EVALUATION OF ALTERNATIVE RESERVOIR-MANAGEMENT PRACTICES IN THE ROCK RIVER BASIN, WISCONSIN

By

William R. Krug and Leo B. House

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FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

For the convenience of readers who may want to use the International System of Units (SI), the data may be converted by using the following factors:

Multiply	By	To obtain
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

Simulation of the operation of upstream impoundments in the Rock River basin to reduce spring floods showed that such operation would reduce flood peaks by 0.11 foot on the average, and would increase flood peaks some years. The most significant reductions would occur during the average-size floods, whereas little or no reductions would occur for larger and smaller floods. Modifying the simulation of impoundment operations to reduce larger floods produced only minor reductions in flood peaks for the larger floods, and slightly increased flood peaks for average-size floods.

Alternative operating procedures for Indianford Dam which controls Lake Koshkonong were simulated with estimated power generation and the use of flashboards during the summer, neither of which are currently used. The simulation showed that, for most periods without significant runoff, the stage of Lake Koshkonong would tend toward the stage at which power generation was prohibited. It also showed that use of flashboards to raise the minimum lake stage during the summer would not raise the peak stage of the lake measurably if the flashboards were removed when the stage rose above its normal level. Simulation showed that winter drawdown of Lake Koshkonong would not lower spring flood peaks significantly downstream.

INTRODUCTION

The Rock River basin is in south-central Wisconsin (fig. 1). The basin has low relief and many lakes and wetlands--both natural and artificially impounded. Most of the impoundments[1] are in the headwaters or on tributary streams. The major exception is Lake Koshkonong--a shallow 11,000 acre lake on the Rock River, which has a drainage area of 2,573 mi^2.

Low-lying areas along the Rock River, especially near Lake Koshkonong, experience periodic flooding. In addition, high water levels on Lake Koshkonong increase property damage from waves and ice. However, low water levels on Lake Koshkonong hinder recreation, reduce potential hydroelectric generation and may threaten the fish population. The most desirable level for Lake Koshkonong is a subject of considerable debate among the various users.

The terrain around Lake Koshkonong makes it an unconventional reservoir. Water levels are controlled by a low dam at Indianford. The dam is in a narrow valley 6 mi downstream from the lake. The channel between the lake and the dam is generally less than 500 ft wide and is similar to the channel downstream from the dam. As discharge in this channel increases, the stage of the lake is controlled less by the dam and more by the constriction of the channel.

[1] In this report the impoundments are referred to as reservoirs because the computer model used in the study simulates their use as flood-control reservoirs.

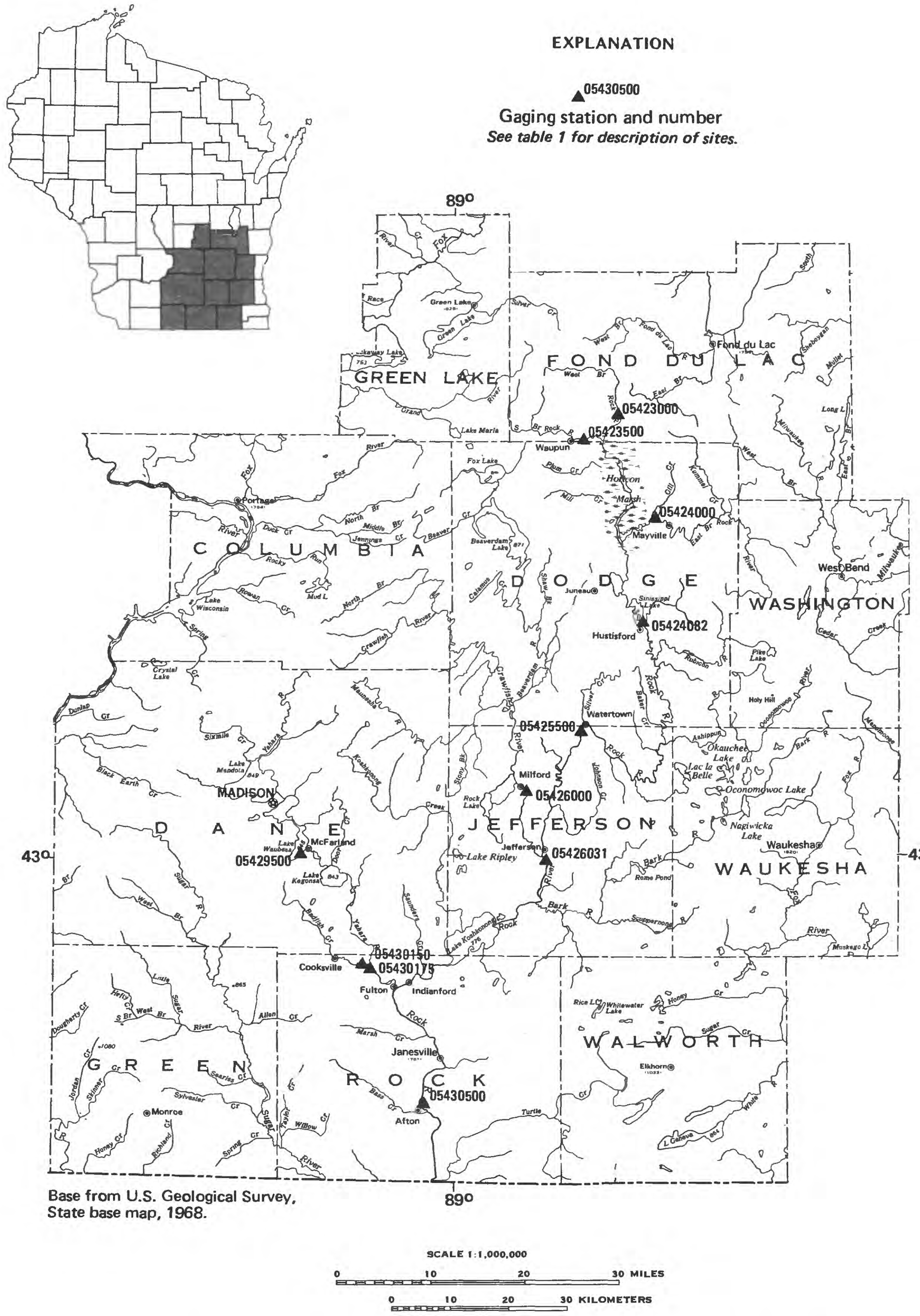

Figure 1. Location of the Rock River basin and gaging stations used in the model.

Purpose and Scope

This project was conducted in cooperation with the U.S. Army Corps of Engineers and with the Wisconsin Department of Natural Resources (DNR). DNR is responsible for establishing limits and rules for the operation of dams and reservoirs in the Rock River basin in Wisconsin. A variety of proposals have been made by various persons and groups regarding changes in the management of reservoirs in the basin to reduce spring floods, and in the water-level management of Lake Koshkonong for various purposes. The purpose of this study is to determine the impacts of proposed alternative reservoir-management practices on discharges and lake levels in the Rock River basin. Specifically, the study evaluates alternative management practices (1) at selected reservoirs upstream from the Indianford Dam, and (2) for operating Indianford Dam.

The effects of managing reservoirs to reduce spring flood peaks were determined by simulating 19 years (October 1950-September 1969) of discharge in the Rock River and stage at Lake Koshkonong. The period from February through May of each year was selected for detailed analysis to include all significant spring runoff. From June through January the reservoirs are maintained at constant or decreasing levels and are not available for flood storage. This study was intended to show the effects of straightforward, readily implemented management procedures rather than to obtain the optimum flood-peak reduction in all situations.

The effects of possible changes in managing water levels in Lake Koshkonong were determined by simulating 20 years (October 1959-September 1979) of stage at Lake Koshkonong and discharge at Indianford Dam. The simulation was repeated for 12 alternative procedures proposed by DNR. The period from May through November each year was selected for detailed analysis as requested by DNR. The differences in the proposed procedures would have the most effects on users of Lake Koshkonong during open-water periods.

Three computer models were used to simulate stage and discharge for the proposed changes in operating procedures. A channel-routing model simulated streamflow in the river channels in the study area. This model was used for both the spring flood reduction and the Lake Koshkonong management parts of the study. A simple storage-routing model was used to simulate operation of the reservoirs in accordance with the spring flood reduction procedures. This model was not used in the simulation of the 12 alternative operating procedures for Lake Koshkonong. A more complicated storage-routing model was used to simulate the alternative operating procedures for Lake Koshkonong. This model was also used to simulate the stage of Lake Koshkonong when spring flood reduction procedures were simulated on the reservoirs. The Lake Koshkonong model and part of the channel-routing model were used for an earlier study (Krug, 1979).

This report first describes the data base for all of the models and the channel-routing model because these are used in all of the simulations. The reservoir model is described in the section dealing with simulation of reservoir operations to reduce spring flood peaks. The Lake Koshkonong model is described in the section dealing with alternative procedures for managing Lake Koshkonong.

DESCRIPTION OF DATA BASE

The streamflow data used in this study were collected at gaging stations listed in table 1. The locations of the stations are shown in figure 1. Additional data were obtained from the Madison Metropolitan Sewerage District (MMSD). Effluent from their treatment plant (averaging 54.9 ft^3/s in 1979) is discharged to Badfish Creek, which flows into the Yahara River downstream from the McFarland gage. Before 1958, the effluent was discharged to the Yahara River upstream from the gage. The MMSD discharges were added to the record at the McFarland gage for 1958-79 to obtain a consistent record.

Records of observed stage of the principal reservoirs in the Rock River basin were obtained from DNR and the dam operators. The records available were for a limited period only. The following table lists the periods for which records were obtained:

Reservoir	Period of record
Beaver Dam Lake	1942-76
Horicon Marsh-North portion	1946-75
Horicon Marsh-South portion	1935, 1942-76
Lake Sinissippi	1952-71

These records were used only for the months of February through May because late winter and spring runoff is the only time these reservoirs could be used for flood reduction. During the summer and early fall, the reservoirs are maintained at constant elevations and flood waters are released downstream.

CHANNEL-ROUTING MODEL

Description

The channel-routing model is based on the unit-response concept and convolution technique described by Sauer (1973, p. 179-193); unit-response functions are computed by the diffusion-analogy method (Keefer, 1974, p. 1047-1058). A unit-response function, as determined by the diffusion-analogy method, depends upon (1) the length of the reach, and (2) the coefficients C_o (wave celerity) and K (wave-dispersion). C_o and K are determined for a selected representative discharge Q_o, and are functions of the channel width, water-surface slope, slope of stage-discharge relation, and Froude number all at discharge Q_o.

The channel characteristics used to determine C_o and K should represent the entire reach. In practice, they can be measured only at selected points. Also, C_o and K vary with discharge, but

Table 1. Gaging stations in the Rock River basin, Wisconsin

Station number and name		Drainage area (mi^2)	Water years of record[1]
05423000	West Branch Rock River near Waupun, Wis.---------------------	40.7	1949-70,78,79
05423500	South Branch Rock River at Waupun, Wis.---------------------	63.6	1949-69
05424000	East Branch Rock River near Mayville, Wis.-------------------	181	1950-70
05424082	Rock River at Hustisford, Wis.-----	511	1978-79
05425500	Rock River at Watertown, Wis.------	969	1931-70, 77-79
05426000	Crawfish River at Milford, Wis.----	762	1931-79
05426031	Rock River at Jefferson, Wis.------	1,850	1978-79
05427570	Rock River at Indianford, Wis.-----	2,573	1975-79
05429500	Yahara River near McFarland, Wis.--	327	1930-79
05430150	Badfish Creek near Cooksville, Wis.	82.6	1977-79
05430175	Yahara River near Fulton, Wis.-----	517	1977-79
05430500	Rock River at Afton, Wis.----------	3,338	1914-79

[1]In most records, the first year is a partial year.

they are evaluated only at one representative discharge. Thus, the computed C_o and K values are estimates and must be tested on a reach where simulated discharges can be compared with observed discharges. Generally, the estimated C_o and K values are adjusted during model calibration to obtain the best possible agreement between simulated and recorded discharges.

The unit-response function defines the discharge at the downstream end of a modeling reach as a function of the discharge at the upstream end. Although the unit-response function is continuous, daily unit-response coefficients for daily routing are computed by averaging the ordinates of the function at intervals of 0.1 day for each day. For a daily discharge at the upstream end, the unit-response coefficients specify the percentage of that discharge that arrives at the downstream end on the same day and on each successive day. Daily discharge at the downstream end for a given day is the summation of the contribution of discharge at the upstream end from that day and each preceding day.

The channel-routing model also is used to compute in the upstream direction. This is called reverse routing. Because this computation scheme is not always stable when used in this direction, the results must be checked more carefully than if used in the downstream direction. If the model is stable, it will accurately estimate streamflow at the upstream end of the reach from the streamflow at the downstream end of the reach. The model generally will be stable if the first daily unit-response coefficient is larger than any other coefficient, and if the streamflow does not have large day to day changes in discharge.

The channel-routing model used for this study consists of 10 routing reaches. The relationships between the routing reaches, reservoir model, the Lake Koskonong model, and gaging stations is shown schematically in figure 2. The 10 channel routing reaches are:

Reach number	Channel represented
1	Rock River from Watertown to confluence with Crawfish River at Jefferson.
2	Crawfish River from Milford to mouth at Jefferson.
3	Rock River from Jefferson to Lake Koshkonong.
4	Yahara River from McFarland to mouth.
5	Rock River from Indianford to Afton.
6	Rock Creek and Crawfish River from Rock Lake to Milford.
7	Beaver Dam River and Crawfish River from Beaver Dam Lake to Milford.
8	Rock River from Horicon Marsh to Lake Sinissippi.
9	Rock River from Lake Sinissippi at Hustiford to Watertown.
10	Oconomowoc River and Rock River from Lac La Belle to Watertown.

Reaches 1-5 were used in the previous study. Reaches 6-10 are new for this study.

Since the previous study by Krug (1979), streamflow data have been collected at several sites in the basin where they were not previously available. This provided an opportunity to verify and recalibrate the channel-routing model used in this study.

Reaches 1 and 2 (fig. 2) were verified by comparing the sum of routed flows from Watertown and Milford with the observed flow at Jefferson. No change in the routing coefficients from the previous study was needed.

Reach 4 was verified by routing flows from McFarland to Fulton (near the mouth of the Yahara River), and adding flows from Cooksville, and comparing the result with the observed flows at Fulton. The celerity and dispersion coefficients on this reach were adjusted to improve the agreement in timing between the routed and observed flows.

Reach 9 was calibrated by routing observed flows from Hustisford to Watertown and comparing with the observed flows at Watertown. The celerity and dispersion coefficients were adjusted slightly from the initial estimates to obtain the best agreement between routed and observed flows.

Reaches 6, 7, 8, and 10 could not be calibrated because there were no records of discharge to use for routing. The celerity and dispersion coefficients computed from physical measurements were used for these reaches.

The wave celerity, dispersion, and unit-response coefficients and lengths for each reach are listed in table 2. As one example of the use of the unit response coefficients, reach 3--Rock River from Jefferson to Lake Koshkonong--has three daily coefficients, 0.62, 0.34, and 0.04. This means, for

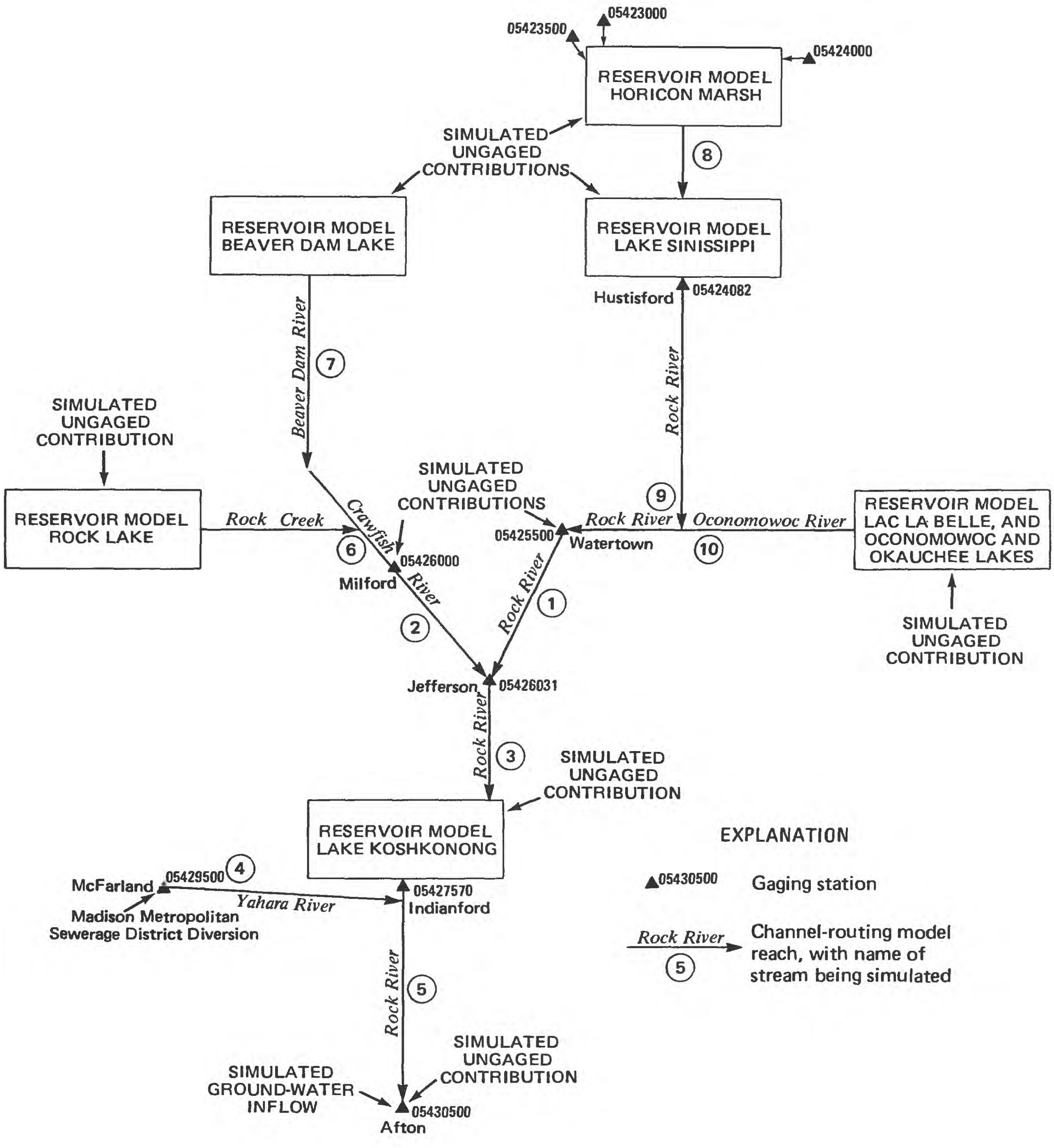

Figure 2. Schematic diagram showing relation of channel routing model, reservoir model and Lake Koshkonong model.

instance, that an increase in the mean daily discharge at Jefferson of 100 ft^3/s would cause an increase in the mean daily discharge into Lake Koshkonong of 62 ft^3/s on the same day, 34 ft^3/s on the following (second) day, and 4 ft^3/s on the third day.

The channel-routing model accounts for water moving from an upstream site to a downstream site, but it does not account for water entering the channel between the sites. This ungaged inflow must be simulated separately. Normally, it is simulated by a drainage-area ratio multiplied by the flow at one or more of the gages in the basin or at a nearby gage. This was applicable only for those reaches upstream from Watertown and Milford in this study.

Simply multiplying a drainage-area ratio times the flow at any of the gaging stations would not adequately simulate the ungaged inflow into the Rock River downstream from Watertown and Milford. A more complex simulation was required. The first part of the ungaged inflow into Lake Koshkonong was simulated by 0.69 multiplied by the flow of the Crawfish River at Milford. The rest of the ungaged inflow was simulated by a "difference record" computed by subtracting routed flows from upstream stations from observed flows at the downstream station.

To compute the "difference record" the observed flows from Milford and Watertown were routed to Jefferson and added together. The sum was routed to Lake Koshkonong and added to 0.69 multiplied by the flows at Milford. This sum was routed through the Lake Koshkonong model from the previous study. The computed outflow from the lake model was added to the Yahara River flows routed from McFarland and routed to Afton. At Afton, 100 ft^3/s was added to the routed flow to simulate the steady ground-water inflow to the reach between Indianford and Afton. This result was then subtracted from the observed flows at Afton to produce the difference record.

The difference record was used to simulate ungaged inflow both upstream and downstream from Lake Koshkonong. The simulated ungaged inflow downstream from the lake was 0.41 times the difference record. The simulated ungaged inflow upstream from the lake was 0.59 times the differ-

Table 2. Unit-response coefficients for channel-routing reaches in the Rock River Basin, Wisconsin

Reach number	Wave celerity C_o	Dispersion coefficient K^o	Reach length (mi)	Unit-response coefficients (days) 1	2	3	4	5	6	7	8
1	1.2	7,000	19.65	0.13	0.74	0.13	---	---	---	---	---
2	2.2	8,100	9.67	.73	.27	---	---	---	---	---	---
3	2.7	152,000	19.03	.62	.34	.04	---	---	---	---	---
4	1.15	3,440	26.52	0	.58	.42	---	---	---	---	---
5	2.6	8,000	19.49	.54	.46	---	---	---	---	---	---
6	Not computed.	-------	5.69	[1] 1.00	---	---	---	---	---	---	---
7	2.08	14,900	40.04	.04	.75	.21	---	---	---	---	---
8	.03	9,390	10.0	.15	.40	.20	.10	.06	.04	.03	.02
9	7.32	124,000	45.4	.62	.38	---	---	---	---	---	---
10	3.50	8,160	23.8	.58	.42	---	---	---	---	---	---

[1]Coefficient of 1.00 is assumed because reach length is small and data are not available. Flow in this reach is small. Therefore, possible errors are negligible compared to total flow of Rock River.

ence record. This was "reverse routed" to account for the travel time from the lake to Afton. The ratios used for ungaged inflow simulation were determined by calibrating the model with the observed flows at Indianford. Various combinations of ratios were tried to determine the set which best simulated the total volume and peak flows at Indianford. The steady inflow of 100 ft^3 was determined by calibration after initial estimates were made from transmissivity and water-table slope.

Accuracy

The accuracy of the entire model is best illustrated by comparing observed and simulated hydrographs for the Rock River at Indianford, Wis. (05427570) (figs. 3 and 4). The simulation includes use of the storage-routing model for Lake Koshkonong which is explained in a later section of this report. Figure 3 shows hydrographs for three periods of high flow in 1978, the first is the spring runoff, and the next two from heavy rainfall. These are average high flows for this site. Other stations in the Rock River basin had peak discharges close to the mean annual flood in 1978. Figure 4 shows hydrographs from the spring of 1979, when the largest flood in 20 years occurred in the basin.

An additional measure of the accuracy of the model in simulating flood peaks is shown in figure 5. This figure compares the maximum simulated and observed daily discharges at Indianford for eight separate periods of high flow between 1976 and 1979.

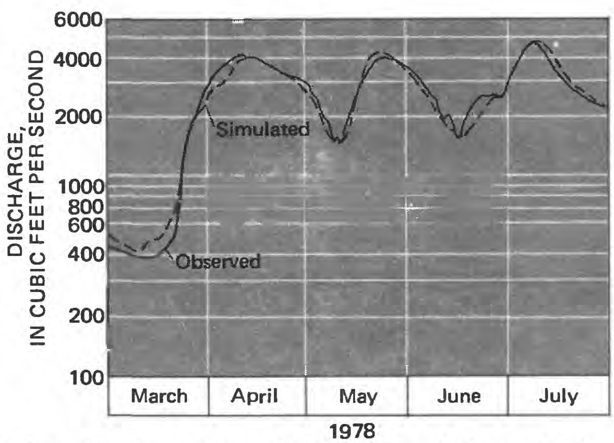

Figure 3. Comparison of simulated and observed daily discharge for the Rock River at Indianford, Wisconsin, for a year of near-average peak discharge.

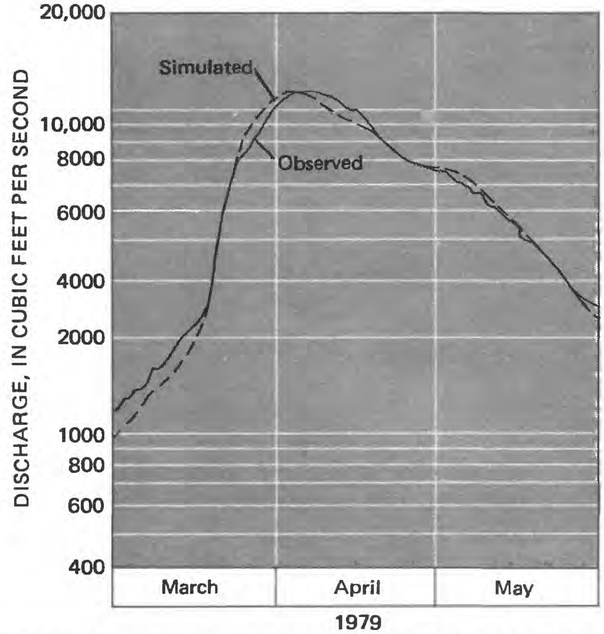

Figure 4. Comparison of simulated and observed daily discharge for the Rock River at Indianford, Wisconsin, for a year of high peak discharge.

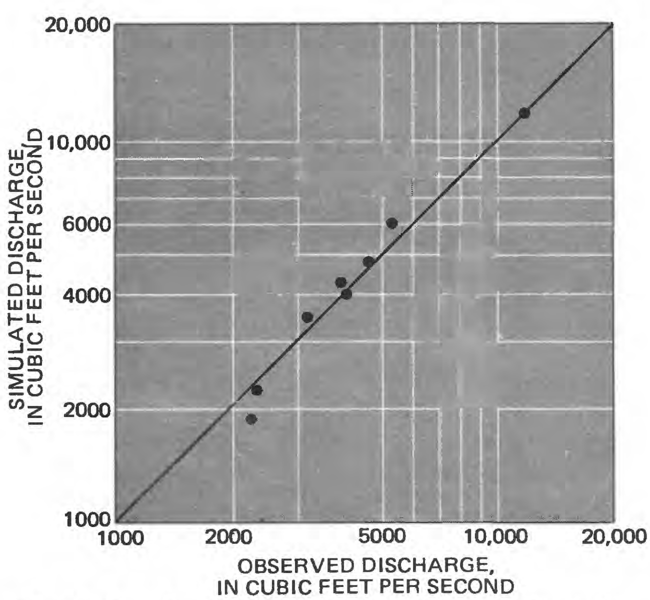

Figure 5. Comparison of simulated and observed maximum daily flows for the Rock River at Indianford, Wisconsin.

SIMULATION OF ALTERNATIVE PROCEDURES FOR OPERATING RESERVOIRS UPSTREAM FROM INDIANFORD DAM

Description of Upstream Reservoirs

Persons and agencies affected by flooding on the Rock River have proposed using upstream reservoirs to store spring floodwaters to reduce downstream flooding. Although the reservoirs were not constructed as storage reservoirs, it may be possible to lower the water levels 1 ft in winter to allow for some storage of spring floodwaters. Other uses of the reservoirs probably preclude greater drawdown. After the spring runoff, other uses of the reservoirs would preclude their use for flood attenuation. The reservoirs to be considered are listed in table 3. Their locations are shown in figure 1. Lake Koshkonong is not included in the table because it was not simulated as a flood-control reservoir. The Indianford Dam, which controls Lake Koshkonong, does not have sufficient discharge capacity to be operated for flood control.

Proposed Operation Procedures

To obtain maximum flood attenuation from the available storage, the reservoirs should be filling at the time of the flood peak at the reservoir. It is not always possible to predict when the peak will occur during a flood. For this reason, a simple method was devised that could readily be applied by part-time dam operators and would allow filling of the reservoir near the time of the flood peak. No attempt was made to achieve maximum flood attenuation for individual years because actual operation according to such a plan would require predictions of runoff volume for each year which are not now available.

To implement this procedure, the operator is given an outflow discharge for each reservoir that signals the time to start filling the reservoir. This discharge is called the index discharge. The initial estimate of an appropriate index discharge was the mean annual, 30-day average high flow at each reservoir. Based on examination of flood hydrographs, it was found that this discharge would occur a few days before the flood peak in most years.

The basic outline of the proposed reservoir-operation procedure, beginning in early spring when the reservoirs are at their winter drawdown level, is as follows:

1. As long as discharge is less than the index discharge, maintain the stage at the winter drawdown level.

2. When discharge becomes equal to the index discharge, begin filling the reservoir by limiting outflow to the index discharge.

3. When the reservoir reaches its maximum regulatory stage, operate the dam to prevent the stage from rising more by releasing a greater discharge.

4. When discharge drops to the index discharge after a flood peak has passed, one of the following alternative actions is taken:

    a. If it is still early in spring and more flooding is expected, allow stage to fall while continuing to release the index discharge.

    b. If no flooding is expected, or if it is too late in the season to permit drawdown, allow the discharge to decrease while maintaining the stage constant at its maximum regulatory level.

Steps 1, 3, and 4b above require operation of the dam to release whatever discharge is necessary to keep the reservoir stage constant. Steps 2 and 4a require operation of the dam to release the index discharge, filling the reservoir in 2 or drawing down the reservoir in 4a.

In practical terms, this would mean that as reservoir inflow starts to increase, dam operators would gradually open gates to keep the reservoir stage constant at the minimum regulatory level by increasing the outflow. When the outflow is equal to the index discharge (which could be determined by the stage downstream from the dam or computed from upstream stage and gate openings) the gates would be adjusted to maintain a steady outflow, and the reservoir would begin to fill. While the reservoir is filling from minimum to maximum stage, little gate manipulation would be required to maintain a steady discharge, because the difference between minimum and maximum stages is only 1 ft. After the reservoir is filled, the gates would be opened gradually as required to keep the stage constant at the maximum regulatory level. After the discharge has peaked the gates could be gradually closed.

The effects of using the reservoirs for flood control was modeled with a digital model. The model used observed streamflow and stage data to simulate the effects of operating the reservoirs according to proposed schemes. Preliminary estimates of possible flood attenuation by the reservoirs indicated some potential for reducing average-size floods, but insufficient storage volume to have a significant impact on the largest floods. Therefore, the initial trial of the reservoir model was based on attempts to control average-size floods.

Adjustment of Measured Streamflow for Past Effects of Reservoirs

A preliminary step to simulating inflow to the reservoirs was adjusting measured streamflow for historical storage and release of water in the larger reservoirs. The "natural" streamflow determined by this adjustment is the basis of simulated inflow to the reservoirs. Stage records were obtained for Beaver Dam Lake, Lake Sinissippi, and both sections of Horicon Marsh, for February through May of each year, 1950-69. These four areas contain over 80 percent of the potential flood storage. The daily change in stage was computed for each reservoir (averaged over several days when daily stage readings were not available). The daily change in stage was multiplied by the surface area to determine the volume of water stored or released. The daily storage (positive) or release (negative) was routed downstream to the nearest gaging station and added algebraically to the observed flows at that station.

The result of adjusting observed streamflow for changes in storage is termed "natural" streamflow. However, this is not an exact description. The adjusting process removed all effects of storage at the four sites, including marsh and channel storage which would have occurred even without dams at the outlets. The computed "natural" streamflow is the streamflow for a basin without large lakes or wetlands. As such, it is a good basis for simulating streamflow into the reservoirs because the tributaries do not have such large lakes or wetlands.

Table 3. Reservoirs in the Rock River basin upstream of Lake Koshkonong considered to have potential for storing spring floodwaters

Name	Surface area (acres)	Drainage area (mi^2)
Horicon Marsh (upstream from Federal Dike)	20,000	220
Horicon Marsh (downstream from Federal Dike)	10,480	456
Lake Sinnissippi	2,855	511
Okauchee Lake	1,187	80.3
Oconomowoc Lake	767	85.6
Lac La Belle	1,117	100
Fox Lake	2,625	58.1
Beaver Dam Lake	6,600	156
Rock Lake	1,371	14.8
Nagawicka Lake	920	44.9
Rome Pond	446	122
Lake Ripley	433	7.71

Simulation of Inflow to Reservoirs

Simulated inflow to the reservoirs was derived from the computed "natural" flow at gaging stations. The "natural" flow for the Crawfish River at Milford was divided into three parts in proportion to the drainage areas of three parts of the basin. The three parts were: inflow to Rock Lake, inflow to Beaver Dam Lake, and inflow downstream from these two lakes. The inflows to the two reservoirs were computed by reverse routing upstream from Milford to the locations of the reservoirs. This was necessary to preserve the proper timing of flow when the simulated, reservoir-regulated outflow was routed down to Milford.

The same general procedure was used for the reservoirs upstream from Watertown with the natural flow for the Rock River at Watertown, except that observed flows from three sites upstream from Horicon Marsh also were considered. Flows from these three gaging stations were routed to Watertown in the channel-routing model, then subtracted from the natural flows at Watertown. The difference was divided into four parts in proportion to the drainage areas of four parts of the basin:

1. Downstream from the tributary gages and upstream from the dam controlling Horicon Marsh,

2. Downstream from the Horicon Dam and upstream from the Lake Sinissippi Dam,

3. Upstream from Lac La Belle,

4. Upstream from Watertown and downstream from Lake Sinissippi and Lac La Belle.

Parts 1, 2, and 3 were reverse routed to their respective locations. The reverse-routed flows for Horicon Marsh were added to the routed flows from the three tributary gages to compute the total inflow for Horicon Marsh.

Simulation of Regulated Flow

The operation of most of the potential reservoirs was simulated in a single computer program which also included the channel-routing model to route the simulated outflow to Milford and Watertown. Lake Koshkonong was simulated in a separate program and several small potential reservoirs were not included in the simulation. The reservoirs included in this simulation are:

Horicon Marsh (both parts)
Lac LaBelle
Okauchee Lake
Rock Lake
Lake Sinissippi
Oconomowoc Lake
Beaver Dam Lake

These reservoirs include 91 percent of the potentially available storage in the Rock River basin upstream of Lake Koshkonong. Because of their relatively small size and location (one upstream of the other), the three lakes on the Oconomowoc River (LaBelle, Oconomowoc, and Okauchee) were treated as a single reservoir. This simplification does not introduce a significant error because the same volume of storage is used at the same time whether the lakes are simulated as one reservoir or three. The two parts of Horicon Marsh were treated as one reservoir because of their close proximity and because flow has been observed from the downstream part into the upstream part during some floods when stage in the downstream reservoir rose higher than stage in the upstream one.

Several smaller lakes were not included, although they might have some storage potential. Fox Lake was not included because the dam controlling Fox Lake can not be manipulated readily to exercise control over floods. Lake Ripley, Nagawicka Lake, and Rome Pond were not included because they have less than 4 percent of the potential storage and no reasonable approximation was available for inflow to these lakes.

The method of reservoir operations outlined previously was simulated as follows. Starting with the winter drawdown condition (arbitrarily assigned a value of zero storage), simulated outflow was equal to inflow each day as long as inflow was less than the index discharge. Storage remained at zero. Whenever inflow exceeded the index discharge, the simulated outflow was equal to the index discharge and the excess of inflow over outflow was added to storage. When storage reached the maximum value, simulated outflow was equal to inflow and storage remained constant again. When inflow was again less than the index discharge, the simulated outflow was equal to the index discharge and the excess outflow subtracted from storage. When storage was again equal to zero, simulated outflow was equal to inflow.

For simplicity in the modeling, no attempt was made to decide when the reservoirs should remain full at their normal summer stage. Reservoirs were always drawn down by the model after the flood peak had passed. Simulated discharge after May of each year was disregarded because flood storage in the reservoirs would not be allowed during summer. The model properly simulates spring operation of the reservoirs, and that is the only time of year this part of the project was intended to analyze.

After outflow for each day was computed for each reservoir, it was routed downstream to the next reservoir, or to the sites of the Watertown or Milford gages. Contributions for all reservoirs and the simulated inflow downstream from the reservoirs (previously computed from "natural" streamflow at Watertown and Milford) were added to simulate total flow for the Rock River at Watertown and Crawfish River at Milford.

The reservoir model was run twice. First, the index discharge was set to approximate the mean annual 30-day mean high flow. This was intended to emphasize controlling the average flood. For the second run, all of the index discharges were raised by 50 percent. This was intended to emphasize controlling somewhat larger floods. Both runs were made for 19 water years (October 1950-September 1969).

The results of the two simulation runs were two sets of simulated flows at Milford and Watertown. Both of these sets of simulated flows were routed to Lake Koshkonong using the channel-routing model. The historical flows at Milford and Watertown were also routed to Lake Koshkonong for comparison with the two sets of simulated flows.

A modification of the Lake Koshkonong model developed for the previous study (Krug, 1979) was used to simulate stage and discharge for Lake Koshkonong for the three sets of inflow. The modifications consisted of explicitly simulating the openings and closings of certain numbers of gates to approximate the rules under which the dam is now operated. Details of the Lake Koshkonong model are explained in subsequent sections of this report, dealing with simulation of proposed changes in the operating procedures.

The channel-routing model was used to route the simulated outflow from Lake Koshkonong downstream to the next gaging station at Afton. Ungaged inflow as simulated by the "difference" file, was added to the flow. The use of the difference file for ungaged inflow made the simulated historical flows at Afton in almost perfect agreement with the gaged flows. The only errors in the simulated flows were minor day to day variations caused by actual operations at Indianford Dam which differed from the rules simulated by the model.

Results of Simulation

The results of the simulation will be illustrated primarily by comparisons of stage at Lake Koshkonong. This is the only location where the model simulates stage as well as discharge. It is also an appropriate location because the Lake Koshkonong area has some of the most frequent flood problems in the area. At high discharges, stage changes in Lake Koshkonong also are fairly representative of stage changes elsewhere along the Rock River, because all of the gates at the Indianford Dam would be open throughout any significant flood and the stage of Lake Koshkonong is determined by the fixed relation of stage and discharge for the dam and channel.

Simulations of stage of Lake Koshkonong for a year of near-average peak stage and a year of high peak stage are shown in figures 6 and 7. Both figures show results of simulations with inflow at Watertown and Milford determined in three ways: (1) historical records, (2) the reservoir simulation model using index discharges equal to the mean

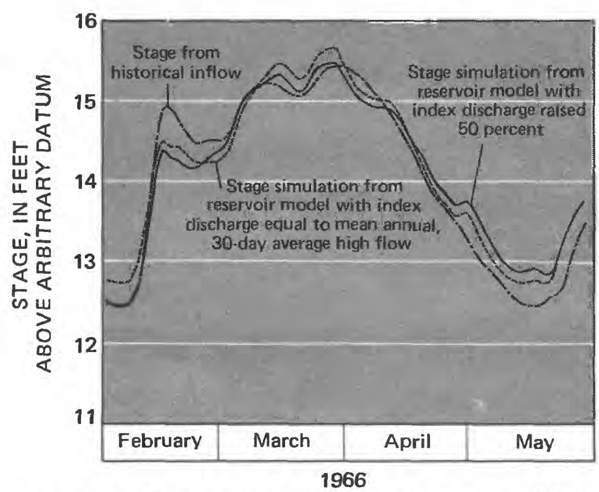

Figure 6. Comparison of simulated stage of Lake Koshkonong for historical inflow with simulated stage for inflow from reservoir model, for a year of near-average peak stage.

annual 30-day high flow, and (3) the reservoir simulation model with index discharges increased by 50 percent.

Simulated Lake Koshkonong stage during February-May 1966 is shown in figure 6. Peak stage for this year was slightly above the median for the period simulated. The peak stage simulated with flows from the reservoir model was higher than the simulated historical peak stage. The apparent reason is the early rise in February which filled the reservoirs, leaving no storage--or very little--for the main part of the runoff in March.

Simulated Lake Koshkonong stage during the spring of 1952 is shown in figure 7. This was the second highest stage during the period simulated. In this case, simulating reservoir regulation produced very little reduction in stage. It appears that this flood filled the reservoirs before the peak.

The effects of using the reservoirs for flood reduction are generally small and variable (figs. 8 and 9). The difference in simulated spring peak stage at Lake Koshkonong between historical conditions and operating the reservoirs with an index discharge of the mean annual 30-day average high flow ranged from an increase of 0.2 ft to a decrease

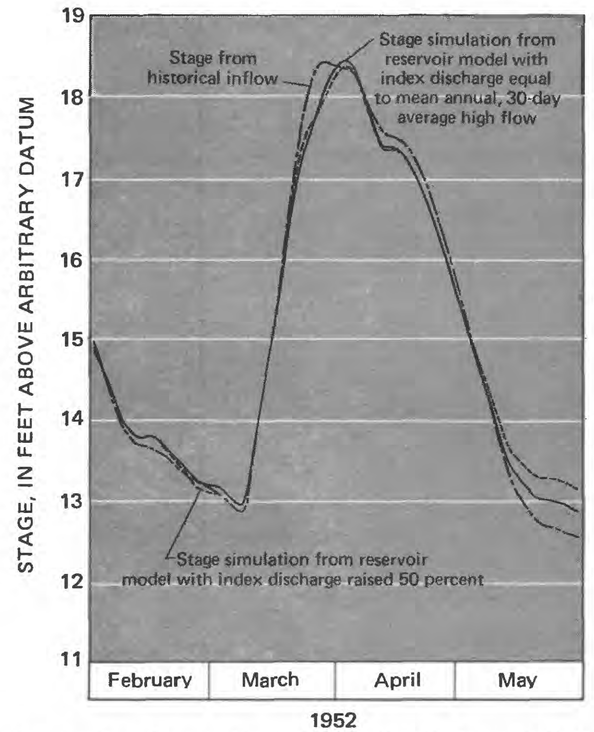

Figure 7. Comparison of simulated stage of Lake Koshkonong for historical inflow with simulated stage for inflow from reservoir model, for a year with high peak stage.

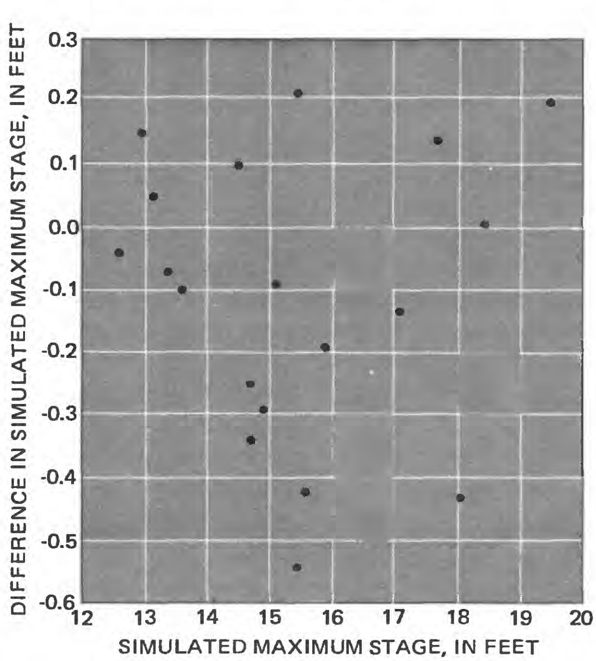

Figure 8. Difference between maximum simulated spring stage of Lake Koshkonong from historical data and from reservoir model,plotted as a function of maximum simulated spring peak stage from historical data.

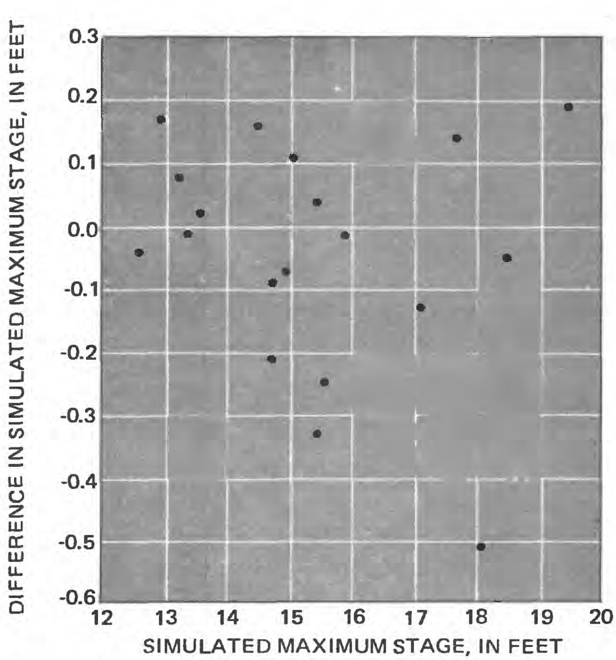

Figure 9. Differences between maximum simulated spring stages of Lake Koshkonong from historical data and reservoir model (with index discharge increased by 50 percent) plotted as a function of maximum simulated spring peak stage from historical data.

of 0.54 ft. The mean peak stage reduction was 0.11 ft. This reduction was statistically significant at the 90 percent level.

Evaluation of figure 8 indicates that there was more reduction in stage around the average peak stage than at the higher and lower values. To test this hypothesis the simulated stage changes for the 10 peak stages nearest the average peak stage between 14.5 and 17.5 ft, were considered separately. For these 10 values the mean peak stage reduction was 0.19 ft, and the reduction was statistically significant at the 95 percent level. That is, the reduction of the stages near the average is more significant than the reduction of all the stages. For the nine values outside this range, the mean reduction was 0.01 ft, and this reduction was not statistically significant at any meaningful level.

The same data, except that reservoir model with index discharge increased by 50 percent was used is shown in figure 9. In this case, the mean reduction in stage was 0.04 ft. For the 10 values between 14.5 and 17.5 ft stage, the mean reduction was 0.08 ft. For the other nine values, the mean reduction was less than 0.01 ft. None of these reductions was statistically significant at the 90 percent level.

Figures 8 and 9 seem to suggest that increasing the index discharge increases the simulated peak stage for the average years, and only slightly decreases the peak stage for the years of highest stage.

The simulated streamflow for the Rock River at Afton for the three conditions was compared. The differences among the spring peak discharges for the three simulations were small. To average out the variability in the differences, flood frequency was computed using the log-Pearson type III method (Water Resources Council, 1981).

The flood frequency at Afton for the flows simulated with the reservoir model, with the lower index discharge differed from the flood frequency for the flows simulated from historical records by less than 1 percent at all frequencies. Smaller flood peaks (those occurring once every 2 years or more frequently) were slightly reduced by the simulated reservoirs. Larger flood peaks were slightly increased.

Comparison of the flood frequency for the two versions of the reservoir simulation shows that increasing index discharge would increase peak discharge for the smaller floods by 1 to 3 percent. Changes on all larger peak discharges would be less than 1 percent.

At the gaging station at Afton, the differences in the simulated flood discharges at all frequencies would mean less than 0.1 ft difference in stage. This was determined from the stage-discharge relation for the gaging station.

SIMULATION OF ALTERNATIVE PROCEDURES FOR OPERATING INDIANFORD DAM

Proposed Operating Procedures

The Department of Natural Resources (DNR) is reviewing its procedures for the operation of Indianford Dam because the dam is being refitted for power generation by installing new generators and turbines. The different interests of the various users of the dam and Lake Koshkonong require that the impacts of any proposed changes be determined carefully. For this reason, a storage-routing and dam-operation computer model (the Lake Koshkonong model) was used to simulate the operation of Indianford Dam under 12 proposed alternative operating procedures. DNR formulated the proposed operating procedures progressively during the present study to try different options and to refine the rules to balance the demands of various interests for higher or lower water levels.

The storage-routing and dam-operation model for Lake Koshkonong and Indianford Dam was developed for the earlier study of Krug (1979). It was extensively modified to add the abilities to simulate precise gate openings, effects of the flashboards on the dam crest, and to simulate operation of turbines at the dam. Inflow for this model was simulated with the channel-routing model explained in preceding sections to route historical streamflow from Watertown and Milford to Lake Koshkonong. This model does not use the results of the reservoir simulation from the preceding section.

The Indianford Dam consists of an uncontrolled spillway and six vertical lift gates. The spillway crest has a mean elevation of 11.48 ft. The lift gates are normally either fully closed or fully open. The minimum and maximum desirable stages for Lake Koshkonong are 11.9 and 12.5 ft, respectively, according to DNR. (Lower stages limit recreation and higher stages begin to damage property.) Within this range the available storage in the lake is very small compared to typical flood flows. The dam has very limited discharge capacity. At a lake stage of 12.5 ft, it will pass only about 1,660 ft^3. It is impossible to prevent the stage from rising above 12.5 ft during any significant runoff. Lake stage rises 7 ft or more above the maximum stage in large floods. This provides a significant amount of storage, but entails flooding property adjacent to the lake.

Each of the procedures proposed by DNR for operating the Indianford Dam included specified levels of stage and discharge at which generation would be restricted or gates would be open. If the sum of discharge measured upstream at Milford and Watertown was less than 400 ft^3/s generation was limited to one-half of the total generation capacity. If the stage was below a specified minimum, generation was forbidden. A specified number of gates was open whenever the stage exceeded specified levels for each rule. If the discharge at the upstream sites exceeded specified levels, more gates were opened than were required by the procedures relating to stage.

Some of the procedures required the stage to be measured at the dam; the rest required stage to be measured at the lake. Eight of the procedures allowed flashboards to be installed on the dam crest in summer. In six of these procedures, the boards were required to be removed (or to break away) when stage exceeded a certain level. Two procedures required a winter drawdown of the lake.

For all procedures allowing flashboards, their use was allowed only from June 1 to November 30. In all cases, they were not installed after June 1 until stage was less than 11.90 ft at the dam. In the case of breakaway flashboards, they would be reinstalled when stage was again below 11.90 ft.

Winter drawdown was accomplished by gradually reducing the stages controlling gate openings and generation between December 1 and December 15. From December 15 until April 1, the gates and generators are operated to keep the stage around 10.00 ft. From April 2 to April 15, the stages for controlling gate openings and limiting generation are raised gradually to their summer values.

The specific procedures considered are listed in table 4. The procedures were formulated to test the effects of different changes in operation. Generally, each procedure differed in only one or two details from some other procedure. A summary of the significant changes between selected procedures is listed in table 5.

Simulation of Proposed Procedures

The Lake Koshkonong model used to simulate operation according to the proposed procedures simulates daily flows and stages, using the average daily inflow and outflow to calculate changes in storage. Changes in gate openings and generation are assumed to be at mid-day, so the mean outflow is calculated as the average of flow at the beginning and end of the day.

There are no turbines in the Indianford powerhouse at present (1983). Power generation was simulated by assuming that new turbines and generators will be similar to the ones removed in 1963. An equation relating the discharge through the turbines to the difference in water surface elevation between the upstream and downstream side of the dam was furnished by DNR (written commun., 1981).

The model adds each day's inflow to the storage in the lake and subtracts an estimate for the outflow, then computes the outflow using the gate openings and generation determined for the previous day. The estimated outflow is revised and outflow recomputed repeatedly until the difference is negligible. The day-end stage is computed from the storage. If the computed stage indicates that a change is required in either generation or gate openings, the outflow and resulting stage is recomputed using the new conditions. The process is repeated until the computed gate openings, generation, and stage agree with the rule being simulated.

When the stage rules for opening and closing gates were followed rigorously, the model simulated some situations where a decision on gate openings was impossible. Simulation with gates open would produce a stage requiring gates to be closed and simulation with gates closed would produce a stage requiring gates to be open. In other situations, the model would simulate opening and closing gates on alternate days for extended periods of time. To relieve both of these problems, the stage was allowed to vary 0.05 ft past the stages requiring gates to be opened or closed before any changes were made in the gate openings.

The model computed the difference in stage between the lake and the dam as a function of the discharge at the dam. This relationship was determined by calculating water surface profiles between the dam and the lake for various discharges from the physical properties of the channel, using a step-backwater procedure.

Results of Simulation

Twenty water years (October 1959-September 1979) of stage and discharge were simulated for Lake Koshkonong for each of the proposed rules. The number of gate and flashboard changes simulated for each of the proposed procedures is summarized in table 6. For each rule, a duration curve was computed from the simulated daily stage values for May through November of each year. These curves are summarized in table 7, which shows the stages which would be exceeded from May 1 to November 30 for certain percentages of time for each rule.

For example, under procedure 6 the simulated stage of Lake Koshkonong was greater than 12.58 ft for 30 percent of the time, or about 73 days per year, during the May through November period. For the same procedure and period, the simulated stage was greater than 11.68 ft for 70 percent of the time (about 171 days per year). It follows that simulated stage was between 11.68 ft and 12.58 ft for 40 percent of the time (about 98 days per year). The number of days when simulated stage was greater than a certain value in any one year could be significantly different from the average given by the table.

There is little difference among the plans at high stages. Except for the procedures 4 and 5 involving fixed flashboards (table 4), there is no significant difference in the stage exceeded 2.5 percent of the time (this is equivalent to 6 days per year on the average). This is caused by two factors. One, when the flashboards are removed whenever the stage exceeds 12.4 ft their effect on peak stage is small (fig. 10). Two, most periods of high water occur before the flashboards are installed. One illustration of the effect of fixed flashboards is shown in figure 10. In this case, 6-in. flashboards raised the peak stage about 3 in. The increase in peak stage is

Table 4. Proposed alternative operating procedures for Indianford Dam

[Stage in feet; discharge in cubic feet per second]

Operating procedure	Alternative procedure number											
	1	2	3	4	5	6	7	8	9	10	11	12
Open two gates when:												
Stage exceeds------------	11.9	11.9	11.9	11.7	----	----	----	----	----	----	----	----
Upstream flow exceeds----	1,000	1,000	1,000	900	----	----	----	----	----	----	----	----
Open three gates when:												
Stage exceeds------------	----	----	----	----	----	----	11.8	12.1	12.1	12.1	12.1	12.1
Upstream flow exceeds----	----	----	----	----	----	----	1,200	1,200	1,200	1,200	1,200	1,200
Open four gates when:												
Stage exceeds-------------	12.1	12.1	12.1	11.9	12.0	12.0	----	----	----	----	----	----
Upstream flow exceeds-----	1,500	1,500	1,500	1,200	1,500	1,500	----	----	----	----	----	----
Open six gates when:												
Stage exceeds-------------	12.2	12.2	12.2	12.0	12.2	12.2	12.0	12.3	12.3	12.3	12.3	12.3
Upstream flow exceeds-----	1,900	1,900	1,900	1,500	1,900	1,900	1,500	1,500	1,500	1,500	1,500	1,500
Measure stage at-----------	---------------------Dam---------------------						---------------Lake---------------					
Stop generation when stage is less than----------------	10.84	11.44	11.60	11.44	11.60	11.60	11.60	11.90	11.90	12.10	12.10	11.90
Inches of flashboard-------	0	0	0	3	6	6	6	6	6	6	6	0
Flashboards removed when stage is more than-------	----	----	----	---[1]	---[1]	12.4	12.4	12.4	12.4	12.4	12.4	----
For winter drawdown:												
Open two gates at--------	----	----	----	----	----	----	----	----	10.18	----	10.18	----
Open three gates at------	----	----	----	----	----	----	----	----	10.28	----	10.28	----
Open six gates at--------	----	----	----	----	----	----	----	----	10.48	----	10.48	----
Stop generation at-------	----	----	----	----	----	----	----	----	9.98	----	9.98	----

[1]Flashboards not removed for rising stage.

Table 5. Significant differences between operating procedures simulated by Lake Koshkonong model

From procedure number	To procedure number	Changes
1	2	Raise minimum stage for generation from 10.84 ft to 11.44 ft.
2	3	Raise minimum stage for generation from 11.44 ft to 11.60 ft.
2	4	Lower stages and discharges at which gates are opened and allow 3-in. fixed flashboards in summer.
3	5	Delete using 2 gates open. Lower stage for opening 4 gates. Allow 6-inch fixed flashboards in summer.
5	6	Require flashboards to break away at a stage of 12.4 ft.
6	7	Change from operating 4 gates to operating 3 gates. Lower stages and discharges at which gates are opened.
7	8	Change from operating with stage at dam to operating with stage at lake. (Add 0.3 ft to all stages for average fall from lake to dam.) Flashboard installation and break away are always controlled by stage at dam.
8	10	Raise minimum stage for generation from 11.90 ft to 12.10 ft.
8	9	Add winter drawdown.
10	11	Add winter drawdown.
8	12	Do not allow flashboards.

always less than the height of flashboards because more water passes through the gates and turbines with the higher stage.

The influence of the stage at which generation is restricted also is indicated by the table. Simulated stage is near this limiting stage for a significant percentage of time. For each procedure, the stage that is exceeded 97.5 percent of the time is slightly greater than the stage at which power generation is limited. For procedure 1, the simulated stage is within 0.5 ft of the limit more than 30 percent of the time. For procedures 2-7, the simulated stage is within 0.5 ft of the limit more than 50 percent of the time, and for procedures 8-12, the simulated stage is within 0.5 ft of the limit more than 70 percent of the time. The characteristic also is illustrated in figure 11, which compares the simulated stages for a period with little runoff for procedures 1-3. The stage for each of the procedures tends to become approximately constant at about the limit for power generation. This occurs because the turbines that will be installed are capable of passing more flow than normally occurs during dry periods.

The duration table shows very little difference in stage attributable to winter drawdown, because the table only includes data from May through November. Any reductions in high stage from the winter drawdown occur before May. Figure 12 shows the results of winter drawdown for one year of significant runoff. Although simulated winter drawdown produced a simulated stage more than a foot lower before the runoff, the peak stage showed very little difference. The extra storage provided by winter drawdown was filled as soon as discharge started to increase. There is insufficient discharge capacity in the gates and turbines at the lowered stages to pass enough flow to keep the stage down once discharge starts to rise.

The differences in simulated stage between many of the procedures are not great. Where there are significant differences, different users of Lake Koshkonong could have different opinions about which is better. Some conclusions can be made about the effects of some of the features of the procedures. Raising the stage which limits generation (for example from procedure 1 to procedure 2 to procedure 3) increases the stage during the times when stage is low. Allowing fixed flashboards (procedures 4 and 5) increases the stage during times of high stage, which would increase the flooding of lakeshore lands. Breakaway flashboards (procedures 6-11) do not cause the same problem. Flashboards tend to raise average and lower stages compared with the same rules without flashboards (procedure 8 compared with procedure 12). Allow-

Table 6. Gate and flashboard operations simulated at Indianford Dam

	Procedure number											
	1	2	3	4	5	6	7	8	9	10	11	12
Average number of days per year with gate changes	25	25	26	46	51	52	65	14	18	19	34	12
Percentage of time with the following number of gates open:												
0	61.2	60.7	60.4	51.3	64.7	64.9	57.7	56.1	44.8	31.1	35.9	58.0
2	11.3	11.8	12.1	16.3	----	----	----	----	1.0	----	1.0	----
3	----	----	----	----	----	----	12.6	10.9	10.6	35.6	19.2	9.4
4	5.3	5.3	5.2	5.3	10.0	10.4	----	----	----	----	----	----
6	22.2	22.2	22.3	27.1	25.3	24.7	29.7	33.0	43.6	33.3	43.9	32.6
Number of times flashboards are installed in 21 years	----	----	----	21	21	27	26	29	29	29	29	----
Average number of days per year with flashboards in place	----	----	----	172	169	151	152	155	155	155	155	----

Table 7. Simulated stage duration for Lake Koshkonong for May through November 1960-78, showing percentage of time a given stage would be exceeded

[Stage in feet]

Percentage of time	Procedure number 1	2	3	4	5	6	7	8	9	10	11	12
2.5	15.54	15.54	15.55	15.65	15.69	15.55	15.55	15.55	15.55	15.55	15.55	15.55
5	14.85	14.86	14.86	14.88	14.98	14.86	14.86	14.85	14.85	14.85	14.85	14.85
10	14.13	14.14	14.14	14.19	14.25	14.15	14.14	14.14	14.14	14.14	14.14	14.12
20	13.12	13.13	13.13	13.04	13.19	13.14	13.04	12.99	12.99	12.99	12.99	12.96
30	12.51	12.52	12.53	12.45	12.59	12.58	12.47	12.31	12.32	12.33	12.33	12.26
40	12.18	12.20	12.21	12.11	12.26	12.26	12.18	12.11	12.14	12.17	12.17	12.08
50	11.84	11.90	11.95	11.85	12.03	12.03	11.92	12.03	12.05	12.15	12.16	11.97
60	11.53	11.68	11.74	11.68	11.87	11.87	11.77	11.97	11.97	12.13	12.15	11.95
70	11.08	11.50	11.67	11.50	11.68	11.68	11.67	11.95	11.95	12.12	12.13	11.92
80	10.95	11.49	11.65	11.49	11.66	11.66	11.65	11.93	11.93	12.10	12.12	11.91
90	10.90	11.47	11.63	11.47	11.63	11.63	11.63	11.91	11.91	12.08	12.11	11.87
95	10.87	11.46	11.62	11.46	11.62	11.62	11.62	11.90	11.90	12.03	12.08	11.74
97.5	10.85	11.45	11.61	11.45	11.61	11.61	11.61	11.84	11.84	11.95	11.95	11.61

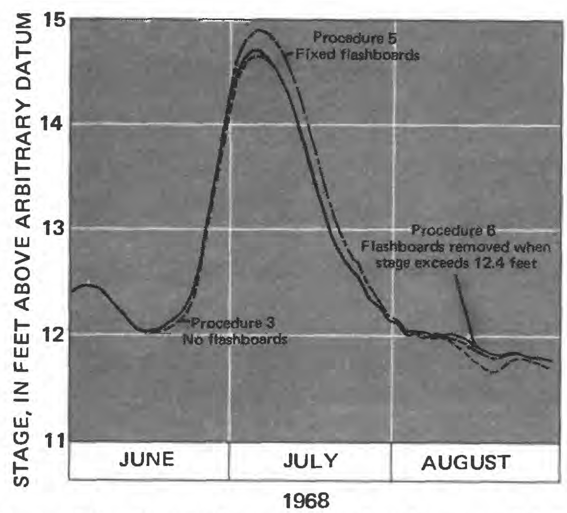

Figure 10. Comparison of simulated stage of Lake Koshkonong for procedures 3, 5, and 6, showing the effects of flashboards.

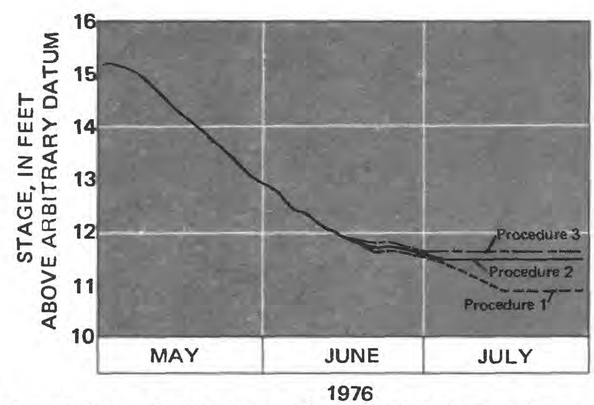

Figure 11. Comparison of simulated stage of Lake Koshkonong for procedures 1, 2, and 3, showing the effects of changes in the power-generation limit.

ing winter drawdown (procedures 9 and 11) proved to be of very little benefit in lowering flood peaks. Operating with stage at the lake (procedure 8) rather than at the dam (procedure 7) significantly reduced the number of times changes in gates would be required (table 6).

CONCLUSIONS

Use of Upstream Impoundments to Reduce Downstream Flooding

The effects of using the existing reservoirs in the Rock River basin to control floods on Lake Koshkonong are limited and variable. On the average, the simulated reservoir operations resulted in a slight decrease of the mean spring flood peak. Although in some years the simulated operation of the reservoirs resulted in simulated spring flood peaks higher than those which actually occurred.

Operating the reservoirs according to the methods simulated by the model would reduce the peak spring stage on Lake Koshkonong about 0.2 ft on the average for peak stages around 15 ft and about 0.1 ft on the average for peak stages around 18 ft. Operating according to modified methods intended to shift the emphasis to larger floods would reduce the peak stage about 0.1 ft on the average for peak stages between about 15 and about 18 ft.

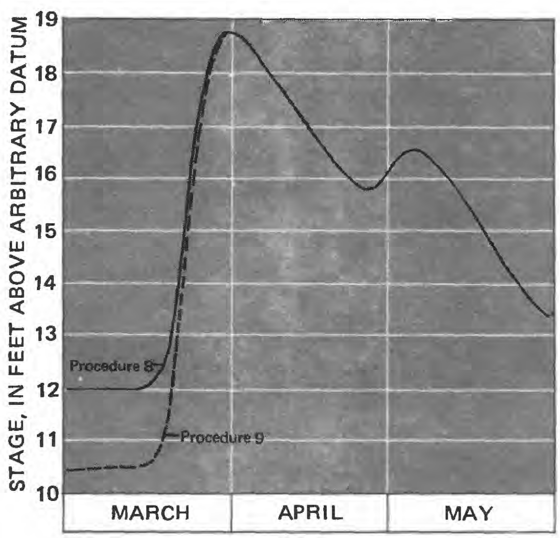

Figure 12. Comparison of simulated stage of Lake Koshkonong for procedures 8 and 9, showing the effects of winter drawdown.

At Afton, the simulated reservoir operations caused variable changes in the peak flood discharge. On the average, as determined by comparing flood frequencies, the reservoir operation with the smaller index discharge would decrease smaller flood peak discharges by less than 1 percent and increase larger flood peak discharges by less than 1 percent. Raising the index discharge would increase the smaller flood peak discharges by 1 to 3 percent, while changing larger discharges by less than 1 percent. All of these changes would mean a difference of less than 0.1 ft in the peak stage at the Afton gaging station.

The reductions in flood stages are not very large under the simple operating scheme used in this study. It is possible that slightly greater reductions could be achieved if the reservoirs were operated differently in different years, depending on the expected volume of spring runoff. This factor should be considered in future model studies of the basin. An optimum operation plan, considering the flood volume for each year, could be determined with the same modeling system and its effects evaluated as they were in this report.

Changes in Operation of Indianford Dam

The differences in Lake Koshkonong stage resulting from the differences in operating rules for Indianford are variable. There are some significant differences at certain flow rates among some of the rules. At other times, the different rules produce no detectable difference in stage.

Flashboards will cause only very slight increases in maximum stage if they are removed or break away when stage starts to rise. If the boards are left in place, they will cause an increase in the maximum stage that is somewhat less than the height of the boards. The impact of rules allowing flashboards is reduced because most periods of high water occur in spring, before flashboards are permitted, or in early summer, before the stage had fallen enough to allow flashboard installation. Thus, the majority of floods would occur when boards are not in use.

The primary factor affecting lake stage during periods of low flow is the stage at which power generation is restricted. The turbines that will be installed were assumed to be capable of passing more flow than normally occurs during dry periods. As a result, the simulated stage during low flow was normally very close to the stage limit for power generation.

Winter drawdown had very little effect on the peak stages the following spring. The storage area in Lake Koshkonong that was made available by winter drawdown was refilled early in the spring because the dam lacks sufficient discharge capacity at low stages to keep the stage down. The extra storage capacity is filled before the maximum flows and stages occur. After the extra storage is filled, the stages with and without winter drawdown are only slightly different.

Operating the dam with reference to stage at the lake, rather than at the dam, simplifies the decision-making process for operating gates. This significantly reduced the number of times the gates would have to be opened or closed. However, it does entail the obvious difficulty for a dam operator to determine the stage at a point more than 6 mi from the dam.

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