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Simulation of Streamflow of Flambeau River at Park Falls, Wisconsin to Define Low-Flow Characteristics

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Simulation of Streamflow of Flambeau River at Park Falls, Wisconsin to Define Low-flow Characteristics

William R. Krug

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Prepared in cooperation with the
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CONTENTS

ILLUSTRATIONS

TABLES

Simulation of Streamflow of Flambeau River at Park Falls, Wisconsin to Define Low-flow Characteristics

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ABSTRACT

Daily streamflows of the Flambeau River at Park Falls were simulated for a 31-year period. Streamflow was simulated using a streamflow-routing model. These simulated daily flows at Park Falls were analyzed for summer (June 1-October 31) low-flow frequency. The resultant 7-day, 10-year summer low flow is 260 cubic feet per second (7.4 cubic meters per second). The standard error of estimate for this 10-year-frequency low flow is equivalent to the standard error of estimate for 16 years of gaging-station records.

INTRODUCTION

The purposes of this study were to simulate daily discharges of the Flambeau River at Park Falls, Wis., from October 1, 1929, to September 30, 1961, to determine low-flow-frequency relations of these simulated daily discharges and to determine the applicability of a streamflow-routing model to this type of study. The study was conducted in cooperation with the Wisconsin Department of Natural Resources. Knowledge of low-flow frequency is needed by the Department to establish regulations for the discharge of municipal and industrial wastes to the river at Park Falls. The low-flow characteristic of primary interest is the annual minimum 7-day mean flow that occurs on the average of once in 10 years ($Q_{7,10}$).

Data-management programs and the streamflow-routing model used in the study were developed by J. O. Shearman, U.S. Geological Survey Gulf Coast Hydroscience Center, Bay St. Louis, Miss.

For use of readers who may prefer to use the International System of Units (SI) rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	By	To obtain SI unit
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.59	square kilometers (km^2)
cubic feet per second (ft^3/s)	2.832×10^{-2}	cubic meters per second (m^3/s)

The Flambeau River basin is in northwest Wisconsin. The area included in this study was the part of the Flambeau River between Flambeau Flowage and the gaging station at Babbs Island near Winter, Wis. (fig. 1).

Flambeau Flowage was created in 1926 by a dam 18 mi (29 km) upstream from Park Falls. The dam is operated by the Chippewa and Flambeau Improvement Company, primarily to increase generating potential of powerplants downstream. Regulation of flow by the dam strongly influences the flow at Park Falls. Unfortunately, there are no streamflow records for the Flambeau River at Park Falls.

Transfer of low-flow characteristics to Park Falls from gaging stations upstream and downstream from Park Falls was not considered reliable because of streamflow regulation and insufficient data. Regulated flow data for 12 years (1927-38) were collected at the Flambeau River gaging station near Butternut (05358000); however, these data were not representative of typical low flows. Data from long-term gaging stations in the area indicated that 1927-38 was a period of below-normal low flows. A longer record is available from Flambeau River at Babbs Island near Winter (05358500), but the regulation of flows by the Flambeau Flowage and by several power dams between Park Falls and Winter casts doubt on the reliability of any direct transfer of low-flow characteristics from the Babbs Island gaging station to Park Falls.

This study included determining the applicability of a streamflow-routing model for simulating adequate streamflow data, from which the necessary low-flow characteristics could be determined. Gaging stations used for modeling, with their drainage areas and periods of record, are listed in table 1.

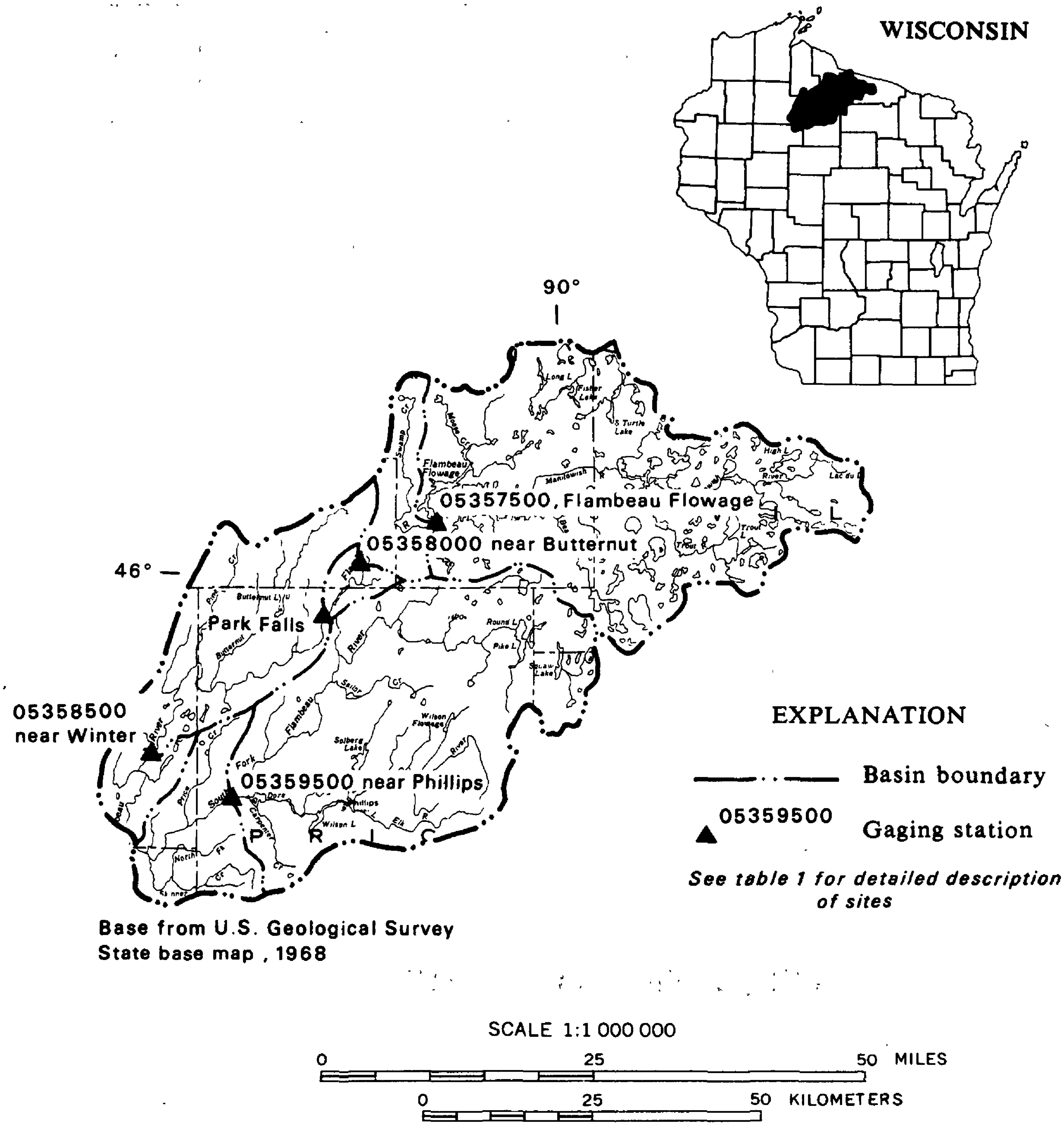


Figure 1. Map of study basin and its location in Wisconsin.

Table 1.--Drainage areas upstream from sites and availability of surface-water records

Station number	Station name[1]	Drainage area (mi^2)	Water years of record
05357500	Flambeau River at Flambeau Flowage	666	1928-61
05358000	Flambeau River near Butternut	737	[2]1915-38
Not a streamflow gaging station	Flambeau River at Park Falls	769	
05358500	Flambeau River at Babbs Island near Winter	1,000	[3]1930-75
05359500	South Fork Flambeau River near Phillips	615	1930-75

[1]In this report these sites will be referred to as Flambeau Flowage, Butternut, Park Falls, Winter, and Phillips.

[2]Unregulated flows for the 1915-26 period.

[3]Streamflow data were collected for the entire period; however, all or part of the data for water years 1940, 1952, and 1960 were missing from the computer files and were not available for analysis at the time of this study.

DESCRIPTION OF MODEL

The streamflow-routing model used in this study is based on the unit-response concept and convolution technique described by Sauer (1973). However, the unit-response functions were computed by the diffusion-analogy method (Keefer, 1974). A unit-response function, as determined by the diffusion-analogy method, is dependent upon:

1. The length of the reach,
2. Co--the wave celerity, and
3. K--the wave-dispersion coefficient.

Co and K are determined for a selected representative discharge Qo and are functions of the channel width, water-surface slope, slope of stage-discharge relation, and Froude number-all at discharge Qo.

The channel characteristics used to determine Co and K should represent the entire reach. In practice, they can be measured only at selected points. Thus, the computed Co and K values are estimates and must be tested on a reach where simulated discharges can be compared with observed discharges. Usually these estimated Co and K values are subsequently adjusted until the best possible agreement between simulated and observed discharges is obtained.

Convolution of the unit-response function with the upstream hydrograph accounts for the volume of flow entering the upstream end of the reach and produces a time distribution of the same volume of flow at the downstream end. Ungaged inflow to the channel within the reach is estimated by using a percentage of the discharge at a nearby gaging station.

MODEL CALIBRATION AND VERIFICATION

Model calibration (determination of the applicable K and Co values) requires comparison with observed discharge data. As there are no observed discharge data at Park Falls, another site must be used to calibrate the model. Therefore, both of the routing schemes shown in figure 2 were used.

The first routing scheme (fig. 2A) was used for model calibration. Daily discharges were routed from the gaging station 0.5 mi (0.8 km) downstream from the outlet of Flambeau Flowage to the gaging station near Butternut. The simulated discharges then were routed from Butternut to the gaging station at Babbs Island near Winter. Ungaged inflow was simulated by the observed discharge of the South Fork Flambeau River near Phillips adjusted by the ratio of ungaged area to drainage area at the Phillips gage. The South Fork Flambeau River was selected as the index of ungaged flow because it is the nearest gage having essentially unregulated flow.

Numerous segments of simulated and observed discharges were compared to arrive at the best values for K and Co. As low flow is the primary objective of the simulation, emphasis was placed on low-flow periods in the calibration. The model was calibrated by comparing simulated discharges and observed discharges at Butternut using 1 month of summer low flow for each year from 1930 to 1938. The mean of the absolute values of errors in daily discharge was 9.7 percent. Several adjustments of Co and K were made, none of which significantly reduced this mean error.

One major difficulty in simulating low flows was the operation of the Flambeau Flowage dam. Most annual low flows at Butternut and at Winter occur during high runoff when dam gates are partly closed to store flood waters. At such times nearly all the flow downstream is local inflow. Thus, the accuracy of the simulated low flow depends mostly on how well the South Fork Flambeau River flow serves as an index of the ungaged inflow on the Flambeau River.

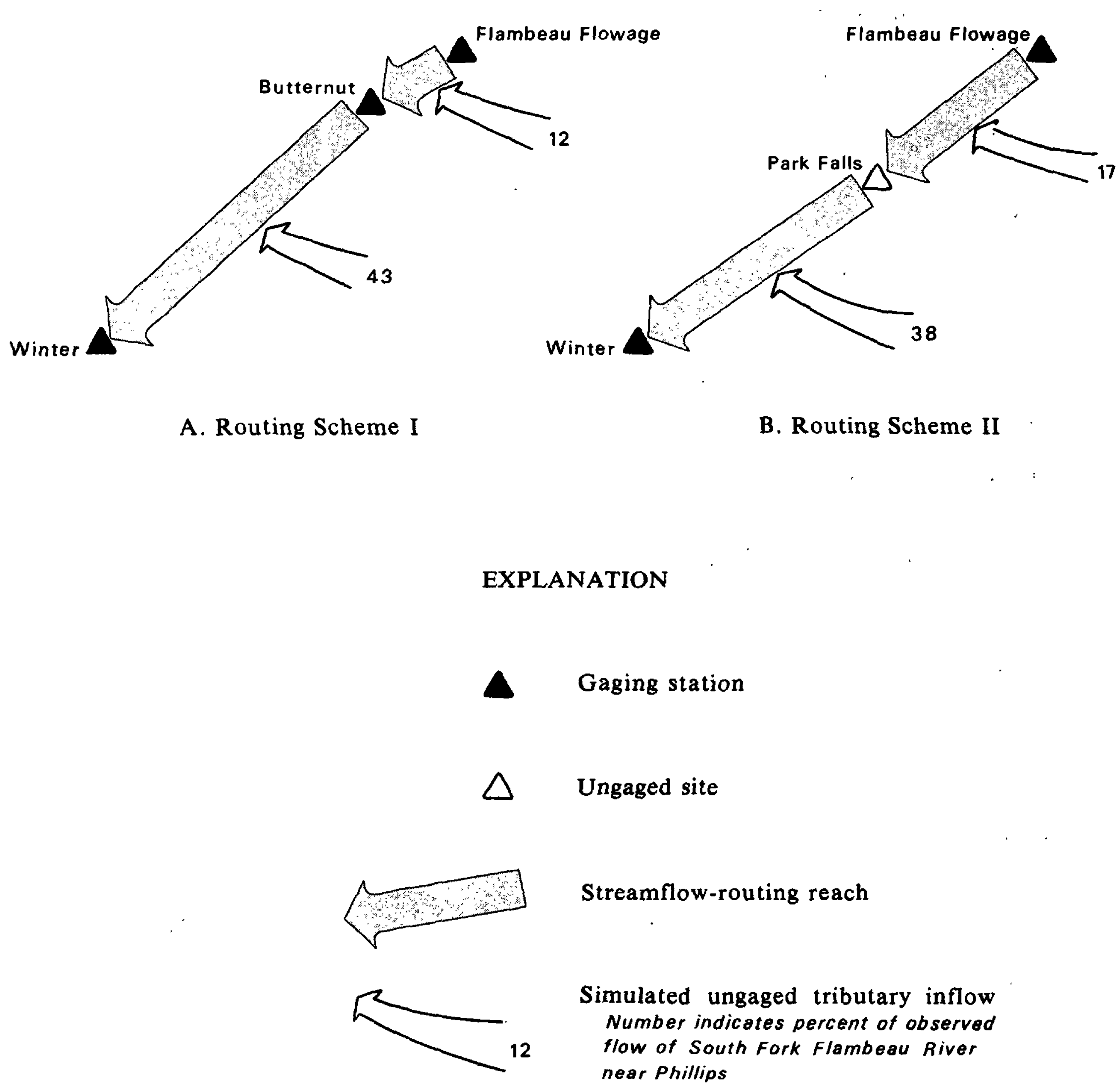


Figure 2. Schematic diagram of streams reaches used in model.

Comparisons of longer periods of actual streamflow with simulated streamflow show small errors in simulating ungaged inflow. The model computed outflows that were slightly high in early summer and slightly low in late summer. This suggests that the local inflow may have included more sustained ground-water contribution than in the South Fork Flambeau River basin. However, this error is small and does not bias the computed low flows.

Figures 3 and 4 compare simulated and observed flows at Butternut for two short low-flow periods. Each shows the simulated flow at Butternut, observed flow at Butternut, observed flow at Flambeau Flowage, and 12 percent of observed flow at Phillips (the index of ungaged inflow). In cases of uniform rains or snowmelt the actual and simulated flows compare very well, but in cases of heavy, local runoff they do not, as shown in the following two examples:

Example 1. Figure 3 shows a period of very good agreement between simulated and observed flows at Butternut. More than 90 percent of the flow at Butternut comes from Flambeau Flowage, and there is little ungaged inflow entering the streams. In this case, Phillips is an adequate index of ungaged inflow.

Example 2. Figure 4 shows a period of somewhat poorer agreement between simulated and observed flow. As much as 80 percent of the flow at Butternut is from the ungaged area between Flambeau Flowage and Butternut. Differences between simulated and observed discharges are due mainly to deficiencies in using the discharges at Phillips as an index of ungaged inflow.

The second routing scheme (fig. 2B) was used to simulate daily discharge at Park Falls. The routing parameters (Co and K) determined by calibration of the model for the first routing scheme (fig. 2A) were assumed to apply to the second scheme as well because Park Falls is close to Butternut and the channel between them is similar to the channel upstream from Butternut. The reach lengths of the second routing scheme were different than those of the first scheme; therefore, the unit response functions were different. An appropriate percentage of the flow at Phillips was used as an index of ungaged flow in each reach.

Simulated discharges at Winter from the two routing schemes are nearly identical. This implicitly verifies that the routing parameters used in the second scheme are appropriate for simulating discharges at Park Falls.

Accuracy of the model in simulating long-term records was verified by comparing low-flow characteristics for the entire period of record. The model was considered adequate for the purposes of this study because low-flow characteristics of the simulated discharges agree reasonably well with the low-flow characteristics of the observed discharges.

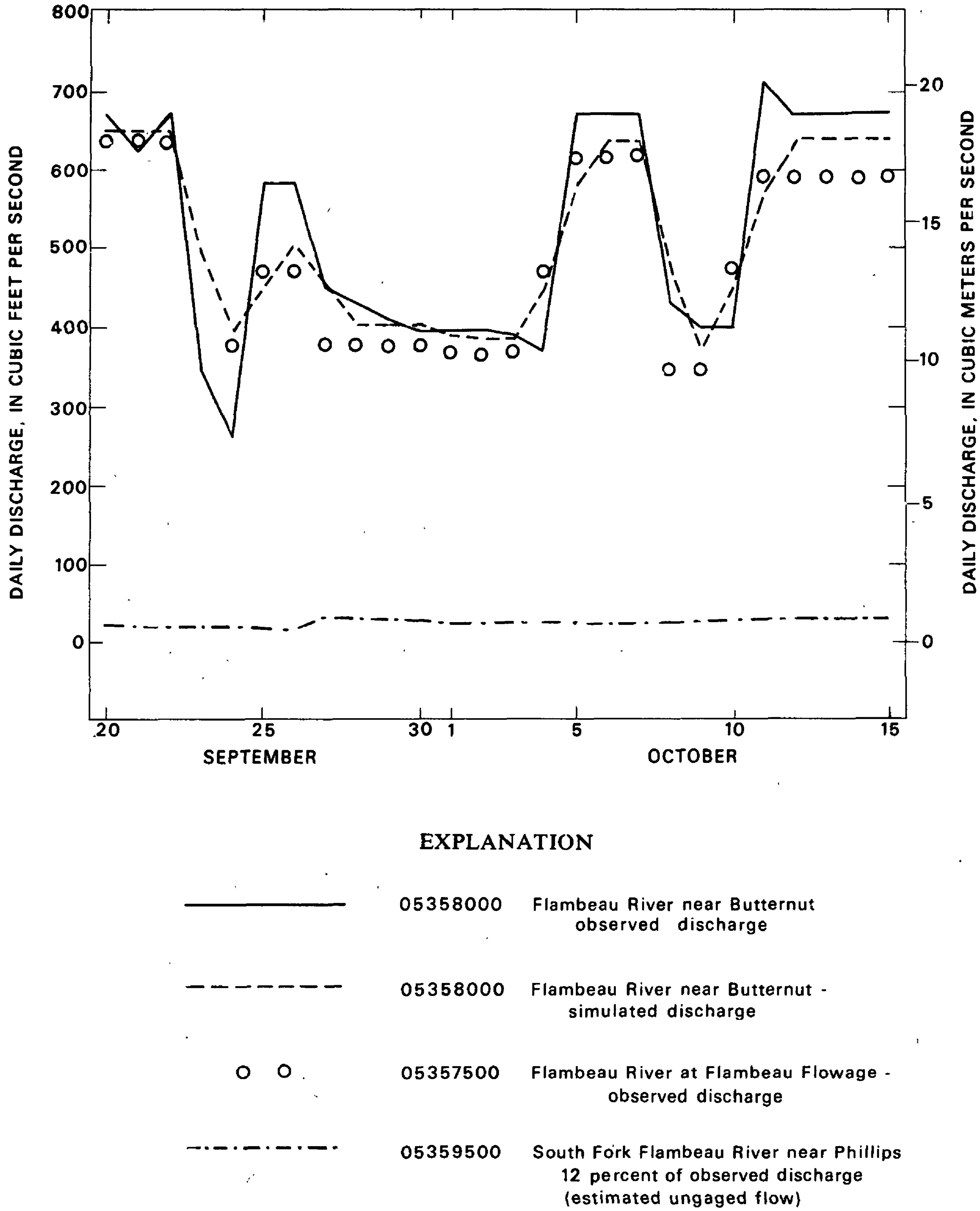
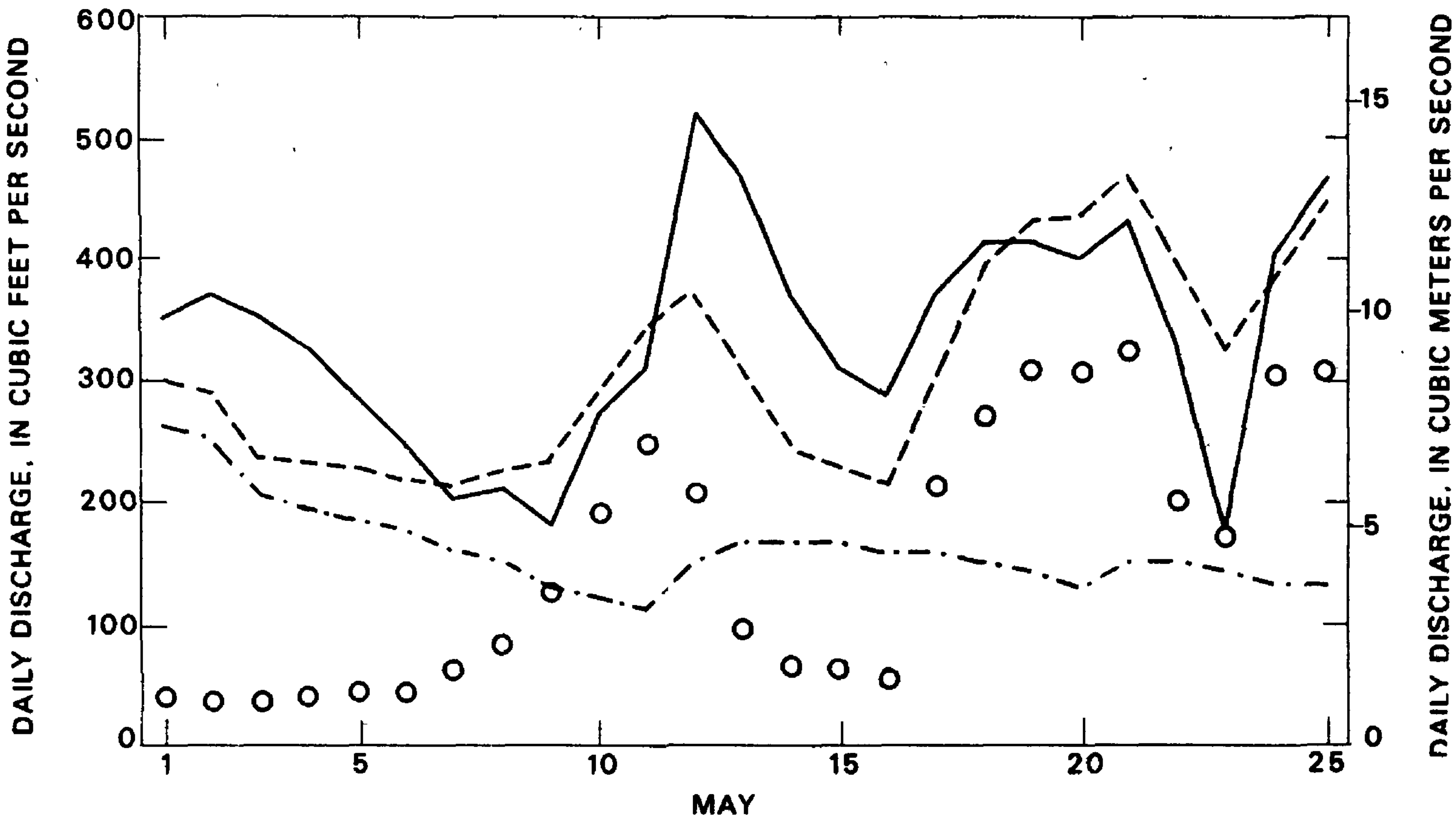


Figure 3. Comparison of simulated discharge at Butternut with observed discharge at Flambeau Flowage, Butternut, and Phillips from September 20 to October 15,1930.



EXPLANATION

————	05358000	Flambeau River near Butternut - observed discharge
– – – –	05358000	Flambeau River near Butternut - simulated discharge
O O	05357500	Flambeau River at Flambeau Flowage - observed discharge
—·—·—·	05359500	South Fork Flambeau River near Phillips 12 percent of observed discharge (estimated ungaged flow)

Figure 4. Comparison of simulated discharge at Butternut with observed discharge at Flambeau Flowage, Butternut, and Phillips from May 1 to 25,1937.

Figure 5 compares the 7-day low flows computed from simulated and observed streamflow data at Butternut from June 1 to October 31, 1930-37. The 7-day low flows computed from simulated discharges seem slightly high, but due to the small sample the observation is not conclusive.

A record of 25 years is available for Winter. This comparison of 7-day low-flow values for simulated and observed streamflow is shown in figure 6. The same years used in figure 5 are denoted by a special symbol in this figure. In figure 6 the points are scattered almost equally on both sides of the 45° line representing equality. Most of the points from 1930-37 plot above the line, as in figure 5. This indicates that for a longer period of record the positive bias shown in the 1930-37 period is greatly reduced.

A summary of modeling errors for the different reaches and periods of record is shown in table 2.

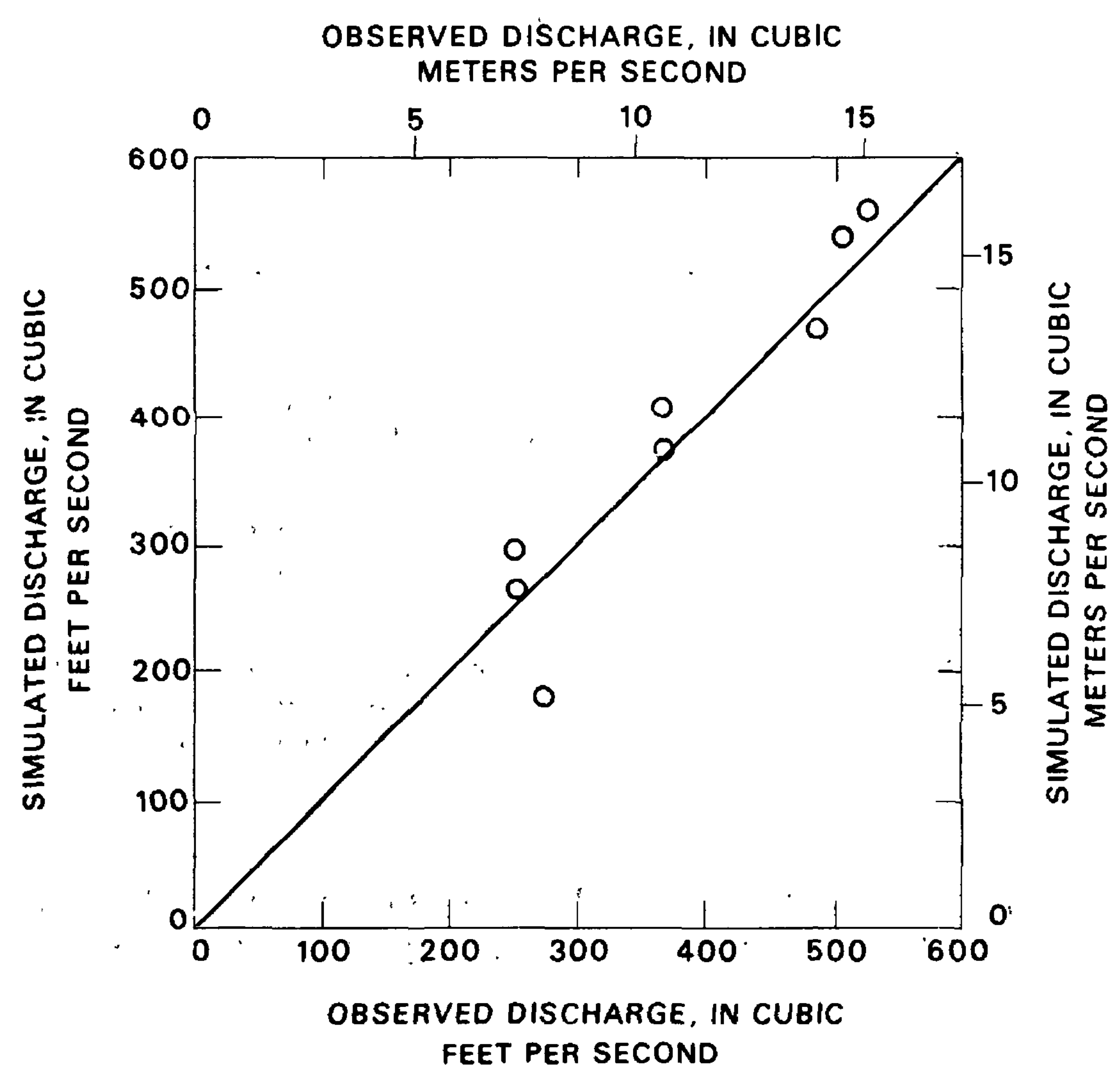
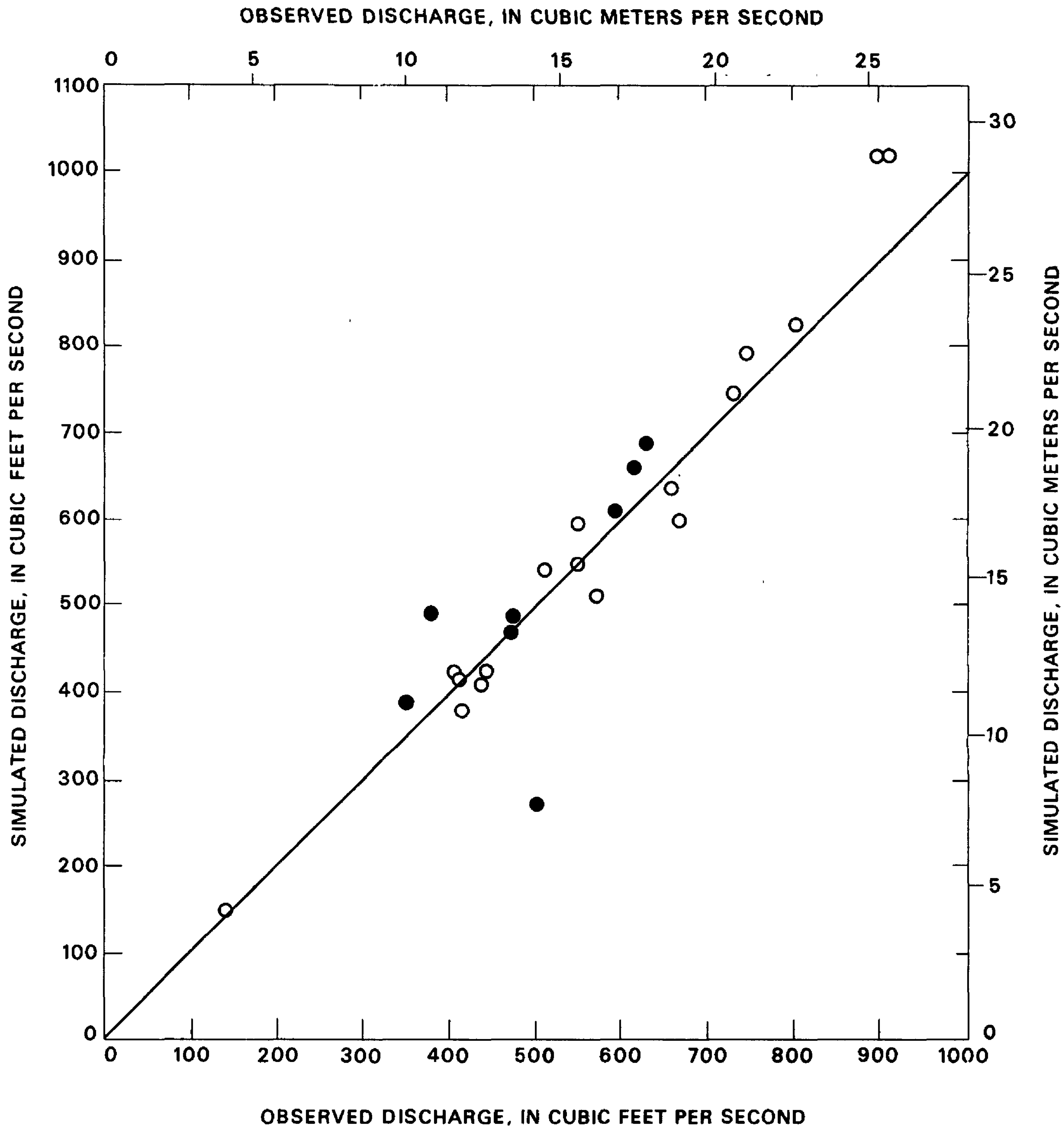


Figure 5. Comparison of simulated and observed 7-day summer low flow flows at Butternut for the period 1930-37.



EXPLANATION

● 1930-37, for comparison with figure 5.

○ 1938, 1940-50, 1953-58

Figure 6. Comparison of simulated and observed 7-day summer low flows at Winter for the period 1930-38, 1941-50, 1953-58.

Table 2.--Summary of modeling errors

Location	Period	7-day annual low flows	
		Mean of absolute value of error (percent)	Standard error of estimate (percent)
Butternut	1930-37 (8 years)	11.0	18.7
Winter	1930-37 (8 years)	13.5	25.0
Winter	1930-38, 1941-50, 1953-58 (25 years)	8.2	14.6

SIMULATED FLOWS AT PARK FALLS

Daily discharges at Park Falls were simulated for October 1, 1929, to September 30, 1961, after the model was calibrated. The frequency curves shown in figure 7 were computed from these simulated daily discharges. The curves were computed from the minimum mean discharges occurring between June 1 and October 31 of each year, for the specified number of days. The Department of Natural Resources does not consider low flows outside of this period to be as critical for water quality because the quality is affected by both water temperature and streamflow (Wis. Dept. Nat. Resources, 1974, p. 4). The $Q_{7,10}$ defined by these curves is 260 ft^3/s (7.4 m^3/s). The $Q_{7,2}$ is 500 ft^3/s (14 m^3/s). That is, the mean discharge for 7 consecutive days will be less than 500 ft^3/s (14 m^3/s) 1 year in 2 on the average and less than 260 ft^3/s (7.4 m^3/s) 1 year in 10.

It is not possible to evaluate directly the accuracy of the $Q_{7,10}$ estimate at Park Falls. The best estimate of accuracy is a comparison with the accuracy at Winter. For 25 years (1930-38, 1941-50, 1953-58) the standard error for the simulated $Q_{7,10}$ at Winter is 23 percent, which is equivalent to 12 years of record (Hardison, 1969). For the same 25 years the standard error for the observed $Q_{7,10}$ at Winter is 18 percent. At Winter the standard error for the simulated $Q_{7,10}$ is equal to the standard error for the $Q_{7,10}$ that could be obtained with half as many years of observed discharge data. If the same relationship applies at Park Falls, the standard error of estimate for the $Q_{7,10}$ should be approximately equivalent to 16 years of gaging-station record at that site.

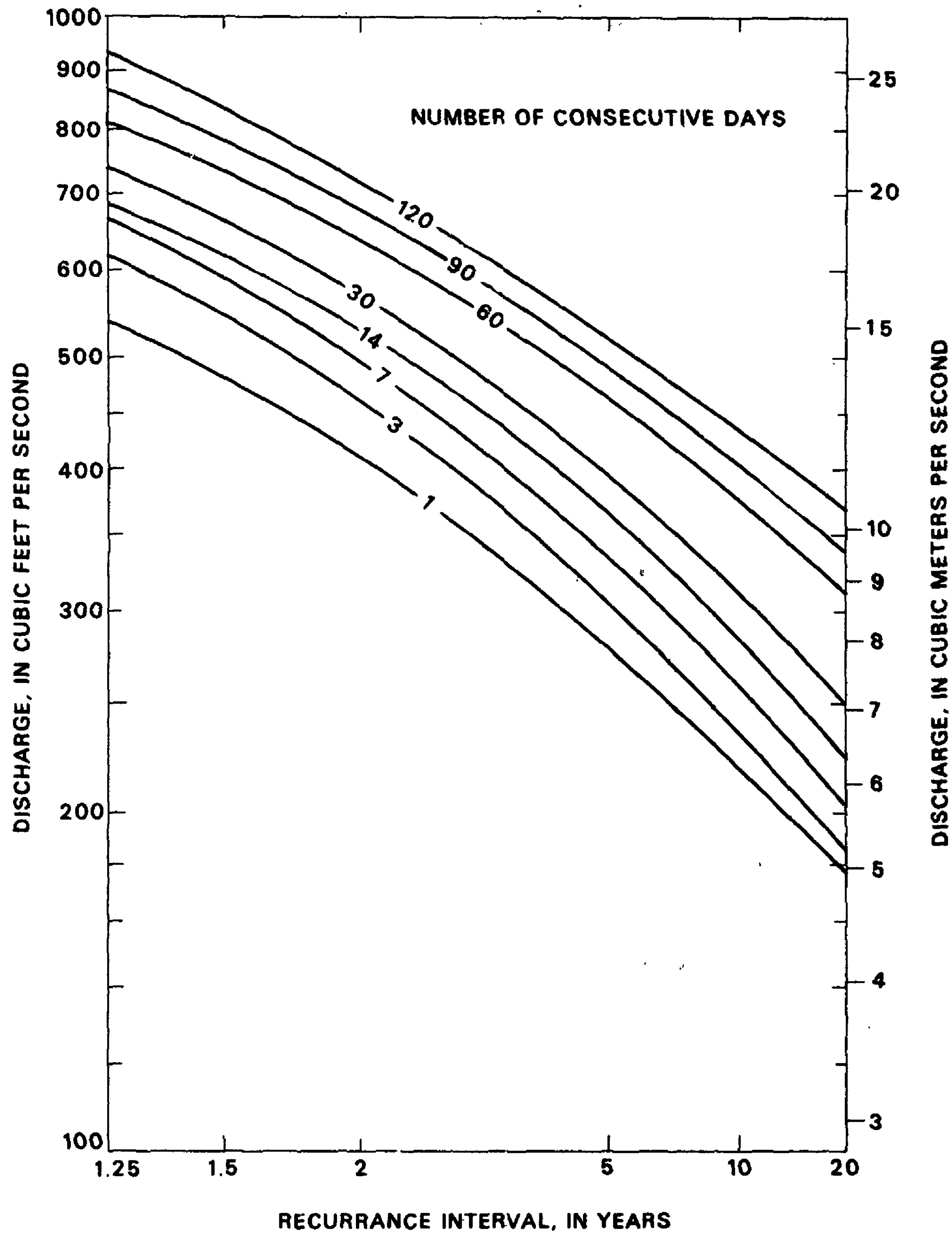


Figure 7. Frequency curves of minimum mean discharge from June 1 to October 31 for Flambeau River at Park Falls.

CONCLUSIONS

Thirty-one years of streamflow records were simulated for the Flambeau River at Park Falls. The 7-day, 10-year summer low flow computed from these simulated streamflow is 260 ft^3/s (7.3 m^3/s). The accuracy of this estimate is equivalent to what might be obtained from a 16-year period of gaging-station record.

The streamflow-routing model used in this study is adequate for simulation of streamflow at Park Falls for the purpose of determining low-flow frequency. Similar routing models are applicable to other sites, provided there are sufficient observed streamflow data at or near the site where long-term data are to be simulated, to calibrate and verify the model.

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