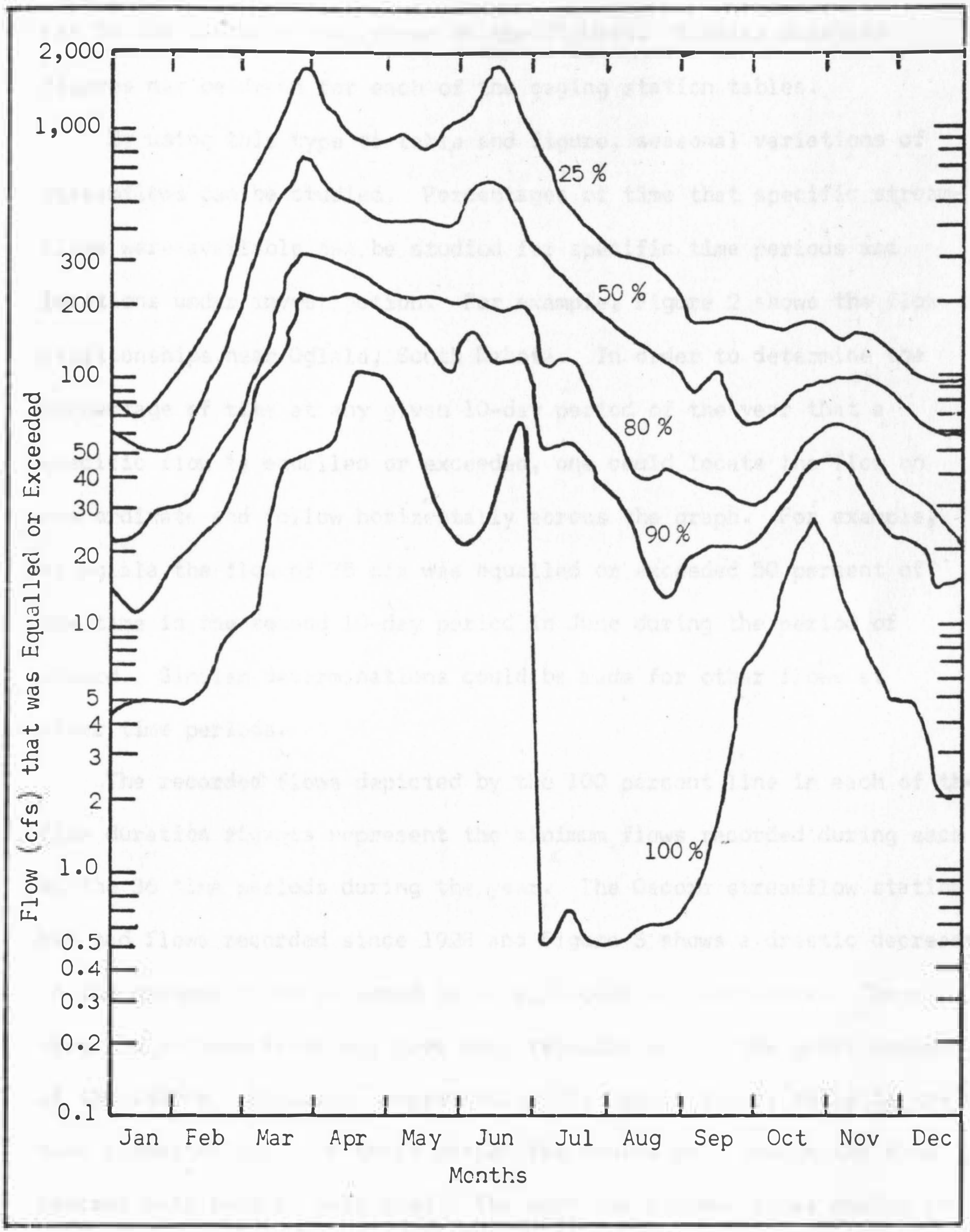

Figure 3. Seasonal flow-duration relationship for the White River at Oacoma, South Dakota.

not in the tables or not shown on the figures. Similar duration figures may be drawn for each of the gaging station tables.

By using this type of table and figure, seasonal variations of streamflows can be studied. Percentages of time that specific streamflows were available can be studied for specific time periods and locations under investigation. For example, Figure 2 shows the flow relationships near Oglala, South Dakota. In order to determine the percentage of time at any given 10-day period of the year that a specific flow is equalled or exceeded, one could locate the flow on the ordinate and follow horizontally across the graph. For example, at Oglala the flow of 75 cfs was equalled or exceeded 50 percent of the time in the second 10-day period in June during the period of record. Similar determinations could be made for other flows at other time periods.

The recorded flows depicted by the 100 percent line in each of the flow duration figures represent the minimum flows recorded during each of the 36 time periods during the year. The Oacoma streamflow station has had flows recorded since 1928 and Figure 3 shows a drastic decrease in the minimum flows recorded in July, August and September. These very low minimum flows may have been recorded during the great drought of the 1930's. Figure 2, representing the Oglala flows, reflects the same characteristic for these respective months even though the flow records date back to only 1943. The very low minimum flows during the July through September period at both stations may in part reflect the

withdrawal of water for irrigation. The minimum flows were so small that an extended drought could make them non-existent.

The compilation of streamflow data may be used to investigate problems in water usage, wastes disposal, power development and sedimentation control (4-14). The shape of the flow duration curves may often reflect river basin characteristics such as geology, topography, vegetation and precipitation (11-1085).

CHARACTERISTICS OF STREAMFLOW IN THE WHITE RIVER BASIN

The average annual precipitation in the White River Basin ranges from 15-18 inches (12). Approximately 80 percent of this precipitation occurs during the April-to-September crop-growing season (13). Early spring snowmelt, spring rains and thunderstorms during these important months, are the principal contributors to the streamflows made available in the White River and its tributaries (14-20). Groundwater storage provides water for flows primarily during the winter months in some areas of the White River Basin (14-20).

Past Minimum Flows

One possible effective method of looking at the characteristics of streamflow in the White River Basin is to study minimum flow classifications or minimum rates of flow. The White River and Big Sioux River, contributors to the Missouri River, are the only two South Dakota tributaries to the Missouri River that have not experienced a zero flow at their junctions with the Missouri River in the last 40 years (13-1). The Little White River is one of the very few small tributaries in South Dakota which does not experience zero flow for extended periods of the year (13-1).

The minimum streamflows at each of the USGS gaging stations varied within the basin and were often zero during the winter months in some areas. The extent to which beneficial uses (such as irrigation) can

be employed are limited directly by minimum available flows in the White River and its tributaries.

The minimum flows above the Little White River at the Oglala station (Table 2) were usually less than 10 cfs throughout the year and less than one cfs from the end of June to the end of December. At Kadoka (Table 3) the minimum flows were less than 20 cfs throughout the year and less than two cfs from mid-July to the first part of March.

By contrast, for those stations along the Little White River and its tributaries (Spring Creek and Lake Creek), the flows have almost never been recorded as zero. One exception was at Tuthill (below refuge). This station is near the discharge point of a small reservoir, where the flow was semi-regulated. At Tuthill (below refuge) the flow was zero or nearly zero from April to November. At St. Francis on Spring Creek the minimum flows have always been less than two cfs and most often they were zero. However, the minimum flows at Rosebud and White River along the Little White River were generally greater than 10 cfs and often greater than 25 cfs.

The station at Oacoma is the only station below the mouth of the Little White River. Oacoma minimum flows were 108 cfs in late April. The lowest minimum for a 10-day period was 0.5 cfs in July.

For a few monthly periods during the year the minimum flows at the station on the Little White River near the town of White River (upstream from the Oacoma station), have been greater than those near

Oacoma on the river mainstrem. This would appear to be a discrepancy. Flow records for the White River station date back to 1949 while the flows at Oacoma were recorded since 1928. Consequently, the low flows resulting from the dry 1930's were not recorded near White River, South Dakota. The fact that these two stations had different lengths of flow records may account for the minimum flow discrepancy.

Mean and Median Flows

The mean or average flow for a specific time period is equal to the sum of all the daily flows during that period, divided by the number of flow values. In many studies of water resources development, mean flows are used to interpret availability of water at specific locations for specific time periods.

The median flow can be defined as that flow which occurs in a stream 50 percent of the time during a specific period. That is, one-half of the total number of flows during a specific time period is above the median flow and the other half of the total number of flows is below the median value.

In this investigation, the median flows were considered to be more characteristic of the past actual available flows in the White River than the mean flows for the same location. In the White River some of the streamflow stations had flows that were so low that a few heavy runoff events could influence the mean flow drastically, giving an unrealistic impression of the available flows. For example, at Kadoka (Table 3) the mean or average flow for the second 10-day period

in September was 151 cfs while the median flow was only 13 cfs. The months of March through June reflect this same general characteristic. The station near Oacoma also had similar differences between mean and median flows.

Figure 4 shows the relationship between the months of the year and the median flows in cubic feet per second at the Oglala, Kadoka and Oacoma stations. Similar figures can be drawn for any of the gaging stations in the White River Basin. The figure shows the variability of the median flows at the three locations. As shown in the figure, the median flows increase for most periods throughout the year from Oglala to Kadoka to Oacoma as drainage basin areas increase. The two most distinctive peaks in median flows occurred about the end of March and the middle of June. After June, the median flows generally decrease at the three locations until the month of September after which the flow in the river increases slightly during the months of October and November (Figure 4). The increase in flow during the fall presumably is associated with the lower transpiration losses from groundwater after frost kills the vegetation in the basin.

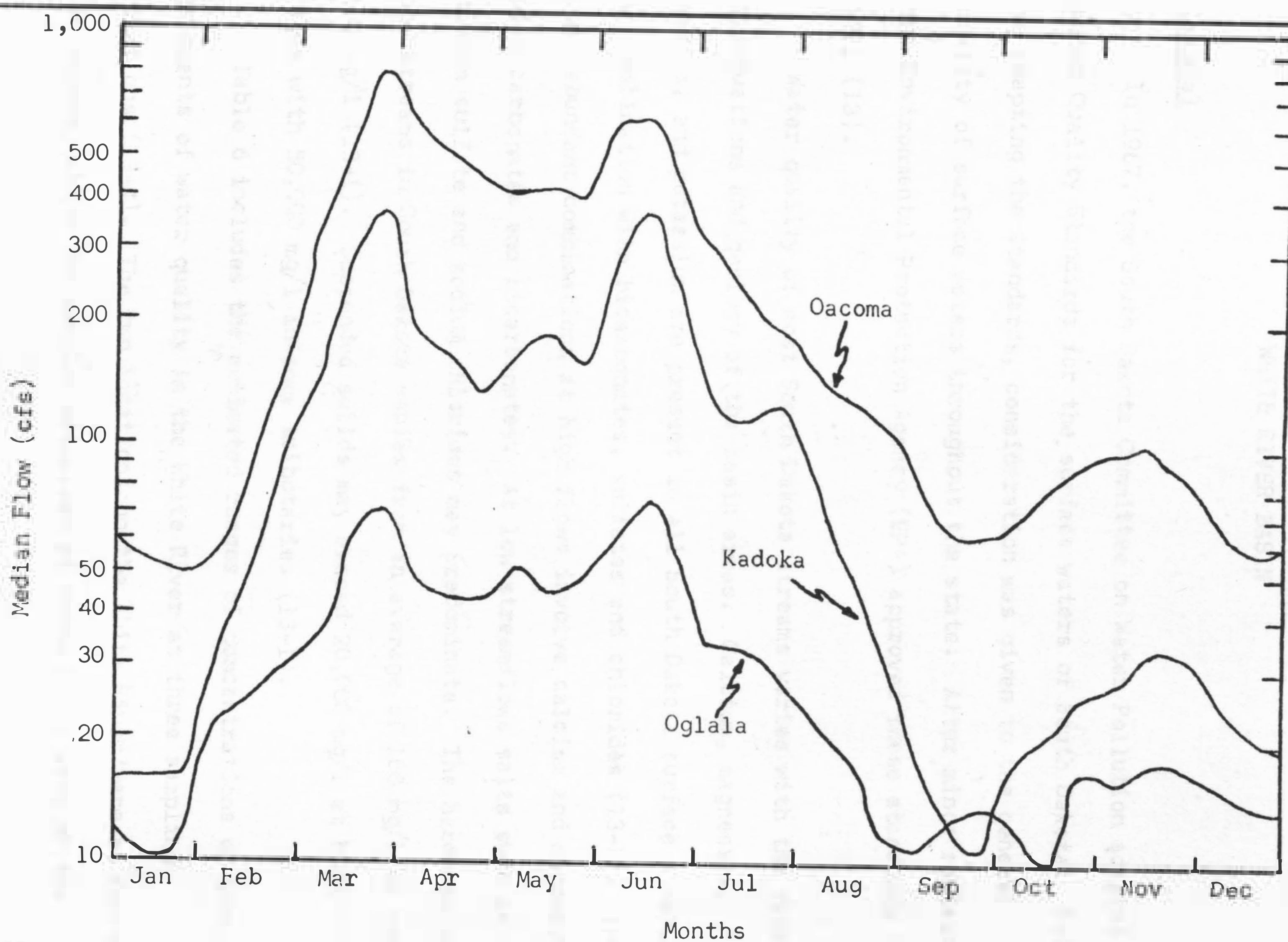

Figure 4. Median flows during various months of the year for the White River near the stations of Oglala, Kadoka, and Oacoma.

WATER QUALITY CONSIDERATIONS FOR THE

WHITE RIVER BASIN

General

In 1967, the South Dakota Committee on Water Pollution adapted Water Quality Standards for the surface waters of South Dakota. Prior to adapting the standards, consideration was given to the general quality of surface waters throughout the state. After minor revisions, the Environmental Protection Agency (EPA) approved these standards in 1971 (13).

Water quality of most South Dakota streams varies with the flow fluctuations and geology of the basin areas. Calcium, magnesium, sodium, and potassium are present in all South Dakota surface waters in combination with bicarbonates, sulfates and chlorides (13-1). The most abundant combinations at high flows involve calcium and magnesium with carbonates and bicarbonates. At low streamflows salts such as sodium sulfate and sodium chlorides may predominate. The hardness in the streams in South Dakota varies from an average of 160 mg/l to over 500 mg/l (13-1). Suspended solids may exceed 20,000 mg/l at high flows with 50,000 mg/l in some tributaries (13-1).

Table 6 includes the estimated ranges of concentrations of constituents of water quality in the White River at three sampling locations (13-4). The two locations on the White River were at Kadoka and Oacoma, while the samples collected at White River were on the

Table 6. Streamflow Water Quality Approximations and Actual Results for Three Locations on the White River and Little White River (13) (15).

	White River				Little White River	
	Kadoka		Oacoma		White River	
Characteristic	Estimated (13)	Actual (Appendix B)	Estimated (13)	Actual (Appendix B)	Estimated (13)	Actual (Appendix B)
Hardness (mg/l, $CaCO_3$)	50-150	64-140	100-200	0-72	100-200	141
Specific Conductance (μmhos/cm @ 25°C)	400-700	435-1505	500-1000	505-540	300-500	416-418
Total Dissolved Solids (TDS) (mg/l)	300-600	421-1230	300-600	332-404	200-400	306-307
Chlorides (mg/l, Cl)	5-20	5-18	5-30	1-2	1-5	0
Sulfates (mg/l, SO_4)	50-200	65-481	100-300	98-155	20-50	16-41

Little White River. The estimated ranges were obtained from water quality samples taken during the late 1950's and early 1960's (13-2).

Water Quality at Three Different Locations in the White River Basin

Unfortunately, streamflow samples from the White River are not routinely tested for water quality. However, several samples have been analyzed by the Division of Sanitary Engineering and Environmental Protection, State Department of Health in Pierre, South Dakota. The streamflow samples have been taken as grab samples in the White and Little White Rivers near the communities of Kadoka, White River and Oacoma (15). Appendix B contains the actual flows and quality characteristics for streamflow samples taken at these three locations.

Table 6 shows a comparison of the estimated streamflow quality to the actual quality results from the tables in Appendix B. It can be observed that the actual quality of streamflow samples for the three locations falls within or close to the approximate ranges in many cases. However, there were some exceptions. At Kadoka, the specific conductance, total dissolved solids and sulfate results were higher at low flows than the approximate ranges in Table 6. The actual water quality results showed that the sulfate, total hardness and chloride concentrations were close to the estimated ranges of the three locations.

Appendix B contains the results of the analysis of only nine samples from the White River Basin, five at Kadoka and two at each of

the other stations. These were the only chemical quality data for the White River that could be located. It is recognized that these few samples would not reveal the entire range of values for the various constituents included in Table 6 and that more samples at various flow ranges would be beneficial.

DESIGNATED BENEFICIAL USES OF THE WHITE RIVER BASIN

After holding public hearings as provided by law, the South Dakota Committee on Water Pollution designated beneficial uses for all the lakes, streams, and rivers in South Dakota (16-III-1). The committee adopted a policy to maintain the existing water quality if better than the established standards unless a change is properly justified. Any new source of pollution or increased pollution from old sources would have to be treated to maintain the high quality present in the streams (16-III-1).

The designation of the beneficial uses does not limit nor prohibit any of the water resources from being used for other than those listed (16-III-2). The major uses of surface waters in South Dakota are divided into seven primary categories with several sub-categories. The beneficial uses included in the Standards (16) are indicated by number and letter as follows:

1. Domestic water supply
2. Fish life propagation
    - 2a. Cold water permanent
    - 2b. Cold water marginal
    - 2c. Warm water permanent
    - 2d. Warm water semi-permanent
    - 2e. Warm water marginal
3. Recreation
    - 3a. Immersion sports
    - 3b. Limited contact recreation
4. Wildlife propagation and stock watering

5. Irrigation

6. Commerce and industry

7. Intermittent stream (category not assigned to particular streams since its application is dependent on streamflow).

The beneficial uses designated for the mainstem of the White River and the South Fork (Little White River) are warm water semi-permanent fish life propagation, limited contact recreation, wildlife propagation, stock watering, and irrigation (16).

Fish Life Propagation

The different categories for fish life propagation were set up mainly because certain fish are more tolerant of adverse conditions than others. The warm water semi-permanent sub-category of fish life propagation was established for the rivers and streams of the White River Basin. The principal species of fish in this category are walleye, perch, northern pike or channel catfish (13-14).

The quality criteria for warm water semi-permanent fish life propagation and results from samples taken near Kadoka, White River and Oacoma are summarized in Table 7. The sample data may not be sufficiently representative for a complete comparison with the Standards in that only a few samples were taken.

A comparison of the quality criteria for the warm water semi-permanent fish life category to the quality of samples taken near Kadoka, White River and Oacoma (Table 7) reveals several quality concerns. Suspended solids, iron and turbidity concentrations were well

Table 7. Quality Criteria and Past Streamflow Quality Near Kadoka, White River, and Oacoma in the White River Basin. Fish Life Propagation Use Category (13) (15).

Parameter	Limit	Kadoka Samples, 1968-1970	White River Samples, 1968	Oacoma Samples 1968-1969
Dissolved Oxygen (mg/l)	greater than 5.0	7.4-12.4	-	-
Iron (mg/l)	0.2	0.0-1.1	0.26-0.34	2.8-4.0
pH	6.3-9.0	7.3-8.8	7.6-8.3	7.6-8.2
Suspended Solids (mg/l)	90	200-1219	180-194	5655-8141
Temperature (^{o}F)	90	< 77	< 69	< 68
Turbidity (j.c.u.)	100	200-670	-	-

above the recommended limits. Suspended solids may cause abrasive injuries to fish life as well as the clogging of gills and respiratory passages. The settling of solids may also blanket stream bottoms to kill fish eggs and food or to destroy spawning areas (17-280). High turbidity can screen out sunlight essential to the production of fish food (17-280). The deposition of iron salts can cause gill irritation and also block respiratory systems (17-202).

The water quality data show that the suspended solid results for the two White River locations (Kadoka and Oacoma) were quite high. The maximum suspended solids value occurred at Oacoma. The flow at that time was 880 cfs and the suspended solid results showed a peak of 8,141 mg/l. Consequently, it would appear that the existing water quality in the White River Basin did not meet the criteria for the warm water semi-permanent sub-category at the particular sampling times at the three locations. With so few samples analyzed, however, it is difficult to judge the overall quality throughout the year although high suspended solids concentrations would be expected at high flows.

Limited Contact Recreation

The sub-category of limited contact recreation (3b) applies to the streams of the White River Basin. This division of recreation includes fishing, boating, sailing, picnicking and other related recreation (13-16). The recreation criteria usually apply during the summer months only; however, if the waters are used for winter recreation, the limited contact recreation criteria would apply (13-17).

Coliform organisms and fecal coliform organisms are of prime concern in this recreation sub-category. At Oacoma the coliform group had a Most Probable Number (MPN) of 1,500 per 100 milliliters of sample (15). Samples taken near White River and Kadoka show fecal coliform concentrations ranging from 14 to 320 per 100 milliliters of sample by membrane filter technique (15). The values set for quality limits for limited contact recreation are well above those actually determined near the three locations of Kadoka, White River and Oacoma (13-17). Although only a few samples have been evaluated for coliform concentrations, the White River does appear to meet the quality standards set for limited contact recreation.

Wildlife Propagation and Stock Watering

The category of wildlife propagation and stock watering provides criteria to help protect water habitat for aquatic and semi-aquatic wild animals and fowl. It also provides quality criteria for domestic stock watering. All surface waters in the state are used to some extent for stock watering (13-3) and this use is ascribed to all streams and lakes within South Dakota. Any pollution prohibiting growth or physical impairment or causing injurious effects to wild and domestic animals or fowl is forbidden (13-17).

Given in Table 8 are the established limits and quality data from river samples near Kadoka, White River and Oacoma. On the dates which the samples were taken at these three locations, the streamflow quality

Table 8. Quality Criteria and Past Streamflow Quality Near Kadoka, White River and Oacoma in the White River Basin. Wildlife Propagation and Stock Watering Use Category (13) (15).

Parameter	Limits	Kadoka Samples 1968-1970	White River Samples 1968	Oacoma Samples 1968-1969
Alkalinity, total (mg/l, $CaCO_3$)	750	152-248	180-184	112-156
Total Dissolved Solids (TDS)(mg/l)	2500	421-1230	487-500	332-404
Conductivity (mmhos/cm @ 25°C)	4000	1505	418	505-540
Nitrates (mg/l, NO_3)	50	0.0	0.0	0.0
pH	6.0-9.5	6.3-9.0	7.3-8.8	7.6-8.2

was very satisfactory for the wildlife and stock watering use based on the established limits. Alkalinity, total dissolved solids (TDS), conductivity, and nitrates were well below the limits.

Irrigation

When water for irrigation is applied to land some runs off the surface, some evaporates or transpires from plants while the remaining infiltrates into the soil. The water retained by the soil is known as "soil solution." The soil solution tends to become more concentrated as relatively pure water is lost or used by plants (17-106). Dilution of the soil solution can be accomplished by applying fresh irrigation water in excess (17-107).

Absolute permissible limits of salt concentrations in irrigation waters are difficult to establish for several reasons. Plants vary widely in their salinity tolerance. Temperature, rainfall, humidity and soil types influence reactions of crops to salt constituents. Interreactions between salt constituents can also have some deleterious effects on the soil and crops (17-107). In an irrigation system, good drainage of the soil may be more important than the salts content of the water being applied. Salt concentrations in natural irrigation waters are rarely so high as to cause immediate crop damage (17-107). If leaching does not take place, salts can eventually accumulate in the soil to harm plant growth (17-107).

Some salts in limited amounts are essential to promote plant growth, but they may be toxic above certain concentrations. Because

there are so many variables involved, the standards for the classification of arbitrary concentration limits for irrigation waters can not be too rigid (17-107).

There are three main characteristics of water which have been generally accepted to determine suitability of water for irrigation. The three include the following:

(a) the salinity hazard as indicated by the total dissolved salts concentration in milligrams per liter or specific conductance in micromhos per centimeter at 25°C,

(b) the percent sodium of the total cation concentrations, and

(c) the Sodium Adsorption Ratio (SAR).

Waters with total dissolved solids (TDS) of less than 500 mg/l can be used with almost no salinity problem (18-170). If the TDS approaches 5,000 mg/l, the irrigation water is probably of little value. Within this range it appears that the suitability of the irrigation water decreases as the salinity increases (18-170). Irrigation water with a TDS of about 2,000 mg/l is used regularly (18-170). The salinity hazard as determined by specific conductance values are used frequently with Sodium Adsorption Ratios to classify water for irrigation suitability.

Proper amounts of calcium and magnesium in the soil provide good soil structure and tilth. If sodium predominates the opposite may be true (17-108). Sodium in soil consists of 3.0 to 7.0 percent of the cations with calcium and magnesium having the larger percentages. The granular soil structure begins to break down if too much sodium is present. With high sodium accumulations in the soil the soil pores break down, the pH increases and the soil can become alkaline (17-109).

Table 9. Sodium Adsorption Ratios (SAR), Percent Sodium (% Na), Conductivity Near Kadoka, White River and Oacoma in the White River Basin (15) (17) (19).

Location, Date	Ca me/l	Mg me/l	Na me/l	K me/l	Na %* %	SAR**	Conductivity mmhos/cm @ 25°C	TDS mg/l
KADOKA								
5-22-68	1.796	0.362	5.525	0.179	70.3	5.32	734	608
10-19-68	2.235	0.559	7.482	0.289	70.8	6.38	990	690
3-30-69	1.437	0.239	2.780	0.079	61.3	3.04	435	1230
9-28-69	1.118	0.156	1.401	0.199	48.8	1.76	1505	1030
5-26-70	1.597	0.280	4.924	0.161	70.7	5.08	520	421
WHITE RIVER								
5-22-68	2.300	0.477	1.201	0.225	28.6	1.02	418	306
8-1-69	2.400	0.403	1.562	0.307	33.4	1.32	416	307
OACOMA								
4-30-68	1.038	0.156	3.563	0.151	72.6	4.61	505	332
3-27-69	1.520	0.321	2.640	0.133	57.2	2.75	540	404

*The percent sodium is equal to $\frac{\text{Na X 100}}{\text{Na + Ca + Mg + K}}$ where the elements are expressed in milliequivalents per liter (me/l) (17-108).

**The sodium adsorption ratio equals $\frac{\text{Na}}{[\frac{1}{2}(\text{Ca + Mg})]^{\frac{1}{2}}}$ where the elements are expressed in milliequivalents per liter (me/l) (17-108).

Calcium will replace sodium in the soil easier than sodium will replace calcium unless the sodium is in excess. The soil solution is always more concentrated than the irrigation water itself (17-109).

Water samples from the White River and Little White River taken near the communities of Kadoka, White River, and Oacoma show that the total dissolved solids range from 300 to 1,200 mg/l. Most of the samples in these areas have TDS values approximately 600 mg/l or less (Table 9). In 1969, the TDS at Kadoka was over 1,000 mg/l. Considering the TDS factor alone, the salinity hazard is not likely to be great.

Three major criteria are considered when examining the sodium relationships of these samples: percent Sodium (% Na), Sodium Adsorption Ratio (SAR), and Specific Conductance (Table 9). The ions used to calculate these criteria must be converted from milligrams per liter (mg/l) to milliequivalents per liter (me/l). Conversion factors used in the % Na and SAR formulas were obtained from Standard Methods for the Examination of Water and Waste Water (19).

With respect to the proper growth of plant life, three primary irrigation suitability classes with designated percent sodium (% Na) ranges are often used as follows (17-109):

Class	% Na	Irrigation Suitability
I	0-45	Excellent to good for most plants under most conditions
II	30-75	Good to injurious, harmful to some under certain conditions of soils, climate, practices
III	70-	Injurious to unsatisfactory, unsuitable under most conditions.

These % Na ranges are approximate ranges and do often overlap each other.

Table 9 shows that the water from the Kadoka and Oacoma samples had relatively high % Na values. The values range from about 50-70 % Na and, consequently, may not be very suitable for irrigation. The White River samples had a % Na value of approximately 30 which is much more acceptable.

The United States Department of Agriculture (USDA) has prepared a diagram to evaluate the suitability of irrigation water based on SAR and specific conductance values (17-111). Irrigation waters with low SAR and low conductivity values are the most acceptable; and, as the SAR and conductivity values increase, the irrigation waters become more detrimental to soils and crops (17-110).

The diagram of the USDA shows that SAR values of less than 10 have a low sodium hazard (17-111). Table 9 indicates that all the SAR values at the three locations are under 10. Therefore, the sodium hazard based on SAR of the water in the White River Basin is quite low.

The USDA figure (17-111) also shows salinity hazards in terms of conductivity. The samples taken near Oacoma and White River had conductivities between 416-540 mmhos/cm at 25^{o}C. This range is in the medium salinity category. The conductivity of the samples near Kadoka seems to be highly variable in that the conductivity ranges from 435-1,505 mmhos/cm. The Kadoka samples show a medium to high salinity hazard.

It must be emphasized that the ranges for sodium hazard are approximate and often overlap because a combination of many factors determines the irrigation water suitability.

For the irrigation beneficial use category for the White River Basin, the South Dakota Committee on Water Pollution has set parameter ranges for quality criteria which apply during the irrigation season only (13-18). The major irrigation season in the White River Basin lasts from May until the end of September. Criteria for coliform organisms only apply to waters used to irrigate root crops or recreation areas. In South Dakota suitability of water for irrigation depends somewhat on soil characteristics. Required quality is established on an individual basis by the Committee on Water Pollution, after soil samples are analyzed (13-18).

The quality criteria and test results of samples analyzed near Kadoka, White River and Oacoma are shown in Table 10. From the table it can be seen that limits for coliform organisms were much above the test results for the sample tested. Sodium Adsorption Ratios (SAR) and % Na results for the three locations also fall into the recommended limiting ranges for irrigation purposes. For the limited number of samples taken at these three locations the quality of the water in the White River Basin appears to be suitable for irrigation.

Table 10. Quality Criteria and Past Streamflow Quality Near Kadoka, White River and Oacoma in the White River Basin. Irrigation Use Category (13) (15).

Parameter	Limits	Kadoka Samples 1968-1970	White River Samples, 1968	Oacoma Samples 1968-1969
Coliform Organisms (organisms/ 100 ml)	The MPN or MF less than 5000/100 ml on a monthly average nor exceed 10,000/100 ml in any one sample	-	-	1500
TDS (mg/l)	700-1500 mg/l	421-1230	487-500	332-404
Conductivity (mmhos/cm @ 25^{o}C)	1000-2500	1505	418	505-540
Sodium Adsorption Ratio (SAR)	10-26	1.76-6.38	1.02-1.32	2.75-4.61
% Na	30-70%	48.8-70.8%	28.6-33.4%	57.2-72.6%

POLLUTION SOURCES IN THE WHITE RIVER BASIN

Agricultural Sources

Many of the people of South Dakota earn their living through or are associated with agricultural activities of the state. There are a few major types of possible pollution resulting from agriculture. Pollution from siltation is the largest problem in the river basins (16-IV-3). Bare or plowed land, or land that has been planted with row crops, leaves the area vulnerable to erosion. Wind and water erosion cannot only increase the sediment load in water courses, but can also carry fertilizers from fields (16-IV-3). Nutrients, such as nitrogen and phosphorus, carried from the land could stimulate an undesirable excess growth of algae in the lakes (20). Crop rotation, contour farming and terracing are possible actions to prevent this water erosion (16-IV-3).

The West River Conservancy Sub-District has recognized sediment pollution as an important problem in the White River Basin, although, man-caused sediment erosion has been slowed up by conservation programs (22-1). The United States Conservation Service and the Agriculture Engineering Department at South Dakota State University have been active in assisting farmers with their man-made erosion problems (16-IV-4).

Erosion of the Badlands in the western portion of the White River Basin is not primarily due to agricultural practices. Badlands erosion is a major troublemaker as far as natural geologic erosion (21). The natural erosion furnishes the largest portion of sediment in western

South Dakota. This source of erosion yields 4,000 tons of sediment per square mile per year in the White River Basin (22-1). The White River carries over 30 tons of sediment for each acre foot of water in the river. It is estimated that 12 million tons of sediment from the White River are deposited each year into Lake Francis Case on the Missouri River (22-1).

Sedimentation control is important in that control can reduce some of the following harmful effects:

(a) The loss of storage capacities in reservoirs so far as water resources are concerned.

(b) High suspended solids in water used for irrigation presents a problem with sediment loads wearing out equipment.

(c) Fish production can be altered by causing a variation in the food pattern growths in that sediment particles may form deltas which block fish travel or destroy food essential to fish life.

(d) Suspended sediment makes recreational area aesthetically undesirable.

Muddy streams may also be hazards to stream users because unseen obstructions under water may cause accidents (22-2).

A needed program for sediment control has been emphasized by the West River Conservancy Sub-District. This program would recognize sediment as a major pollutant. Special projects such as small dam sites on the White River or its tributaries have been recommended by the Sub-District (22-4).

The Corps of Engineers is currently conducting a study on the White River Basin to consider some alternative plans for water resource use and development. Sediment control programs may be implemented following their study.

A second problem caused by agricultural activities is pollution resulting from runoff from livestock feeding operations. This problem is not considered a major cause of pollution at this time in the White River Basin area. There are some livestock feeding operations in the basin, but based on the livestock average yearly waste contribution to pollution, they are not significant at present (16-IV-4).

Municipal Waste Sources

In 1968, the Environmental Protection Agency (EPA) published an inventory of municipal waste facilities for all of the states in the United States (23). Volume eight contains the facilities listings for the communities in South Dakota, including those in the area of the White River Basin (Table 11). Listed in the inventory are six communities with municipal waste water treatment facilities in the White River Basin area (23). These communities are listed in the downstream direction in the White River Basin and according to where the stream tributaries enter the mainstem.

The location, type of treatment, point of discharge, degree of treatment (where provided) are given for each of the six communities (23-1). Where data were not reported, an "X" will appear in Table 11.

The design population equivalent (Design P.E.) shows the capacity for removal of biodegradable organic materials for which the facility was designed (23-2). Each type of treatment was designed in terms of the P.E. of the biochemical oxygen demand (BOD--five-day 20°C). The P.E. is computed on the basis of 0.17 pounds per day per capita of

Table 11. Treatment, Flow, and Discharge Point for Municipal Waste Water Sources in the White River Basin (23).

Community Name (County)	Type Treatment Design P. E.*	Flow MGD (cfs) Design Flow	P. E. BOD (mg/l BOD)** Raw	P. E. BOD (mg/l BOD)** Discharged	Discharge Point	% BOD Removal
PINE RIDGE (Shannon)	Secondary Stabilization Pond X	X	X	X	White River (White Clay Creek)	X
MARTIN (Bennett)	Secondary Activated Sludge 1500	0.080 MGD (0.124 cfs) 0.185 MGD	1150 (294)	450 (115)	Bear in the Lodge Creek to White River	61%
ST. FRANCIS (Todd)	Secondary Stabilization Pond 620	0.040 MGD (0.062 cfs) 0.062 MGD	X	X	Tributary to Little White River	X
WHITE RIVER (Mellette)	Secondary Stabilization Pond 500	0.035 MGD (0.054 cfs) 0.100 MGD	580 (338)	58 (34)	Little White River	90%
MURDO (Jones)	Secondary Stabilization Pond 913	0.050 MGD (0.077 cfs) 0.100 MGD	780 (318)	80 (33)	Dry Draw to White River	90%
WINNER (Tripp)	Secondary Standard Rate*** Trickling Filters 3000	0.250 MGD (0.39 cfs) 0.288 MGD	3500 (286)	1480 (121)	Dog Ear Creek to White River	58%

*P. E. is an abbreviation for Population Equivalent.

**mg/l BOD was computed in each case from the P. E. BOD and flow values reported.

***Winner is designated as needing additional waste water treatment.

BOD (23-2). With this conversion factor, and the plant flow, the P.E. BOD can be converted to mg/l BOD both for the raw and discharged waste at all the locations but Pine Ridge and St. Francis (Table 11).

According to the 1968 Inventory (23), the actual flow in million gallons per day (MGD) from each community treatment unit is less than the design flow. Hence, the treatment facilities are not hydraulically overloaded. The raw BOD ranges from 338 mg/l at White River to a value of 286 mg/l at Winner, South Dakota. The discharged municipal wastes range from 121 mg/l BOD at Winner to 33 mg/l BOD at Murdo. These computed effluent BOD concentrations of the municipal discharges exceed the 30 mg/l limit for discharge to an intermittent stream. The percent removal of BOD values vary between 58 percent and 90 percent removal (Table 11). The secondary stabilization ponds at White River and Murdo were removing 90 percent of the influent BOD.

In that all of the communities in the White River Basin with sewage systems provide treatment and only the community of Winner is listed as needing additional treatment, it would appear that municipal discharges presently represent only localized problems with respect to water quality in the basin. These localized problems may exist primarily in the tributaries to which the treated wastes are discharged.

INVESTIGATION OF THE INTERMITTENT STREAM USE CATEGORY IN THE WHITE RIVER BASIN

There are only a few rivers or major streams in the state of South Dakota that fall into the intermittent stream category. This category is one of the designated beneficial uses for South Dakota watercourses (13-19). The intermittent stream category is entered when 50 percent or more of the total flow in a watercourse is waste water (24-18).

The communities in the White River Basin with waste water treatment units do not discharge waste flows with volume much larger than 0.25 MGD (0.39 cfs) as shown in Table 11. The very low waste flows discharged in the basin area would not be expected to put the mainstem White River or the Little White River in the intermittent stream use category. However, the tributaries to these two main watercourses may often contain only waste water flows from the treatment units of the communities of Pine Ridge, Martin, St. Francis, White River, Murdo, and Winner. Consequently, the intermittent stream category is not likely to be in effect in the near future in the White River Basin except in the tributaries.

WHITE RIVER FLOWS AND IRRIGATION DEVELOPMENT

The South Dakota Water Resources Commission has general surveillance over the use of the surface and groundwaters which belong to the people of South Dakota (4-34). The Commission supervises the measurement, appropriation and the distribution of the water. The power to regulate and control this water for beneficial uses and prior appropriation also lies with the Commission (4-34).

In 1955, the State of South Dakota passed the latest revision to its state water law. The law set forth what are called "vested rights" for those parties who had been using the water three years prior to the date of the law's passage (4-34). "Vested rights" enable the consumer to continue to use the water for the beneficial uses he had developed (4-34).

Any public, association, corporation or person who wishes to use the state waters must apply for a permit through the Commission before the water use can be obtained. Reasonable use of the state waters for domestic purposes does not have to be verified by the Commission (4-34). If the Water Resources Commission grants the water permit, the construction for the water usage facility may begin. After construction is completed, the Commission checks the capacity, efficiency, and safety of the facility before the facility is put into operation. The Commission issues a license indicating acreage that may be developed for irrigation. The irrigation rights license provides for possible future irrigation expansion (4-35).

Water Requirements

Water requirements for irrigation for the areas near the White River will vary from year to year depending upon the rainfall and temperature. Two factors are important in considering the water requirements for irrigation needs. The two factors are the consumptive use of irrigation water and the return flows after irrigation (14-22). The consumptive use of water for irrigated crops is that portion of the water applied to the field which evaporates or transpires (14-23). For the White River Basin, the Bureau of Reclamation estimates that about 64 percent of the water applied is consumptively used (14-24). The other 36 percent of irrigation water applied is termed return flow. This non-consumptive use flows back into the ground or runs off the surface to be possibly used again in the basin. Most of this return flow is employed and returned during the irrigation season (14-24).

The White River is the major source of water for irrigation in the basin. Streamflows of the river are derived principally from early spring snowmelt, spring rains or heavy localized thunderstorms during late spring and summer months (14-20). Some of the White River headwaters flow out of the sandhills of Nebraska. Flow from groundwater storage into the river may be a major source of streamflow supply during winter months on many parts of the Little White River.

Past Irrigation Usage (1971)

For the past four years questionnaires have been sent to the holders of irrigation water rights in South Dakota. The Water

Resources Commission has collected the irrigation information each crop-growing season (25-1).

In 1971, the average depth of water applied to each acre of irrigated land in the White River Basin area was 13.4 inches. The prime irrigation months were May, June, July, August, and September. Respectively by month, the inches of water applied in 1971 per irrigated acre were 0.6, 1.9, 5.9, 5.6 and 1.0. For all other months combined, the application of water totaled 0.5 inches (25-3).

The Water Resources Commission Survey showed that people in the White River Basin had been granted water rights permits to irrigate a system acreage of approximately 21,690 acres. Of this total about 17,560 acres were irrigated from surface water sources. The remaining irrigation water was to be obtained from groundwater supplied (25-5).

The actual projected pumping amounts for 1971 for the total White River Basin were tallied. Summarized in Table 12 are the projected pumping amounts according to the primary months of irrigation. The percentages of the total amount pumped are also given. July was the month with the highest pumping rate at 4,067 acre-feet (66.45 cfs). August rates followed behind July with 2,470 acre-feet (40.25 cfs).

<u>Past Water Rights Permits for Irrigation</u>

In order to investigate the irrigation systems in the White River Basin, records of water rights permits issued in the basin were obtained from the South Dakota Water Resources Commission in Pierre, South Dakota (26). These records of permits dated back to the year 1935.

Table 12. Projected Actual Monthly Water Pumping Amounts for Irrigation for 1971 in the White River Drainage Area (25).

Irrigation Months	Projected Pumping Amount		Inches Applied	% of Total Pumped
	Acre·feet/Month	CFS*		
May (31 days)	451	7.35	0.6"	4.8%
June (30 days)	1300	21.90	1.9"	14.0%
July (31 days)	4067	66.45	5.9"	43.6%
August (31 days)	2470	40.25	5.6"	26.5%
September (30 days)	687	11.60	1.0"	7.4%
Others (30 days)	348	5.85	0.5"	3.7%

*Computed from the acre feet per month included in the table from the irrigation questionnaire (25).

The permit information showed the party obtaining the permit, the irrigation flow to be pumped and the permit acreage (26). The permit holders were designated by county. Dates of priority were given to each permit according to the years in which the permit was first issued.

Table 13 shows the total increase per year of irrigation permit flows and acreage in the White River Basin. From the table, it appears that the permit irrigation acres and flows have increased substantially since about 1960. The cumulative irrigation permit flows on Table 13 will be used later in the study to predict future irrigation flows.

For further investigations of the water rights permit data, it appeared to be logical to divide the White River Basin into three area categories with each permit designated for one of the three areas. The three basin areas were the irrigation areas along the White River upstream from the mouth of the Little White River, the areas irrigated using water from the Little White River, and irrigation areas downstream from the Little White River.

Table 14 contains the tabulation of total irrigation permit flows and acreage by county in the three designated permit areas. The total acres (16,433) differs from the 17,560 acres previously indicated as being under irrigation permit. The approximate difference of 1,100 acres were designated as being irrigated from dry draws in the basin and were not considered in this investigation. The total irrigation

[illegible] Total Increases Per Year and Cumulative Totals of Irrigation Permit Flows and Acres for the Total White River Basin (26).

[illegible]	Total Increase/Year		Cumulative Totals	
	cfs	Acres	cfs	Acres
[illegible]	4.40	308.80	4.40	308.80
[illegible]	7.11	498.87	11.51	807.67
[illegible]	5.80	276.28	17.31	1083.95
[illegible]	1.12	82.23	18.43	1166.18
[illegible]	1.60	117.79	20.03	1283.97
[illegible]	6.49	456.14	26.52	1740.11
[illegible]	14.24	1008.15	40.76	2748.26
[illegible]	0.0	0.0	40.76	2748.26
[illegible]	8.30	131.09	49.06	2879.35
[illegible]	2.17	159.70	51.23	3039.05
[illegible]	5.99	423.00	57.22	3462.05
[illegible]	0.0	0.0	57.22	3462.05
[illegible]	0.55	38.30	57.77	3500.35
[illegible]	0.0	0.0	57.77	3500.35
[illegible]	6.60	463.40	64.37	3963.75
[illegible]	0.0	0.0	64.37	3963.75
[illegible]	13.17	940.90	77.54	4904.65
[illegible]	3.33	233.80	80.87	5138.45
[illegible]	18.49	1291.72	99.36	6430.17
[illegible]	2.22	154.30	101.58	6584.47
[illegible]	17.76	1241.80	119.34	7826.27
[illegible]	14.64	1034.18	133.98	8860.45
[illegible]	11.49	792.50	145.47	9652.95
[illegible]	38.85	2943.40	184.32	12596.35
[illegible]	17.71	1245.58	202.03	13841.93
[illegible]	10.73	752.80	212.76	14594.73
[illegible]	10.26	719.69	223.02	15314.42
[illegible]	4.84	336.80	227.86	15651.22
[illegible]	9.08	782.00	236.94	16433.22

Table 14. The Total Irrigation Permit Flow and Acreage by County in the Three Designated Areas of the White River Basin Through July, 1972 (26).

County	CFS	Acres
IRRIGATION UPSTREAM FROM THE LITTLE WHITE RIVER:		
Fall River	8.60	603.70
Shannon	16.46	891.61
Jackson	42.31	2845.88
Washabaugh	23.88	1696.17
Jones	13.20	931.60
Mellette	6.66	467.20
Sub Totals	111.11	7436.16
IRRIGATION FROM THE LITTLE WHITE RIVER AND ITS TRIBUTARIES:		
Bennett	4.29	299.40
Todd	8.08	712.00
Mellette	13.67	960.72
Sub Totals	26.04	1972.12
IRRIGATION DOWNSTREAM FROM THE MOUTH OF THE LITTLE WHITE RIVER:		
Jones	42.85	3036.36
Mellette	13.17	924.50
Lyman	34.19	2389.40
Tripp	9.58	674.68
Sub Totals	99.79	7024.94
Totals	236.94	16433.22

acreage under permit, drawing water from the White and Little White Rivers, was considered to be 16,433 acres.

Irrigation permit flows were of about 111 cubic feet per second (cfs) above the mouth of the Little White River (Table 14). Permit flows of 26 cfs were designated to be taken from the Little White River and its tributaries. Below the mouth of the Little White River permitted irrigation flows totalled about 100 cfs. In a subsequent section, these permit flow values are compared to actual available streamflows at specific locations within the basin.

Future Water Rights Permits for Irrigation

Future irrigation permits were projected for the year 1980 using past records for permit flows in the White River Basin. Appendix C shows the permit flows and acreage granted new for each year for the three designated irrigation areas--upstream, downstream and from the Little White River. Appendix D contains the cumulative flows and acreages by year for the same three divisions. Trends in the issuing of permit flows can be determined by studying these two Appendices.

Figure 5 represents graphically a portion of Appendix C--the permit flows in the three irrigation areas. Using this figure, possible future increases in water rights permits could be estimated by extending the curves for the cumulative flows in the three designated irrigation areas.

Of the three irrigation areas, the irrigation permit cumulative flows upstream from the Little White River have had the most consistent

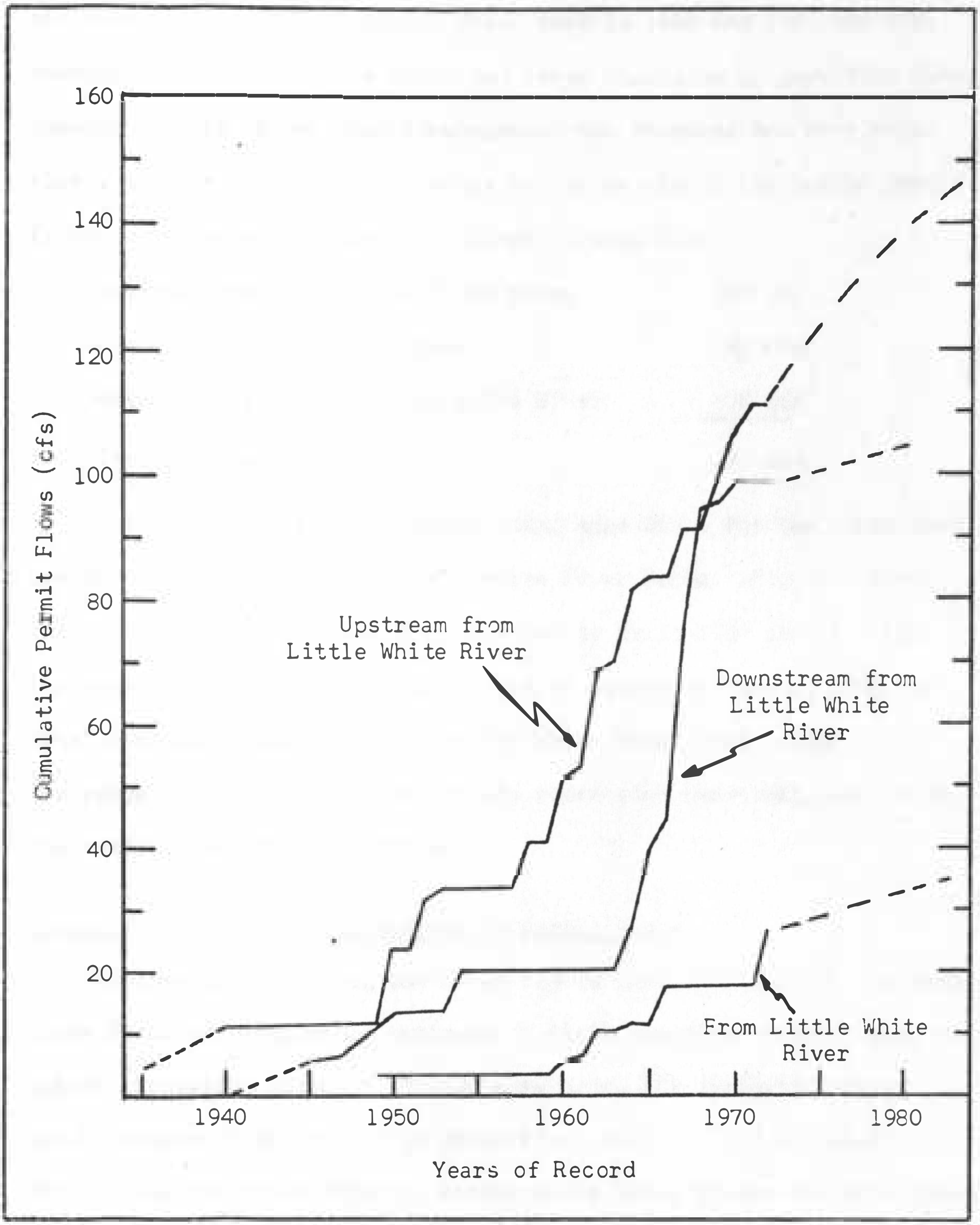

Figure 5. Cumulative flows allowed by irrigation permits for the years of record and predictions for future usage in three designated areas of the White River Basin.

increases since 1960. Figure 5 shows that in 1966 and 1967 the area downstream from the Little White had large increases in permitted flows. However, in the Oacoma area (downstream) the increase has been relatively small since 1968. Estimates for water rights irrigation permit flows in the year 1980 were as follows (Figure 5):

Upstream from the Little White River	139 cfs
Along the Little White River	33 cfs
Downstream from the Little White River	105 cfs
Total for Basin	277 cfs

A similar figure can be drawn using Appendix D for the cumulative permit flow totals for the entire White River Basin. Figure 6 shows the cumulative total basin flows allowed by irrigation permit since the year 1960. From the figure it can be estimated that by 1980 the total irrigation permit flows for the White River Basin might be in the range of 270-275 cfs. This range correlates reasonably well with the totals from Figure 5 (277 cfs).

Comparison of Present Streamflows to Permit Flows

Theoretically, all of the water rights permit holders in the White River Basin could possibly irrigate at their permitted rates during the entire irrigation season. If this were done, the irrigation flows taken upstream from the Little White River would be approximately 111 cfs. Permitted flows from the Little White River itself would be about 26 cfs. Permit flows taken downstream from the mouth of the Little

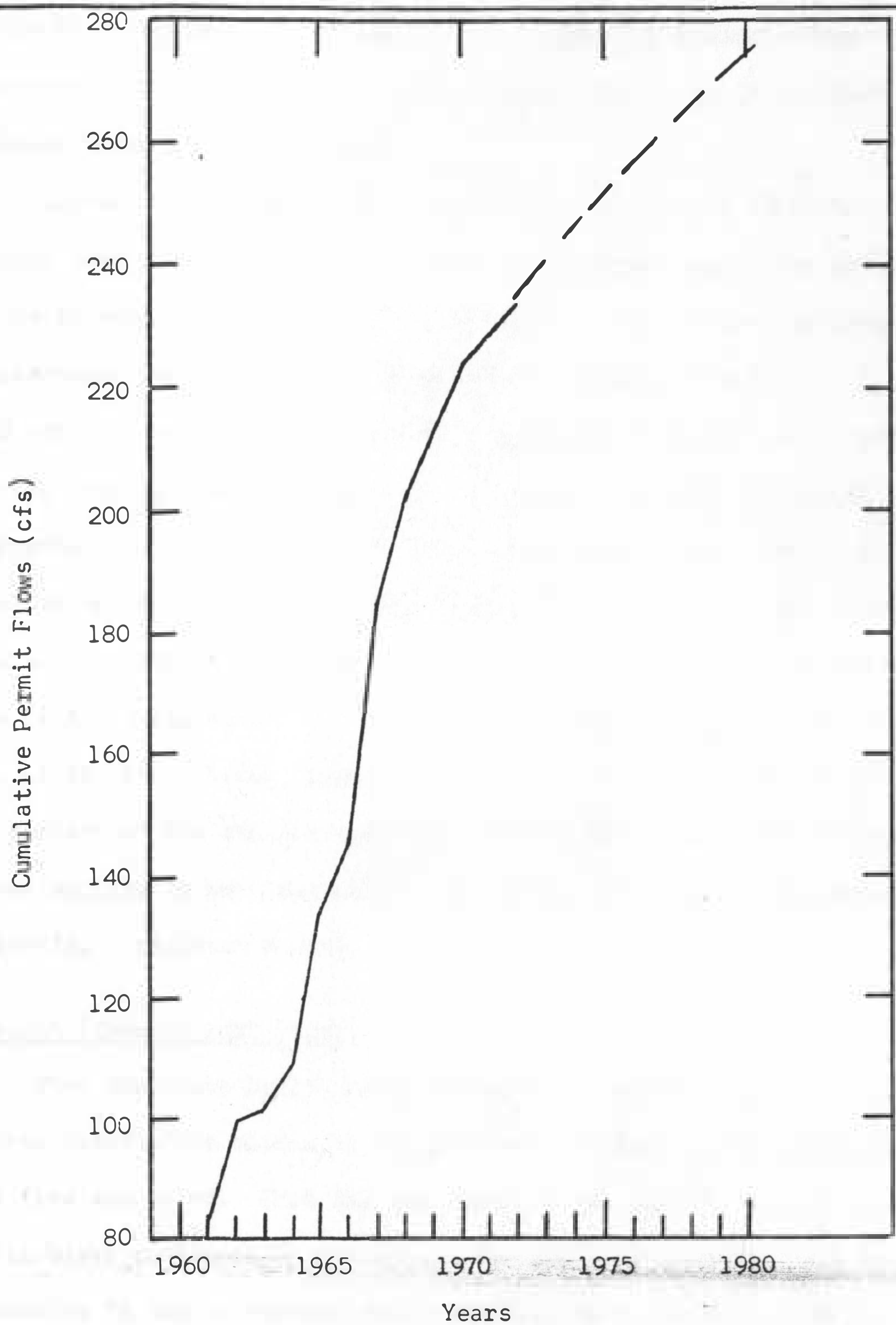

Figure 6. Cumulative flows allowed by irrigation permits for the entire White River Basin since 1960.

White River would total about 100 cfs. These three permit flows were compared to the past actual flows available at the three stations near Kadoka, White River and Oacoma.

Table 15 shows the percentages of time during the irrigation months when the streamflows at the three stations would have been adequate to support the permit flows in those areas. These approximate percentages were obtained by comparing the permit flows (111, 26, and 100 cfs) to the percent of time that actual streamflows have occurred in the past as shown in Tables 3, 4, and 5. The months of August and September would be the most critical irrigation months (Table 15). Irrigation continuously at permitted rates by all the permit holders would have been possible less than 20 percent of the time upstream from the Little White River. In September, downstream from the mouth of the Little White River, permit holders could have irrigated only about 25 percent of the time at their permitted flows. The Little White River appears to have sufficient streamflows to have met the permitted potential irrigation demand.

Present "Transferred" Flows

When the South Dakota Water Resources Commission grants a water rights permit, the holder of the permit is allowed to use continuously the flow indicated. That is, the permit flow could be pumped from the White River continuously throughout the irrigation season. However, according to the irrigation questionnaire, this constant usage was not maintained during the irrigation season throughout the White River Basin.

Table 15. Percentages of Time for Adequate Streamflow at Present If All Permit Holders Irrigate Continuously at Permitted Rates in the Three Irrigation Areas.

Months	Upstream from Little White River		Along the Little White River		Downstream from Little White River	
	Total Present Permit Flows	% of Time @ Kadoka	Total Present Permit Flows	% of Time @ White River	Total Present Permit Flows	% of Time @ Oacoma
May	111 cfs	60%	26 cfs	100%	100 cfs	90%
June	111 cfs	60%	26 cfs	100%	100 cfs	90%
July	111 cfs	50%	26 cfs	90%	100 cfs	70%
August	111 cfs	20-25%	26 cfs	90%	100 cfs	50%
September	111 cfs	15%	26 cfs	90%	100 cfs	25%

For the White River Basin, the total irrigation permitted flows for the three areas (Table 14) can be prorated by month according to the actual percentages of total water pumped (see Table 12). The percentages of total irrigation usage for the months of May, June, July, August and September were 4.8, 14.0, 43.6, 26.5 and 7.4 percent, respectively. In this study, the above percentages were applied to proportion the permitted flows by month for the three irrigation areas (Table 16). These proportioned water rights flows were termed "transferred" flows. The "transferred" flow is the projected use for irrigation had all the permit holders irrigated according to their water rights. The "transferred" flows on a monthly basis in the three designated irrigation areas are shown in Table 16.

The present transferred flows by month for the three irrigation areas (Table 16) can also be related to the flow duration relationships in Tables 3, 4, and 5. The flow-duration tables for stations near Kadoka, White River and Oacoma are in the best geographic position to be correlated to the irrigation areas, upstream from the Little White River, along the Little White River, and downstream from the Little White River, respectively.

Table 17 indicates the percentage of time during the irrigation season when the streamflow in the White River Basin was adequate for the present transferred flows (Table 16). The most critical period seems to be during August and September, upstream from the Little White River near Kadoka, when the past streamflow would have been adequate

Table 16. Irrigation Water Rights Transferred Flows by Month in Three Designated Areas of the White River Basin (26).

Months	% of Total	Transferred Flows - cfs: Upstream from the Little White River	Along Little White River	Downstream from the Little White River	Totals/ Month
May	4.8%	5.33	1.25	4.79	11.37
June	14.0%	15.56	3.65	13.97	33.18
July	43.6%	48.45	11.35	43.52	103.32
August	26.5%	29.44	6.90	26.44	62.78
September	7.4%	8.22	1.93	7.38	17.53
Other	3.7%	4.11	0.96	3.69	8.76
Totals	100%	111.11	26.04	99.79	236.94

Table 17. Percentages of Time During the Irrigation Months when the Streamflow in the White River Basin at Three Locations Would Equal or Exceed Present Transferred Flows in Those Areas.

Months	Upstream from the Little White River @ Kodaka	Along the Little White River @ White River	Downstream from the Little White River @ Oacoma
May	100%	100%	100%
June	90%	90%	100%
July	70%	90%	80%
August	50%	100%	80%
September	50%	100%	90%

only about 50 percent of the time (Table 17). The flows near White River and Oacoma would have been adequate at least 80 percent of the time.

Future Transferred Flows

In 1980, the granting of water right permits in the White River Basin may follow somewhat the same trends as the last few years. The projected irrigation permit flows for 1980 can be "transferred" by percentages for each of the three irrigation areas.

Table 18 shows the "transferred" flows by irrigation month for the year 1980 and the percentages of time that the "transferred" flows would have been available at stations near Kadoka, White River, and Oacoma. The critical irrigation periods appear near Kadoka, during August and September upstream from the mouth of the Little White River in the Basin. Adequate flows for irrigation in the Kadoka area would be available for the transferred flow approximately 45 percent of the time in August and 50 percent of the time during September. The areas near White River and Oacoma would have available flows for irrigation greater than 80 percent of the time.

Table 18. Percentages of Time for Adequate Transferred Irrigation Flows in 1980 Near the Gaging Stations at Kadoka, White River, and Oacoma.

Months	% of Total Flow	Upstream from Little White River: Transferred Flows (1980)	Upstream from Little White River: % of Time @ Kadoka	Along the Little White River: Transferred Flows (1980)	Along the Little White River: % of time @ White River	Downstream from Little White River: Transferred Flows (1980)	Downstream from Little White River: % of time @ Oacoma
		(cfs)		(cfs)		(cfs)	
May	4.8	6.65	100%	1.58	100%	5.04	100%
June	14.0	19.45	90%	4.62	100%	14.70	100%
July	43.6	60.55	70%	14.38	90%	45.76	80%
August	26.5	36.05	45%	8.76	90%	27.84	80%
September	7.4	10.56	50%	2.44	100%	7.78	90%
Others	3.7	5.14	--	1.22	--	3.88	--
Totals	100%	139.00	--	33.00	--	105.00	--

SUMMARY AND CONCLUSIONS

The main objectives of this study were to determine and evaluate the streamflow variations in the White River Basin to estimate the percentages of time that specific flows existed in the river and to investigate the probable effects of increased water resources development on the White River flow. Efforts were also made to investigate the adequacy of river water quality for beneficial uses within the Basin.

Ten different streamflow gaging stations located on the White and Little White Rivers were used in this study. Flow-duration tables for these 10 stations were prepared using one-third month periods throughout the year. The maximum and mean flows were also determined for each of the 10-day periods.

Conclusions drawn from this investigation are based on the assumption that the past flows in the Basin are relatively representative of future flows and that excess flows within the White River Basin are not stored and later released. The results from this investigation indicate the following conclusions:

1. The wide variety of physical features, such as the South Dakota Badlands, in the White River Basin may have a pronounced effect on the quality and flows in the White River. The Badlands are a probable contributor to the high suspended solids in the White River.

2. Mean and median flows of 10 cfs or more have occurred on the White River Basin for all 10-day periods throughout the year which

would seem to indicate that flows have been adequate for most uses; however, periods with zero or near zero flow have occurred for extended periods of time which indicate limitations to water resources development, particularly for irrigation. In contrast, minimum flows for the Little White River have seldom been near zero to limit past water uses.

3. Of the designated beneficial uses for the White River and Little White River, the fish life use seems to have its quality parameter limits violated most often. The suspended solids concentrations greatly exceeded the limits designated for this use. Based on the limited information available, the river water quality seems to be satisfactory for all the other designated uses for the basin.

4. The quality and suitability of streamflow used as irrigation water varies with location in the White River Basin. The irrigation areas adjacent to the Little White River seem to have access to the best quality of water for irrigation. Streamflow quality in the White River was also relatively suitable for irrigation purposes.

5. The high degree of suspended solids seems to be a major pollution problem in the White River Basin. The West River Conservancy Sub-District is trying to implement action to reduce sediment loads carried by the rivers.

6. At present waste water flows, the White River itself does not enter the intermittent streamflow use category and it appears doubtful that this category will be in effect in the near future. Flows in the minor tributaries to the main course of the White River may, however, consist totally of treated waste water flow.

7. Considering past trends, it may be projected that irrigation permits issued by 1980 may increase the permit flows taken from the White River and its tributaries to approximately 277 cfs. By 1980, the permitted flows would be expected to increase by about 17 percent.

8. If water right permit holders would utilize their entire permitted flows continuously, the streamflows in the White River would be adequate according to past records only a relatively small percentage of the time in the late summer.

9. Using the "transferred" flow interpretation, which recognizes that flow usage varies with time, past streamflow records would indicate that adequate flows would be available a greater percentage of the time presently and in the future.

RECOMMENDATIONS

Based on the results of this investigation, the following recommendations are made:

1. Additional samples should be collected and analyzed to define more clearly the range of quality of the streamflow in the White River Basin.

2. Consideration should be given to informing future irrigators located along the White River and Little White River of the probable frequency of adequate river flows for irrigation purposes.

3. A future study could be made to investigate the possibility of issuing irrigation permits on a monthly basis, considering seasonal streamflow variation in different areas of the river basins.

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APPENDIX A

Flow-Duration Tables for Six USGS Streamflow Gaging Stations Located on the White and Little White Rivers

TABLE A-1 FLOW DURATION AND MEAN FLOW FOR THE LITTLE WHITE RIVER FOR INDICATED PERIODS OF THE YEAR

Station: Martin
Period of Record: 3/1938-9/1940, 8/1962-9/1970
USGS Station No.: 64475

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record									MEAN FLOW(cfs)
	Percent of Time									
	100%*	90%	80%	70%	60%	50%	25%	10%	MAX	
January										
1-10	5.0	6.0	8.0	9.0	10.0	10.0	11.0	13.0	16.0	10.0
11-20	4.0	6.0	7.0	8.0	8.0	8.0	11.0	13.0	15.0	9.0
21-31	5.0	6.0	6.0	7.0	8.0	9.0	15.0	20.0	32.0	11.7
February										
1-10	6.0	7.0	11.0	11.0	11.0	12.0	19.0	27.0	30.0	14.5
11-20	8.0	9.0	10.0	10.0	11.0	11.0	15.0	24.0	27.0	13.5
21-28/29	8.0	11.0	11.0	12.0	13.0	13.0	17.0	18.0	24.0	14.3
March										
1-10	13.0	13.0	15.0	19.0	22.0	25.0	36.0	50.0	400.0	34.4
11-20	15.0	19.0	22.0	28.0	30.0	32.0	42.0	100.0	800.0	63.6
21-31	12.0	14.0	22.0	24.0	27.0	30.0	48.0	59.0	160.0	36.5
April										
1-10	12.0	17.0	18.0	23.0	27.0	28.0	42.0	54.0	137.0	33.8
11-20	16.0	19.0	21.0	24.0	27.0	30.0	36.0	41.0	82.0	30.9
21-30	15.0	17.0	21.0	24.0	25.0	27.0	46.0	61.0	130.0	36.6
May										
1-10	10.0	13.0	15.0	18.0	20.0	24.0	30.0	40.0	137.0	26.5
11-20	8.0	12.0	15.0	19.0	21.0	24.0	30.0	40.0	108.0	25.6
21-31	8.0	11.0	15.0	17.0	18.0	20.0	25.0	37.0	228.0	27.9
June										
1-10	6.0	10.0	14.0	15.0	16.0	18.0	24.0	39.0	235.0	28.2
11-20	3.2	8.0	10.0	12.0	15.0	18.0	36.0	124.0	550.0	54.8
21-30	3.0	6.0	7.0	9.0	11.0	13.0	25.0	89.0	394.0	32.3
July										
1-10	2.3	4.7	6.0	7.4	8.5	12.0	18.0	31.0	139.0	16.1
11-20	1.2	4.1	6.0	7.7	8.8	9.8	15.0	21.0	325.0	20.2
21-31	0.8	3.6	4.2	6.0	7.0	9.0	14.0	27.0	165.0	16.9
August										
1-10	0.9	2.7	3.6	4.6	5.8	7.6	12.0	14.0	21.0	8.1
11-20	0.6	1.9	3.7	4.6	6.0	6.7	9.3	11.0	40.0	7.2
21-31	0.8	2.8	3.7	6.0	6.7	7.4	8.8	10.0	35.0	7.3
September										
1-10	1.9	2.9	5.0	6.0	6.7	7.8	9.0	12.0	77.0	8.6
11-20	2.7	3.9	6.0	6.4	6.8	7.8	9.2	11.0	20.0	8.0
21-30	3.2	4.4	6.0	7.0	7.8	8.7	11.0	15.0	33.0	9.3
October										
1-10	6.0	7.0	8.0	8.4	9.5	10.0	12.0	14.0	22.0	10.6
11-20	7.0	8.0	10.0	11.0	11.0	12.0	14.0	16.0	35.0	12.4
21-31	9.0	10.0	11.0	11.0	12.0	13.0	15.0	17.0	36.0	13.8
November										
1-10	9.0	12.0	12.0	13.0	14.0	15.0	17.0	18.0	21.0	14.9
11-20	6.0	11.0	12.0	14.0	14.0	15.0	18.0	20.0	21.0	15.3
21-30	5.0	8.0	11.0	13.0	14.0	15.0	19.0	21.0	24.0	15.1
December										
1-10	6.0	8.0	8.5	10.0	11.0	13.0	17.0	20.0	22.0	13.7
11-20	4.0	5.0	7.0	9.0	12.0	12.0	16.0	18.0	23.0	12.6
21-31	5.0	6.0	7.0	8.0	9.0	9.5	12.0	15.0	17.0	10.2

* Equivalent to the minimum flow recorded

TABLE A-2 FLOW DURATION AND MEAN FLOW FOR THE LAKE CREEK FOR INDICATED PERIODS OF THE YEAR

Station: Tuthill (above refuge)
Period of Record: 3/1938-9/1940, 8/1962-9/1970
USGS Station No.: 64480

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record — Percent of Time: 100% *	90%	80%	70%	60%	50%	25%	10%	MAX	MEAN FLOW(cfs)
January										
1-10	7.0	13.0	16.0	17.0	18.0	18.0	20.0	22.0	30.0	18.1
11-20	10.0	13.0	13.0	16.0	17.0	18.0	20.0	22.0	25.0	17.5
21-31	10.0	13.0	15.0	17.0	18.0	18.0	22.0	25.0	28.0	19.0
February										
1-10	5.0	7.0	18.0	19.0	21.0	22.0	24.0	25.0	26.0	20.3
11-20	5.0	16.0	18.0	19.0	20.0	21.0	23.0	25.0	32.0	20.5
21-28/29	9.0	15.0	20.0	21.0	22.0	23.0	25.0	27.0	30.0	22.0
March										
1-10	11.0	19.0	22.0	24.0	24.0	25.0	26.0	30.0	110.0	26.8
11-20	18.0	22.0	23.0	25.0	25.0	26.0	32.0	39.0	83.0	29.5
21-31	13.0	18.0	21.0	22.0	24.0	25.0	27.0	31.0	39.0	24.7
April										
1-10	13.0	18.0	21.0	22.0	23.0	24.0	27.0	32.0	60.0	25.0
11-20	10.0	18.0	19.0	20.0	21.0	22.0	26.0	30.0	45.0	23.4
21-30	12.0	17.0	20.0	21.0	22.0	23.0	27.0	36.0	65.0	25.3
May										
1-10	10.0	13.0	17.0	18.0	19.0	20.0	23.0	29.0	75.0	21.5
11-20	7.0	12.0	15.0	18.0	19.0	20.0	22.0	27.0	76.0	20.7
21-31	1.3	13.0	14.0	17.0	18.0	18.0	21.0	24.0	41.0	18.2
June										
1-10	0.1	10.0	13.0	15.0	17.0	18.0	20.0	24.0	103.0	19.4
11-20	4.4	11.0	14.0	16.0	17.0	18.0	21.0	31.0	59.0	20.1
21-30	4.9	10.0	14.0	15.0	16.0	17.0	20.0	26.0	42.0	18.0
July										
1-10	8.0	11.0	13.0	13.0	14.0	15.0	18.0	19.0	26.0	15.2
11-20	8.0	11.0	12.0	13.0	13.0	14.0	16.0	21.0	40.0	15.6
21-31	6.3	9.0	10.0	12.0	14.0	16.0	17.0	19.0	68.0	15.5
August										
1-10	6.7	8.0	9.7	12.0	14.0	15.0	16.0	18.0	35.0	14.0
11-20	8.5	9.4	12.0	13.0	14.0	14.0	16.0	18.0	49.0	14.9
21-31	4.4	10.0	11.0	13.0	14.0	15.0	16.0	19.0	29.0	14.5
September										
1-10	4.2	11.0	14.0	15.0	16.0	16.0	18.0	19.0	22.0	15.7
11-20	7.6	12.0	14.0	15.0	16.0	16.0	18.0	20.0	27.0	16.4
21-30	10.0	13.0	14.0	14.0	16.0	16.0	18.0	20.0	27.0	16.4
October										
1-10	13.0	15.0	16.0	16.0	17.0	18.0	19.0	21.0	33.0	17.9
11-21	15.0	16.0	17.0	18.0	18.0	18.0	19.0	21.0	40.0	18.7
21-31	15.0	16.0	17.0	18.0	18.0	19.0	20.0	21.0	26.0	18.8
November										
1-10	11.0	15.0	17.0	18.0	19.0	20.0	21.0	22.0	24.0	19.3
11-20	8.0	16.0	18.0	19.0	20.0	21.0	22.0	24.0	27.0	20.3
21-30	4.0	12.0	17.0	20.0	21.0	21.0	22.0	23.0	25.0	19.3
December										
1-10	7.0	12.0	15.0	18.0	20.0	20.0	22.0	23.0	26.0	18.9
11-20	6.0	8.0	13.0	15.0	17.0	20.0	22.0	23.0	27.0	17.7
21-31	4.0	7.0	13.0	17.0	19.0	20.0	22.0	24.0	36.0	18.3

* Equivalent to the minimum flow recorded

TABLE A-3 FLOW DURATION AND MEAN FLOW FOR THE LAKE CREEK FOR INDICATED PERIODS OF THE YEAR

Station: Tuthill (below refuge)
Period of Record: 8/1962-9/1970
USGS Station No.: 64490

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record									MEAN FLOW(cfs)
					Percent of Time					
	100% *	90%	80%	70%	60%	50%	25%	10%	MAX	
January										
1-10	0.1	6.4	8.5	15.0	16.0	17.0	19.0	22.0	26.0	15.2
11-20	3.0	5.0	10.0	17.0	17.0	19.0	22.0	22.0	28.0	16.8
21-31	4.0	6.0	15.0	16.0	18.0	19.0	21.0	23.0	39.0	18.2
February										
1-10	6.6	13.0	14.0	18.0	18.0	19.0	22.0	25.0	28.0	18.9
11-20	6.3	13.0	13.0	17.0	18.0	19.0	25.0	31.0	32.0	20.3
21-28/29	13.0	18.0	19.0	20.0	20.0	25.0	33.0	36.0	49.0	25.9
March										
1-10	3.0	5.2	6.3	13.0	24.0	28.0	37.0	47.0	49.0	25.4
11-20	1.3	2.5	3.0	6.0	9.0	14.0	39.0	44.0	55.0	21.6
21-31	0.3	0.6	2.7	4.0	5.0	18.0	45.0	53.0	100.0	26.6
April										
1-10	0.0	0.2	0.3	0.5	24.0	33.0	48.0	54.0	101.0	29.3
11-20	0.0	0.0	0.1	0.3	7.9	22.0	43.0	55.0	60.0	24.5
21-30	0.0	0.1	0.2	8.5	23.0	34.0	53.0	71.0	77.0	32.0
May										
1-10	0.1	0.2	1.5	24.0	26.0	33.0	49.0	74.0	79.0	33.1
11-20	0.1	0.2	1.0	2.6	3.7	8.4	35.0	53.0	70.0	19.1
21-31	0.0	0.1	0.3	1.0	2.5	3.7	10.0	18.0	42.0	6.7
June										
1-10	0.0	0.4	0.9	1.7	3.2	5.8	26.0	43.0	67.0	15.7
11-20	0.4	0.5	3.8	5.8	7.3	10.0	32.0	62.0	173.0	27.8
21-30	0.5	4.7	9.5	17.0	23.0	27.0	39.0	137.0	158.0	40.4
July										
1-10	0.5	2.2	3.6	14.0	23.0	33.0	38.0	115.0	128.0	36.9
11-20	0.0	1.0	2.0	3.9	5.8	26.0	36.0	48.0	85.0	22.3
21-31	0.0	0.0	0.6	0.8	3.5	10.0	35.0	40.0	64.0	17.2
August										
1-10	0.0	1.0	1.8	2.5	4.2	5.0	29.0	37.0	46.0	13.8
11-20	0.0	0.0	0.6	1.3	2.4	3.1	6.6	33.0	35.0	8.6
21-31	0.0	0.0	0.7	1.2	1.5	1.8	7.1	29.0	39.0	7.3
September										
1-10	0.0	0.1	0.7	0.2	1.4	1.7	9.4	18.0	32.0	6.3
11-20	0.0	0.1	0.1	0.4	0.7	1.1	8.9	17.0	17.0	4.6
21-30	0.0	0.1	0.1	0.4	0.7	1.5	4.9	12.0	18.0	3.8
October										
1-10	0.0	0.0	0.5	1.0	1.5	2.0	6.0	17.0	37.0	5.5
11-20	0.0	0.0	0.0	0.5	0.9	1.2	4.9	14.0	38.0	4.3
21-31	0.0	0.1	0.8	1.1	1.3	1.7	5.0	13.0	17.0	4.3
November										
1-10	0.0	0.1	0.8	1.4	1.5	2.7	15.0	16.0	30.0	6.7
11-20	0.0	0.1	0.4	2.5	4.9	5.5	18.0	29.0	40.0	10.6
21-30	0.0	0.8	1.3	3.4	4.6	4.9	16.0	19.0	28.0	8.2
December										
1-10	1.5	1.9	2.9	4.2	5.3	5.9	19.0	23.0	32.0	11.3
11-20	1.5	1.8	3.0	5.5	6.6	9.5	23.0	33.0	43.0	14.4
21-31	1.4	1.7	5.0	9.0	12.0	13.0	20.0	22.0	26.0	13.2

* Equivalent to the minimum flow recorded

TABLE A-4 FLOW DURATION AND MEAN FLOW FOR THE LITTLE WHITE RIVER FOR INDICATED PERIODS OF THE YEAR

Station: Vetal
Period of Record: 8/1959-9/1970
USGS Station No.: 64491

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record									MEAN FLOW(cfs)
	Percent of Time									
	100% *	90%	80%	70%	60%	50%	25%	10%	MAX	
January										
1-10	20.0	24.0	25.0	27.0	30.0	30.0	45.0	50.0	60.0	35.3
11-20	18.0	20.0	25.0	27.0	30.0	30.0	38.0	45.0	50.0	32.3
21-31	15.0	20.0	25.0	26.0	30.0	35.0	49.0	58.0	75.0	37.4
February										
1-10	25.0	30.0	30.0	35.0	40.0	40.0	50.0	57.0	77.0	43.0
11-20	25.0	32.0	34.0	35.0	40.0	42.0	60.0	73.0	96.0	48.7
21-28/29	20.0	34.0	44.0	46.0	50.0	55.0	65.0	86.0	97.0	57.0
March										
1-10	18.0	30.0	42.0	50.0	55.0	58.0	80.0	95.0	124.0	61.3
11-20	20.0	28.0	42.0	57.0	63.0	70.0	92.0	150.0	1,010.0	100.7
21-31	25.0	36.0	60.0	66.0	75.0	88.0	150.0	216.0	978.0	128.0
April										
1-10	35.0	39.0	50.0	55.0	91.0	97.0	140.0	160.0	229.0	101.0
11-20	28.0	37.0	48.0	61.0	69.0	73.0	103.0	147.0	177.0	82.9
21-30	18.0	31.0	39.0	55.0	63.0	70.0	110.0	135.0	248.0	86.3
May										
1-10	18.0	33.0	48.0	54.0	61.0	74.0	115.0	154.0	217.0	86.0
11-20	30.0	43.0	47.0	50.0	55.0	60.0	84.0	117.0	290.0	72.6
21-31	29.0	39.0	43.0	45.0	46.0	49.0	66.0	161.0	287.0	71.3
June										
1-10	20.0	24.0	28.0	32.0	37.0	54.0	74.0	143.0	343.0	66.0
11-20	21.0	27.0	32.0	42.0	50.0	65.0	146.0	240.0	528.0	109.6
21-30	17.0	23.0	35.0	47.0	58.0	70.0	122.0	237.0	533.0	106.0
July										
1-10	14.0	20.0	28.0	36.0	42.0	48.0	73.0	160.0	357.0	70.7
11-20	16.0	19.0	20.0	22.0	28.0	36.0	74.0	106.0	196.0	53.4
21-31	16.0	17.0	19.0	20.0	23.0	36.0	82.0	150.0	277.0	61.5
August										
1-10	11.0	16.0	18.0	20.0	24.0	31.0	46.0	63.0	79.0	35.0
11-20	13.0	16.0	18.0	20.0	23.0	29.0	45.0	57.0	106.0	34.3
21-31	12.0	16.0	19.0	21.0	23.0	24.0	32.0	54.0	92.0	30.1
September										
1-10	10.0	15.0	18.0	19.0	23.0	24.0	34.0	44.0	72.0	27.9
11-20	12.0	17.0	20.0	21.0	22.0	24.0	37.0	69.0	177.0	33.0
21-30	15.0	19.0	20.0	21.0	22.0	23.0	29.0	42.0	65.0	26.5
October										
1-10	17.0	19.0	22.0	24.0	25.0	26.0	33.0	46.0	66.0	30.1
11-20	16.0	21.0	23.0	25.0	28.0	31.0	35.0	46.0	69.0	31.9
21-31	21.0	23.0	24.0	28.0	30.0	31.0	40.0	50.0	62.0	34.4
November										
1-10	18.0	25.0	27.0	29.0	30.0	31.0	47.0	54.0	85.0	37.3
11-20	20.0	27.0	30.0	31.0	33.0	36.0	48.0	55.0	59.0	38.8
21-30	24.0	28.0	30.0	33.0	35.0	38.0	47.0	52.0	72.0	39.5
December										
1-10	20.0	25.0	28.0	30.0	34.0	36.0	45.0	50.0	64.0	38.3
11-20	10.0	20.0	25.0	28.0	30.0	30.0	50.0	57.0	80.0	37.2
21-31	20.0	24.0	25.0	28.0	29.0	30.0	52.0	60.0	73.0	36.9

* Equivalent to the minimum flow recorded

TABLE A-5 FLOW DURATION AND MEAN FLOW FOR THE SPRING CREEK
FOR INDICATED PERIODS OF THE YEAR

Station: St. Francis
Period of Record: 10/1959-9/1970
USGS Station No.: 04492.5

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record — Percent of Time: 100% *	90%	80%	70%	60%	50%	25%	10%	MAX	MEAN FLOW(cfs)
January										
1-10	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	1.1	0.1
11-20	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.5	0.1
21-31	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	2.1	0.1
February										
1-10	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.3	7.5	0.6
11-20	0.0	0.0	0.0	0.0	0.0	0.1	0.5	4.0	12.0	1.1
21-28/29	0.0	0.0	0.0	0.1	0.2	0.3	2.3	4.0	11.0	1.4
March										
1-10	0.0	0.0	0.0	0.1	0.2	1.7	8.1	13.0	21.0	4.6
11-20	0.0	0.0	0.2	0.3	4.4	7.1	11.0	16.0	48.0	7.7
21-31	0.0	0.2	3.0	6.7	8.3	9.8	17.0	24.0	38.0	11.8
April										
1-10	0.1	2.6	4.8	6.4	8.5	11.0	18.0	28.0	48.0	13.2
11-20	1.7	4.0	6.0	8.0	9.4	13.0	17.0	19.0	49.0	12.8
21-30	1.1	3.2	4.5	5.4	9.6	11.0	17.0	28.0	39.0	13.1
May										
1-10	0.8	2.5	4.1	4.7	8.1	9.0	15.0	20.0	47.0	11.2
11-20	1.4	2.3	4.6	5.9	7.0	8.1	11.0	14.0	21.0	8.4
21-31	0.9	1.8	3.2	4.3	5.3	6.0	8.8	16.0	52.0	8.0
June										
1-10	0.9	1.4	1.8	2.3	2.7	3.3	5.2	30.0	53.0	7.5
11-20	0.3	0.5	0.7	1.1	1.9	2.6	12.0	31.0	59.0	9.5
21-30	0.0	0.2	0.4	0.8	1.7	3.3	9.1	24.0	63.0	8.7
July										
1-10	0.0	0.0	0.1	0.6	0.8	1.3	4.0	13.0	55.0	5.4
11-20	0.0	0.0	0.0	0.2	0.3	0.6	1.8	4.3	28.0	2.9
21-31	0.0	0.0	0.0	0.0	0.1	0.1	0.5	1.6	15.0	1.1
August										
1-10	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	9.2	0.7
11-20	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.2	4.0	0.3
21-31	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	5.9	0.5
September										
1-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	2.9	0.2
11-20	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	2.3	0.2
21-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.2	0.1
October										
1-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
11-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	0.1
21-31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.1
November										
1-10	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	1.1	0.1
11-20	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.9	0.2
21-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.0	0.2
December										
1-10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.4	0.3
11-20	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.6	3.0	0.2
21-31	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.9	1.2	0.2

* Equivalent to the minimum flow recorded

TABLE A-6 FLOW DURATION AND MEAN FLOW FOR THE LITTLE WHITE RIVER FOR INDICATED PERIODS OF THE YEAR

Station: Rosebud
Period of Record: 6/1943-9/1970
USGS Station No.: 64495

Time Period	Flow (cfs) That Was Equalled or Exceeded during Indicated Period of Record — Percent of Time									MEAN FLOW(cfs)
	100%*	90%	80%	70%	60%	50%	25%	10%	MAX	
January										
1-10	10.0	40.0	50.0	60.0	70.0	80.0	90.0	110.0	130.0	75.1
11-20	15.0	50.0	55.0	65.0	70.0	80.0	90.0	100.0	123.0	74.8
21-31	15.0	45.0	55.0	60.0	70.0	75.0	90.0	100.0	140.0	74.1
February										
1-10	30.0	50.0	65.0	29.6	78.0	90.0	100.0	115.0	190.0	84.8
11-20	10.0	55.0	70.0	80.0	85.0	90.0	110.0	140.0	340.0	96.7
21-28/29	40.0	70.0	84.0	90.0	100.0	100.0	140.0	170.0	250.0	114.0
March										
1-10	40.0	70.0	95.0	105.0	120.0	130.0	160.0	260.0	1,000.0	157.0
11-20	48.0	90.0	110.0	130.0	151.0	168.0	300.0	450.0	1,300.0	232.3
21-31	50.0	116.0	138.0	174.0	189.0	205.0	278.0	382.0	1,430.0	246.4
April										
1-10	89.0	112.0	155.0	170.0	189.0	204.0	251.0	306.0	434.0	213.9
11-20	83.0	113.0	127.0	138.0	149.0	163.0	220.0	251.0	338.0	174.5
21-30	68.0	95.0	113.0	124.0	130.0	150.0	184.0	223.0	353.0	157.8
May										
1-10	74.0	96.0	110.0	123.0	135.0	144.0	183.0	242.0	486.0	162.0
11-20	78.0	96.0	110.0	121.0	131.0	138.0	181.0	219.0	1,810.0	158.0
21-31	78.0	92.0	96.0	102.0	108.0	120.0	162.0	226.0	890.0	144.0
June										
1-10	66.0	79.0	88.0	94.0	106.0	119.0	150.0	198.0	1,590.0	137.0
11-20	59.0	71.0	82.0	95.0	108.0	126.0	200.0	304.0	956.0	174.0
21-30	46.0	62.0	81.0	94.0	103.0	120.0	162.0	232.0	698.0	144.0
July										
1-10	40.0	66.00	72.0	79.0	90.0	98.0	133.0	183.0	413.0	114.0
11-20	39.0	57.0	60.0	64.0	69.0	75.0	110.0	180.0	644.0	102.0
21-31	44.0	48.0	54.0	59.0	62.0	65.0	101.0	149.0	298.0	86.8
August										
1-10	42.0	48.0	50.0	54.0	59.0	63.0	83.0	98.0	159.0	70.9
11-20	39.0	46.0	54.0	58.0	63.0	67.0	84.0	118.0	358.0	76.5
21-31	39.0	50.0	52.0	56.0	59.0	62.0	74.0	94.0	336.0	67.1
September										
1-10	41.0	50.0	54.0	56.0	59.0	60.0	70.0	84.0	205.0	64.8
11-20	45.0	54.0	57.0	60.0	63.0	66.0	75.0	90.0	443.0	72.4
21-30	52.0	55.0	57.0	60.0	62.0	65.0	74.0	83.0	115.0	67.6
October										
1-10	50.0	58.0	62.0	64.0	66.0	68.0	77.0	89.0	193.0	72.1
11-20	50.0	64.0	66.0	68.0	70.0	72.0	78.0	92.0	138.0	75.3
21-31	56.0	67.0	70.0	74.0	76.0	79.0	88.0	97.0	166.0	82.8
November										
1-10	54.0	68.0	73.0	77.0	80.0	83.0	94.0	105.0	135.0	85.8
11-20	35.0	60.0	70.0	76.0	81.0	86.0	96.0	107.0	151.0	85.5
21-30	45.0	64.0	74.0	75.0	80.0	88.0	96.0	111.0	151.0	87.3
December										
1-10	35.0	60.0	65.0	73.0	80.0	87.0	100.0	120.0	160.0	87.1
11-20	27.0	40.0	55.0	65.0	70.0	77.0	100.0	113.0	140.0	80.2
21-31	25.0	50.0	55.0	60.0	65.0	70.0	95.0	110.0	140.0	76.3

* Equivalent to the minimum flow recorded

APPENDIX B

Water Quality Data Obtained by South Dakota Health Department
From Streamflow Samples Taken Near Kadoka,
White River and Oacoma in the
White River Basin

Table B-1. Quality of Streamflow Samples Taken Near Kadoka, South Dakota, from the White River (mainstem) (15).

Characteristic*	Date of Sample 5-22-68	10-19-68	3-30-69	9-28-69	5-26-70
Mean Daily Flow (cfs)	123	12	384	0**	88
Dissolved Oxygen	--	10.2	12.4	8.5	7.4
pH	8.3	8.3	7.3	8.8	7.8
P. Alkalinity (mg/l, $CaCO_3$)					
T. Alkalinity (mg/l, $CaCO_3$)	7	1	0	22	0
Total Hardness (mg/l, $CaCO_3$)	110	140	98	64	97
Specific Conductance	--	990	435	1505	520
Total Solids	1827	890	1505	1505	1166
Dissolved Solids	608	690	1230	1030	421
Suspended Solids	1219	200	275	475	745
Turbidity (j.c.u.)	--	200	460	500	670
Iron	0.6	0.0	0.7	0.0	1.1
Potassium	7.0	11.3	3.1	7.8	6.3
Sodium	127	172	63.9	32.2	113.2
Calcium	.36	44.8	28.8	22.4	32
Magnesium	4.4	6.8	2.9	1.9	3.4
Chlorides	9.5	11.0	5.0	18.0	9.0
Sulfates	164	284	65	481	137

*All parameters are given in milligrams/liter except pH, specific conductance (mmhos/cm @ 25°C), and turbidity (jackson candle units).

**The sample at Kadoka for September 23, 1969, must have been taken from a large hole under a bridge. The mean daily flow on that day was recorded as zero.

Table B-2. Quality of Streamflow Samples Taken Near the Town of White River, South Dakota, from the Little White River (15).

Characteristic*	Date of Sample 5-22-68	8-1-68
Mean Daily Flow (cfs)	133	92
Dissolved Oxygen	--	--
pH	8.3	7.6
P. Alkalinity (mg/l, $CaCO_3$)	60	0
T. Alkalinity (mg/l, $CaCO_3$)	180	184
Total Hardness (mg/l, $CaCO_3$)	141	141
Specific Conductance	418	416
Total Solids	500	487
Dissolved Solids	306	307
Suspended Solids	194	180
Turbidity (j.c.u.)	--	--
Iron	0.3	0.3
Potassium	8.8	12.0
Sodium	27.6	35.9
Calcium	45.6	48.1
Magnesium	5.8	4.9
Chlorides	0.0	0.0
Sulfates	15.6	41.0

*All parameters are given in milligrams/liter except pH, specific conductance (mmhos/cm @ 25°C), and turbidity (jackson candle units).

Table B-3. Quality of Streamflow Samples Taken Near Oacoma, South Dakota, from the White River (mainstem) (15).

Characteristic*	Date of Sample 4-30-68	3-27-69
Mean Daily Flow (cfs)	880	2490
Dissolved Oxygen	--	--
pH	8.2	7.6
P. Alkalinity (mg/l, $CaCO_3$)	8	0
T. Alkalinity (mg/l, $CaCO_3$)	156	112
Total Hardness (mg/l, $CaCO_3$)	72	0
Specific Conductance	505	540
Total Solids	8473	6059
Dissolved Solids	332	404
Suspended Solids	8141	5655
Turbidity (j.c.u.)	--	--
Iron	4.0	2.8
Potassium	5.9	5.2
Sodium	81.9	60.7
Calcium	20.8	50.5
Magnesium	1.9	3.9
Chlorides	1.0	2.0
Sulfates	98.3	155.1

*All parameters are given in milligrams/leter except pH, specific conductance (mmhos/cm @ 25°C), and turbidity (jackson candle units).

APPENDIX C

Water Rights Permit Flows and Permit Acreage Granted
By the South Dakota Water Resources
Commission Each Year in
Three Designated Areas

Table C-1. Water Rights Permit Flows and Permit Acreage Granted by the South Dakota Water Resources Commission Each Year (26).

Years	Upstream from Little White River cfs	Upstream from Little White River Acres	Along the from Little White River cfs	Along the from Little White River Acres	Downstream from Little White River cfs	Downstream from Little White River Acres
1935	--	--	--	--	4.40	308.80
1940	--	--	--	--	7.11	498.87
1945	5.80	276.28	--	--	--	--
1947	1.12	82.23	--	--	--	--
1948	1.60	117.79	--	--	--	--
1949	3.22	226.22	3.27	229.92	--	--
1950	11.76	834.26	--	--	2.48	173.89
1952	8.30	131.09	--	--	--	--
1953	2.17	159.70	--	--	--	--
1954	--	--	--	--	5.99	423.00
1956	--	--	--	--	0.55	38.30
1958	6.60	463.40	--	--	--	--
1960	10.62	762.40	2.55	178.50	--	--
1961	2.68	188.00	0.65	45.80	--	--
1962	14.20	992.32	4.29	299.40	--	--
1963	2.22	154.30	--	--	--	--
1964	10.91	762.00	0.83	58.30	6.02	421.50
1965	1.91	134.08	--	--	12.73	900.10
1966	--	--	6.37	448.20	5.12	344.30
1967	7.68	728.70	--	--	31.17	2214.70
1968	--	--	--	--	17.71	1245.58
1969	7.83	548.20	--	--	2.90	204.60
1970	7.94	557.19	--	--	2.32	162.50
1971	4.55	318.00	--	--	0.29	18.80
1972	--	--	8.08	712.00	1.00	70.00
Totals	111.11	7436.16	24.06	1972.12	99.79	7024.94

APPENDIX D

Total Cumulative Permit Irrigation Flows and Acres

By Year in Each of Three Irrigation

Areas in the White River Basin

Table D-1. Total Cumulative Permit Irrigation Flows and Acres By Year in Each of Three Irrigation Areas in the White River Basin (26).

Year	Upstream from the Little White River		Along the Little White River		Downstream from the Little White River	
	cfs	Acres	cfs	Acres	cfs	Acres
1935	0.0	0.0	0.0	0.0	4.40	308.80
1940	0.0	0.0	0.0	0.0	11.51	807.67
1945	5.80	276.28	0.0	0.0	11.51	807.67
1947	6.92	358.51	0.0	0.0	11.51	807.67
1948	8.52	476.30	0.0	0.0	11.51	807.67
1949	11.74	702.50	3.27	229.92	11.51	807.67
1950	23.50	1536.78	3.27	229.92	13.99	981.56
1951	23.50	1536.78	3.27	229.92	13.99	981.56
1952	31.80	1667.87	3.27	229.92	13.99	981.56
1953	33.97	1827.57	3.27	229.92	19.99	981.56
1954	33.97	1827.57	3.27	229.92	19.98	1404.56
1955	33.97	1827.57	3.27	229.92	19.98	1404.56
1956	33.97	1827.57	3.27	229.92	20.53	1442.86
1957	33.97	1827.57	3.27	229.92	20.53	1442.86
1908	40.56	2290.97	3.27	229.92	20.53	1442.86
1959	40.56	2290.97	3.27	229.92	20.53	144 .86
1960	51.19	3053.37	5.82	408.42	20.53	1442.86
1961	53.87	3241.37	6.47	454.22	20.53	1442.86
1962	68.07	4233.69	10.76	753.62	20.53	1442.86
1963	70.29	4387.99	10.76	753.62	20.53	1442.86
1964	81.20	5149.99	11.59	811.92	26.55	1864.36
1965	83.11	5284.07	11.59	811.92	39.28	2764.46
1966	83.11	5284.07	17.96	1260.12	44.40	3108.76
1967	90.79	6012.77	17.96	1260.12	75.57	5323.46
1968	90.79	6012.77	17.96	1260.12	93.28	6569.04
1969	98.62	6560.97	17.96	1260.12	96.18	6773.64
1970	106.56	7118.16	17.96	1260.12	98.50	6936.14
1971	111.11	7436.16	17.96	1260.12	98.79	6954.94
1972	111.11	7436.16	26.04	1972.12	99.79	7024.94