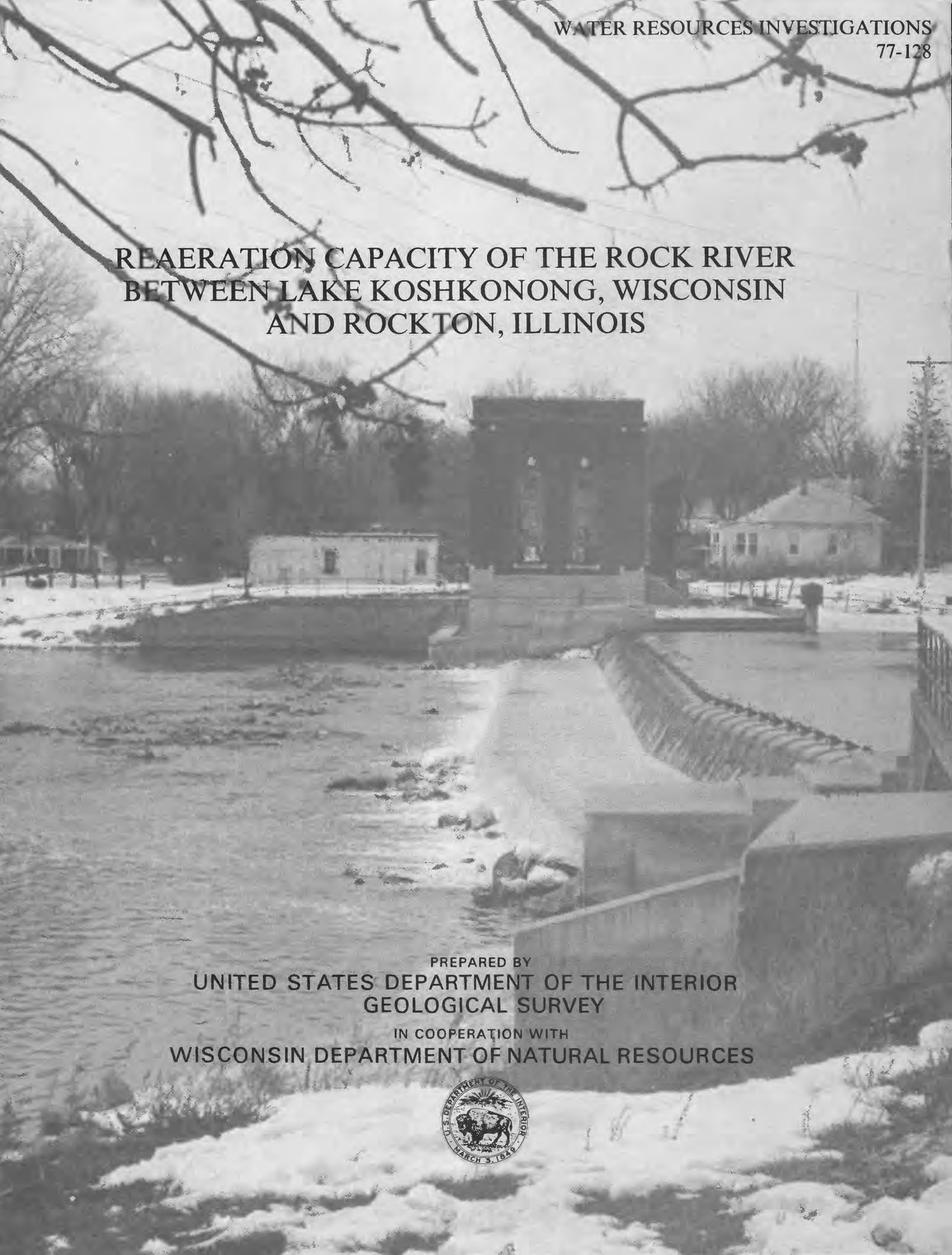
WATER RESOURCES INVESTIGATIONS
77-128

REAERATION CAPACITY OF THE ROCK RIVER BETWEEN LAKE KOSHKONONG, WISCONSIN AND ROCKTON, ILLINOIS



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Reaeration coefficients (K_2) were computed for the annual minimum 7-day mean discharge that occurs on the average of once in 10 years ($Q_{7,10}$).

A time-of-travel model was developed using river discharge, slope, and velocity data from three dye studies. The model was used to estimate traveltime for the $Q_{7,10}$ for use in the energy-dissipation model.

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Reaeration Capacity of the Rock River between Lake Koshkonong, Wisconsin and Rockton, Illinois

R. S. Grant

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March 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

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Madison, Wisconsin 53706

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CONVERSION FACTORS

Multiply English unit	By	To obtain SI unit
inches (in)	2.540	centimeters (cm)
feet (ft)	30.48	centimeters (cm)
feet (ft)	.3048	meters (m)
feet per second (ft/s)	30.48	centimeters per second (cm/s)
miles (mi)	1.609	kilometers (km)
miles per hour (mi/h)	1.609	kilometers per hour (km/h)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)

Reaeration Capacity of the Rock River between Lake Koshkonong, Wisconsin and Rockton, Illinois

R. S. Grant

ABSTRACT

The reaeration capacity of the Rock River from Lake Koshkonong, Wisconsin, to Rockton, Illinois, was determined using the energy-dissipation model, $K_2 = C \frac{\Delta h}{t}$, where K_2 is the reaeration-rate coefficient for a reach of river, C is the escape coefficient, Δh is the drop in water-surface elevation in the reach, and t is the time of travel through the reach. The model was calibrated using data from radioactive-tracer measurements of K_2 in the study reach together with concurrent measurements of Δh and t.

K_2 was computed for the annual minimum 7-day mean discharge that occurs on the average of once in 10 years ($Q_{7,10}$). K_2 at 25°C (base e) for the $Q_{7,10}$ ranged between 0.01 and 0.09 per day for 32 miles of the study reach. In the remaining 7 miles, which contain sections of rapids, K_2 for the $Q_{7,10}$ was about 0.8 per day.

During one radiotracer study, 17 miles-per-hour winds apparently increased the reaeration coefficient about 40 times.

A time-of-travel model was developed using river discharge, slope, and velocity data from three dye studies. The model was used to estimate traveltime for the $Q_{7,10}$ for use in the energy-dissipation model. Five dams cause flow velocities for the $Q_{7,10}$ to average about 0.2 foot per second through the 39-mile study reach.

INTRODUCTION

The purpose of this report is to present reaeration-rate coefficients for the Rock River between Lake Koshkonong, Wis., and Rockton, Ill., for the annual minimum 7-day mean flow that occurs on the average of once in 10 years ($Q_{7,10}$) (fig. 1). The study was conducted by the U.S. Geological Survey in cooperation with the Wisconsin Department of Natural Resources (DNR). The information generated will be useful in implementing water-quality standards for the Rock River.

For implementation of water-quality standards stream-reaeration capacity must be determined so that the self-purifying ability of a stream receiving oxygen-depleting wastes can be evaluated. Reaeration capacity can be determined using predictive models or direct-measurement techniques such as the dissolved-oxygen balance technique, disturbed-equilibrium technique, or the tracer technique (Bennett and Rathbun, 1972). The radioactive-tracer technique (Tsivoglou and Wallace, 1972) for measuring reaeration-rate coefficients was used in this study on six reaches of the Rock River. The data collected were used to calibrate the energy-dissipation model from which reaeration-rate coefficients were predicted for the $Q_{7,10}$.

The $Q_{7,10}$ was determined by statistical analysis of streamflow data. In addition, time-of-travel data provided by the Wisconsin Electric Power Company were used in this study.

The Rock River study reach flows through pleasant countryside and is bordered by wooded and agricultural lands. Many cottages and year-round residences line the river, which is used extensively for boating, fishing, duck hunting, and other recreation.

The study reach alternates from free-flowing to backwater-affected conditions, the latter caused by dams at Rockton, Beloit, Janesville, and Indianford (figs. 2-7). The river ranges in width from about 150 ft to 400 ft in the free-flowing reaches. Maximum widths of about 1,200 ft occur in the Beloit and Monterey Dam (Janesville) pools. Stream depths ranged from less than 1 ft in rapids sections to more than 10 ft behind the Wisconsin Power and Light Dam in Beloit and Ford's Dam in Janesville. Rapids were observed at Boney Island in South Beloit and in a long reach below Monterey Dam.

The long, narrow pools behind the five dams create an illusion that the Rock River is larger than it really is. A more proper perspective perhaps may be gained by viewing the river at the Monterey Dam in Janesville during a late summer low-flow period. Here the river is much closer to its natural state. The long, shallow rapids section downstream from the dam is less than knee deep and can be waded easily. The stream looks more like a small river than the apparently large river that can be observed, for example, at the Interstate Highway 90 crossing near Newville.

The cities of Janesville, Beloit, and South Beloit discharge waste water directly into the study reach. The Yahara River, which enters the

Base from U.S. Army Map Service, Corps of Engineers, Rockford, 1:250,000, 1958, photorevised 1971

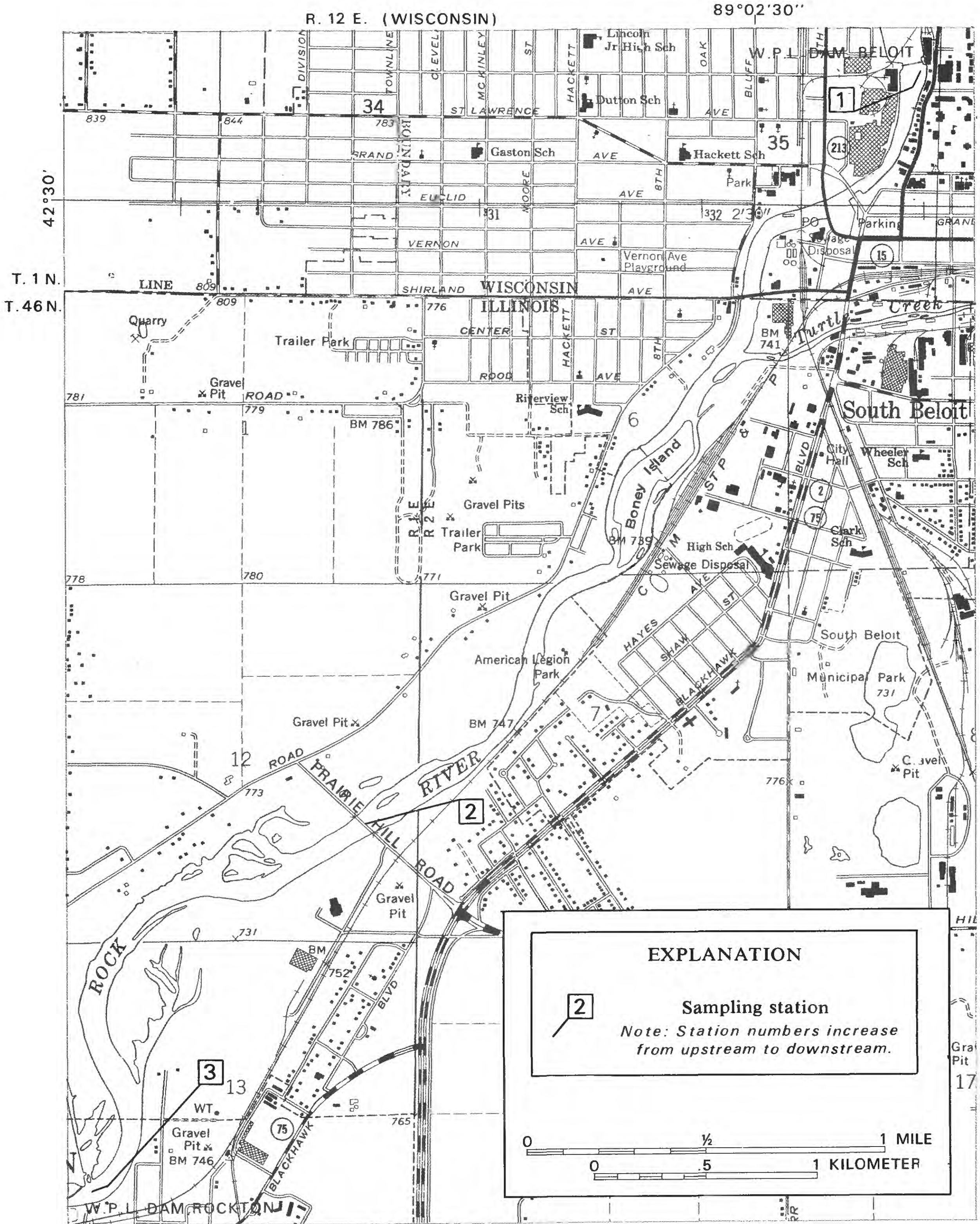
0 5 10 MILES

0 5 10 KILOMETERS

EXPLANATION

(2) Radiotracer study reach number

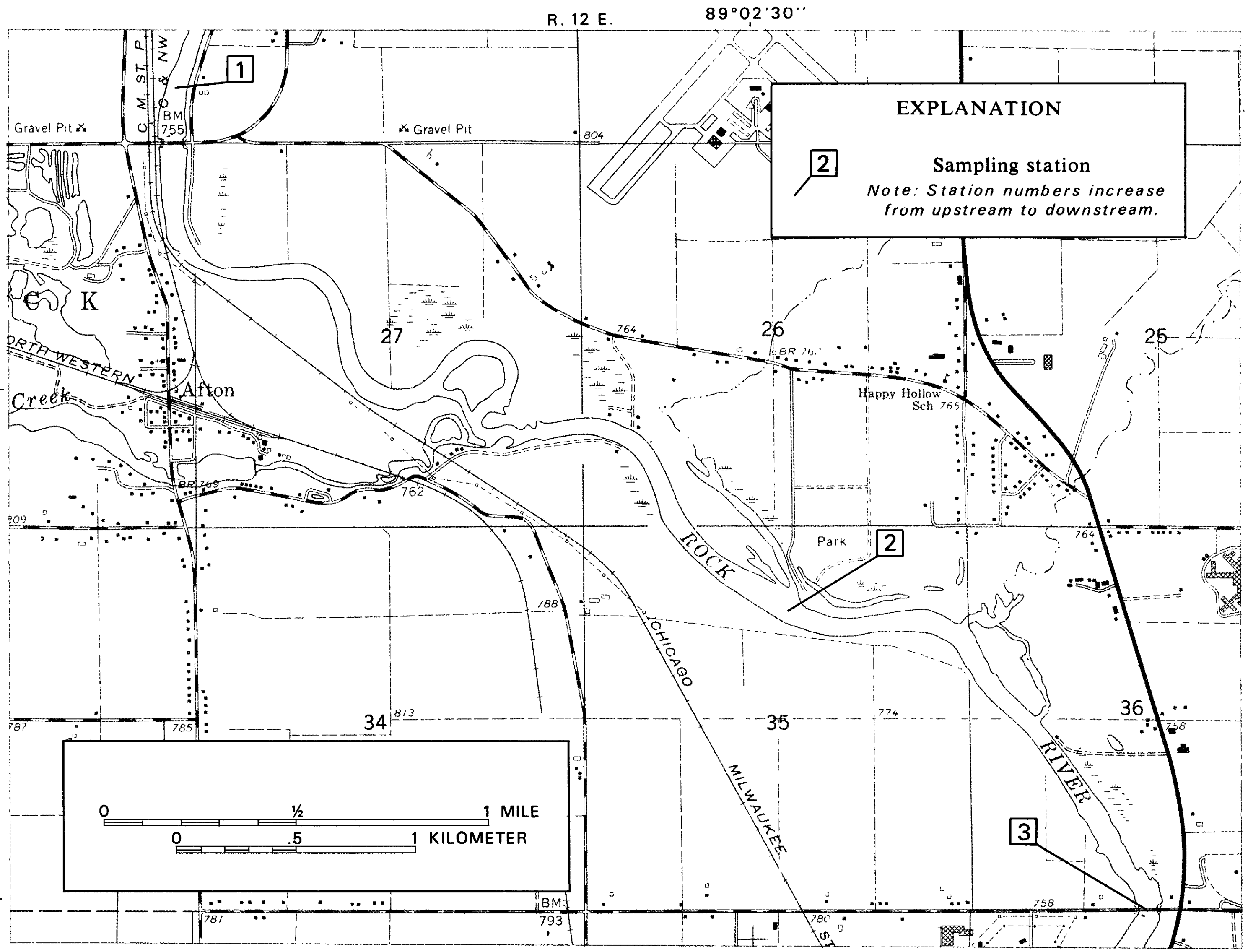
Figure 1. Location of Rock River radiotracer study reaches in Wisconsin and Illinois.



Base from U.S.Geological Survey Beloit, South Beloit, 1:24,000, 1962. Interim revisions as of 1971, 1971 S. Beloit.

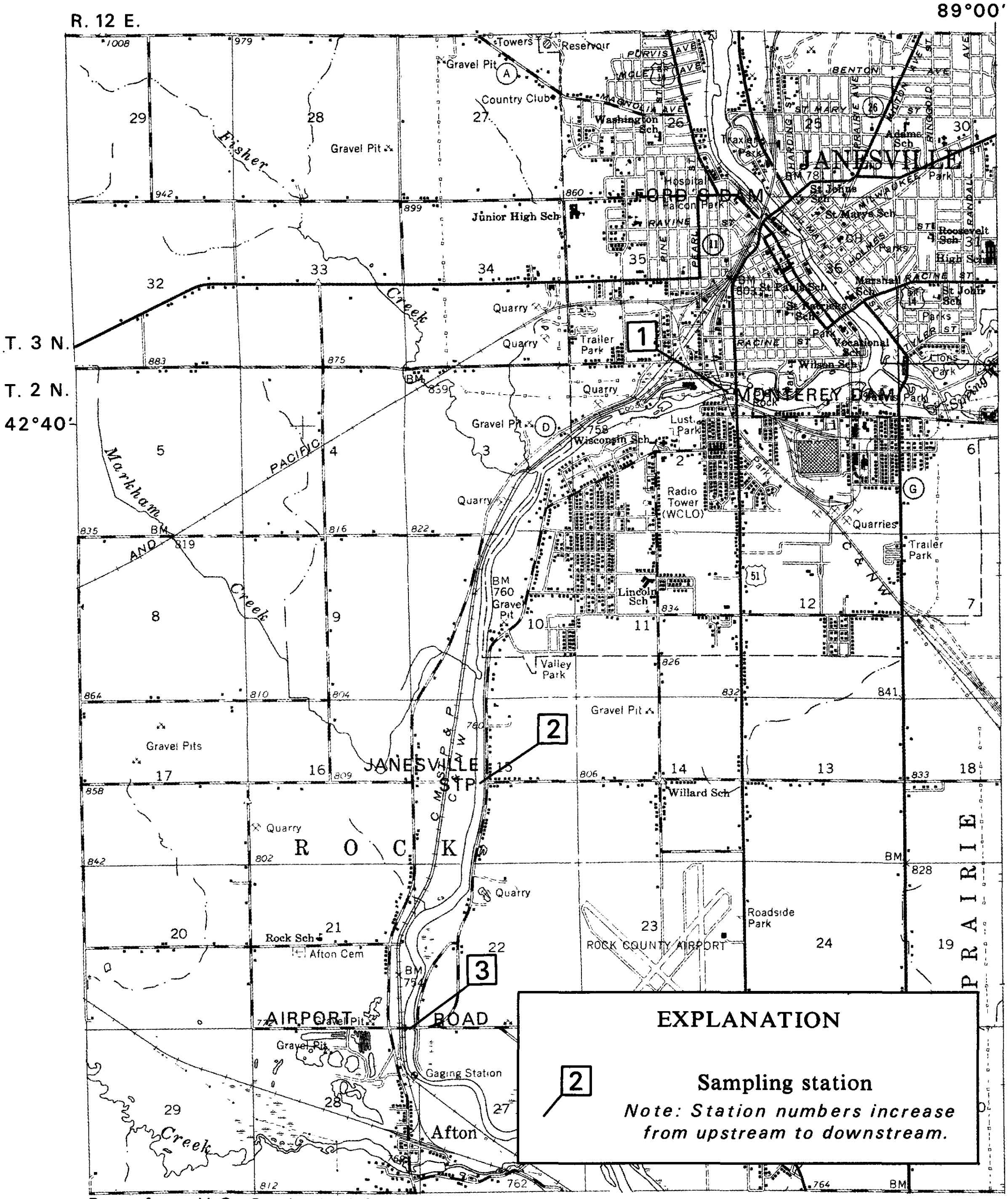
R. 1 E. R. 2 E. (ILLINOIS)

Figure 2. Radiotracer study reach I.



Base from U.S.Geologial Survey
Beloit, 1:24,000, 1962, Interim revisions as of 1971.

Figure 3. Radiotracer study reach II.



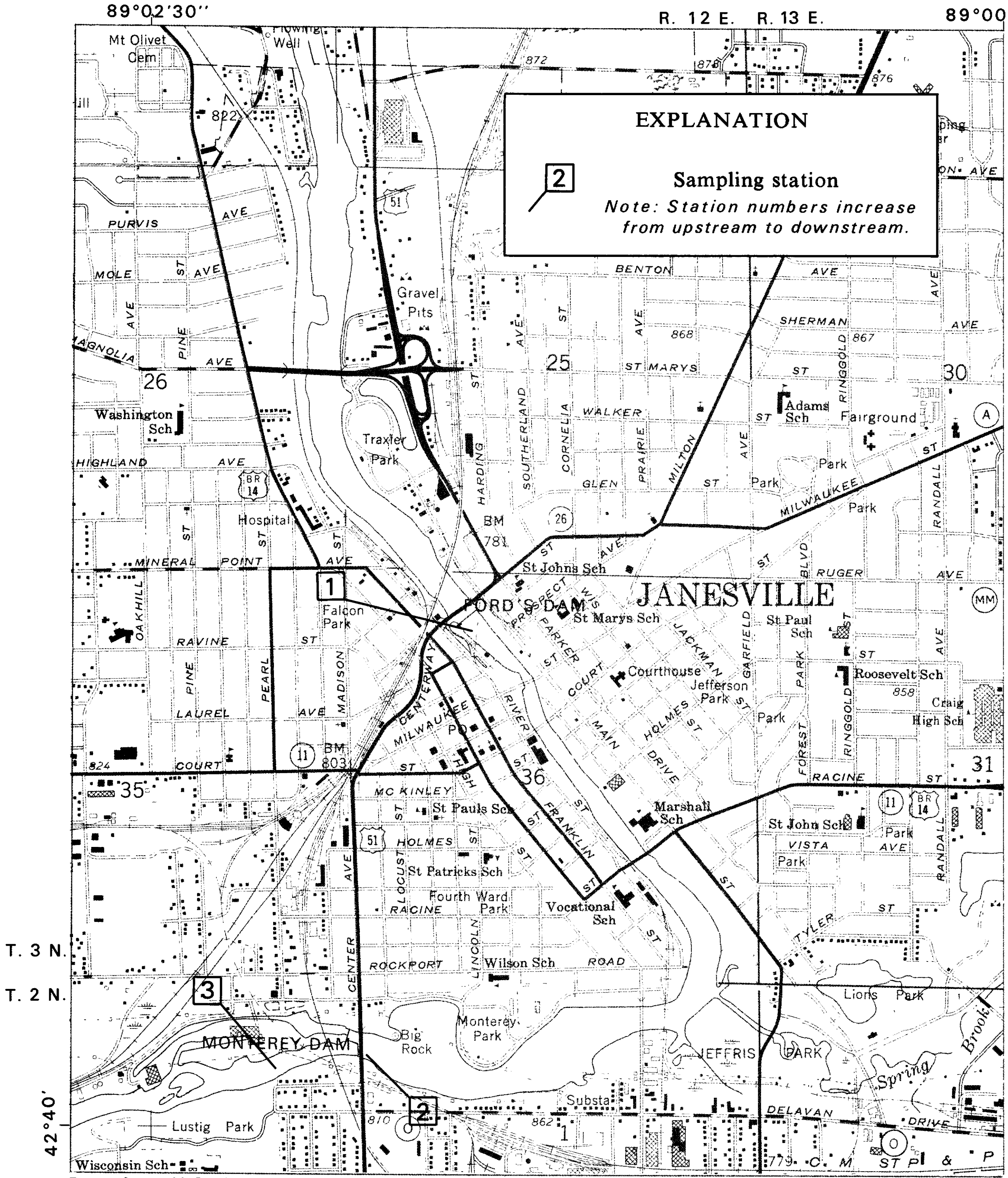
Base from U.S. Geological Survey
Janesville, 1:62,500, 1962

SCALE 1:62,500

0 ½ 1 2 3 MILES

0 .5 1 2 3 4 KILOMETERS

Figure 4. Radiotracer study reach III.



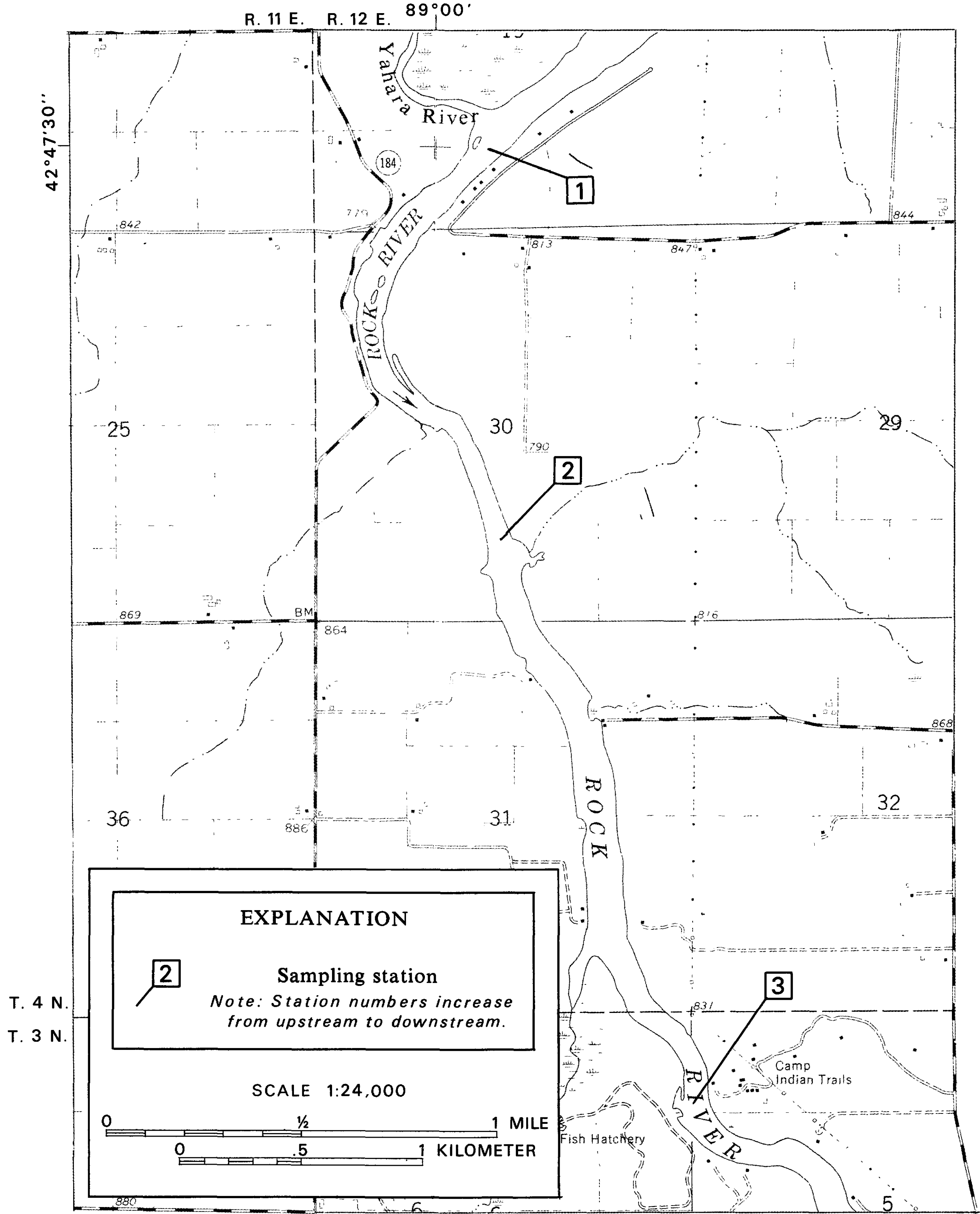
Base from U.S. Geological Survey
Janesville West, 1:24,000, 1961, Interim revisions as of 1971.

SCALE 1:24,000

0 ½ 1 MILE

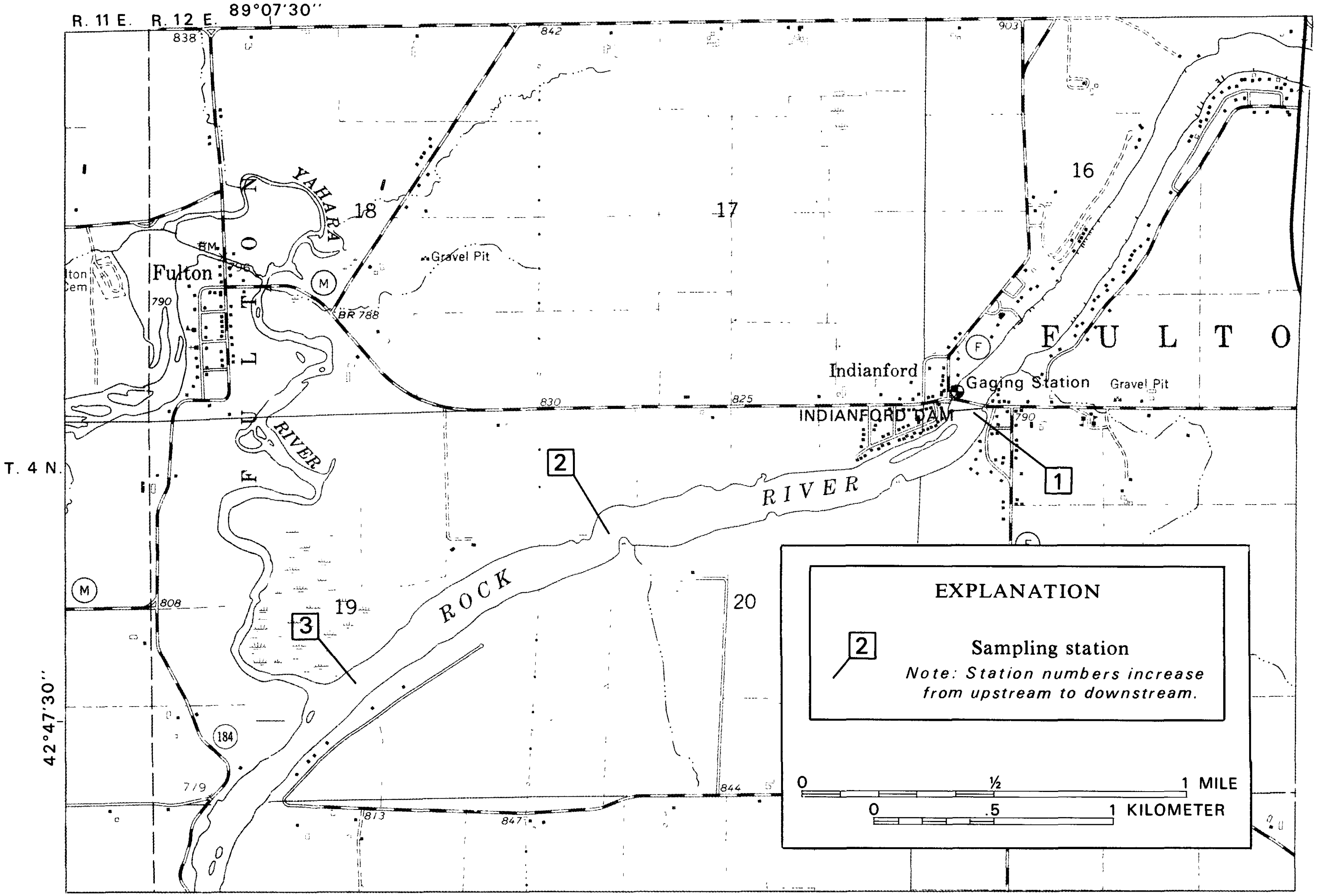
0 .5 1 KILOMETER

Figure 5. Radiotracer study reach IV.



Base from U.S.Geological Survey
Cooksville, Edgerton, 1:24,000, 1961, Interim revisions as of 1971.

Figure 6. Radiotracer study reach V.



Base from U.S.Geologial Survey
Cooksville, Edgerton, 1:24,000, 1961 Interim revisions as of 1971.

Figure 7. Radiotracer study reach VI.

Rock River at mile 190.5, carries additional waste water discharged from the waste-water-treatment plants at Madison, Stoughton, and Oregon. Waste water from Edgerton is carried by Saunders Creek into the Rock River at about mile 194. Industrial waste waters also are discharged into the river at Janesville and in the Beloit area (Wis. Dept. Nat. Resources, 1971). Sources of waste-water discharge in Illinois were not located.

7-DAY, 10-YEAR LOW FLOW ($Q_{7,10}$)

Estimates were made of the annual minimum 7-day mean discharge that occurs on the average of once in 10 years ($Q_{7,10}$) for the Rock River between Lake Koshkonong and Rockton (fig. 8). The data used to develop figure 8 are discussed in the following sections of this report.

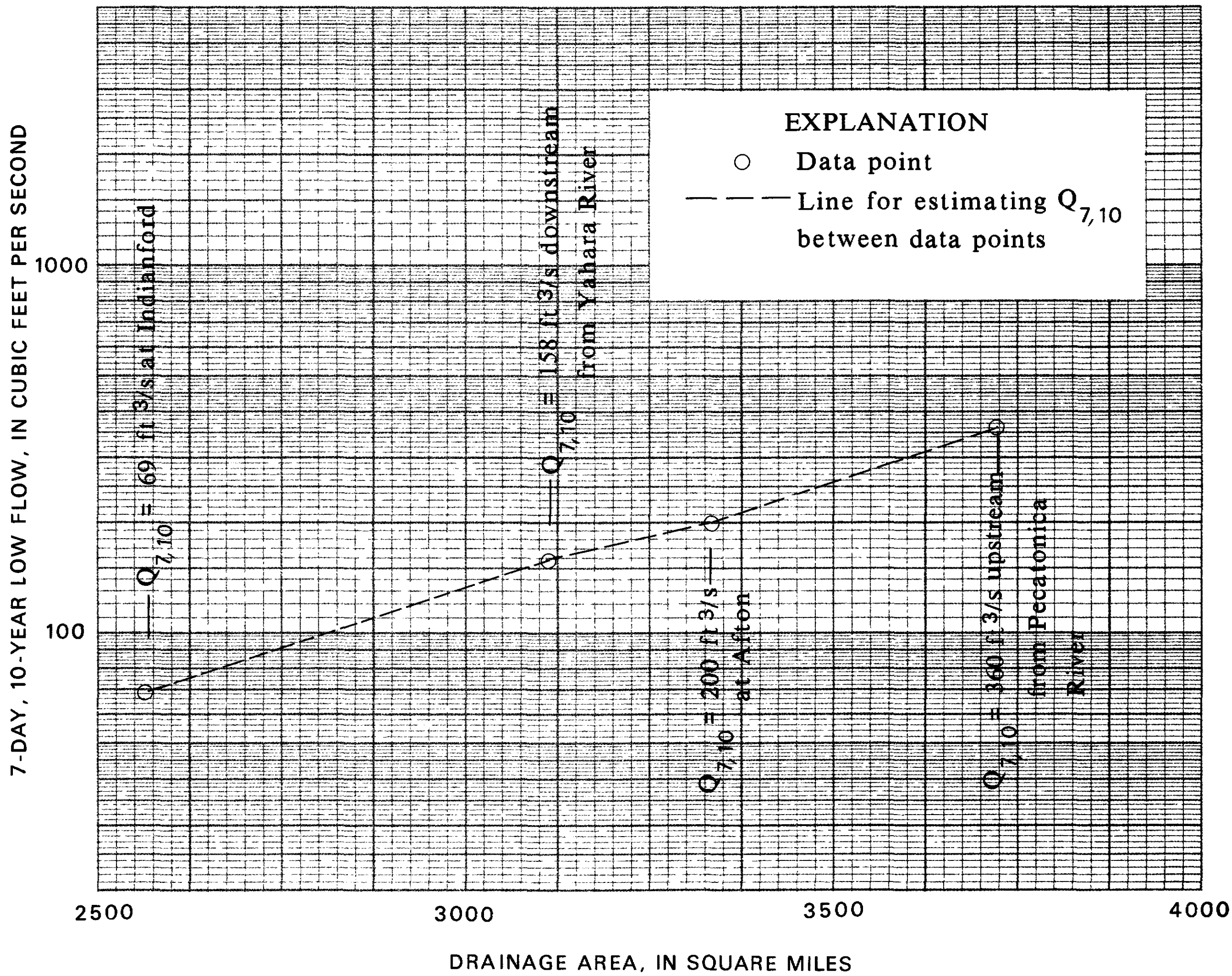


Figure 8. 7-day, 10-year low flow ($Q_{7,10}$) for Rock River from Indianford, Wisconsin to Rockton, Illinois.

ROCK RIVER AT INDIANFORD GAGING STATION

Discharge data collected at the U.S. Geological Survey gaging station (05427570) on the Rock River at Indianford were plotted against concurrent discharge data from the U.S. Geological Survey gaging station on the Rock River at Afton (05430500) (fig. 9). The data represent concurrent 7-day mean discharge at the gaging stations for the period July 1, 1976, to September 29, 1976.

A relation line was fitted to the data in figure 9 using regression analysis. The $Q_{7,10}$ at the Afton gaging station (page 12) was transferred through the relation line to estimate a $Q_{7,10}$ at Indianford of 69 ft^3/s. Because the Indianford station has been in operation only since May 1975, the $Q_{7,10}$ thus determined is considered a preliminary estimate until more adequate data become available.

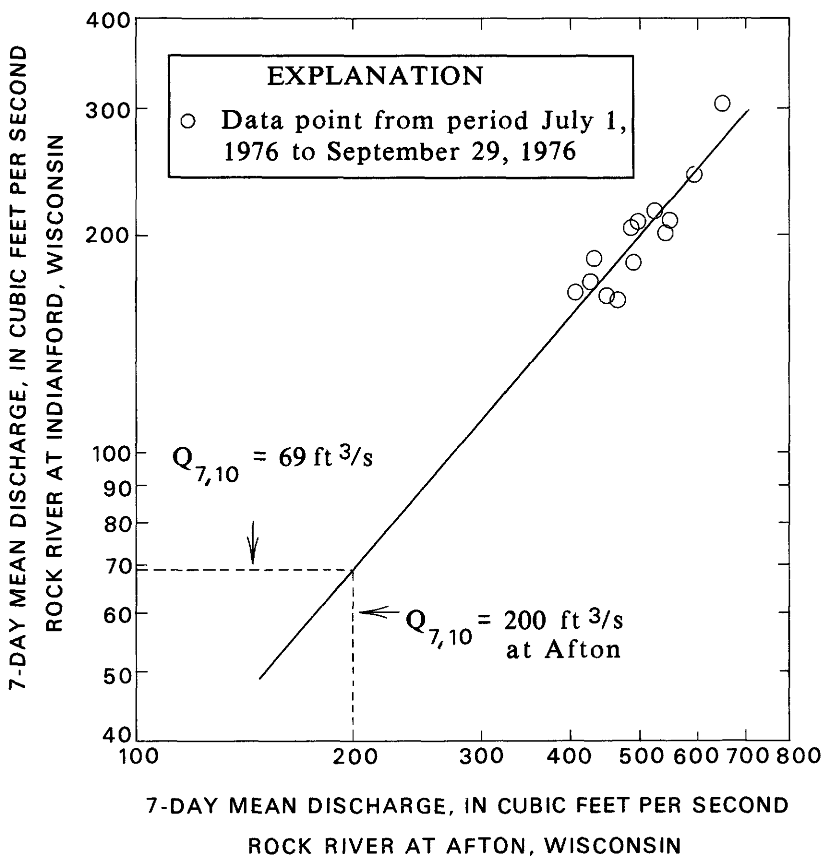


Figure 9. $Q_{7,10}$ for Rock River at Indianford, Wisconsin.

ROCK RIVER DOWNSTREAM FROM YAHARA RIVER

A $Q_{7,10}$ of 158 ft^3/s for the Rock River just downstream from its confluence with the Yahara River was determined by adding the $Q_{7,10}$ at Indianford to that of the Yahara River at its mouth, plus the additional inflow (0.3 ft^3/s) between Indianford and the Yahara River. The inflow was calculated on the basis of drainage area by multiplying the discharge per square mile at Indianford by the drainage area of the Rock River just upstream from its confluence with the Yahara River. The current discharge of the Madison Metropolitan Sewerage District (MMSD) of 54 ft^3/s, which reaches the Yahara River from Badfish Creek, then was added to the above.

The $Q_{7,10}$ of the Yahara River at its mouth was determined from estimates of $Q_{7,10}$ made at gaging stations, low-flow partial-record stations, and sewage-treatment-plant sites in the nearby Koshkonong Creek basin and in the Yahara River basin. The $Q_{7,10}$ was plotted for each location against its corresponding drainage area, producing the relationship shown in figure 10. A $Q_{7,10}$ of 34 ft^3/s was estimated for the Yahara River at the mouth based on this relationship and exclusive of discharge from MMSD.

ROCK RIVER AT AFTON GAGING STATION

The gaging station on the Rock River at Afton (05430500) has been in operation since January 1914. The $Q_{7,10}$ at this location is 200 ft^3/s based on a frequency analysis of the recorded 7-day annual minimum flows. A log-Pearson type III probability distribution was used to compute the frequency values.

ROCK RIVER UPSTREAM FROM PECATONICA RIVER

The $Q_{7,10}$ for the Rock River upstream from its confluence with the Pecatonica River was estimated at 360 ft^3/s by subtracting the estimated $Q_{7,10}$ of the Pecatonica River at its mouth from the $Q_{7,10}$ on the Rock River at Rockton (05437500).

The gaging station on the Rock River at Rockton has been operating continuously since October 1939. The $Q_{7,10}$ of 775 ft^3/s was determined by a frequency analysis of 7-day annual minimum flows for the period 1915-75. Flows before October 1939 were synthesized using a correlation with the Rock River at Afton. A log-Pearson type III probability distribution was used to compute the frequency values. Just upstream from the gaging station, however, the Pecatonica River, a major tributary, merges with the Rock River.

Data from a gaging station on the Pecatonica River at Freeport, Ill., (05435500) for the period 1915-75 were used with data for an 18-year period from a discontinued gaging station on the Pecatonica River at Shirland (05437000) to estimate the $Q_{7,10}$ of 397 ft^3/s at that location. This estimate was projected downstream on a drainage-area-ratio basis to determine the $Q_{7,10}$ of 413 ft^3/s for the Pecatonica River at its mouth.

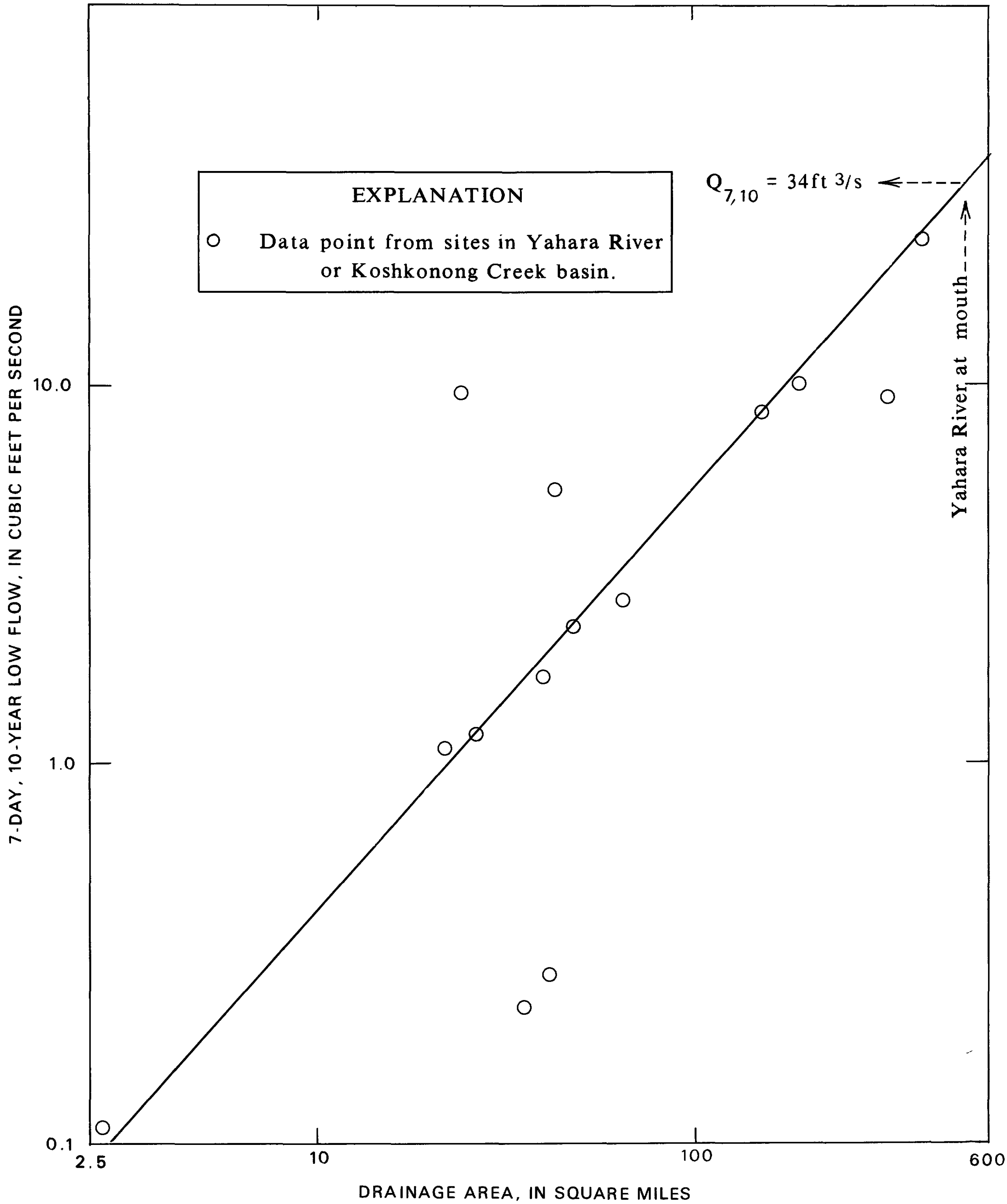


Figure 10. $Q_{7,10}$ determination for Yahara River at mouth.

TIME OF TRAVEL

Three time-of-travel studies were made using dye tracers in the lower Rock River during the summer and autumn of 1975. Two of the dye studies were conducted by the Wisconsin Electric Power Company (Wepco) and the third was done by the U.S. Geological Survey (USGS) as part of the radiotracer studies. Data from the three dye studies were used to develop a model for estimating traveltime during the $Q_{7,10}$ discharge.

DYE STUDIES

Wepco conducted dye studies July 29-31 and September 11, 1975. River discharge during the first study ranged from about 600 ft^3/s at Indianford to 1,500 ft^3/s at Afton, and during the second study from about 900 ft^3/s to 1,400 ft^3/s, respectively. The study reach began at the outlet of Lake Koshkonong and ended at the Beloit Dam (fig. 1).

Dye studies were conducted between September 22 and October 3, 1975, in six segments of the lower Rock River by the U.S. Geological Survey (figs. 1-7). Discharge in the study reach ranged from about 260 to 1,030 ft^3/s. Traveltime through the pools above the Wisconsin Power and Light Dam in Beloit and Ford's Dam in Janesville was not determined because radiotracer studies were not made in those reaches.

TRAVEL TIME FOR THE $Q_{7,10}$

The Wepco and USGS dye-study data were combined to develop a model to estimate time of travel (equation 7) through the lower Rock River for the $Q_{7,10}$ discharge. The following paragraphs discuss development of that model.

Dye velocities were determined for the common reaches studied and plotted against river discharge in each reach (figs. 11-15). No curve is shown for radiotracer reach I because Wepco did not make dye studies in that reach. Velocities measured by current meter during low-flow periods at the gaging station at Afton were plotted in figure 12 along with dye velocities. The velocities were mean velocities taken from discharge measurements made since the gaging station has been in operation.

The velocity and discharge data were used to develop a relationship for each reach of the form

$$V = \alpha Q^{\beta} \qquad (1)$$

where: V is the average velocity through the reach;

Q is the average discharge in the reach; and

α and β are coefficients determined by regression analysis forcing the line through the origin.

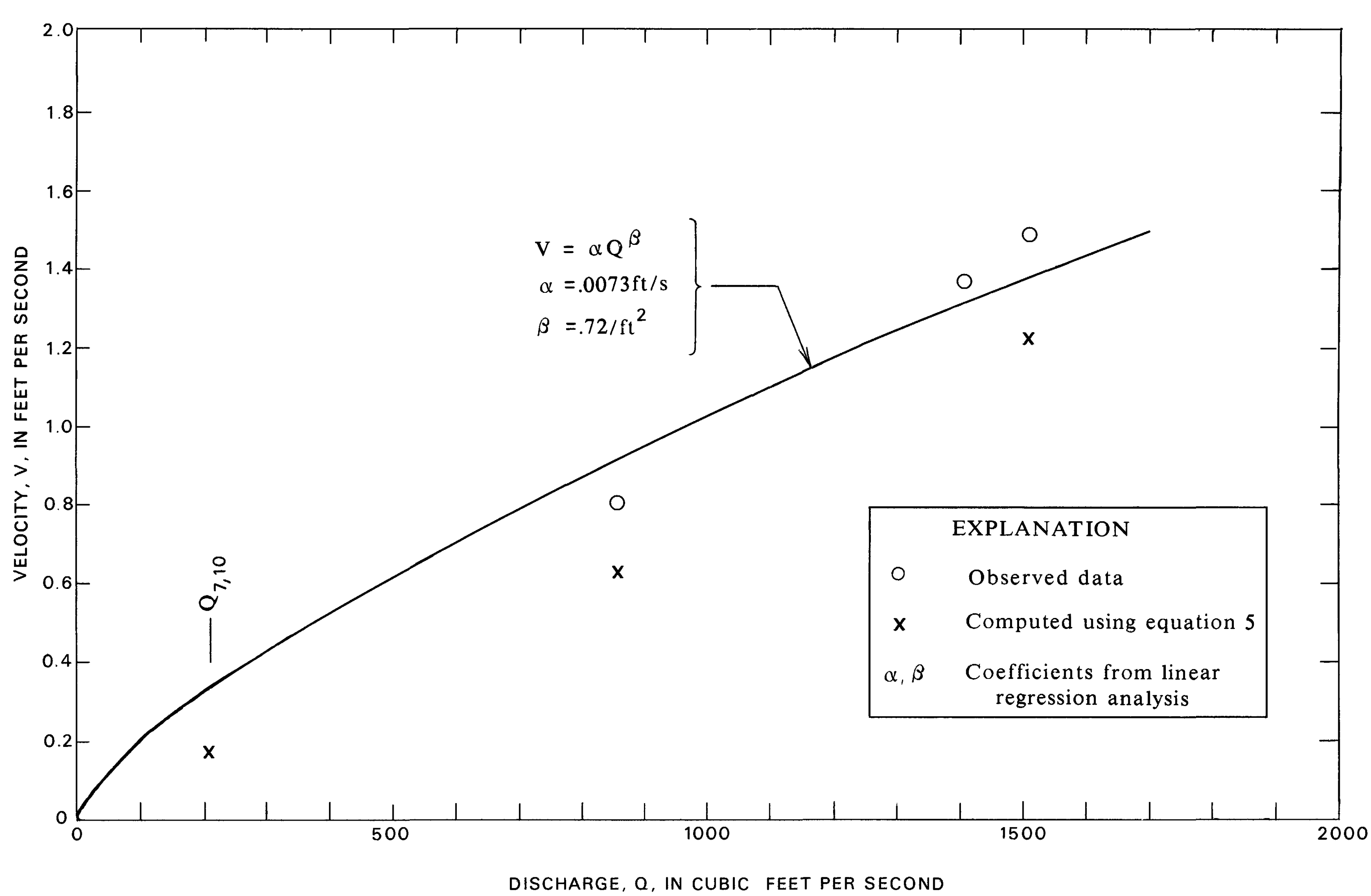


Figure 11. Velocity-discharge curve, radiotracer reach II.

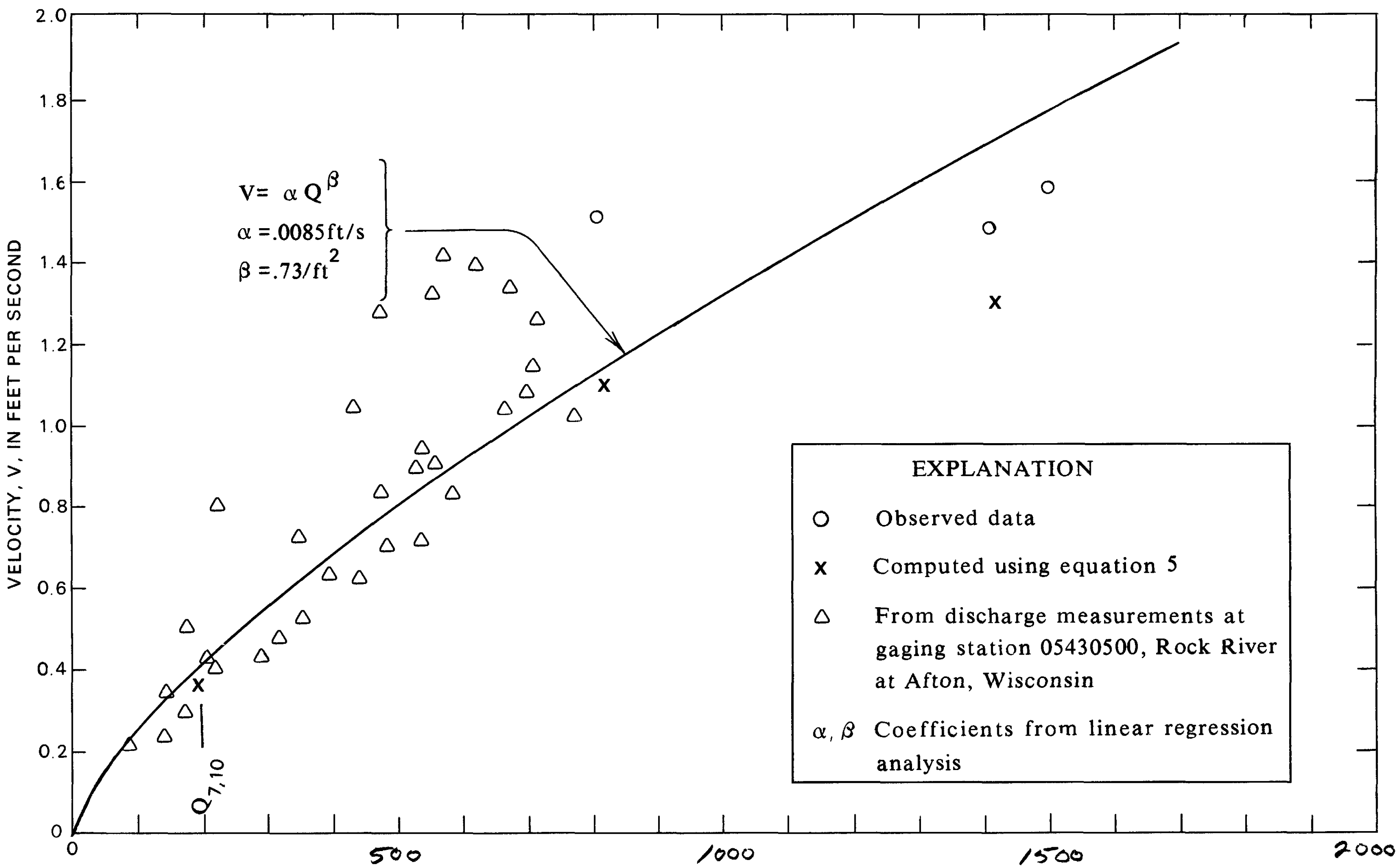


Figure 12. Velocity-discharge curve, radiotracer reach III.

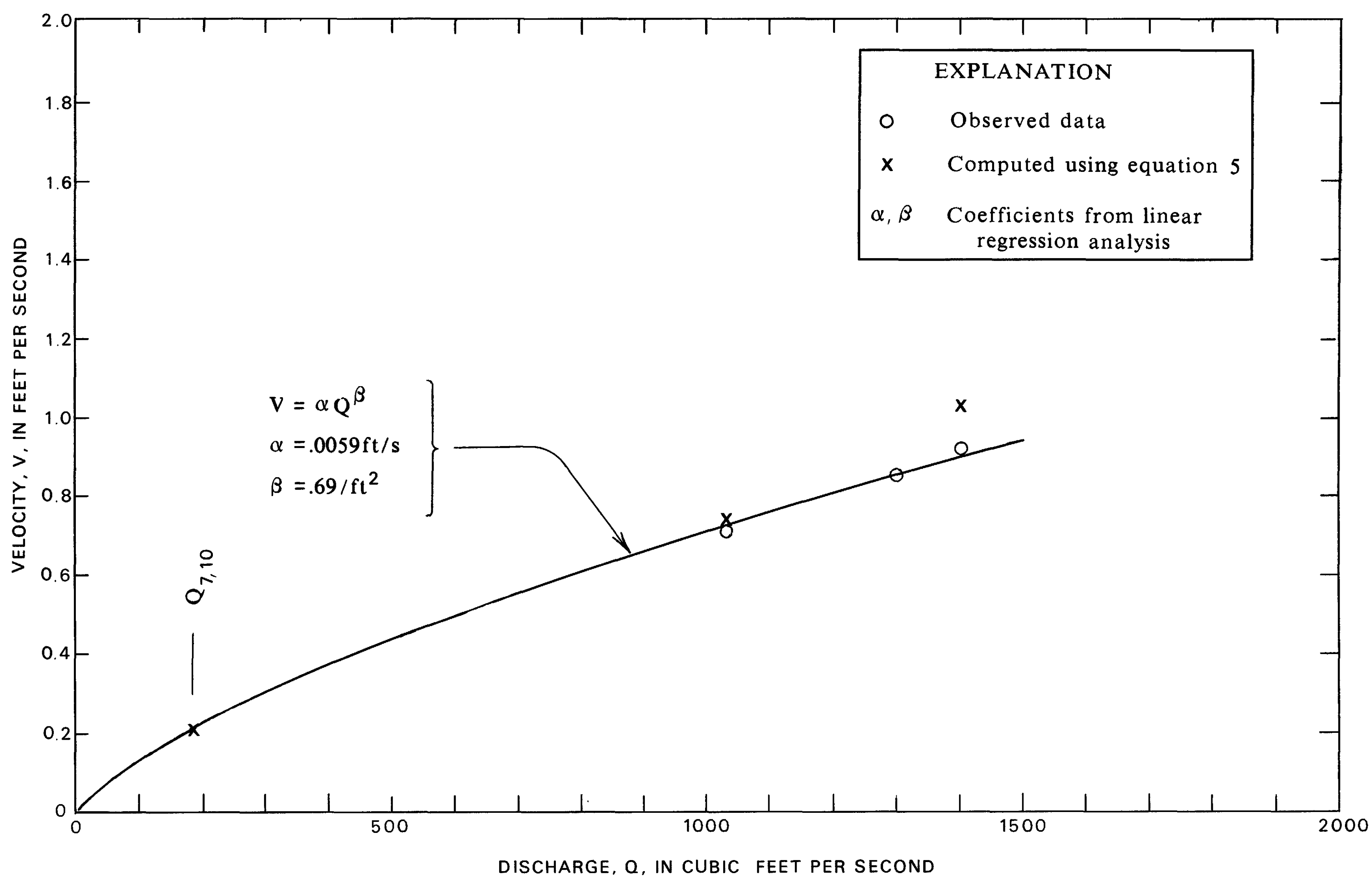


Figure 13. Velocity-discharge curve, radiotracer reach IV.

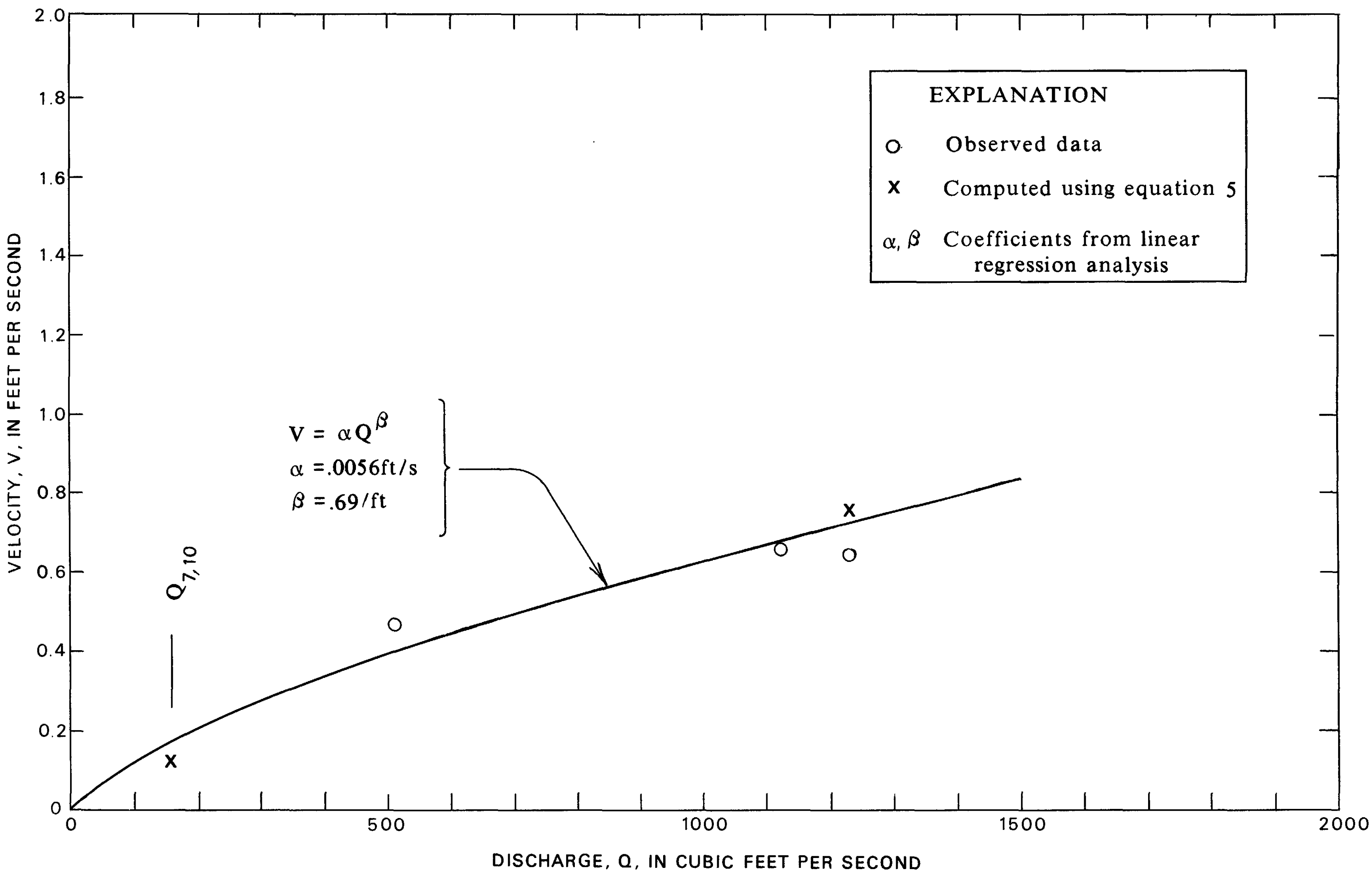


Figure 14. Velocity-discharge curve, radiotracer reach V.

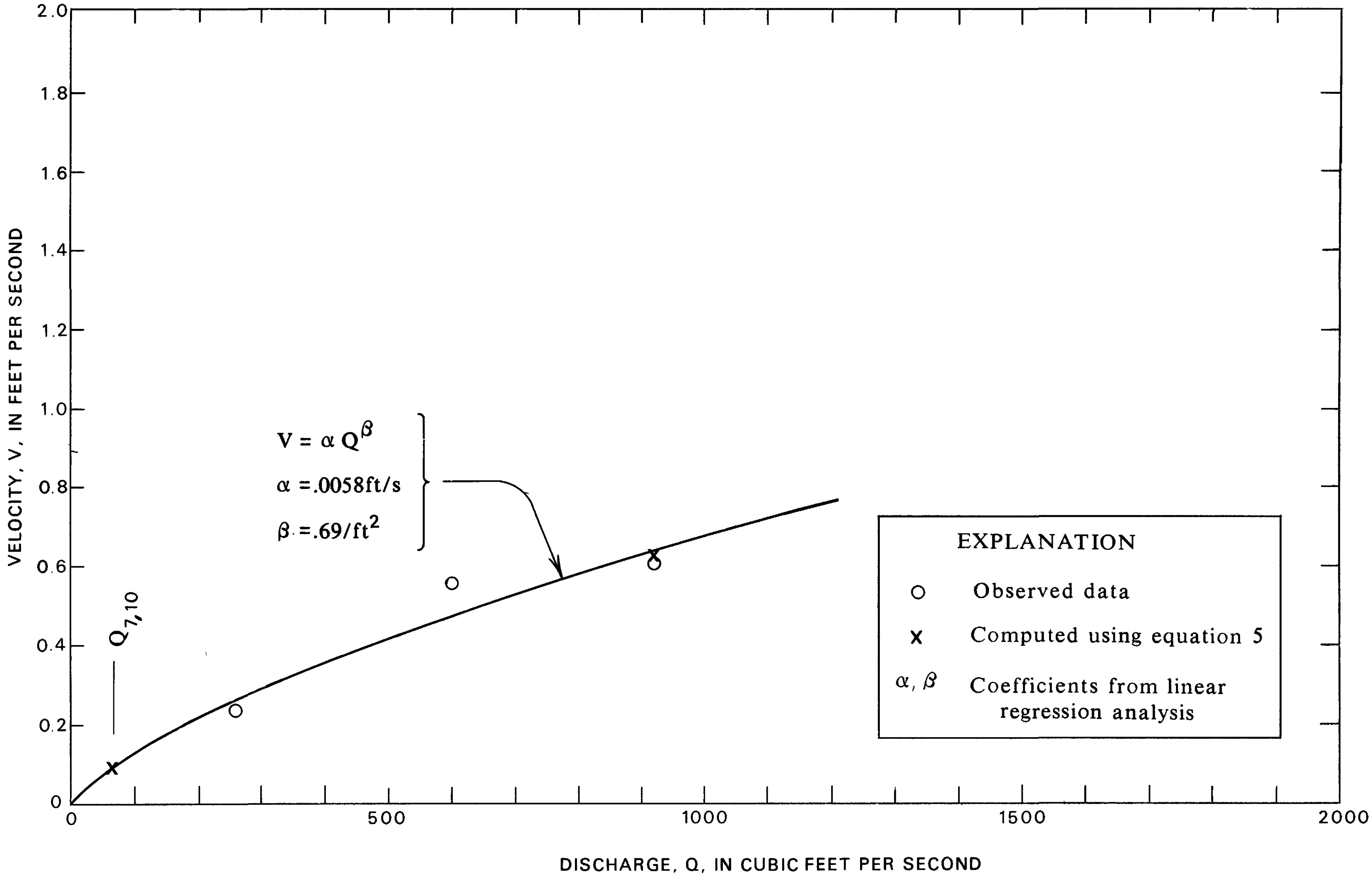


Figure 15. Velocity-discharge curve, radiotracer reach VI.

The α coefficients for all the reaches were plotted against the respective water-surface slopes (fig. 16). Slopes were based on water-surface elevations at sampling stations determined by field surveys. The α and slope data subsequently were used in a regression analysis to develop a relationship of the form

$$\alpha = \gamma S^{\delta} \tag{2}$$

where: α is the empirical coefficient as defined in equation 1;

S is the reach water-surface slope; and

γ and δ are coefficients determined by linear regression analysis. Equation 2 then took the form

$$\alpha = 0.0075 S^{0.203}. \tag{3}$$

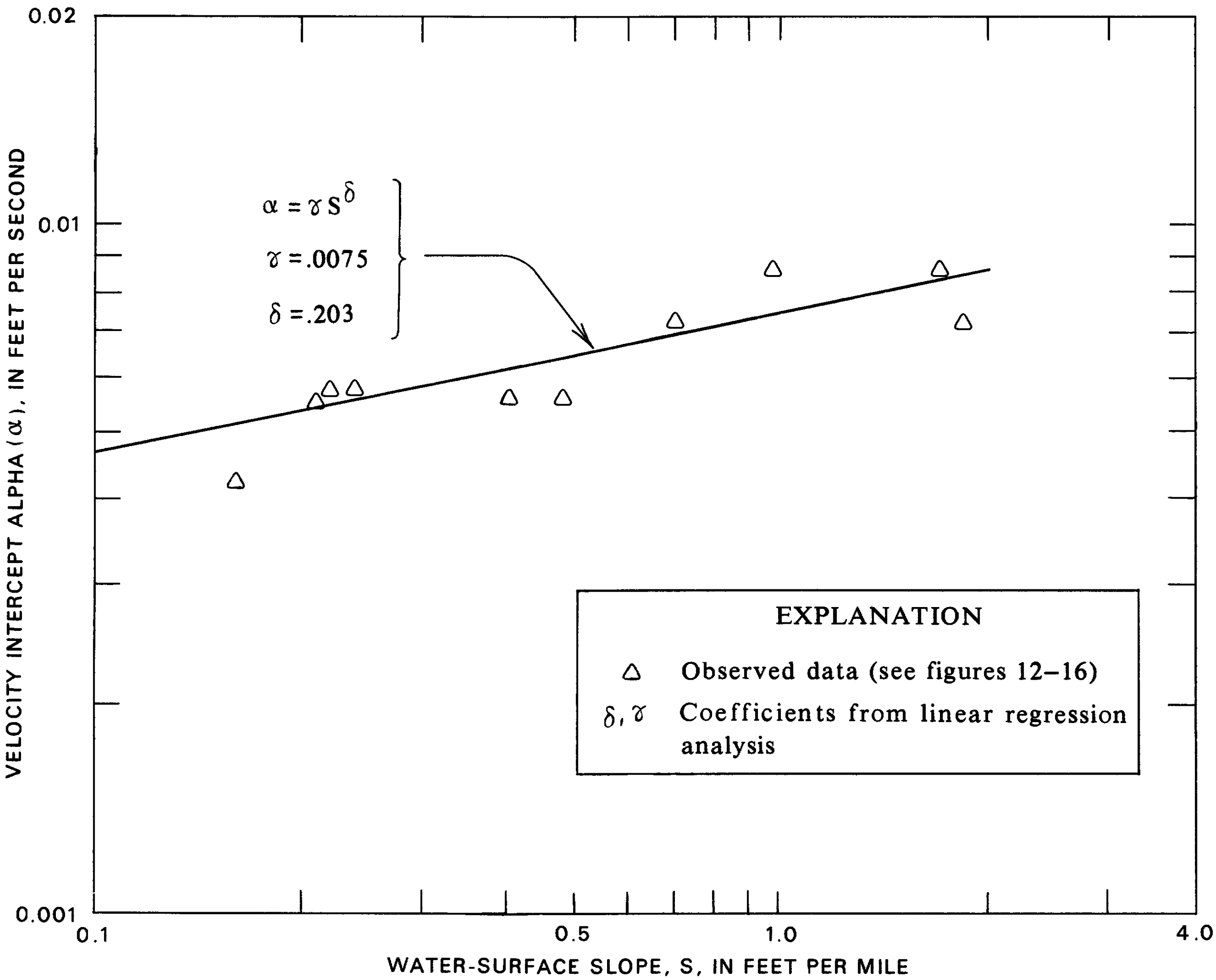


Figure 16. Alpha-slope relationship.

The coefficient β in equation 1 was very nearly 0.7 in the five reaches where it was determined (figs. 11-15) and was accepted, therefore, as a constant in this analysis. Consequently, equation 1 took the form

$$V = 0.0075S^{0.203}Q^{0.7}. \qquad (4)$$

Equation 4 was then modified to

$$V = 0.0075 \left(\frac{\Delta h}{L}\right)^{0.203} Q^{0.7} \qquad (5)$$

where: V is average velocity through the reach, in feet per second;

$\frac{\Delta h}{L}$ is reach slope, in feet per mile;

Δh is the change in water-surface elevation in the reach, in feet;

L is the length of the reach, in miles; and

Q is average discharge in the reach, in cubic feet per second.

To test the validity of equation 5 for general use in the lower Rock River, it was used to compute velocities for the reaches where velocities had been measured by dye studies. The computed velocities, when plotted on the appropriate graphs, closely approximated those measured (figs. 11-15).

Velocities during the $Q_{7,10}$ ($V_{7,10}$) then were computed using equation 5 and plotted on the respective graphs (figs. 11-15). The $V_{7,10}$ computed by equation 5 plots relatively close to the individual reach curves.

The water-surface slope used in equation 5 to compute $V_{7,10}$ was based on the estimated water-surface profile for the lower Rock River during the $Q_{7,10}$ (fig. 17). The profile is based on historical water-surface-elevation data for low-flow conditions, and on the elevations of controlling channel bars and impoundment pools.

Based on the preceding analysis, equation 5 was assumed to be adequate for estimating velocity through the free-flowing reaches and impoundments in the lower Rock River between Lake Koshkonong and Rockton.

Traveltime in the lower Rock River then was computed using the relationship

$$T = \frac{L}{V} \qquad (6)$$

where: T is traveltime through a reach;

L is reach length; and

V is average velocity in the reach.

Equation 5 was substituted into equation 6 and then velocity was converted to miles per day, yielding the relationship

$$T = 0.061\ L\{0.0075\ (\frac{\Delta h}{L})^{0.203} Q^{0.7}\}^{-1} \qquad (7)$$

where: T is traveltime through a reach, in days;

L is reach length, in miles;

Δh is drop in water-surface elevation in reach, in feet; and

Q is average discharge in reach, in cubic feet per second.

Equation 7 then was used to compute traveltime during the $Q_{7,10}$ on the lower Rock River from Lake Koshkonong to the dam in Rockton, Ill. Figure 18 is a plot of traveltime versus distance.

REAERATION-RATE COEFFICIENTS

A predictive model was used to estimate reaeration-rate coefficients (K_2) for the $Q_{7,10}$ discharge for the Rock River from Lake Koshkonong to Rockton, Ill. The model was calibrated using radioactive-tracer measurements of K_2 in selected reaches of the river.

MEASURED REAERATION-RATE AND ESCAPE COEFFICIENTS

Reaeration-rate coefficients were measured on six reaches of the Rock River between September 22 and October 3, 1975, (figs. 1-7) using the radioactive-tracer method developed by Tsivoglou (1967).

During the tracer studies, data were collected for calibration of the energy-dissipation model developed by Tsivoglou and Wallace (1972). The model takes the form

$$K_2 = C\frac{\Delta h}{T} \qquad (8)$$

where: K_2 is the base e reaeration-rate coefficient;

Δh is the change in water-surface elevation in the stream reach;

T is the time of flow through the reach; and

C is the escape coefficient.

K_2, Δh, and T were measured during the field studies and subsequently C was computed. These and other related data are presented in table 1. The escape coefficient C ranged from 0.058 to 0.061 per foot at 25°C for all but the two segments of the river affected by spillway aeration or high winds. The escape coefficients computed closely agree with those measured by Tsivoglou and Wallace (1972) during other studies on large streams.

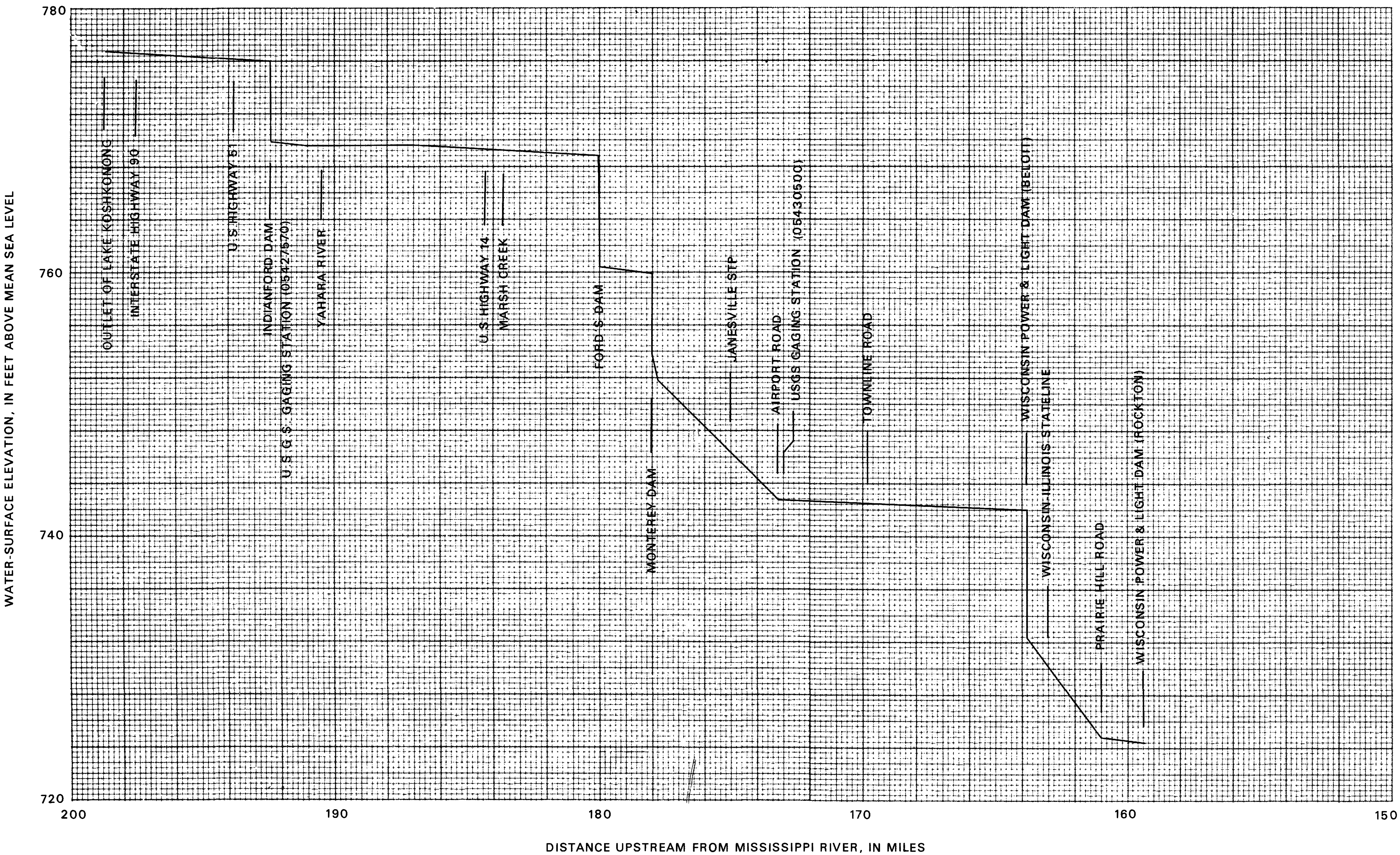


Figure 17. Estimated $Q_{7,10}$ water-surface profile.

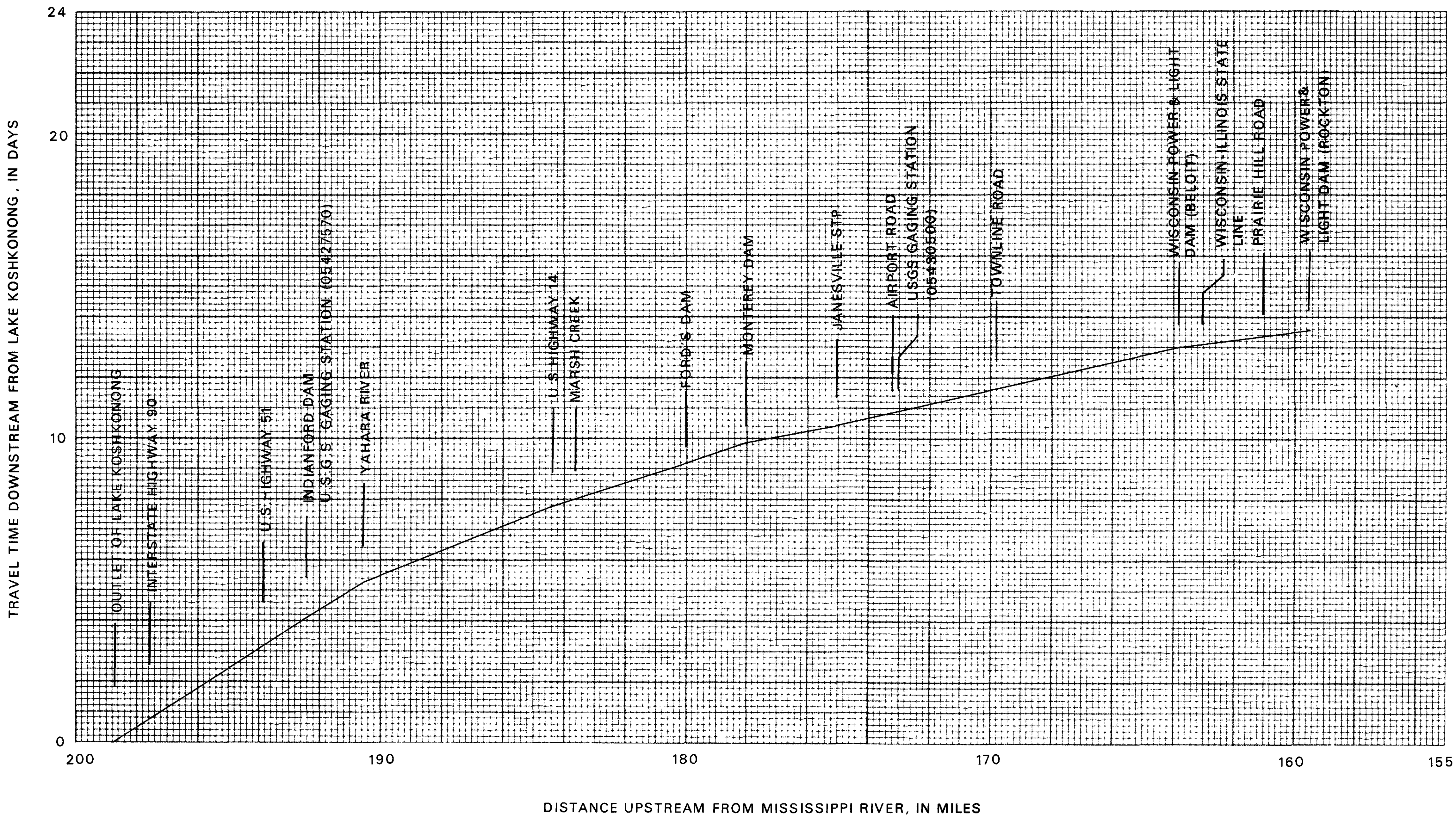


Figure 18. Time of travel for the $Q_{7,10}$.

Tsivoglou (1976, p. 2,686) recommended that the following C values be used at 20°C for streams discharging at the following levels:

C	Stream discharge
0.054 per foot (0.060 at 25°C)	25 - 3,000 ft^3/s*
0.110 per foot (0.124 at 25°C)	1 - 10 ft^3/s**
0.025 - 0.030 per foot	For large, heavily polluted streams

Tsivoglou (1976, p. 2,686) reported that in 577 observations on streams discharging more than 25 ft^3/s, "C" ranged from 0.011 to 0.118 per foot at 20°C, with 80 percent of the results falling within the range 0.03 to 0.08 per foot. Some escape coefficients for the Rock River differed significantly from 0.054 per foot at 20°C, mostly because of wind and spillway effects which are discussed in the following paragraphs.

Strong winds apparently increased the escape coefficient about 40 times in segment 1-2 of reach VI (fig. 7) the day of the radiotracer study. Winds of about 17 mi/h were blowing up the river channel. Wind-generated wave heights were about 2 to 4 in. The force of the wind kept anchored boats upstream from the anchors. The reach was shallow enough that navigation during the fieldwork was very difficult because the outboard boat motors continually struck bottom. The river width ranged from about 500 to 700 ft. Because of strong winds, shallow depths, and wide widths, vertical mixing of the river waters in this reach apparently occurred much more rapidly than on days with light winds as indicated by the measured escape coefficient C of 2.28 per foot at 25°C.

Segment 2-3 of reach IV (fig. 5) extends from the upstream side of the Monterey Dam into a rapids downstream from the dam. A relatively high escape coefficient of 0.094 per foot at 25°C was measured in this segment because of lower nappe aeration and the great turbulence at the downstream side of the dam and in the downstream rapids.

At the Indianford Dam in reach VI (fig. 7), the flow over the spillway crest was shallow and uniform. Depth on the downstream face of the spillway and the apron was less than 0.1 ft. The lower nappe clung to the surface of the spillway eliminating the possibility of significant lower nappe aeration. Hulsing (1967) stated that in such cases, "... the weir crest becomes a reach of open channel in which frictional resistance predominates, and for which the discharge is more properly evaluated by one of the open-channel flow formulas than by a weir formula." Thus the measured C of

*For "moderately polluted and reasonably well-mixed" streams where steady, uniform open-channel flow conditions prevail.

**For stream "segments that are moderately polluted".

Table 1.--Measured reaeration-rate coefficients and hydrologic data

Reach	Segment	K_2 per day		C	Δh	time
		Measured	at 25°C	(at 25°C)	(ft)	(h)
I	1-3	1.60	1.94	0.058	8.05	5.75
	1-2	3.26	4.00	.061	7.37	2.70
	2-3	.1	.2	-----	.68	3.05
II	1-3	.2	.2	.06	.97	6.43
III	1-3	.81	.98	-----	----	4.57
	1-2	1.6	1.9	-----	----	2.87
	2-3	0	0	-----	----	1.70
IV	1-3	2.5	3.1	-----	----	4.85
	1-2	.4	.5	-----	----	3.93
	2-3	39	49	.094	7.41	.3
V	1-3	<.4	<.5	-----	----	8.82
	1-2	.4	.5	-----	----	2.75
	2-3	-----	-----	-----	----	6.07
VI	1-3	1.76	2.21	2.28	.44	10.88
	1-2	-----	-----	-----	----	5.80
Indianford Dam	Spillway	4,400	5,700	.06	5.97	.001
Montery Dam	Spillway	-----	-----	-----	6.0	------

Table 1.--Measured reaeration-rate coefficients and hydrologic data--Continued

Mean water temperature (°C)	Wind speed (mi/h)	Segment length (mi)	Slope (ft/mi)	Velocity (ft/s)	Discharge (ft^3/s)
16.2	---	4.4	1.8	1.1	790-870
15.6	---	2.8	2.6	1.5	790-870
16.8	3.2	1.6	.4	.76	870
15.1	[1]5.6	3.6	.3	.82	860
15.9	---	4.7	1.7	1.5	820
15.4	[2]1.6	2.9	2.2	1.5	820
16.7	---	1.8	.8	1.6	820
14.8	---	2.1	[3]3.5	.64	1,030
14.8	---	1.9	[3].5	----	1,030
14.8	---	.2	---	----	1,030
13.0	---	2.8	---	.47	520
14	[4]	1.2	---	.64	520
----	[4].2	1.6	---	.38	520
14.5	[5]	1.8	.2	.25	260
14.2	[5]	1.0	---	----	260
13.0	---	---	---	----	260
----	---	---	---	----	1,030

[1]Average wind speed at station 2 while in operation. Wind was blowing upstream producing 2-in waves. Wind meter not operated at station 3. Wind was still blowing hard when tracers reached station 3, but direction had changed to north to northeast.

[2]Average wind speed at station 2 while in operation. Water surface like glass at station 3.

[3]Rounded to nearest 0.5 ft.

[4]Wind blew down channel at station 2 while in operation producing 2-in waves. Wind speed declined to 0.2 mi/h at station 3 later in day.

[5]No wind-meter data. However, wind blowing hard up channel producing 2- to 4-in waves. Boats were blown upstream from anchors. Weather Bureau in Madison reported wind speeds of 17 mi/h from azimuth 210° during tracing period.

0.060 per foot at 25°C appears realistic given the prevalence of steady, uniform open-channel flow conditions.

Based upon measurements, an escape coefficient C = 0.060 per foot at 25°C with light breezes can be applied for the entire study reach between Lake Koshkonong and Rockton, except in the short segments affected by spillway aeration.

PREDICTED REAERATION-RATE COEFFICIENTS

Reaeration-rate coefficients were calculated for the $Q_{7,10}$ using the energy-dissipation model (equation 8) and the traveltime model (equation 7). Estimates of water-surface elevation for the $Q_{7,10}$ were used with an escape coefficient of C = 0.060 per foot at 25°C. It is possible that a smaller escape coefficient would be more accurate for the sluggish flow conditions that would prevail during the $Q_{7,10}$. However, there is no documented means available at this time to make such an adjustment.

The model for time of travel (equation 7) was substituted for the T in the energy-dissipation model (equation 8). The energy-dissipation model then took the form

$$K_2 = C\ \Delta h(0.061L)^{-1} 0.0075\left(\frac{\Delta h}{L}\right)^{0.203} Q^{0.7} \qquad (9)$$

where: K_2 is the average base e reaeration-rate coefficient per day for a reach;

C is the escape coefficient, per foot;

Δh is the change in water-surface elevation in the reach, in feet;

L is the reach length, in miles; and

Q is the average discharge in the reach, in cubic feet per second.

The K_2 values computed using equation 9 for the $Q_{7,10}$ are presented in table 2 with other data used in the analysis. Accuracy of equation 9 is dependent upon the limitations of the energy-dissipation model (p. 25) and the velocity model (figs. 11-15). Because no attempt was made to incorporate wind effects into the predictive model, the estimated reaeration coefficients for the $Q_{7,10}$ are valid only for very light wind conditions.

The K_2 data in table 2 do not include estimates of spillway aeration. During low-flow conditions, the entire flow of the Rock River can pass through turbines at Ford's Dam in Janesville and at the Wisconsin Power and Light Dams in Beloit and Rockton with probably very little aeration occurring. However, significant spillway discharge occurs at the Indianford and Monterey Dams. Reaeration over these spillways may be computed using the equation

$$D_u - D_D = \lambda \Delta h D_u \qquad (10)$$

where: D_u is the dissolved-oxygen deficit at the upstream side of the spillway;

D_D is the dissolved-oxygen deficit downstream from the spillway;

Δh is the drop in water-surface elevation over the spillway; and

λ is an empirical coefficient based on dissolved-oxygen measurements at a specific spillway.

SUMMARY AND CONCLUSIONS

Reaeration-rate coefficients (K_2) were measured in the Rock River between Indianford, Wis., and Rockton, Ill., using the radioactive-tracer method. The data collected were used to calibrate the energy-dissipation model, $K_2 = C \frac{\Delta h}{T}$, which in turn was used to predict K_2's for the $Q_{7,10}$. The K_2's predicted are generally very small, ranging from about 0.01 to 0.09 per day at 25°C (base e) for 32 of the 39 mi of the study reach. A few significant rapids increased the average K_2 in the remaining sections of the study reach to about 0.8 per day at 25°C.

The $Q_{7,10}$ estimates and the associated reaeration-rate coefficients for the Rock River upstream from the Afton gaging station are considered tentative until more adequate data become available at the Indianford gaging station. Currently, the $Q_{7,10}$ at Indianford is estimated to be 69 ft^3/s.

A time-of-travel model was developed for the study reach, input requirements being river discharge and slope. Based on the model, low-flow velocities will be relatively small through most of the study reach, averaging approximately 0.2 ft/s during the $Q_{7,10}$. Because of the small velocities caused by the presence of the five dams, most of the lower Rock River is like a long, narrow lake during summer low-flow periods. Turbulence and, consequently, reaeration is so small, that the oxygen produced in the stream during the day by photosynthesis, at times approaching supersaturation levels, cannot readily escape to the atmosphere at night. Thus, in some locations, summer nighttime dissolved-oxygen concentrations may not fall to critical levels even though plant respiration is occurring. The resulting daily dissolved-oxygen fluctuations are perhaps more characteristic of a lake than a river.

Insufficient data were collected to analyze the effects of wind on reaeration in the study reach. In one reach, strong winds apparently increased the reaeration-rate coefficient about 40 times. However, because of the sinuous path of the river, its narrow width, and its generally high wooded banks, a wind of given speed and direction will not equally affect gas exchange at the water surface throughout the study reach. One segment will be more affected than another, to an indeterminate degree. Also,

Table 2.--Predicted reaeration-rate coefficient data for $Q_{7,10}$

Reach	K_2 per day ($25^{\circ}C$)	Time of travel (days)	Δh (ft)	Average discharge (ft^3/s)	Reach length (mi)
Outlet Lake Koshkonong to Indianford Dam	0.010	4.1	0.7	69	6.3
Indianford Dam to Yahara River	.016	1.2	.3	69	1.9
Yahara River to U.S. Highway 14	.010	2.5	.4	160	6.2
U.S. Highway 14 to Ford's Dam	.016	1.5	.4	175	4.3
Ford's Dam to Monterey Dam	.042	.6	.4	190	2.0
Monterey Dam to Janesville sewage-treatment plant	.68	.5	6.0	195	3.0
Janesville sewage-treatment plant to Wisconsin Power and Light Dam (Beloit)	.093	2.6	4.0	220	11.2
Wisconsin Power and Light Dam (Beloit) to Wisconsin Power and Light Dam (Rockton)	.82	.6	8.0	300	4.4

because of the unpredictability of wind direction, duration, or occurrence, an analysis of wind effects on reaeration was not considered justified in this study.

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RADIOTRACER DATA

The following table contains radiotracer data not included in the main body of the report. The quantities of radiotracers injected into the Rock River are presented, along with resulting downstream maximum concentrations. The ratio $^{85}Kr/^{3}H$, which was used to compute the reaeration coefficient K_2, also is tabulated for each sampling station.

Table 3.--Radiotracer data

Reach	Dosage (curies)		Segment	$^{85}Kr/^{3}H$		Downstream concentration ($\mu Ci/ml \times 10^{-5}$)	
	^{85}Kr	^{3}H		Upstream end	Downstream end	^{85}Kr	^{3}H
I	2.0	1.0	1-2	1.494	1.207	1.541	1.277
			2-3	1.207	1.189	.909	.765
II	3.5	2.0	1-2	1.364	1.323	1.807	1.366
			2-3	1.323	1.309	1.532	1.170
III	4.0	2.0	1-2	1.757	1.504	6.514	4.330
			2-3	1.504	1.547	4.923	3.183
IV	2.5	1.0	1-2	2.143	2.040	1.753	.860
			2-3	2.040	[1]1.285	.626	.487
			1-3	2.143	1.343	1.343	1.000
V	3.5	2.0	1-2	1.411	1.357	13.1	9.66
			2-3	1.357	1.433	3.570	2.492
VI	2.5	1.5	1-2	1.083	.338	.969	2.865
			2-3	.338	.559	1.022	1.864

[1]Ratio for tracers that flowed only over spillway on main channel of river.