REPORT ON HYDROGRAPHIC STUDIES OF THE MISSISSIPPI, MINNESOTA, & ST. CROIX RIVERS

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
TWIN CITIES-UPPER MISSISSIPPI RIVER PROJECT

DECEMBER, 1965

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INTRODUCTION

This document represents an accumulation of individual reports prepared on the hydrographic aspects of the rivers within the Project's study area for utilization with data characterizing the quality of these waters. The individual reports have been redesignated herein as chapters and have been numbered sequentially for the readers benefit.

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CHAPTER I

HYDROGRAPHS

INTRODUCTION

Hydrographs of the average daily discharge at various gaging stations on the Mississippi, Minnesota and St. Croix Rivers within the Project study area are presented in this chapter. Eight stations have been selected such that the flow occurring in any segment of any of the streams under study may be determined. The average daily discharges are presented for the period of the Project's routine and intensive surveys from April 20, 1964, through September 30, 1965.

OBJECT

These hydrographs are presented in order that instantaneous pollution loadings and assimilative capacities of the rivers may be determined, and so that the general conditions of flow occurring during the period of survey may be compared with predicted conditions of average and drought flow.

GENERAL INFORMATION

In selecting appropriate gaging stations to adequately represent the numerous segments of stream under study, several factors were considered and some simplifying assumptions were required. Only dams, lock & dam combinations and gaging stations where consistent, daily records are maintained were considered. Their location relative to reaches of stream of particular interest to the Project and their location relative to significant tributaries were also important considerations. The availability of particular records at an early date was a factor in selecting

the stations as well as in selecting the source of the data. For example, two agencies often keep records for the same gaging station, but the data were obtained from the agency which was able to provide the information at the earliest time.

STATIONS SELECTED

Hydrographs are presented for the selected gaging stations by the following Figures:

I-1. Rum River near St. Francis, Minnesota

I-2. Mississippi River at Lock & Dam #1

I-3. Minnesota River near Carver, Minnesota

I-5. Minnesota River at Mankato, Minnesota

I-7. Mississippi River at St. Paul, Minnesota

I-8. St. Croix River at St. Croix Falls, Wisconsin

I-9. St. Croix River at Stillwater, Minnesota

I-10. Mississippi River at Lock & Dam #3

The exact location of the gaging station, the method of measurement, the data source, its reliability and the segments of stream to which it may be applied are discussed below. When applying a point discharge to several miles of stream it is recognized that runoff and groundwater contributions, usually occur along that stream segment. Unless specially noted these contributions are considered negligible as a percent increase of the main stream flow. Where a significant change does occur, provisions for adjustment are provided. Such is the case on the Minnesota River.

In describing the accuracy of the stream flow data, "excellent" indicates that, in general, the error in the daily records is believed to be less than 5 percent; "good", less than 10 percent; and "fair",

less than 15 percent.

Unpublished records provided by the U. S. Geological Survey (U.S.G.S.) are provided to the Project on a provisional basis but are rated for accuracy herein in accordance with the history of the record.

St. Francis - Figure I-1

Records for the Rum River near St. Francis are provided by the U. S. Geological Survey in a provisional basis for water years 1964 and 1965. The site is located on the right* bank at the upstream side of a highway bridge, 4 miles south of St. Francis, Minnesota and 15 3/4 miles upstream from the mouth. The gage is a water stage recorder, and the records are good except for periods of ice effect during which they are fair. These flows may be applied to the Rum River from its mouth upstream to the gage. It may also be subtracted from the flow at Lock & Dam #1 to obtain the Mississippi River flow above the confluence of the Rum River. In making such a subtraction, the Rum River flow for the day in question may be subtracted from the Lock & Dam #1 flow for the same day.

Lock & Dam #1 - Figure I-2

The flow record of the Mississippi River at Lock & Dam #1 is provided by the U. S. Corps of Engineers (U.S.C.E.) for the period of the Project survey. Lock & Dam #1 is located at Mississippi River mile UM 847.6 (UM 0.0 is at the confluence of the Ohio and Mississippi Rivers). The Ford Motor Company operates a hydroelectric plant at this site; and flow is determined by them by means of headwater and generator ratings and supplied

* In keeping with the U.S.D.H.E.W., F.W.P.C.A. STORET System, right and left are determined by facing upstream.

to the U.S.C.E. several times a day. The record is excellent. These flows may be applied to the Mississippi River from just above the mouth of the Minnesota River (UM 844.0) upstream to just below the mouth of the Rum River (UM 871.4). Lock & Dam #1 flows normally agree closely with flows recorded at the Coon Rapids Dam (UM 866.2).

Mankato - Figure I-3

Records for the Minnesota River at Mankato, Minnesota are provided to the Project by the U.S.G.S. on a provisional basis for water years 1964 & 1965. The gage site is located on the right bank at the downstream side of the Main Street Bridge in Mankato, 1.8 miles downstream from the Blue Earth River at MN 106.4. The gage is a water stage recorder and the records are good except for periods of ice effect during which they are fair. There is some diurnal fluctuation at low and medium stages caused by power plants on the Blue Earth River. These flows are used in conjunction with the record of the Carver gage to determine Minnesota River flows between MN 106.4 and MN 36.0 and may be applied directly to the Minnesota River from MN 106.4 upstream to the mouth of the Blue Earth River (MN 109.3).

In order to best define the flow occurring at any point between the Mankato and Carver gages, a graphical method is provided in Figure I-6 by which the two flows may be prorated. Again a linear increase in flow may be assumed between the two stations (MN 106.4 to MN 36.0) because of numerous small streams and springs located along this stream segment. No single source is significant in itself. To determine the flow at any point between the two stations for a particular day the flows at Mankato and Carver are used for the same day. It is recognized that since the two stations are 70 miles apart, the degree of accuracy may be reduced because changes in flow do not take place simultaneously at the two gaging stations. The effect, however, would be slight except midway between the stations when the flow regime is greatly altered within one or two days. Even under these circumstances the degree of accuracy would not be less than that of either of the two gaging stations.

Carver - Figure I-4

Records for the Minnesota River near Carver, Minnesota are provided by the U.S.G.S. on a provisional basis for water years 1964 and 1965. The site is located on the right bank 2 1/2 miles south of Carver at Minnesota River mile MN 36.0 (MN 0.0 is at the confluence of the Minnesota and Mississippi Rivers). The gage is a water stage recorder, and the records are good except for periods of ice effect, which are fair. These flows may be applied to the Minnesota River from its mouth upstream to the gage (MN 36.0).

If a more accurate description of the flow condition is desired for stations below MN 36.0, the flow may be increased linearly such that from MN 36.0 to MN 0.0 the total added flow is 5 percent of the flow at MN 36.0 (Carver gage). This rule of thumb is utilized by engineers of the U.S.G.S. and U.S.C.E. and has been found to be the most generally applicable correction factor. It represents the total additions of groundwater and runoff, and may be applied linearly because of the numerous springs and streams located along the lower reaches of the Minnesota River. Figure I-5 provides a simple method of prorating this 5 percent correction over the 36 miles of river segment to determine the flow at any point from the flow at the Carver gage.

St. Paul - Figure I-7

Records for the Mississippi River at St. Paul, Minnesota are provided to the Project by the U.S.G.S. on a provisional basis for water years 1964 and 1965. The site is located at UM 839.3 on the left bank in St. Paul, 300 feet upstream from the Robert Street Bridge. The gage is a water stage recorder, and the records are good. There is slight regulation, except during extreme floods, by reservoirs on headwaters and by power plants. Beginning June 20, 1938, sewage from Minneapolis and St. Paul, which formerly entered above the station, was diverted to the Minneapolis-St. Paul Sanitary District sewage treatment plant, thence to the river below the station. Figures of daily discharge do not include this diversion. These flows may be applied to the Mississippi River from just above the mouth of the St. Croix River (UM 811.3) upstream to just below the mouth of the Minnesota River (UM 844.0).

If a more accurate description of the flow condition is desired below the outlet of the Minneapolis-St. Paul Sanitary District (MSSD) sewage treatment plant, the plant discharge may be added to the flow recorded at St. Paul and applied to the Mississippi River from UM 836.3 to UM 811.3.

St. Croix Falls - Figure I-8

Records for the St. Croix River at St. Croix Falls, Wisconsin are provided by the Northern States Power Company (NSP), which operates a hydroelectric plant there at St. Croix River mile SC 52.5 (SC 0.0 is at the confluence of the St. Croix and Mississippi Rivers). Flow is computed on the basis of gate openings, head, and plant efficiency, and the records are good. The flow is regulated by another power plant farther upstream. However, fluctuations are moderate and of a short duration, thereby not significantly altering the average daily flow.

Flows at St. Croix Falls may be applied to the St. Croix River from SC 44.8 upstream to the falls (SC 52.5).

Stillwater - Figure I-9

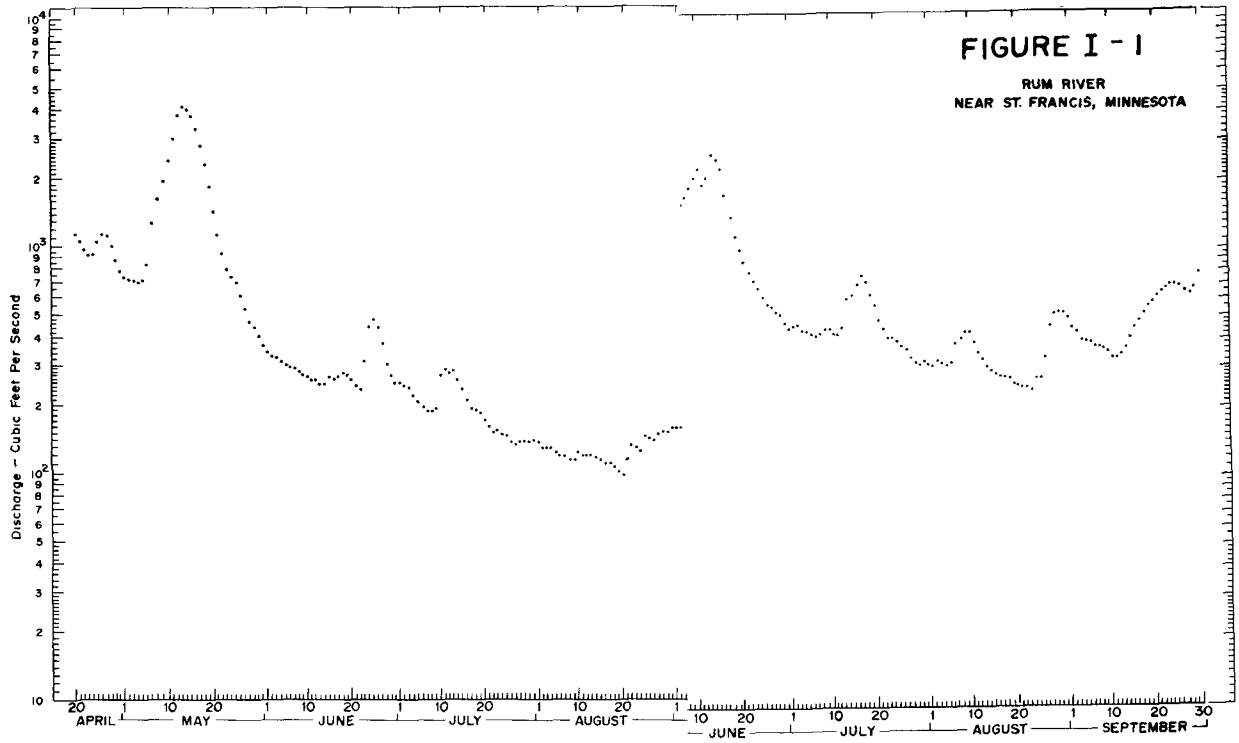
Records for the St. Croix River at Stillwater, Minnesota SC 23.3 are derived from the addition of the St. Croix River flow at St. Croix Falls, Wisconsin and the Apple River flow near Somerset, Wisconsin. The Apple River flow is measured at the NSP power plant 3.5 miles downstream from Somerset. Headwater and tailwater gages are read hourly and flow is computed on the basis of gate openings, head, and plant efficiency. Records are good except those below 100 cubic feet per second, which are fair. The flow is regulated by another power plant upstream. Both plants are classed as run of the river plants.

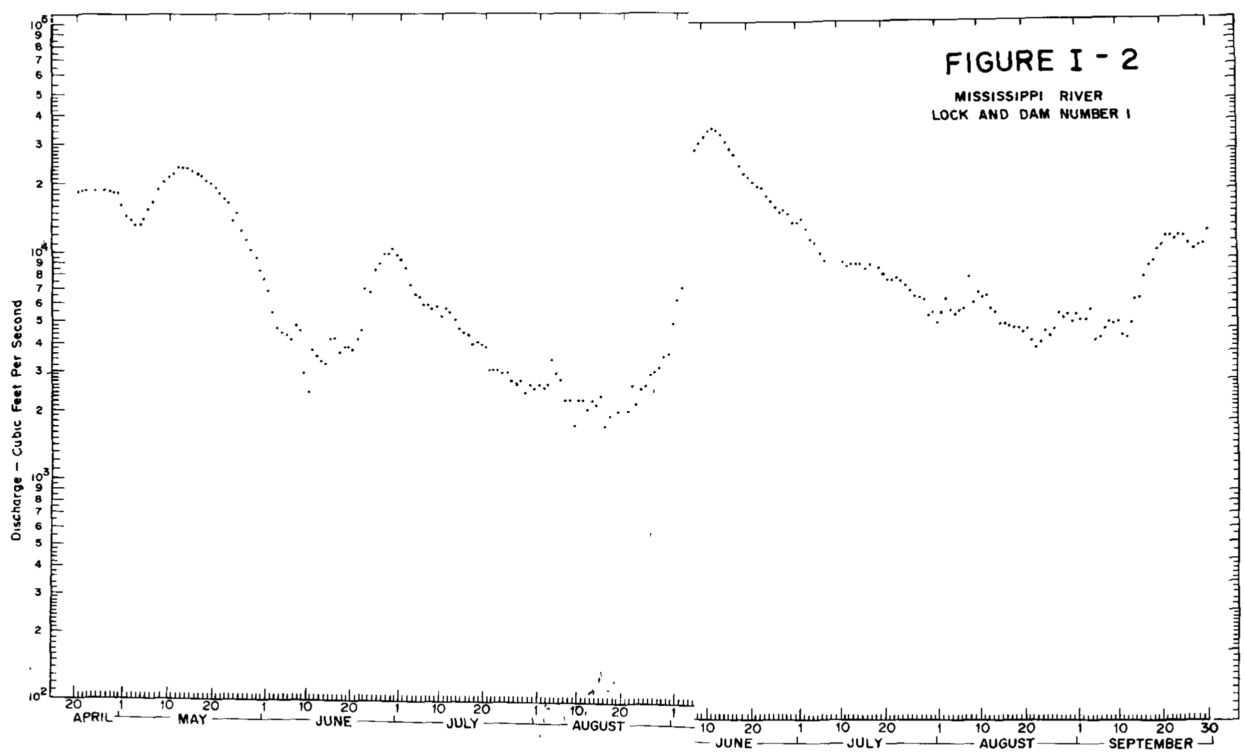
When adding these St. Croix and Apple River flows, they may not be added directly day by day. The St. Croix Falls flow recorded one day does not combine with the Apple River flow recorded near Somerset until the following day. The Somerset flow reached the St. Croix River the same day. Consequently, in combining these records, a one-day shift must be applied prior to addition. The resulting flow shortly reaches Stillwater (SC 23.3). Therefore, the daily flow at Stillwater has been recorded as the flow of the Apple River near Somerset for the same day. plus the flow at St. Croix Falls for the previous day.

This combined flow record may be applied to the St. Croix River from its mouth upstream to the mouth of the Apple River (SC 31.0).

Lock & Dam #3 - Figure I-10

The flow record of the Mississippi River at Lock & Dam #3 is provided by the U.S.C.E. for the period of the Project survey. Lock & Dam #3 is located at UM 796.9. The flow is determined from gate opening computations during normal and low flows and from tailwater ratings during high flows. The record is excellent and normally agrees closely with the U.S.G.S. gage at Prescott, Wisconsin just below the mouth of the St. Croix River. These flows may be applied to the Mississippi River from just above the mouth of the Chippewa River (UM 763.5) upstream to just below the mouth of the St. Croix River (UM 811.4).





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DAILY HYDROGRAPH
FOR PERIOD OF
WATER QUALITY STUDY
ʼRIL 1964 - SEPTEMBER 1965

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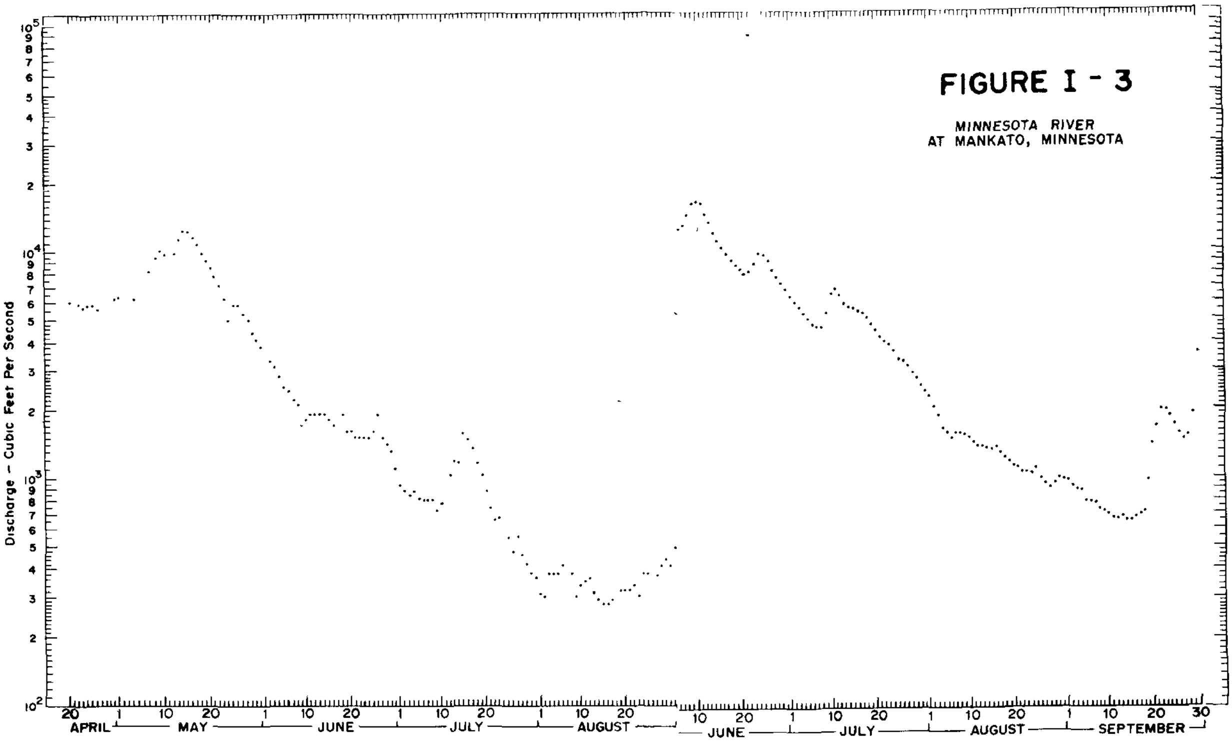

FIGURE I - 3

MINNESOTA RIVER
AT MANKATO, MINNESOTA

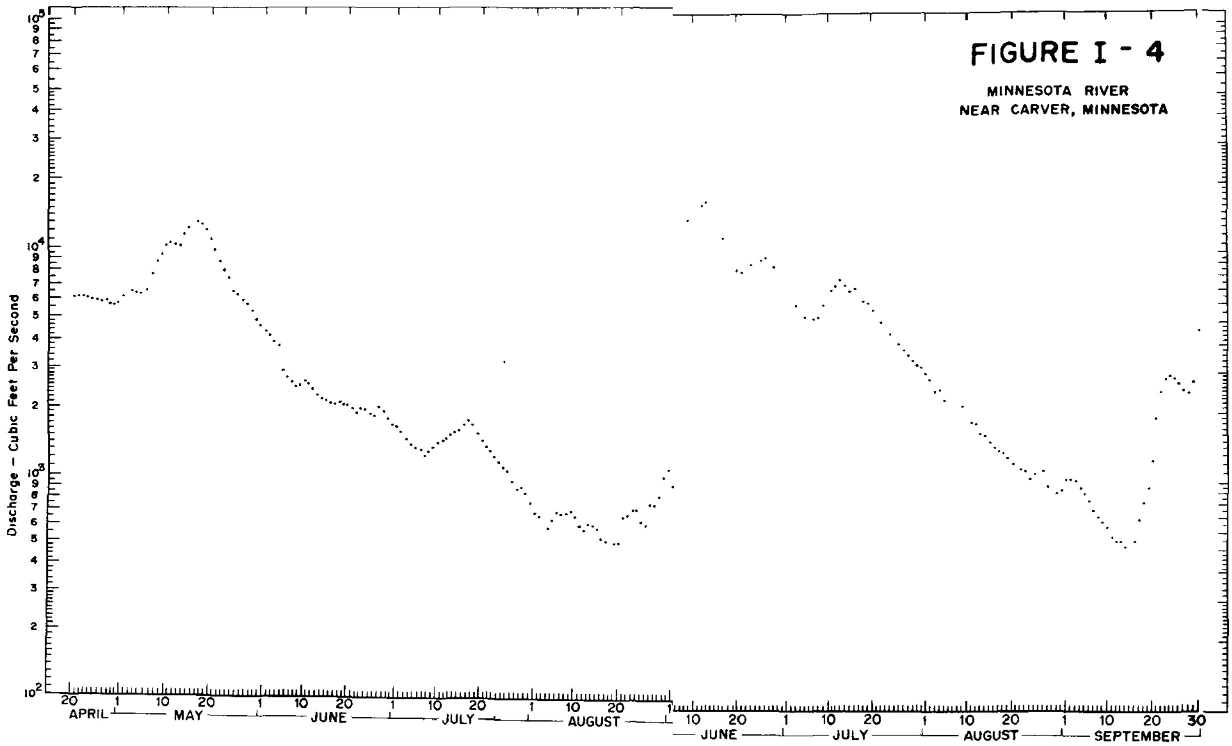

FIGURE I - 4

MINNESOTA RIVER
NEAR CARVER, MINNESOTA

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DAILY HYDROGRAPH
FOR PERIOD OF
WATER QUALITY STUDY
APRIL 1964 - SEPTEMBER 1965

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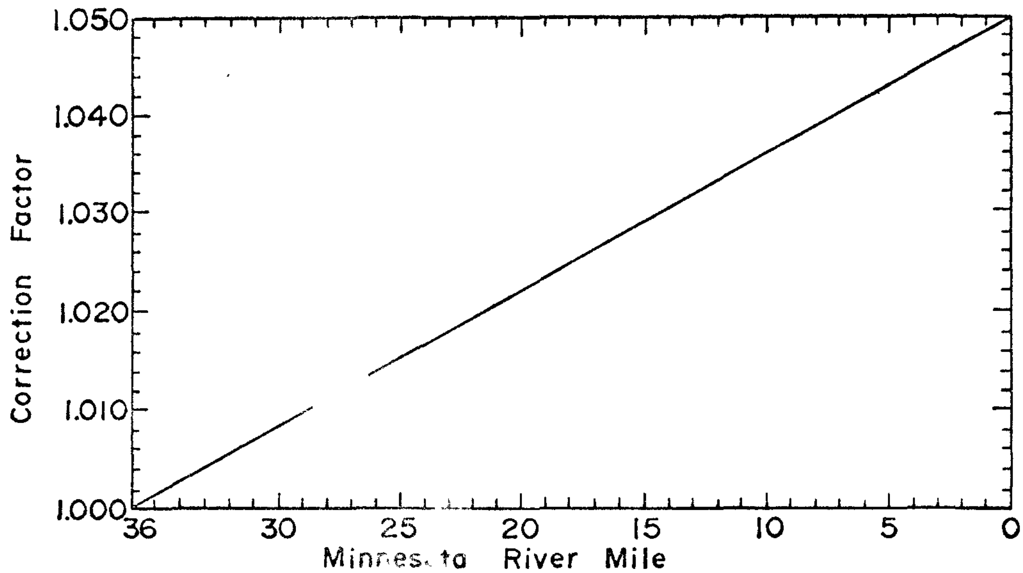

Flow at river mile N = flow at Carver gage x correction factor for river mile N

SAMPLING STATION CORRECTION FACTORS

Station	Correction
MN 1.9	1.047
MN 7.4	1.040
MN 10.8	1.035
MN 14.3	1.030
MN 16.8	1.027
MN 23.0	1.018
MN 25.1	1.015
MN 27.5	1.012
MN 29.6	1.009

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LOWER MINNESOTA

FLOW CORRECTION

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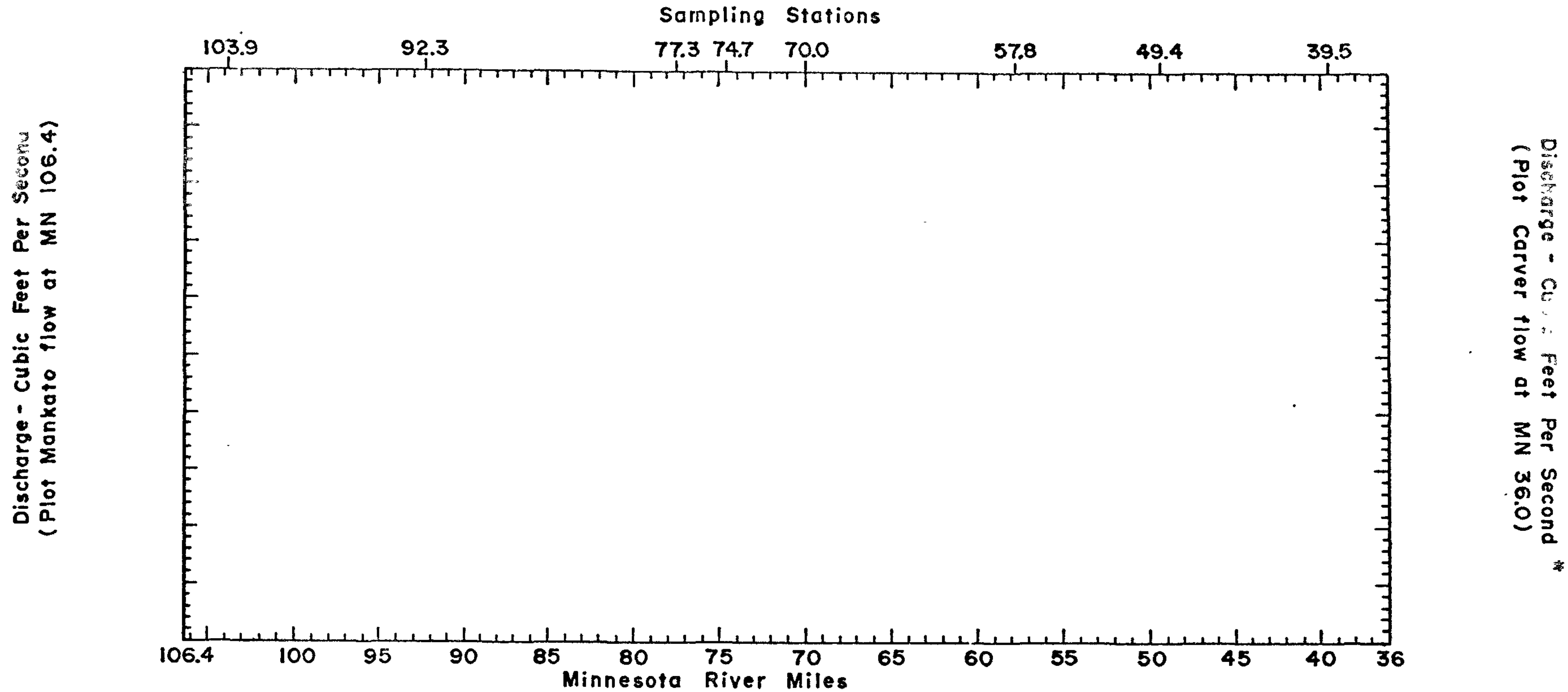
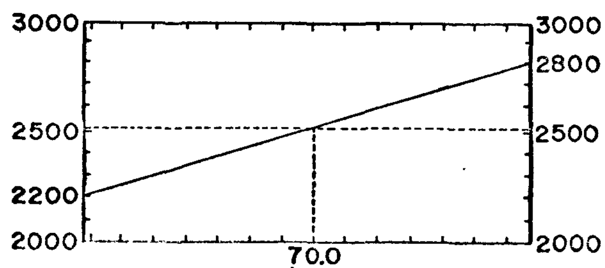
FIGURE I-[illegible]



Example:
Mankato - 2200 cfs
Carver - 2800 cfs
MN 70.0 - ?



Flow at
MN 70.0 = 2510 cfs

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MINNESOTA RIVER
MANKATO TO CARVER
PRORATED FLOWS

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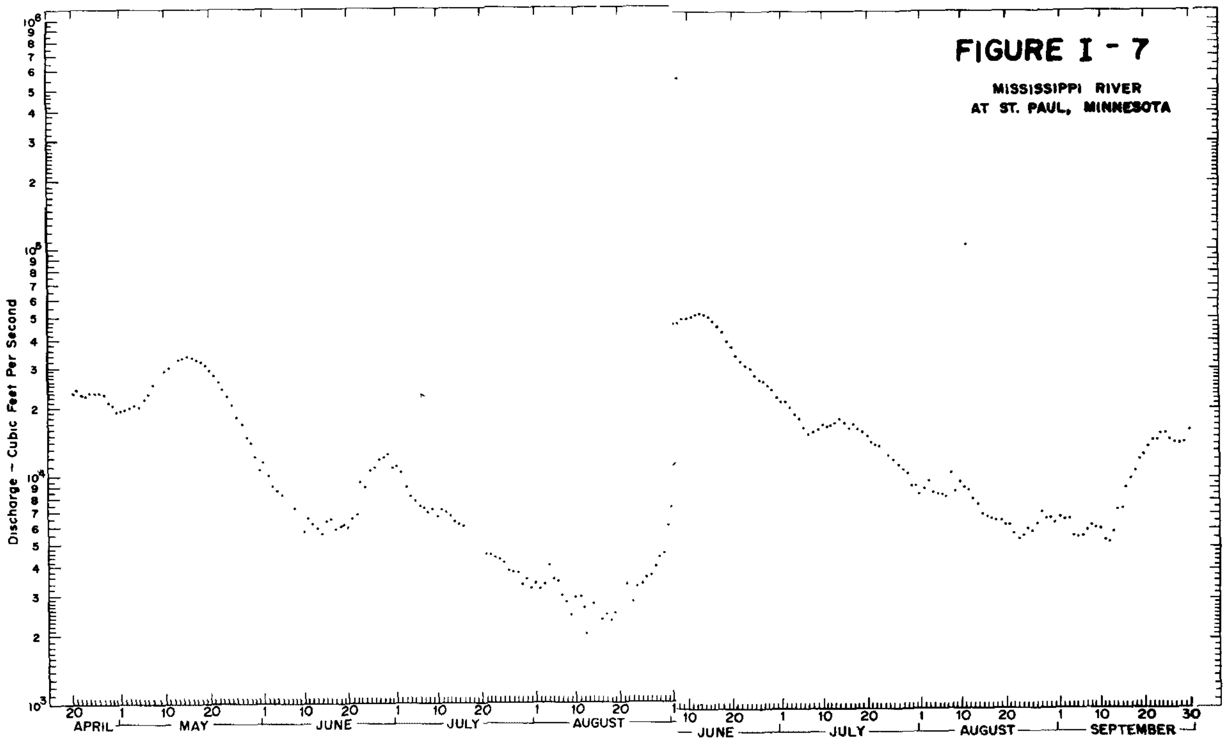
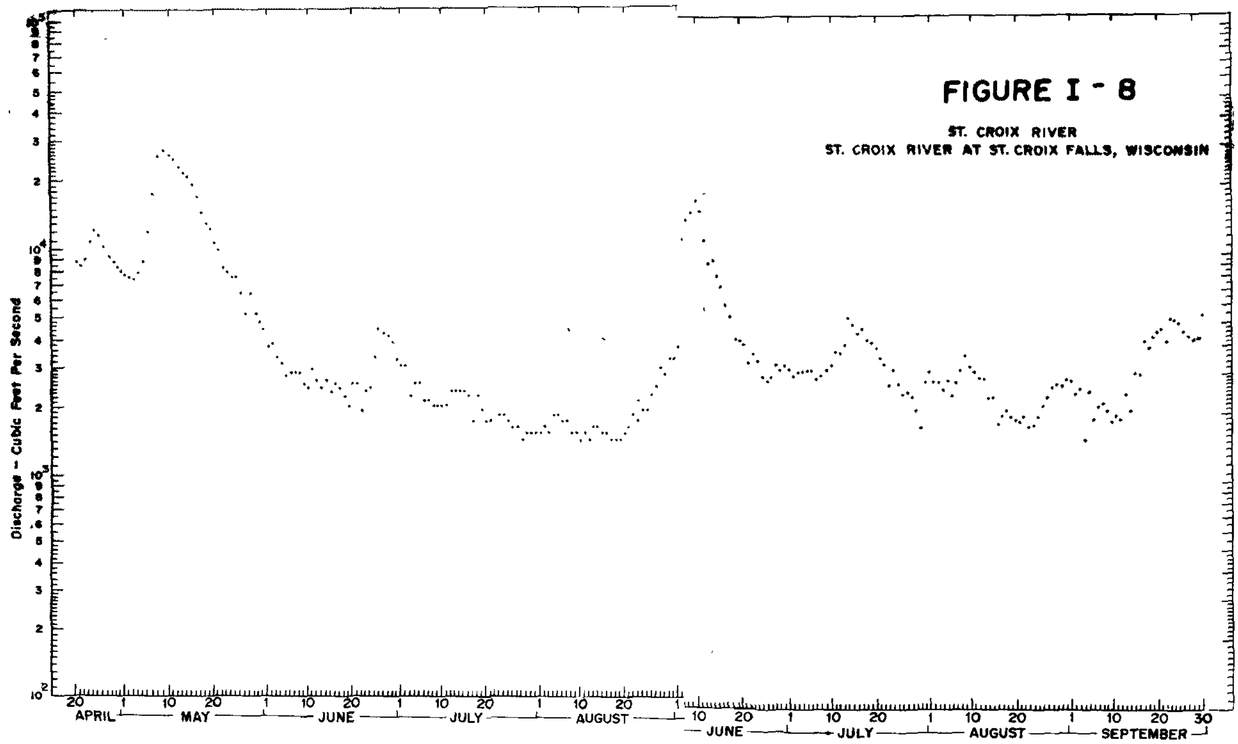
*Select appropriate scale to include Mankato and Carver, Minnesota, flows. The scal for Mankato and Carver must be identical. Plot flows for the same day.

FIGURE I-6





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DAILY HYDROGRAPH FOR PERIOD OF WATER QUALITY STUDY
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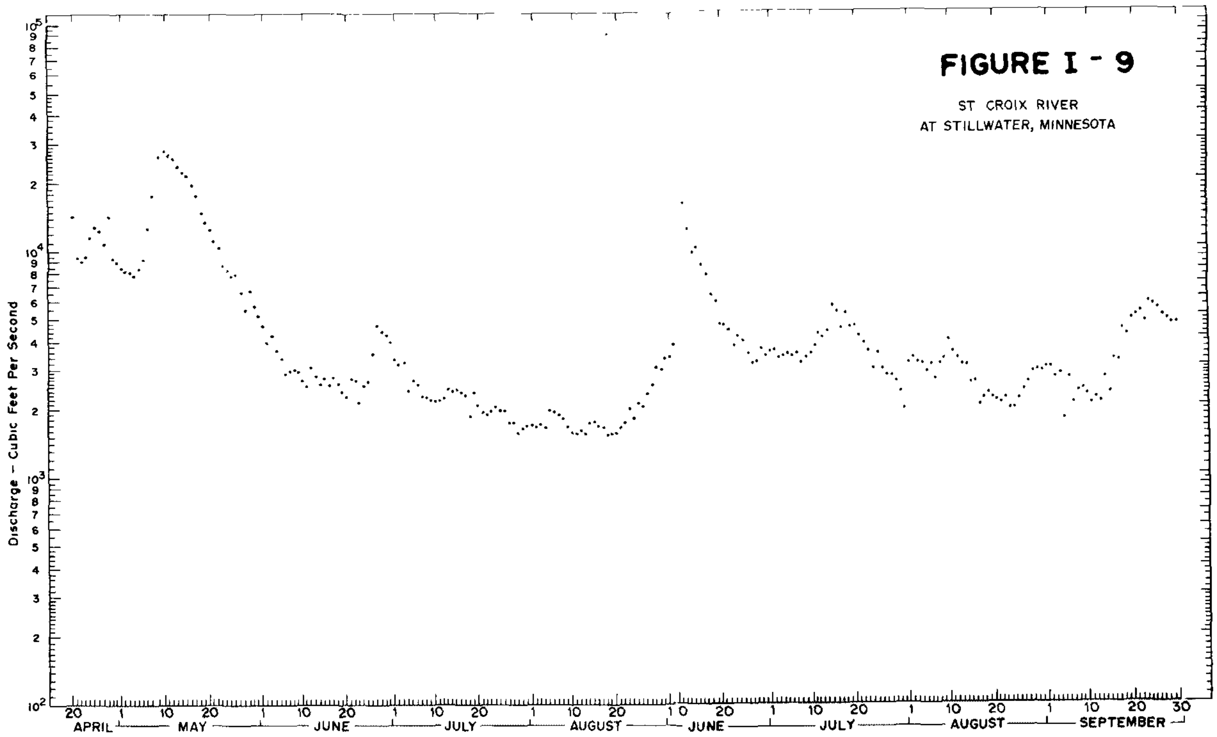

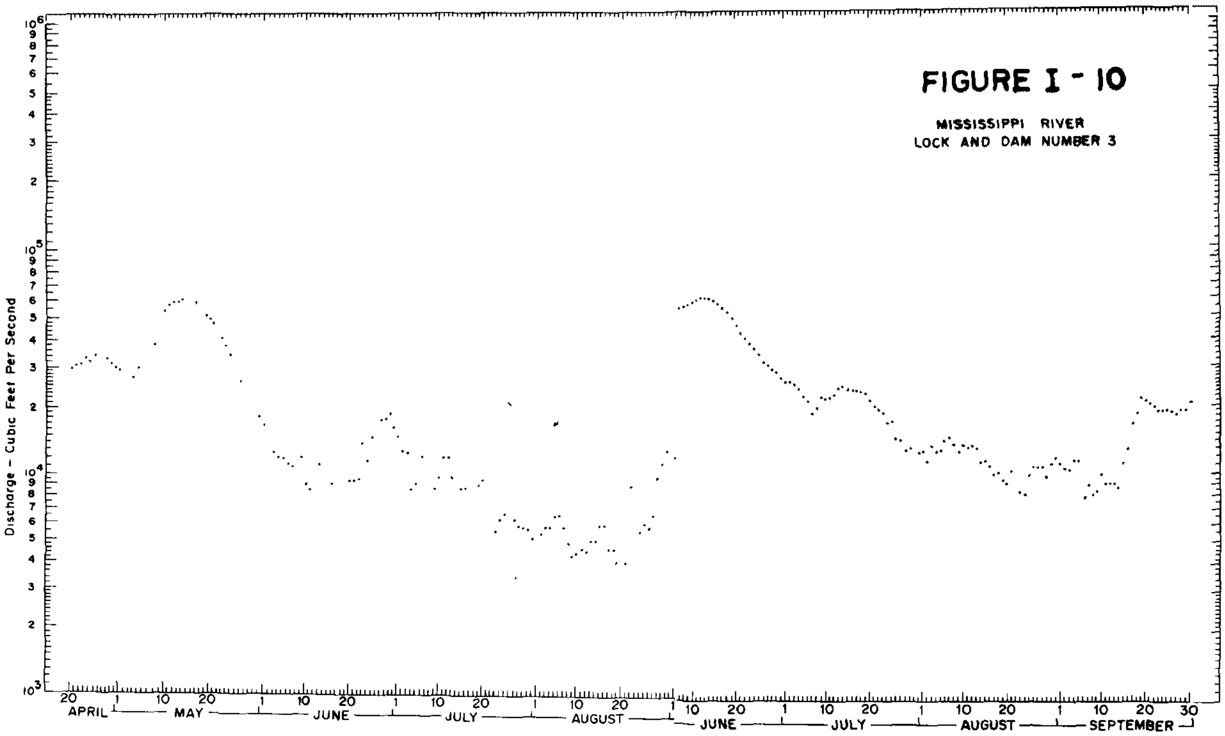

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DAILY HYDROGRAPH FOR PERIOD OF WATER QUALITY STUDY

PRIL 1964 - SEPTEMBER 1965

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CHAPTER II

MEAN STREAM DEPTHS

INTRODUCTION

Mean stream depths for a range of discharges are presented for the Mississippi River from river miles UM 871.0 to UM 764.9[1] in Figures II-1 through II-11, the Minnesota River from river miles MN 109.3 to MN 0.1[2] in Figure II-12, and the St. Croix River from river miles SC 48.0 to SC 0.8[3] in Figure II-13. Discharge-depth relationships have been established for numerous segments of these rivers. The segments were selected on the basis of significant natural and man-made changes in the hydrologic regime, the location of principle wastewater inputs, and to match the river segments used in the discharge-velocity relationships presented in the Chapter "Mean Flow Velocity".

OBJECT

Mean stream depths have been determined for use in calculating the reaeration constant (k_2) for insertion into the oxygen sag equation.

GENERAL INFORMATION

The mean stream depths for the numerous stream segments were calculated for three conditions of stage and flow from cross sections determined by the Project or obtained from other agencies. Cross sections

1 UM 0.0 is at the confluence of the Ohio and Mississippi Rivers.

2 MN 0.0 is at the confluence of the Minnesota and Mississippi Rivers.

3 SC 0.0 is at the confluence of the St. Croix and Mississippi Rivers.

obtained from other agencies were for the Mississippi River from UM 859.0 to UM 797.0 and were taken at 1/4 to 1/2 mile intervals. This includes the entire stretch of the Mississippi River from above Minneapolis to Lock & Dam #3. Time and budgetary considerations prevented the development of cross sections at such close intervals on all other segments of the 3 major streams studied by the Project. However, these other segments were cross sectioned by the Project at intervals which provided representation sufficient for the use of the data and in keeping with the Project's needs.

Water surface profiles were developed for three conditions of stage and flow in order to prorate the cross sections. Each flow condition provided a mean stream depth and thus a coordinate for the discharge-depth relationship. Plotting the log of the three coordinates results in a straight line for each segment of stream.

METHOD OF COMPUTATION

The computations described were carried out using areas and widths derived from the prorated cross sections. The mean stream depth for the segment of stream between every adjacent pair of cross sections was calculated.

Mean stream depth for any stream segment is defined as the volume of that segment divided by its surface area. From a pair of cross sections the average volume is given by:

$$\frac{A_1 + A_2}{2} \times L$$

the average surface area by:

$$\frac{W_1 + W_2}{2} \times L$$

where:

A_1 & A_2 = areas of the respective cross sections.

W_1 & W_2 = widths of the respective cross sections.

L = distance between the respective cross sections.

Combining these, the formula reduces to:

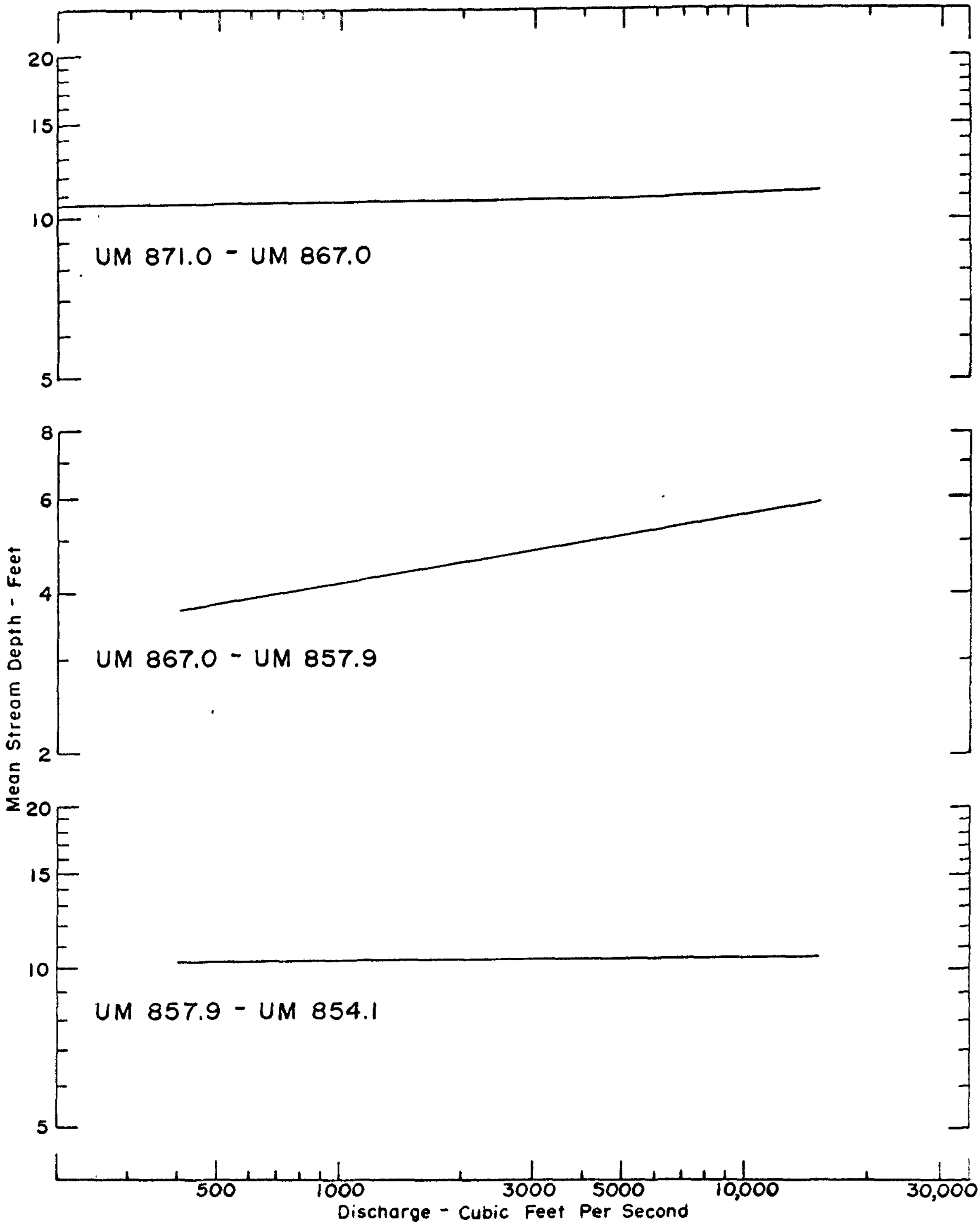
$$\text{Mean Stream Depth} = \frac{A_1 + A_2}{W_1 + W_2}$$

The mean stream depths for the larger stream segments presented in the Figures are distance-weighted averages of the depths obtained from the numerous smaller segments.

The depth values derived are to be used in determining the stream's reaeration capability. Since a stream is not always totally effective from bank to bank in reaerating a water mass moving downstream, the full cross section of a stream was not always used in determining the mean depth. Special judgments were made in areas of slack water, back channels, and extensive submerged floodplains. Slack water and nearly stagnant back channels were not considered in calculating the mean stream depth. The region of submerged floodplains from UM 825.0 to UM 815.2 was the most extensive segment of stream where the percent effectiveness was reduced. In this region the areas of submerged floodplains outside the main channel were considered to be 60 percent effective. This percent effectiveness is the same as that established by the MSSD investigation[5] in developing mean flow velocities which were checked by tracer studies conducted by the Project.

5 "Pollution and Recovery Characteristics of the Mississippi River", A Project sponsored by the Minneapolis-St. Paul Sanitary District, 1961, Volume One-Part Three.

All special changes from 100 percent effective areas are noted in the original calculations available in the Project's Hydrologic Studies-Basic Data file.



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DISCHARGE - DEPTH RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 871.0 - 854.1

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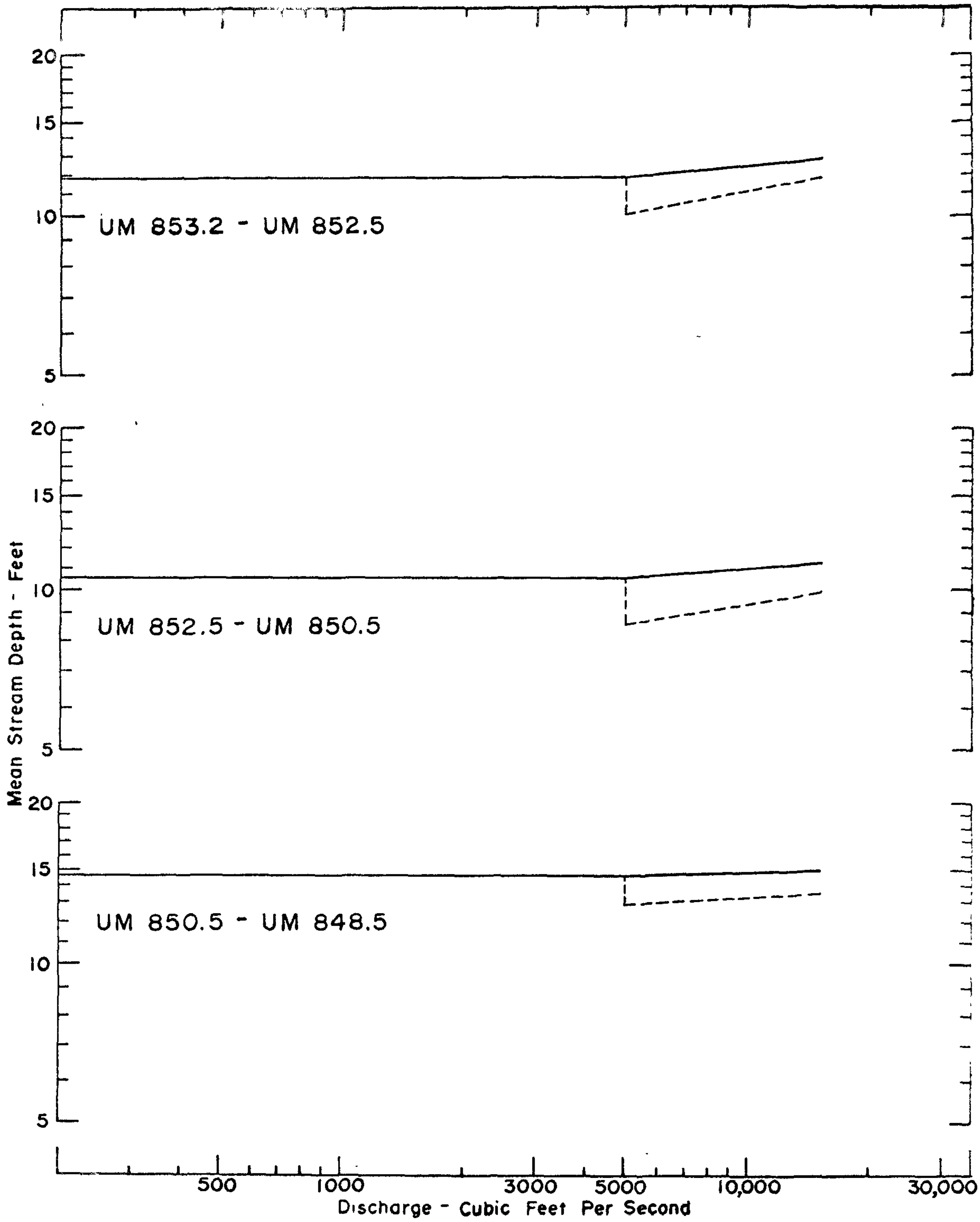
FIGURE II-1



NOTE:

-------- Flashboards down at Lock and Dam Number 1. Use this for decreasing stages where flows have been in excess of 10,000 cubic feet per second.

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DISCHARGE - DEPTH RELATIONSHIPS MISSISSIPPI RIVER RIVER MILE 853.2 - 848.5

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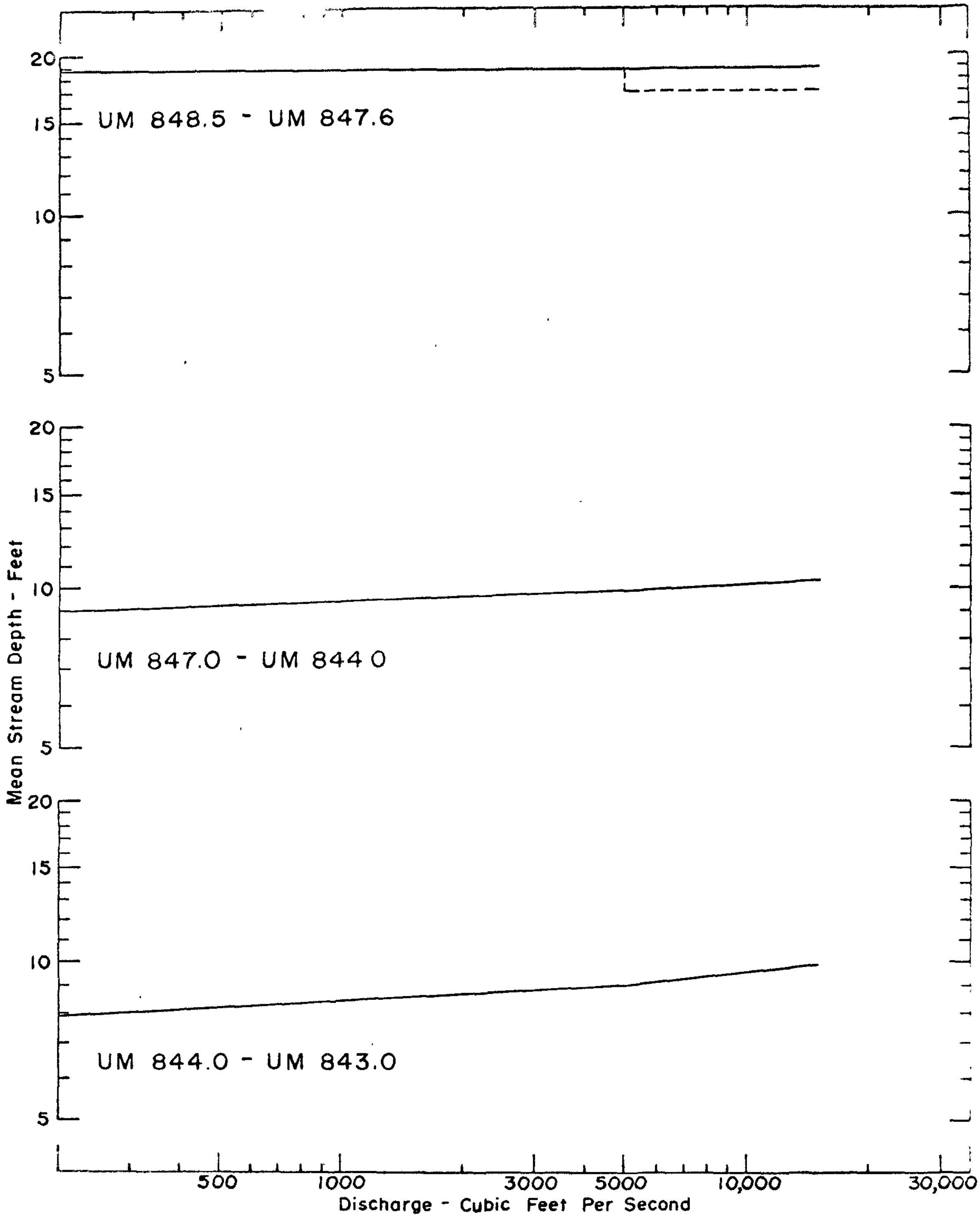
FIGURE II-2



NOTE:

-------- Flashboards down at Lock and Dam Number 1. Use this for decreasing stages where flows have been in excess of 10,000 cubic feet per second.

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DISCHARGE - DEPTH RELATIONSHIPS MISSISSIPPI RIVER RIVER MILE 848.5 - 843.0

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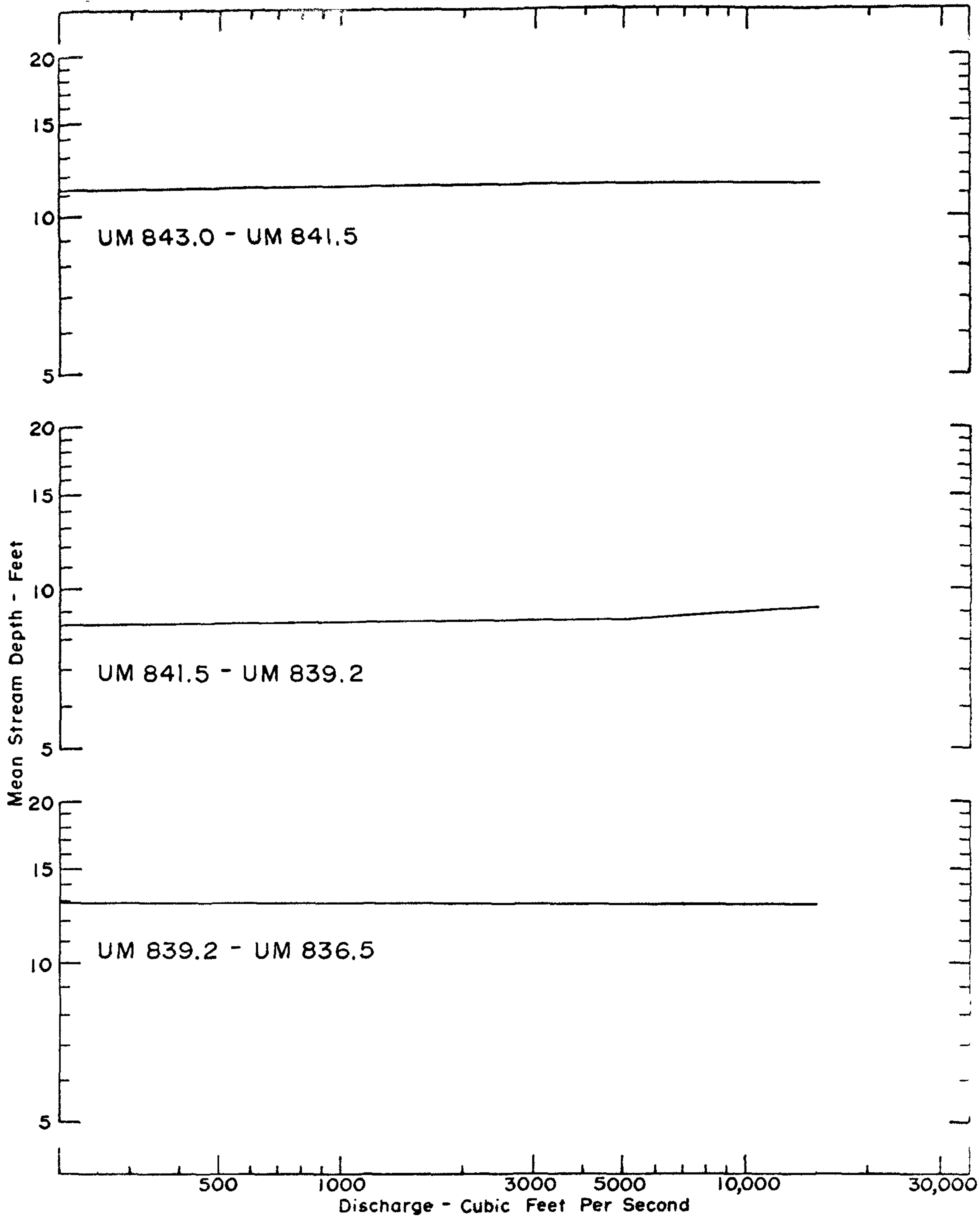
FIGURE II-3



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DISCHARGE - DEPTH RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 843.0 - 836.5

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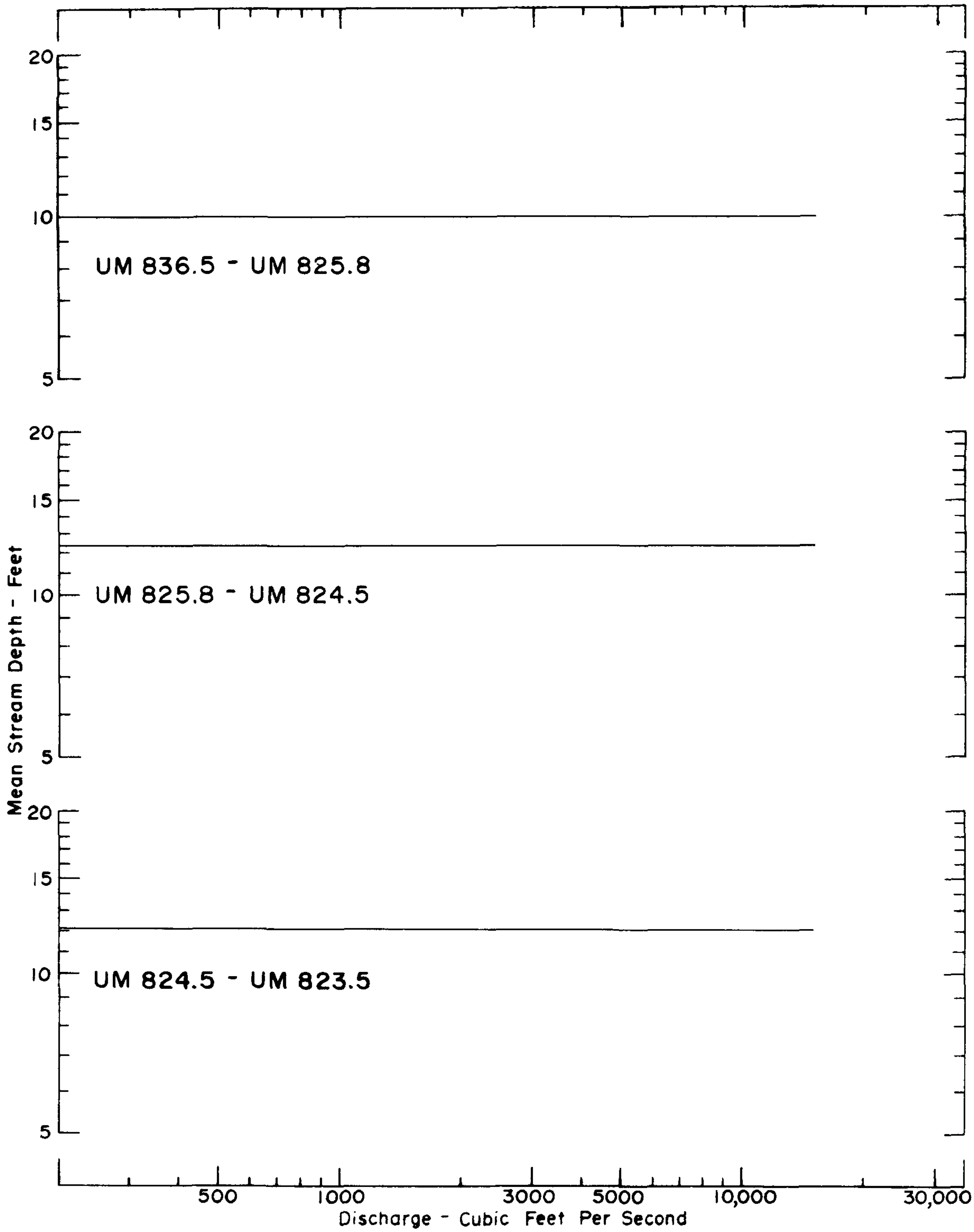
FIGURE II-4



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DISCHARGE - DEPTH RELATIONSHIPS MISSISSIPPI RIVER RIVER MILE 836.5 - 823.5

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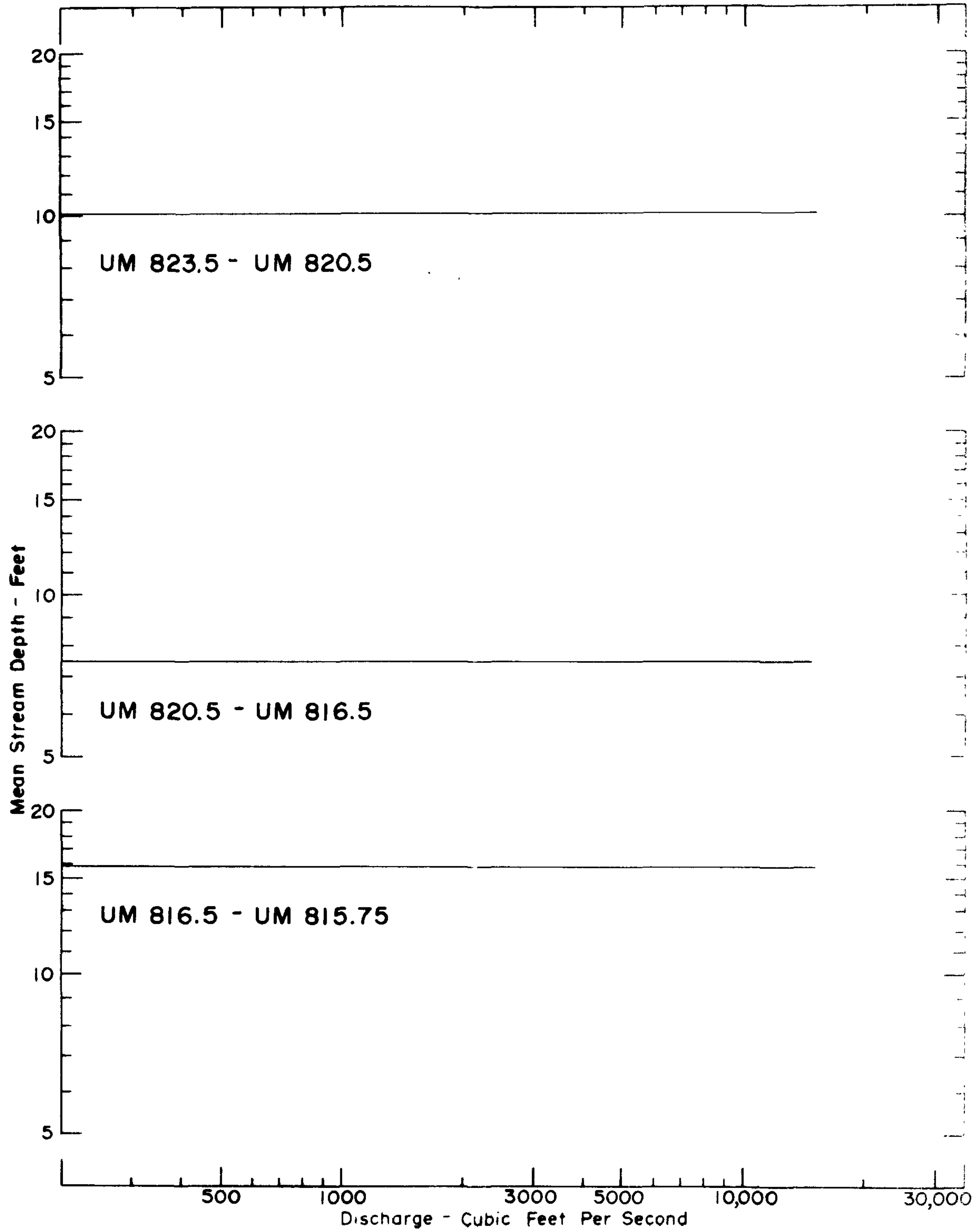
FIGURE II-5



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DISCHARGE - DEPTH RELATIONSHIPS MISSISSIPPI RIVER RIVER MILE 823.5 - 815.75

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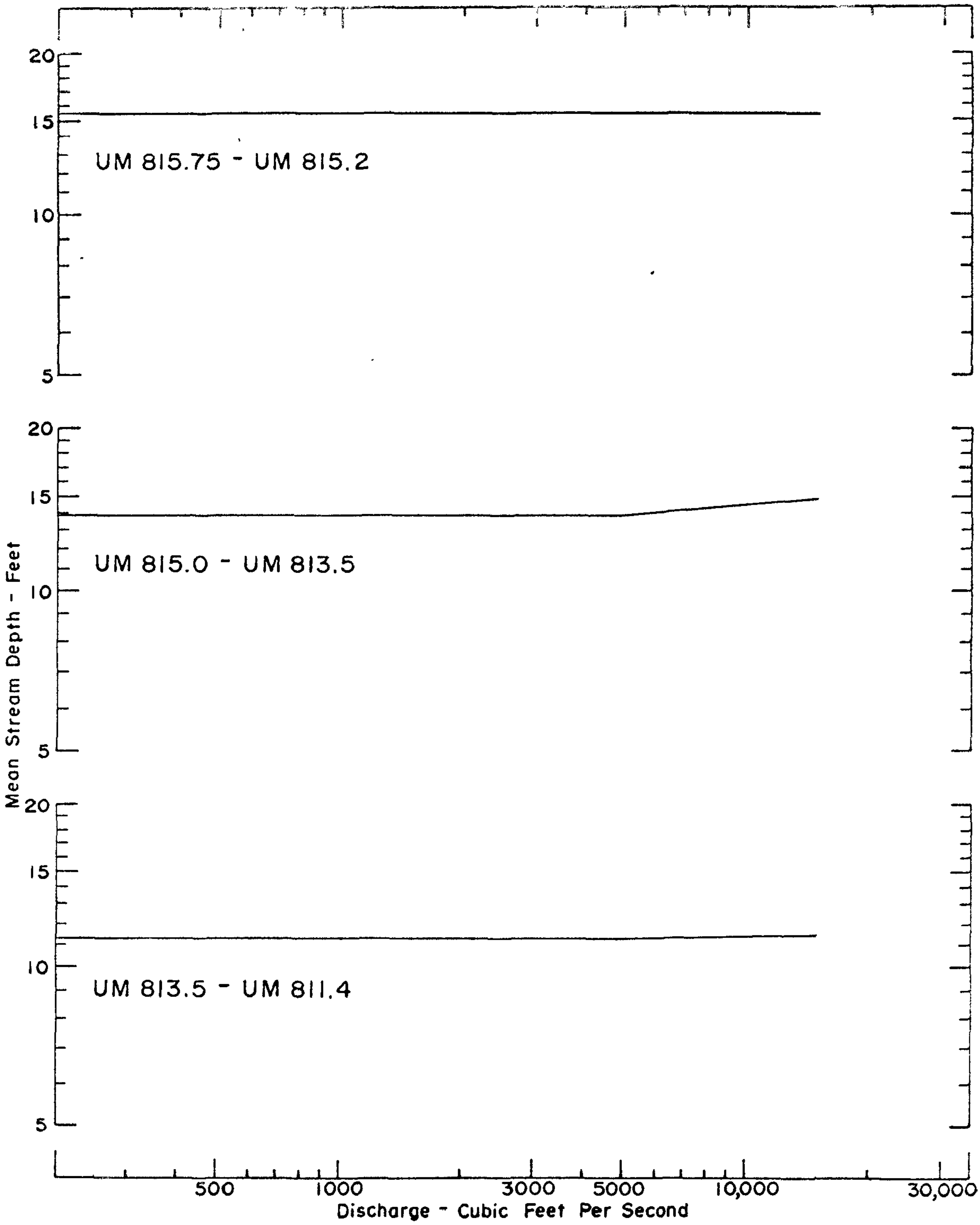
FIGURE II-6



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DISCHARGE - DEPTH RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 815.75 - 811.4

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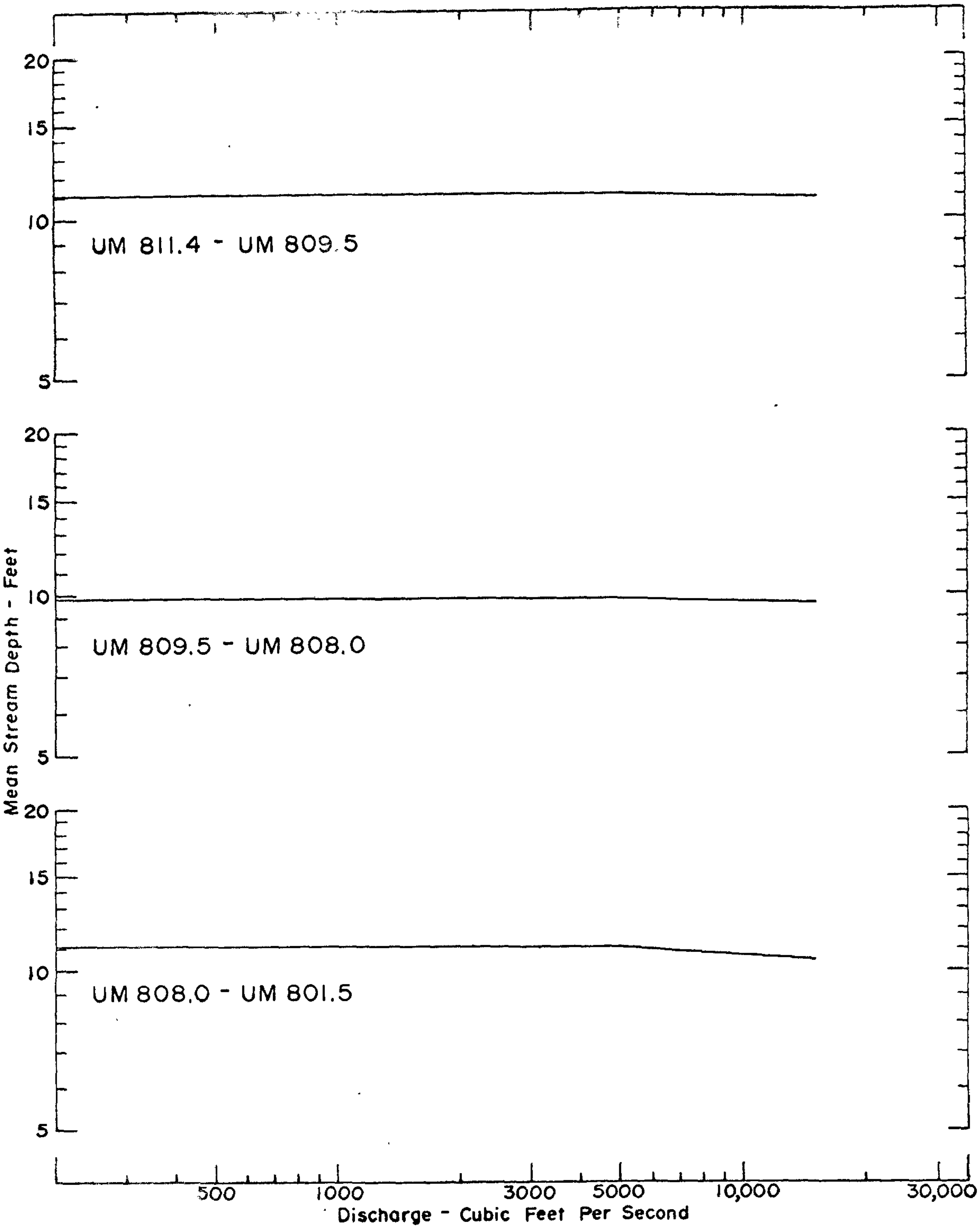
FIGURE II-7



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DISCHARGE - DEPTH RELATIONSHIPS MISSISSIPPI RIVER RIVER MILE 811.4 - 801.5

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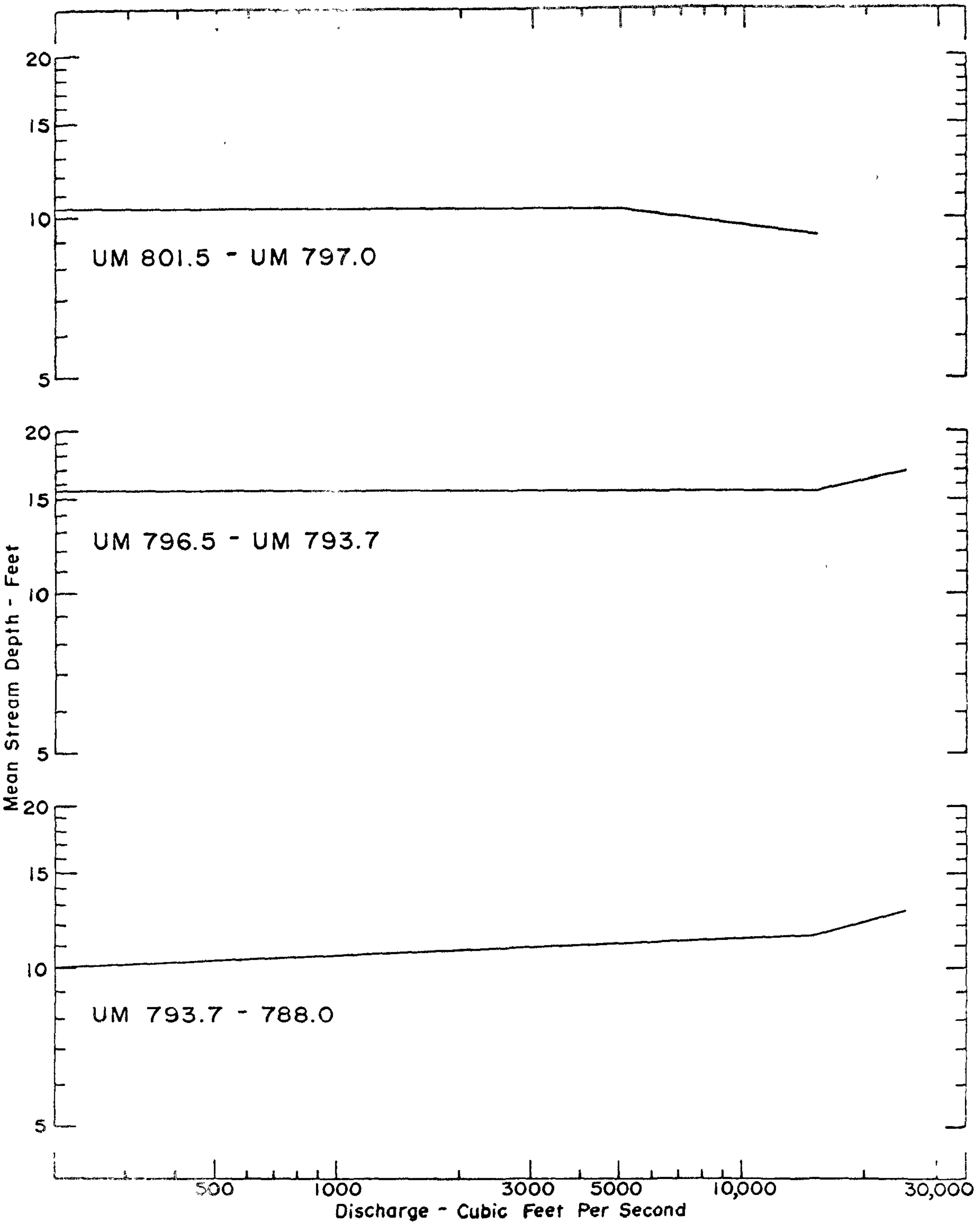
FIGURE II-8



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DISCHARGE - DEPTH RELATIONSHIPS MISSISSIPPI RIVER RIVER MILE 801.5 - 788.0

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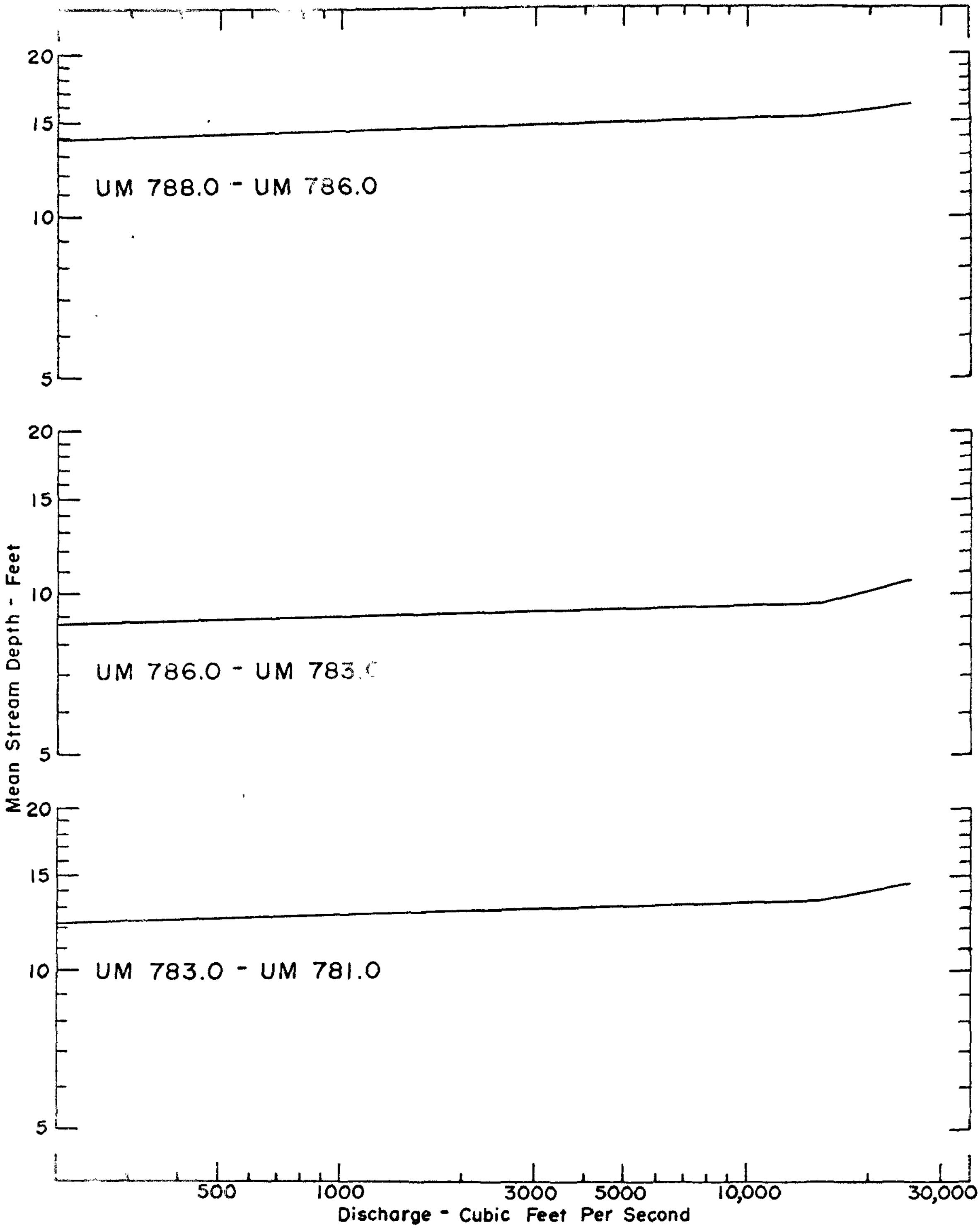
FIGURE II-9



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - DEPTH RELATIONSHIPS MISSISSIPPI RIVER RIVER MILE 788.0 - 781.0

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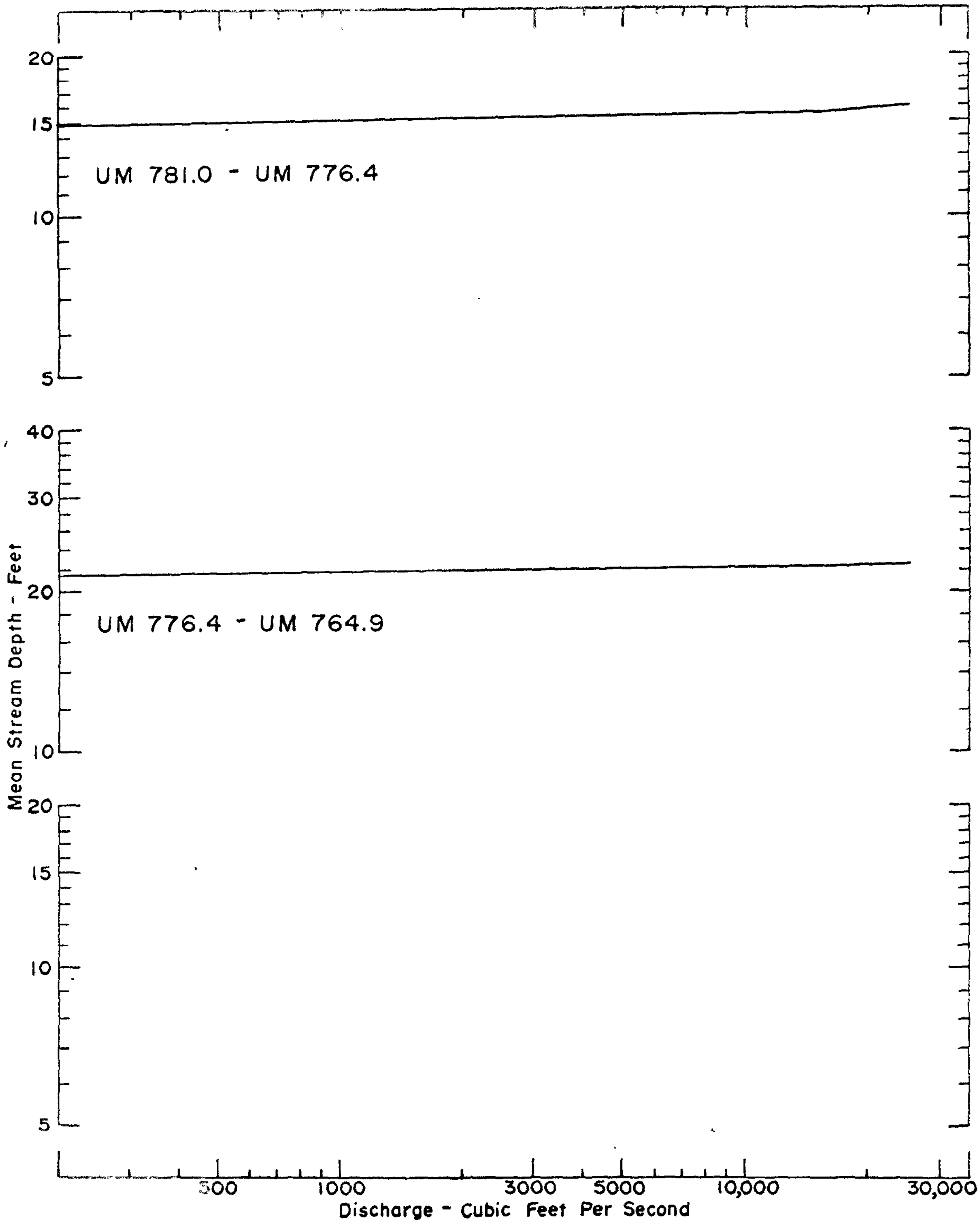
REGION V CHICAGO, ILLINOIS

FIGURE II-10



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - DEPTH RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 781.0 - 764.9

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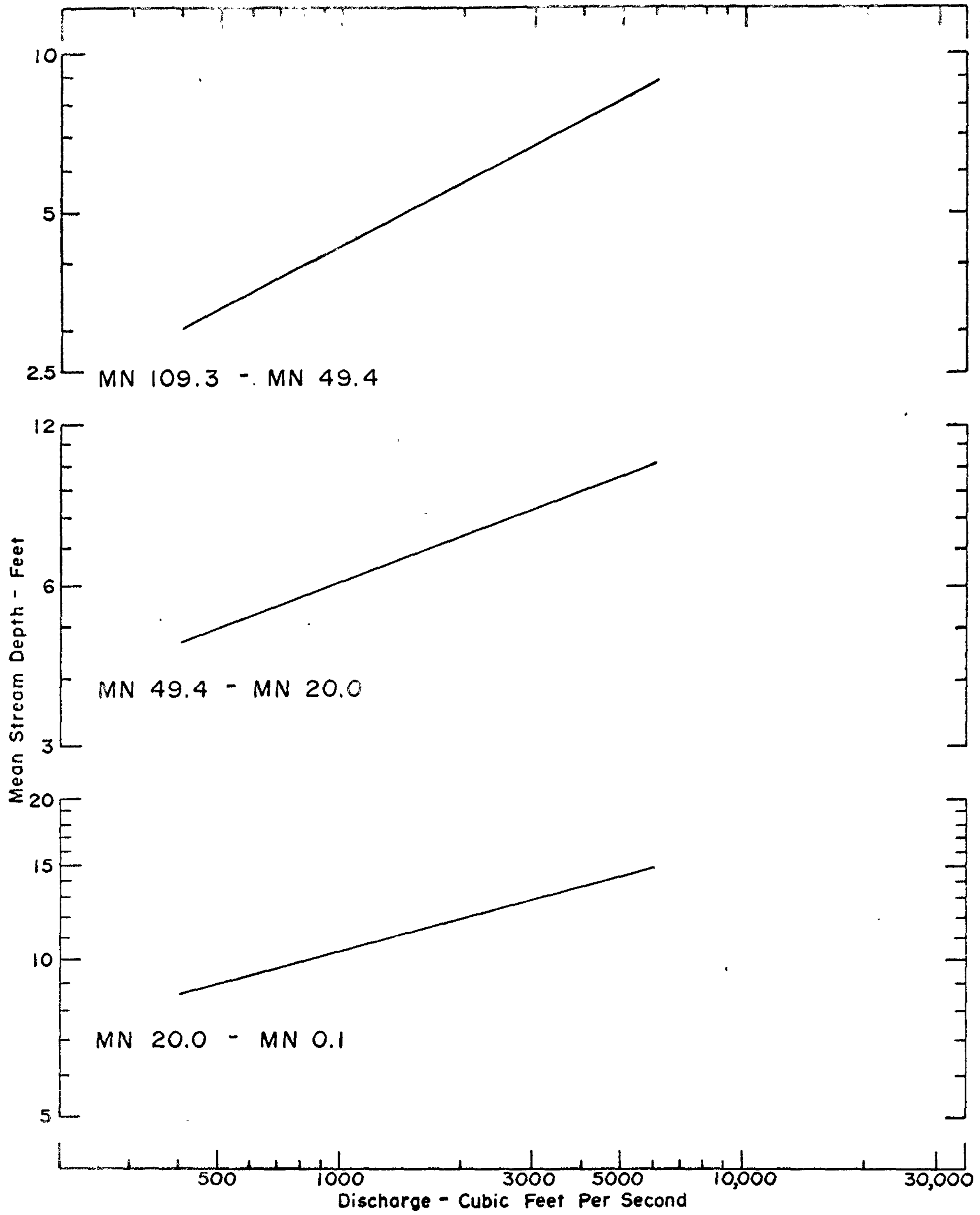
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE II-11



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - DEPTH RELATIONSHIPS MINNESOTA RIVER RIVER MILE 109.3 - 0.1

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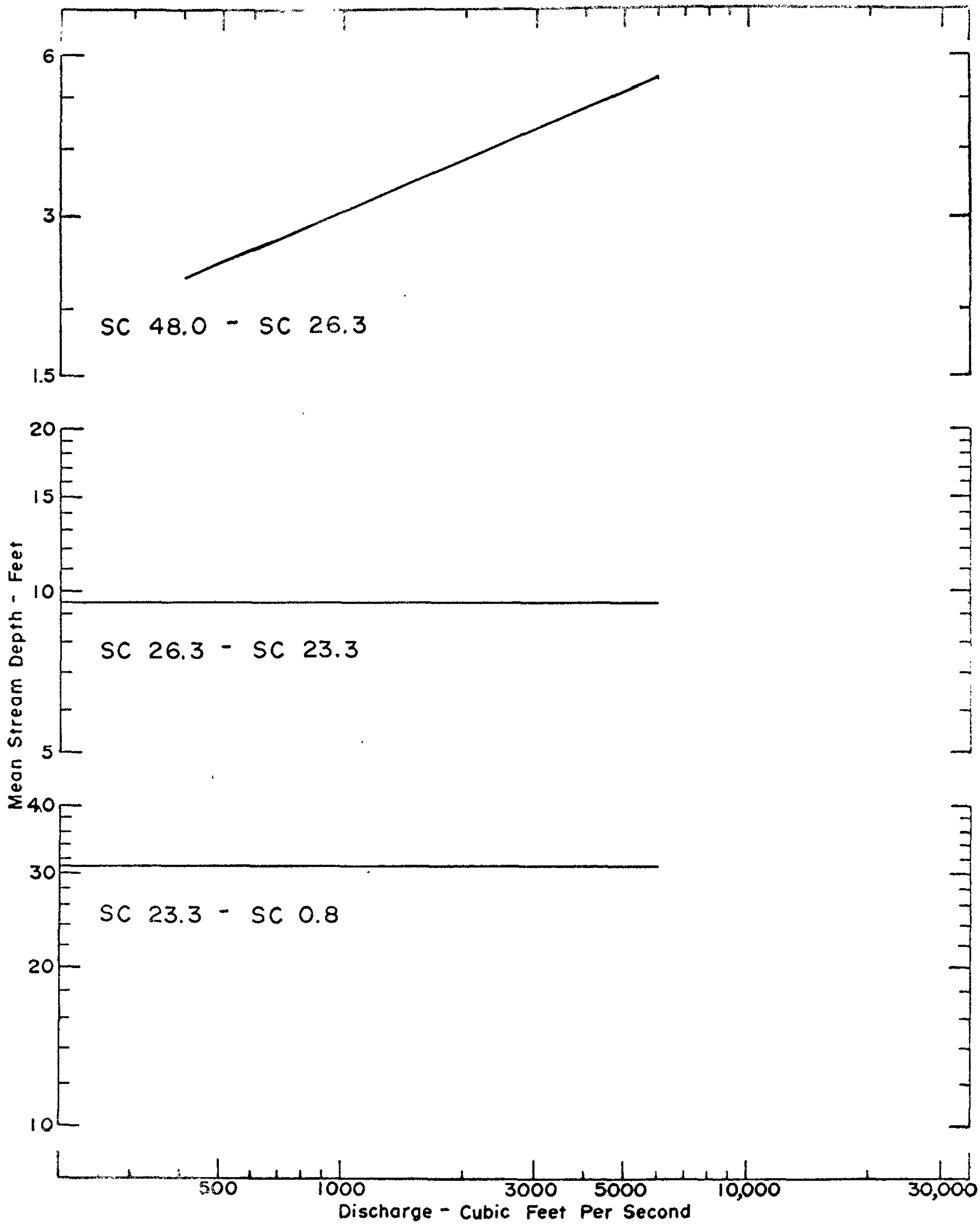
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE II-12



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - DEPTH RELATIONSHIPS
ST. CROIX RIVER
RIVER MILE 48.0 - 0.8

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FIGURE II-13

CHAPTER III

RANGE OF MEAN MONTHLY DISCHARGES

INTRODUCTION

Mean monthly discharges for various gaging stations on the Mississippi, Minnesota and St. Croix Rivers within the Project study area are presented in this chapter. Five gaging stations were selected such that mean monthly discharges may be determined for any segment of these three streams. The maximum, mean and minimum of the mean monthly discharges were derived from the 25-year period of record from Water Year 1940 through Water Year 1964.

OBJECT

These monthly plots of average discharge provide a basis for comparison and discussion of general stream conditions and illustrate the direction and magnitude of seasonal variations.

GENERAL INFORMATION

The range of mean monthly discharges for the selecting gaging stations are given by the following Figures:

III-1. Mississippi River at Lock & Dam #1

III-2. Minnesota River near Carver, Minnesota

III-3. Mississippi River at St. Paul, Minnesota

III-4. St. Croix River at Stillwater, Minnesota

III-5. Mississippi River at Lock & Dam #3

The chapter "Hydrographs" includes a discussion of each of these stations as well as general comments concerning their selection. The segment of stream to which the flows may be applied as well as the source and reliability of the record are also provided.

The 25-year period of record used in the determination of the "Range of Mean Monthly Discharges" was selected after scrutiny of each stream's hydrologic history. Most of the information was obtained through consultation with personnel of the U. S. Army Corps of Engineers, U. S. Geological Survey, Minnesota Department of Conservation and the Northern States Power Company. The following general conditions applicable to the rivers under study were most relevant in selecting water years 1940 through 1964:

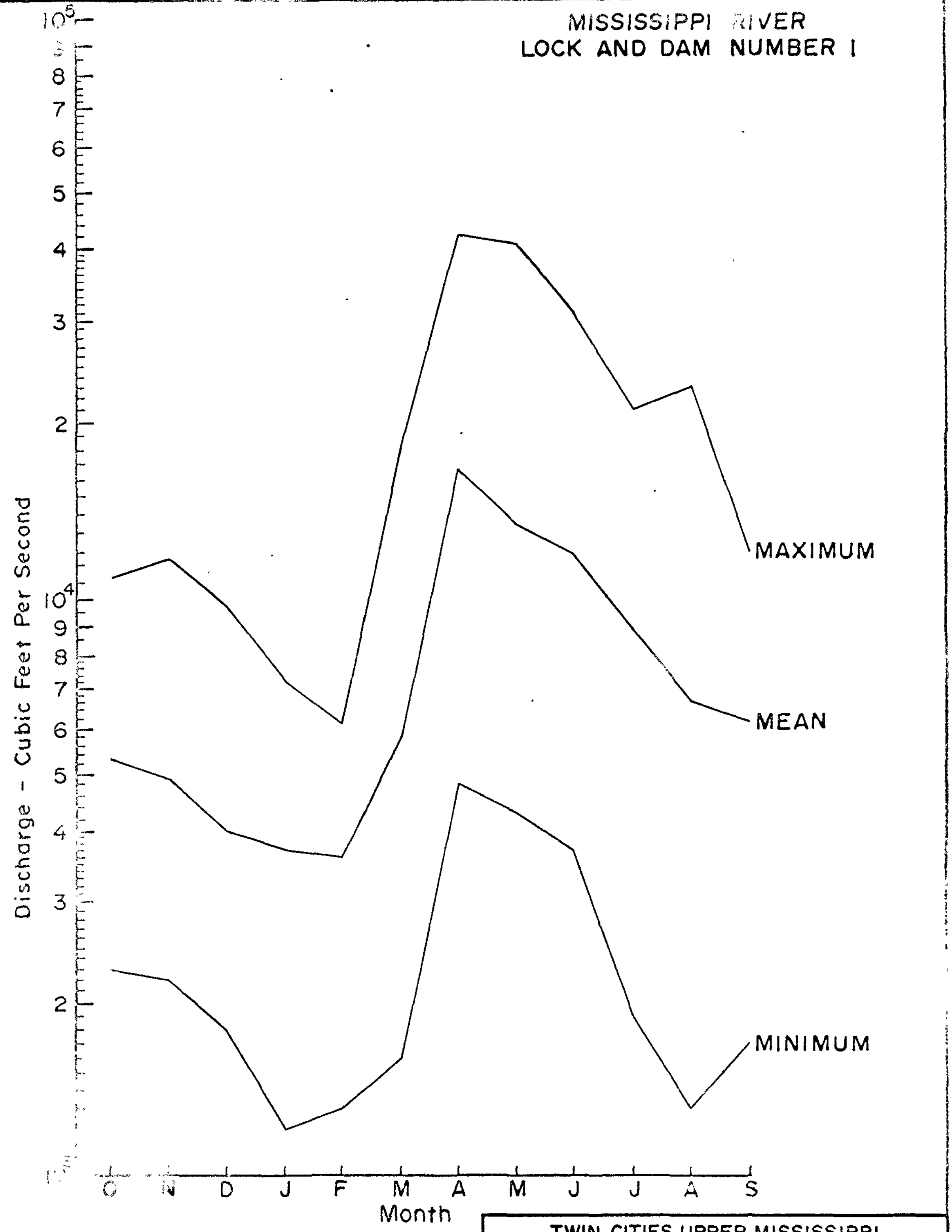
1. Major dam construction was completed about 1938.

2. There have been no significant changes in storage capacity during this time.

3. Operating procedures for the numerous locks, dams, power plants and reservoirs have remained relatively constant.

Concerning the derivation of flow of the St. Croix River at Stillwater, the mean monthly discharges of the St. Croix River at St. Croix Falls and of the Apple River near Somerset were added directly with no regard being given to the one day required for flows from St. Croix Falls to reach the mouth of the Apple River. No appreciable error can be noted in utilizing this technique.

The maximum, minimum and mean of the mean monthly discharges for each station were derived from the compilation of mean monthly discharges presented in Appendix "III-A". The mean discharge for a given month was listed for the 25 consecutive water years, the highest and lowest selected, and the average computed. The same was done for each month thus defining the three curves presented in Figures III-1 through III-5.



NOTE

MAXIMUM - MAXIMUM OF MEAN MONTHLY DISCHARGE

MEAN - MEAN OF MEAN MONTHLY DISCHARGE

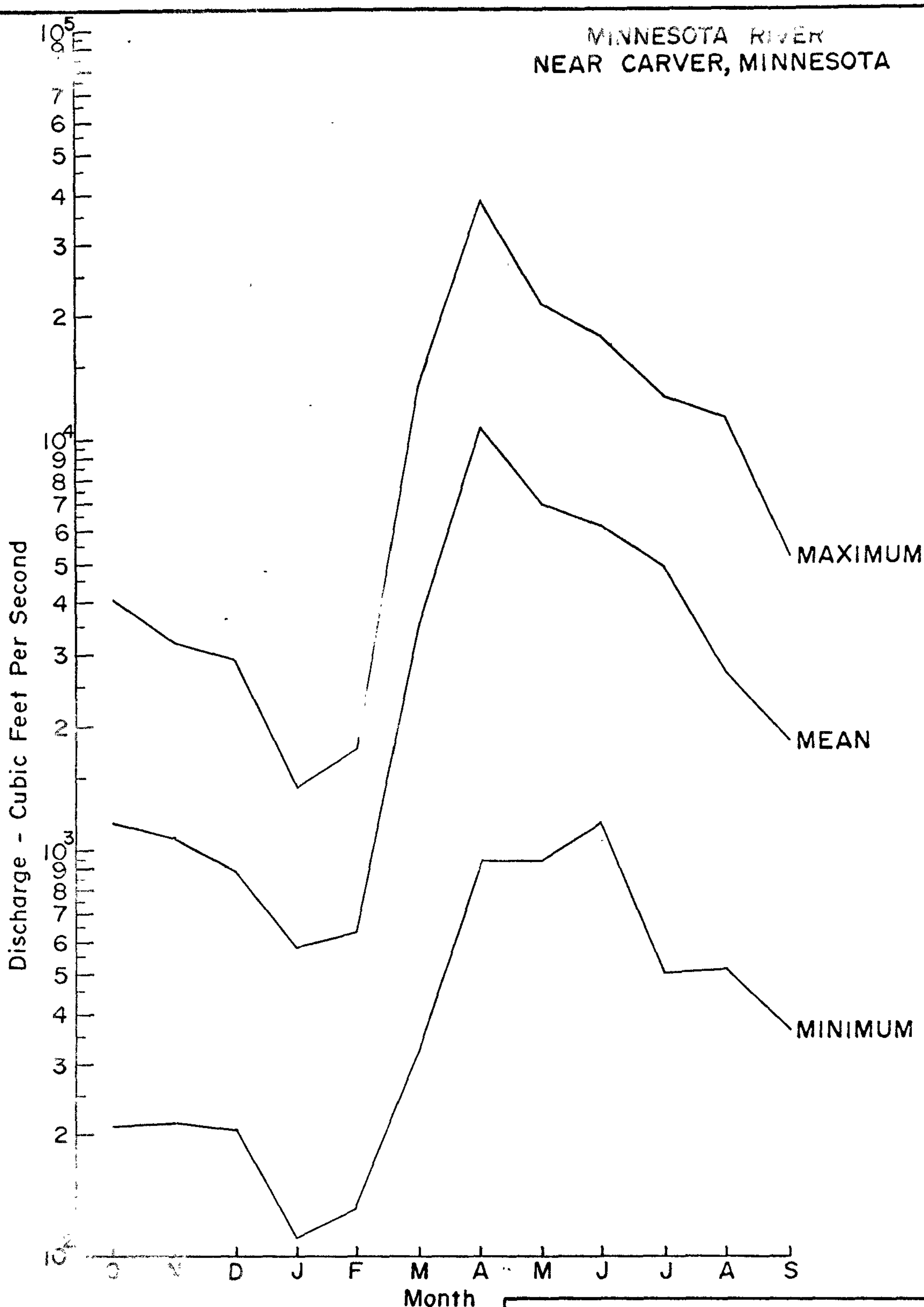
MINIMUM - MINIMUM OF MEAN MONTHLY DISCHARGE

TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

RANGE OF MEAN MONTHLY DISCHARGES WATER YEARS 1940 - 1964

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE III-1



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

RANGE OF MEAN MONTHLY DISCHARGES

WATER YEARS 1940 - 1964

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.

REGION V CHICAGO, ILLINOIS

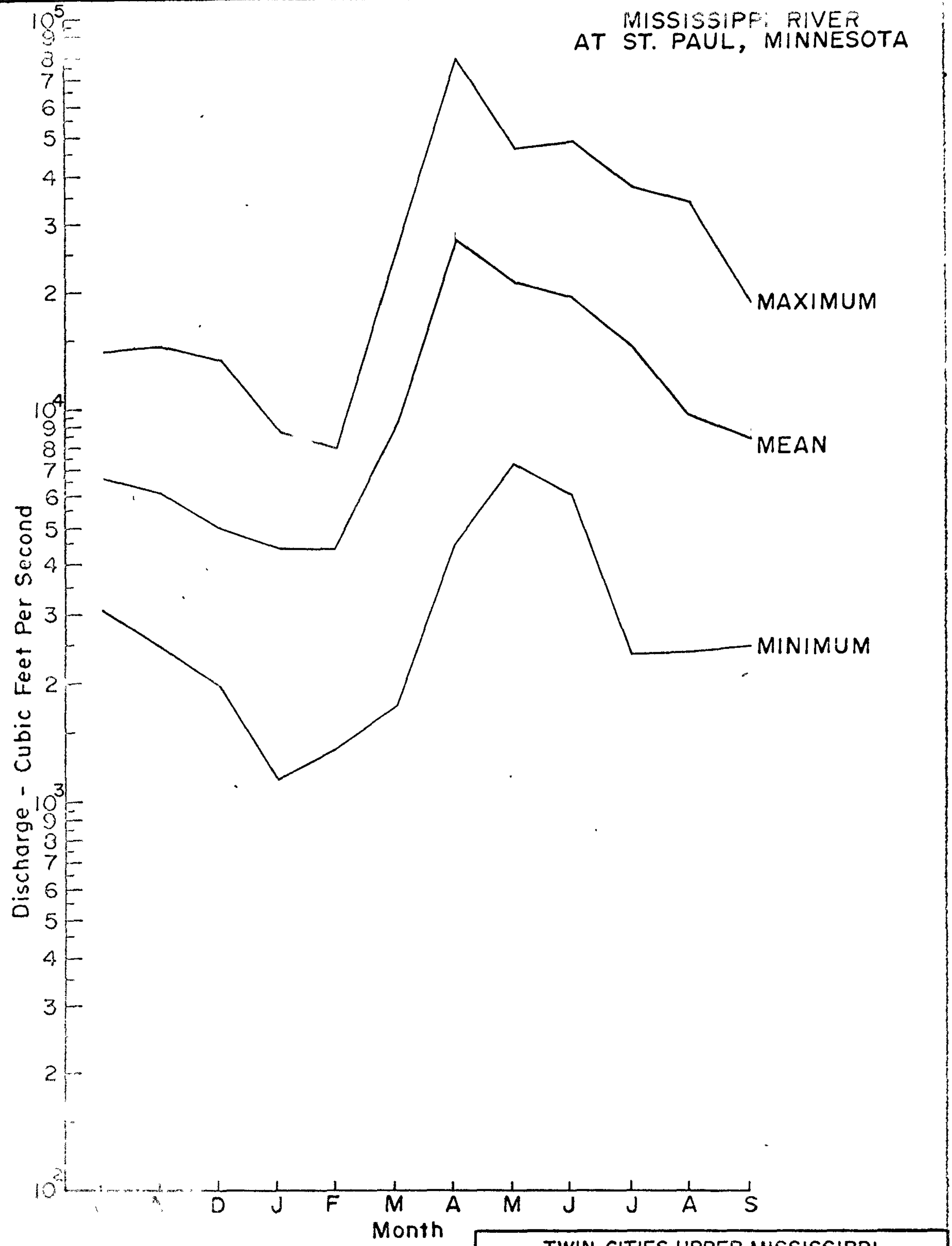
FIGURE III-2

NOTES

MAXIMUM - MAXIMUM OF MEAN MONTHLY DISCHARGE

MEAN - MEAN OF MEAN MONTHLY DISCHARGE

MINIMUM - MINIMUM OF MEAN MONTHLY DISCHARGE



NOTES

MAXIMUM - MAXIMUM OF MEAN MONTHLY DISCHARGE

MEAN - MEAN OF MEAN MONTHLY DISCHARGE

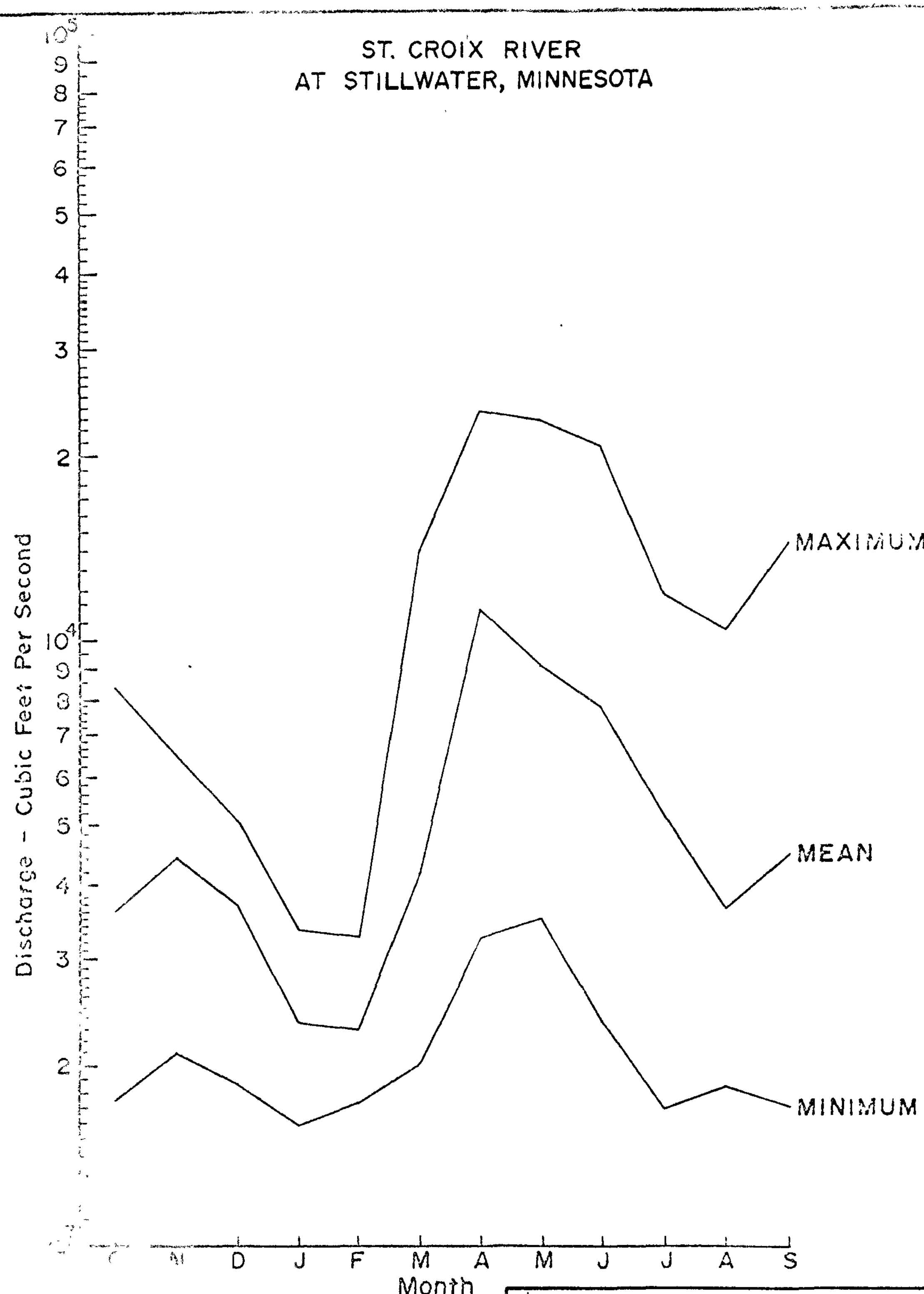
MINIMUM - MINIMUM OF MEAN MONTHLY DISCHARGE

TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

RANGE OF MEAN MONTHLY DISCHARGES WATER YEARS 1940 - 1964

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE III-3



NOTE

MAXIMUM – MAXIMUM OF MEAN MONTHLY DISCHARGE

MEAN – MEAN OF MEAN MONTHLY DISCHARGE

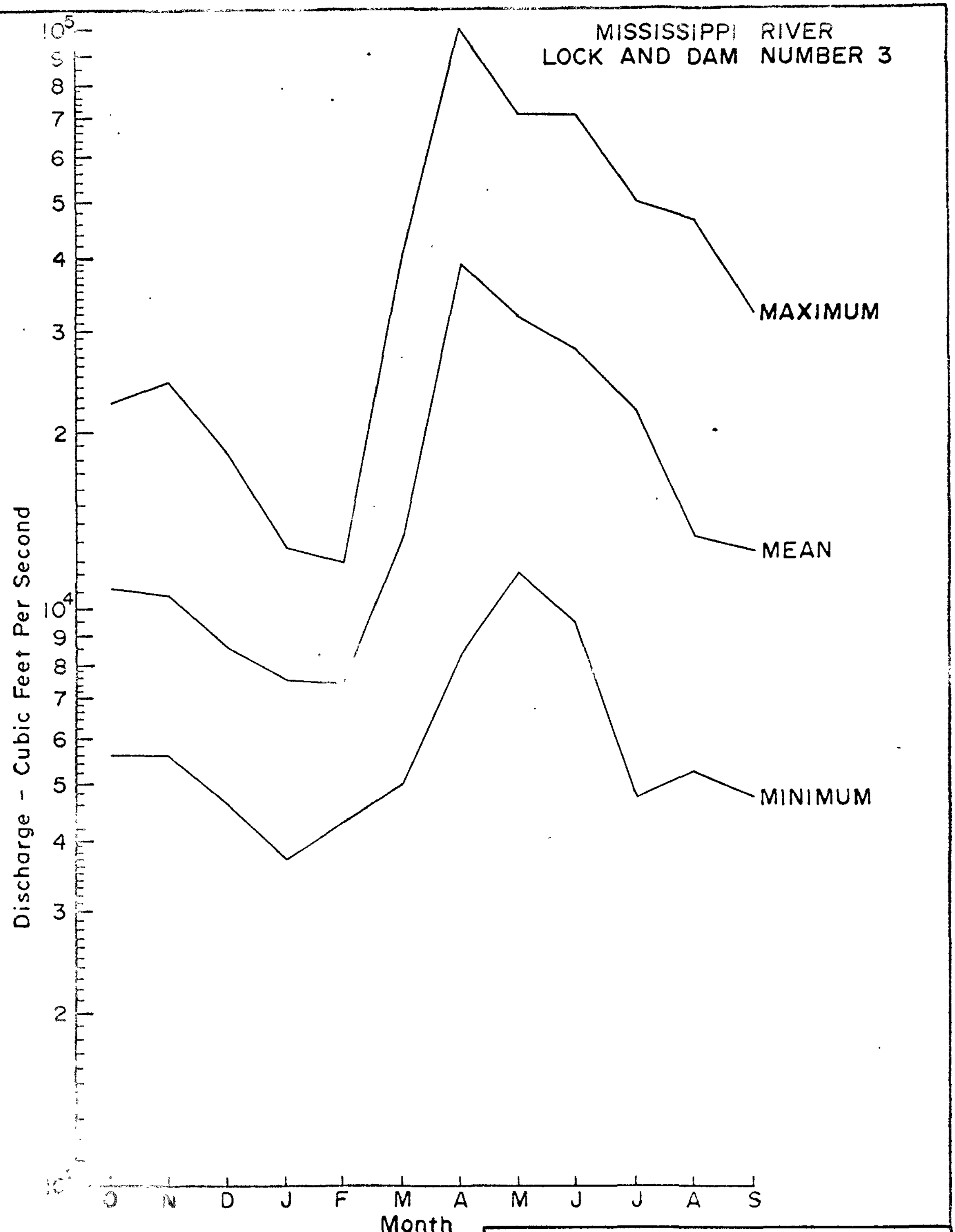
MINIMUM – MINIMUM OF MEAN MONTHLY DISCHARGE

TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

RANGE OF MEAN MONTHLY DISCHARGES WATER YEARS 1940 - 1964

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE III-4



NOTE

MAXIMUM – MAXIMUM OF MEAN MONTHLY DISCHARGE

MEAN – MEAN OF MEAN MONTHLY DISCHARGE

MINIMUM – MINIMUM OF MEAN MONTHLY DISCHARGE

TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

RANGE OF MEAN MONTHLY DISCHARGES WATER YEARS 1940 - 1964

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE III-5

CHAPTER IV

MEAN FLOW VELOCITIES

INTRODUCTION

Mean flow velocities for a range of discharges are presented for the Mississippi River from river mile UM 871.0 to UM 764.9[1] in Figures IV-1 through IV-10, the Minnesota River from river miles MN 109.3 to MN 0.1[2] in Figure IV-11, and the St. Croix River from river miles SC 48.0 to SC 0.8[3] in Figure IV-12.

Discharge-velocity relationships have been established for numerous segments of these rivers. The segments were selected on the basis of significant natural and man-made changes in the hydrologic regime, the location of principle wastewater inputs, and to match the river segments used in the discharge-depth relationships presented in the chapter,""Mean Stream Depths".

OBJECT

Mean flow velocities have been determined for use in calculating the reaeration constant (k_2) for insertion into the oxygen sag equation and for use in conjunction with the oxygen sag equation to establish the physical downstream location of the sag and stages of recovery.

GENERAL INFORMATION

The mean flow velocities for the numerous stream segments were determined by one of the following three methods and checked by one or both of the other methods:

1 UM 0.0 is at the confluence of the Ohio and Mississippi Rivers.

2 MN 0.0 is at the confluence of the Minnesota and Mississippi Rivers.

3 SC 0.0 is at the confluence of the St. Croix and Mississippi Rivers.

1. Fluorometric tracer studies.

2. Values presented in "Pollution and Recovery Characteristics of the Mississippi River", Volume One, Part Three.[4]

3. Volume displacement calculations.

Fluorometric tracer studies were conducted over all reaches of the Mississippi, Minnesota and St. Croix Rivers under study by the Project, with the exception of Lake St. Croix and lower Lake Pepin. Tracer studies were conducted using Rhodamine "B" dye as the fluorescing tracer and the Turner Model 111 fluorometer for detection. Three general methods of detection were employed: 1) individual analysis of discrete stream samples, 2) continuous monitoring at a fixed point in a stream, and 3) continuous monitoring while traveling by boat up or down the main channel of a stream. The majority of the studies were conducted utilizing the third method for which the details of planning and execution are presented in "Study Plan - Time of Travel Determination Using Tracer Techniques".[5] The first and second methods of detection were avoided as being time consuming and were used only where circumstances prohibited the use of a boat.

Fluorometric readings of relative concentration were converted to a concentration vs. time plot either by Rustrak recorder where continuous monitoring was employed or by plotting the analyses of discrete samples. Where sampling was not conducted at a fixed point, time and river mile were directly related. From these plots the time and point of the tracer's arrival were determined; a velocity was computed; and knowing discharge, the coordinates of a point were provided for the discharge-velocity relationship.

4 An investigation sponsored by the Minneapolis-St. Paul Sanitary District. Hereafter referred to as the MSSD investigation.

5 Twin Cities-Upper Mississippi River Project. "Study Plan - Time of Travel Determination Using Tracer Techniques." 1965. (Mimeographed.)

Three major tracer studies, covering 210 miles of the Mississippi, Minnesota, and St. Croix Rivers, were conducted at times of distinctly different conditions of flow. Each provided a coordinate for the discharge velocity relationship. Plotting the log of these coordinates results in a straight line for each segment of stream.[6,7,8]

Values of time of travel for limited segments of the Mississippi River are presented in the MSSD investigation and are easily converted to mean flow velocity. These values were treated in the same manner to establish the discharge-velocity relationships as were the results of the tracer studies.

Volume displacement calculations were used to develop mean flow velocities for assumed discharges from the cross sections discussed in "Mean Stream Depths". These calculations were carried out to check and compare with the results obtained by tracer study. Where tracer studies were not economically feasible as in the case of Lake Pepin and Lake St. Croix, volume displacement calculations provided the basic data for the discharge-velocity relationships.

The following outlines is a synopsis of the methods used for the various reaches of river to provide the basic data and check for the discharge-velocity relationships.

6 Worley, John Larry, "A System Analysis Method for Water Quality Management by Flow Augmentation in a Complex River Basin," June, 1963, USPHS, DWS&PC, Region IX.

7 Velz, C. J., "Factors Influencing Self-Purification and Their Relation to Pollution Abatement, Part II, Sludge Deposits and Drought Probabilities," Sewage and Industrial Wastes Journal, Vol. 21-3, March, 1949.

8 O'Connor, Donald J., "The Effect of Stream Flow on Waste Assimilation Capacity," Proceedings Seventeenth Purdue Industrial Waste Conference, May, 1962.

I. Mississippi River.

A. Anoka to Lock & Dam #1 (UM 871 - UM 847.6).

1. Tracer studies - basic data.
2. Volume Displacement - check.

B. Lock & Dam #1 to Lock and Dam #3 (UM 847.0 - UM 797.0).

1. MSSD investigation - basic data.
2. Tracer studies - check.

C. Lock & Dam #3 through upper Lake Pepin (UM 796.5 - UM 776.4).

1. Volume displacement - basic data. (Judgments were made concerning the percent effectiveness of the stream cross section. See notes with Figures.)
2. Tracer studies - check.

D. Lower Lake Pepin (UM 776.4 - UM 764.9).

1. Volume displacement - basic data.
2. No check was provided. However, the judgments of percent effectiveness in upper Lake Pepin correlated very well with the tracer studies, and the same reasoning was applied to this portion of the Lake. See notes with Figures.

II. Minnesota River.

A. Mankato to the mouth (MN 109.3 - MN 0.1).

1. Tracer studies - basic data.
2. Volume displacement - check.

III. St. Croix River.

A. Upper St. Croix River (SC 48.0 - SC 26.3).

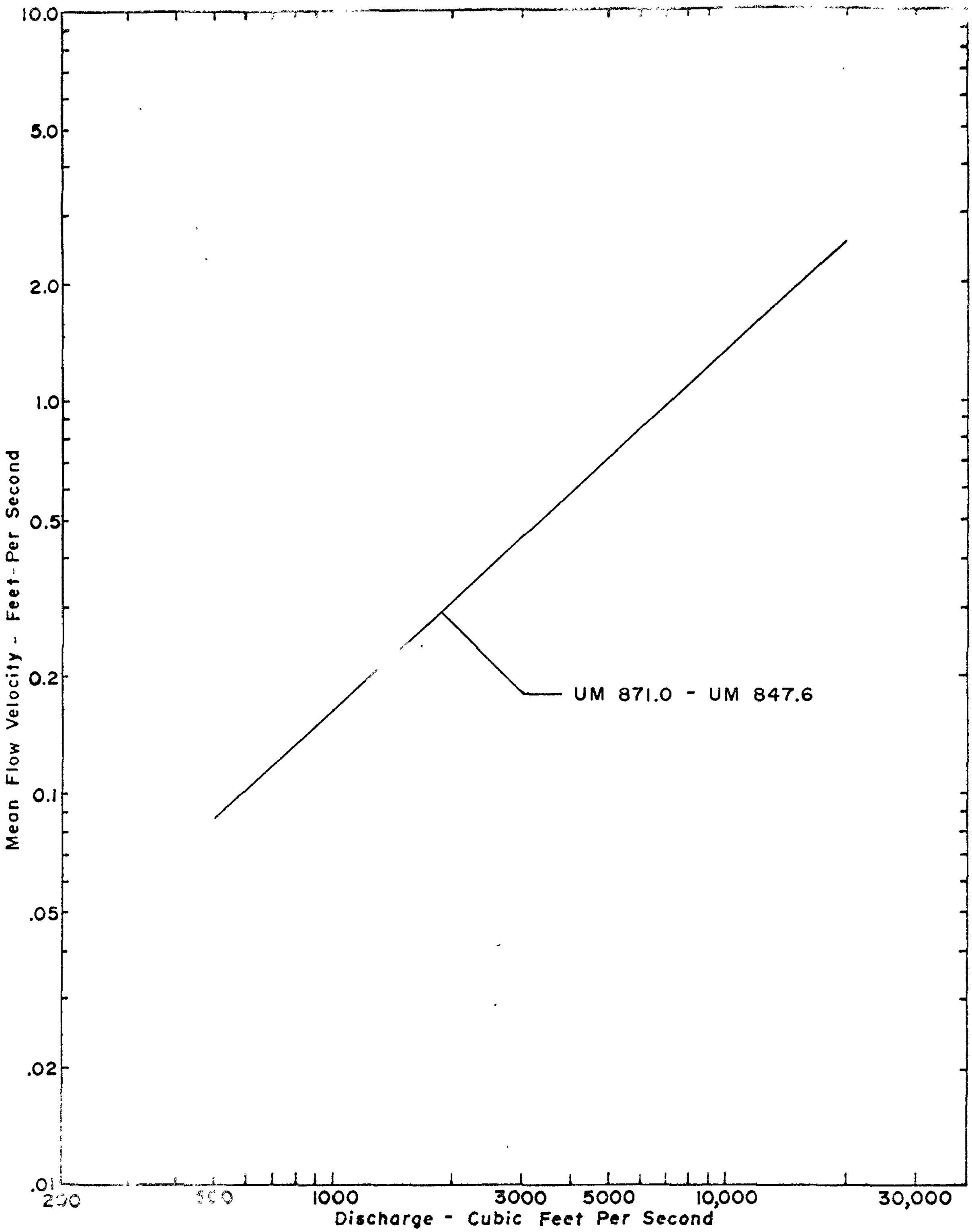
1. Tracer studies - basic data.
2. Volume displacement - check.

B. Lower St. Croix River (SC 26.3 - SC 23.3) and Lake St. Croix (SC 23.3 - SC 0.8).

1. Volume displacement - basic data.
2. No check was provided. However, the percent effectiveness was judged in the same manner as in Lake Pepin where tracer studies supported the assumptions. See notes with Figures.

The agreement between the basic data and the check was in most cases excellent, regardless of the combination of methods. There were slight variations for two segments of the Minnesota River, one segment of the St.

Croix River and in the Spring Lake area of the Mississippi River. In each of these cases, however, the correlation was still very good. The variation usually occurred when the results of one tracer study did not coincide with the relationship established by the results of other tracer studies, the MSSD investigation, and the volume displacement calculations. Such a variation in one study could have been caused by rapidly fluctuating stage or flow, special wind conditions, or a variety of special hydraulic circumstances.



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 871.0 - 847.6

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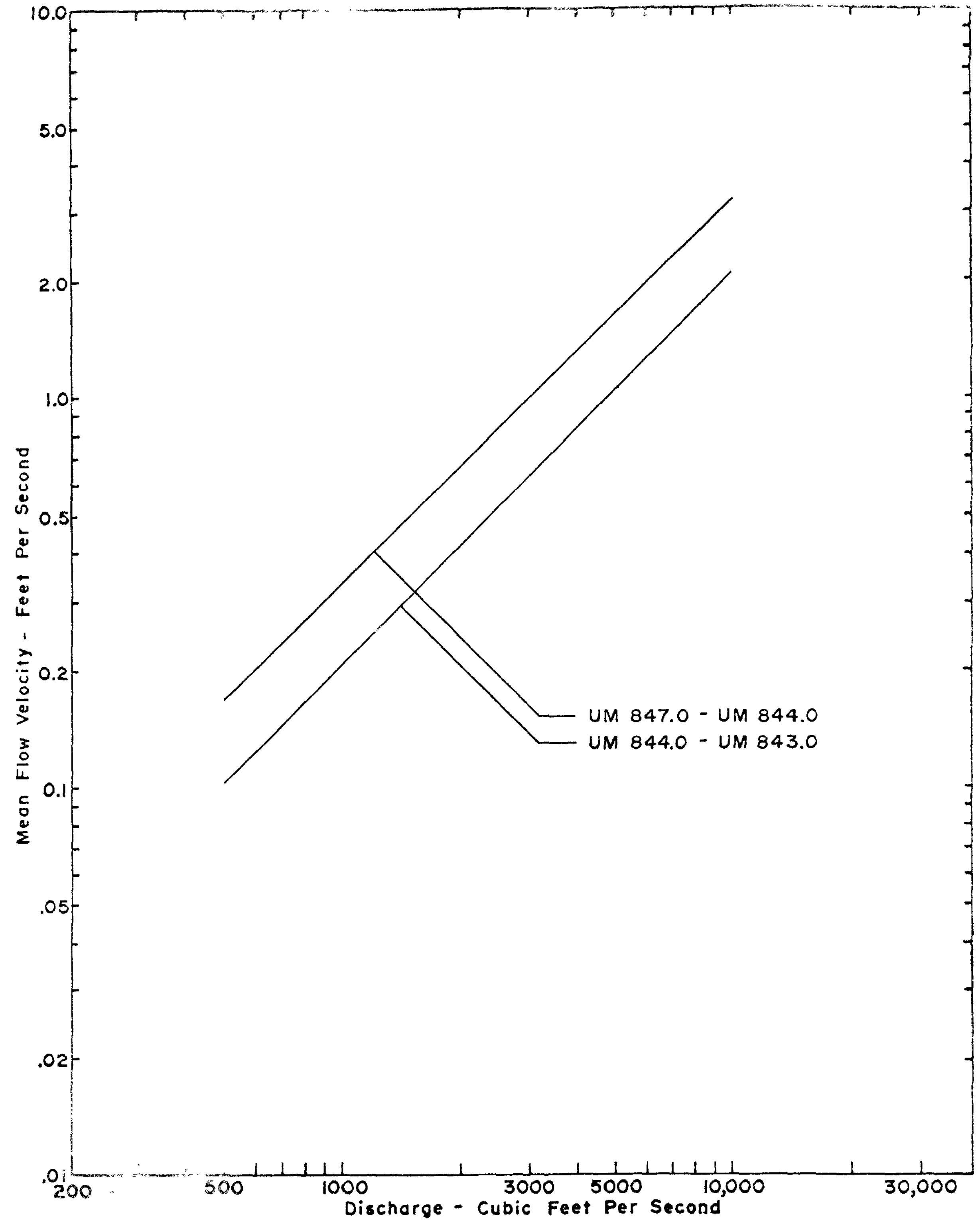
REGION V CHICAGO, ILLINOIS

FIGURE IV-1



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 847.0-843.0

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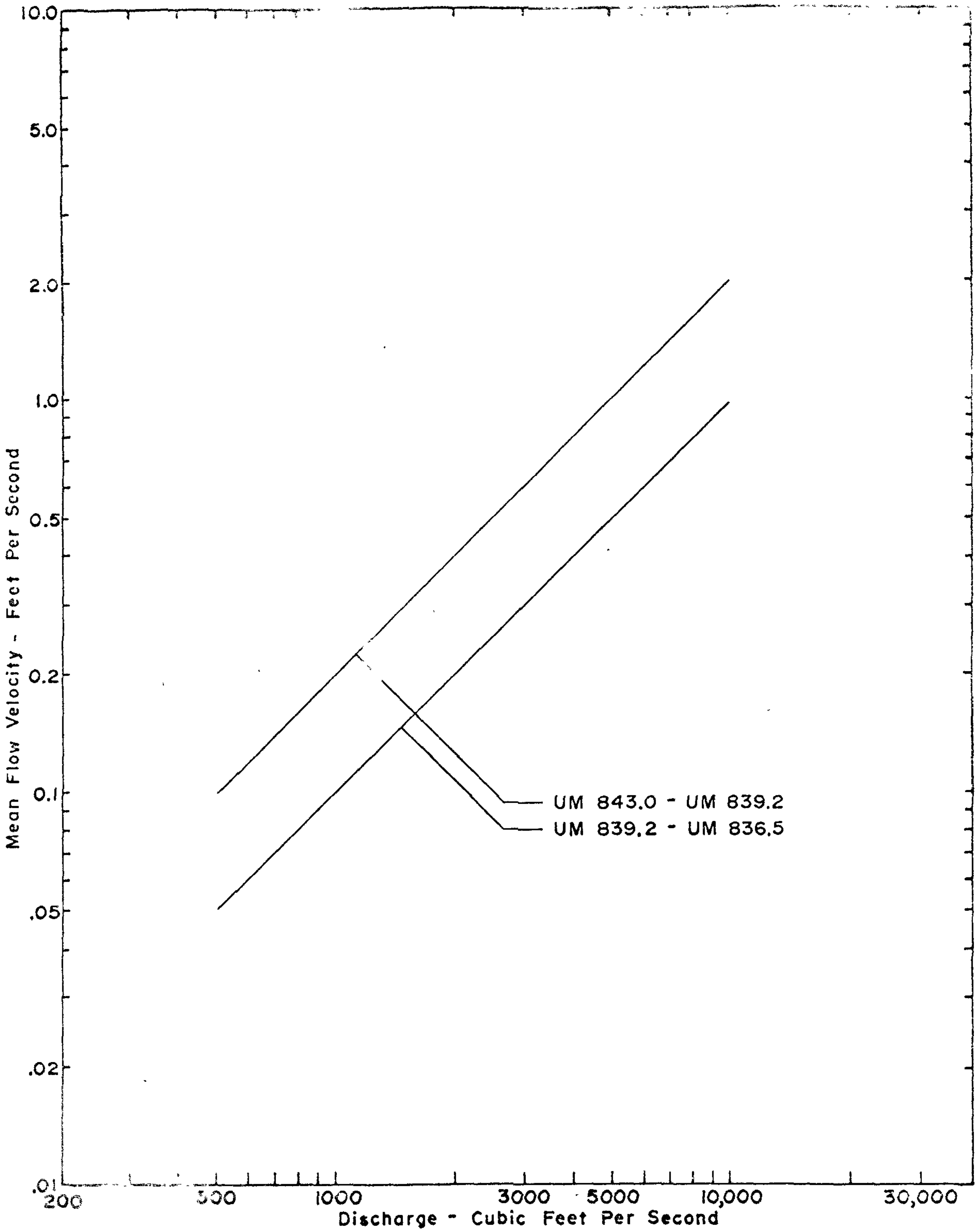
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-2



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 843.0-836.5

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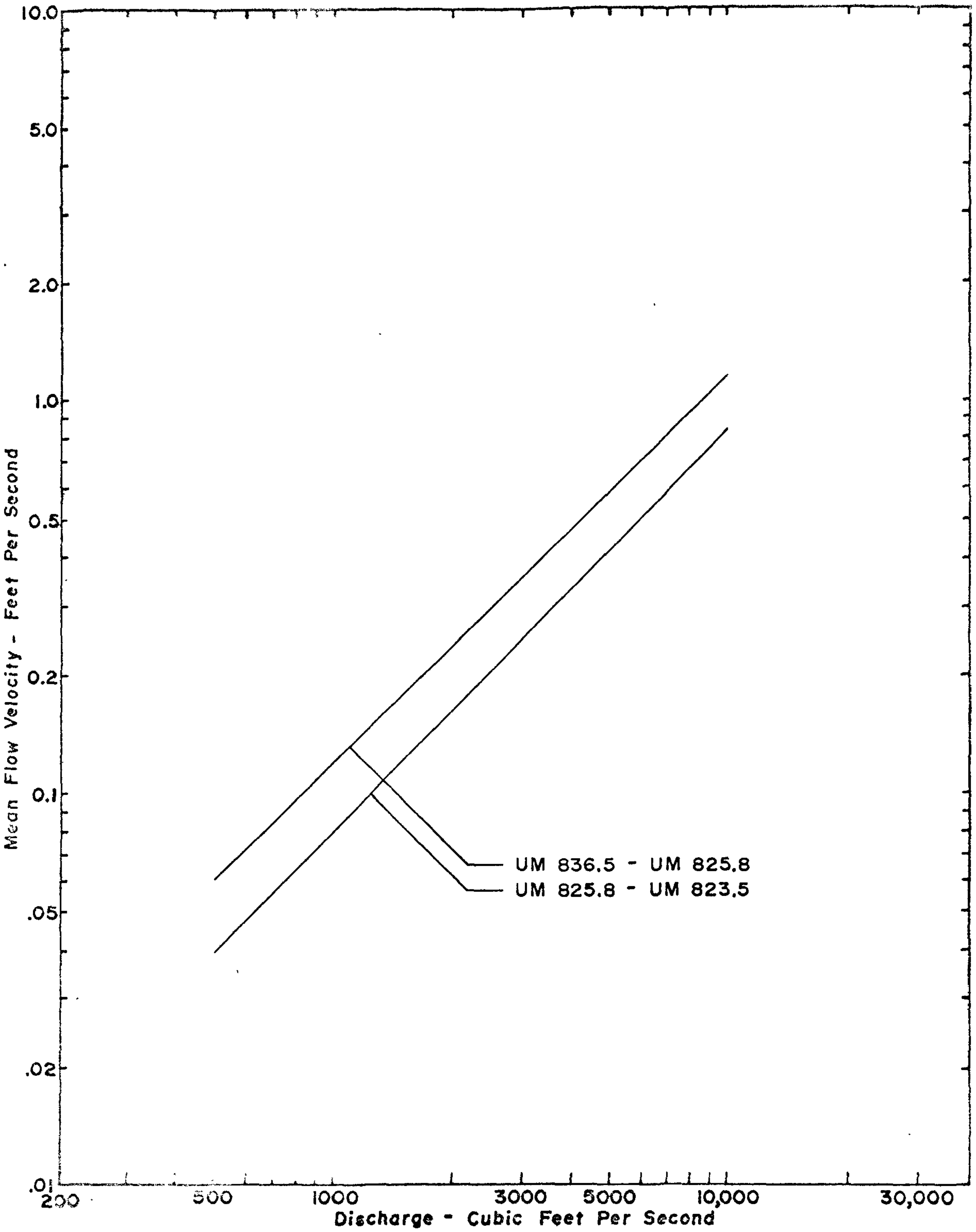
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-3



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 836.5 - 823.5

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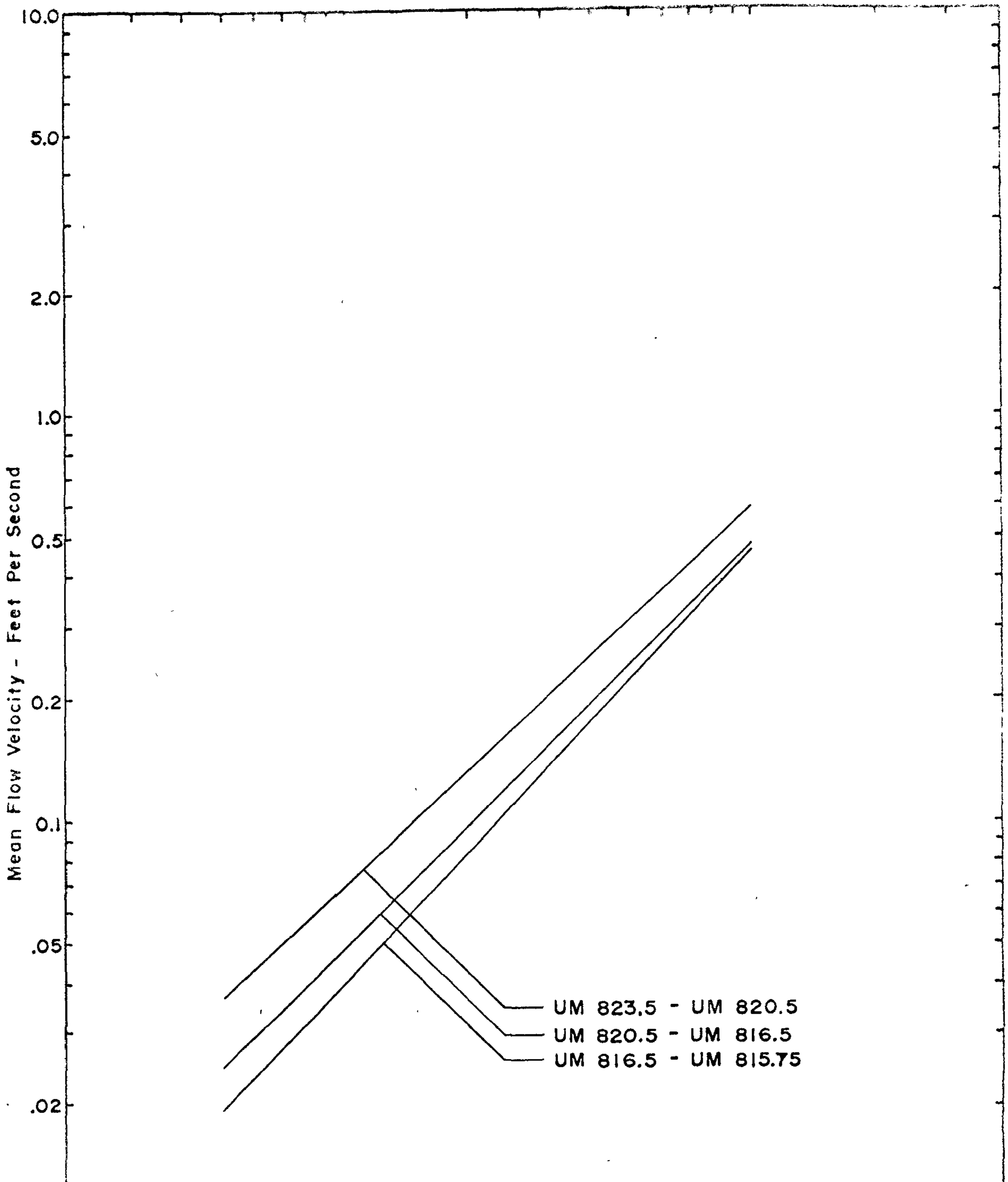
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-4



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 823.5-815.75

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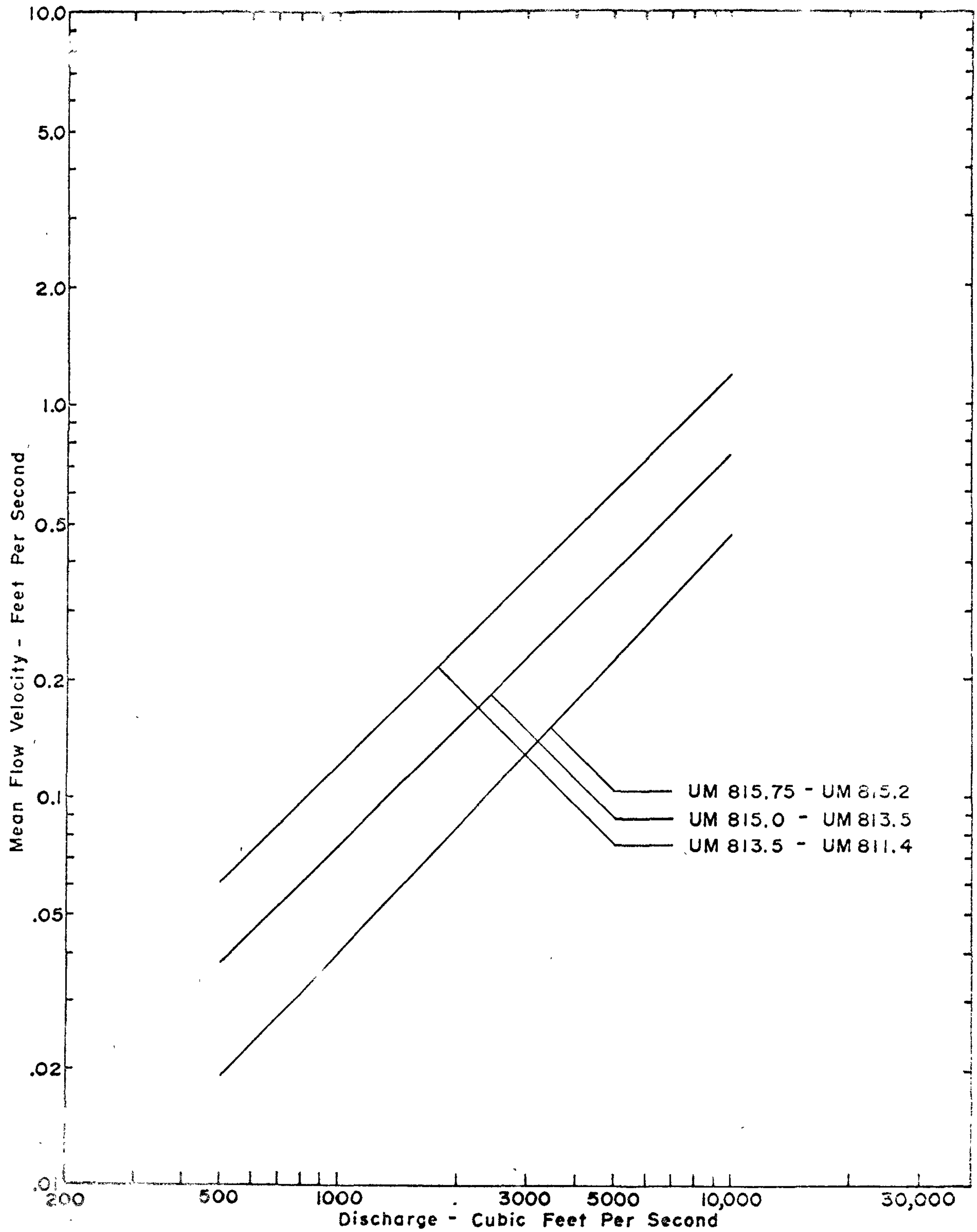
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-5



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 815.75 - 811.4

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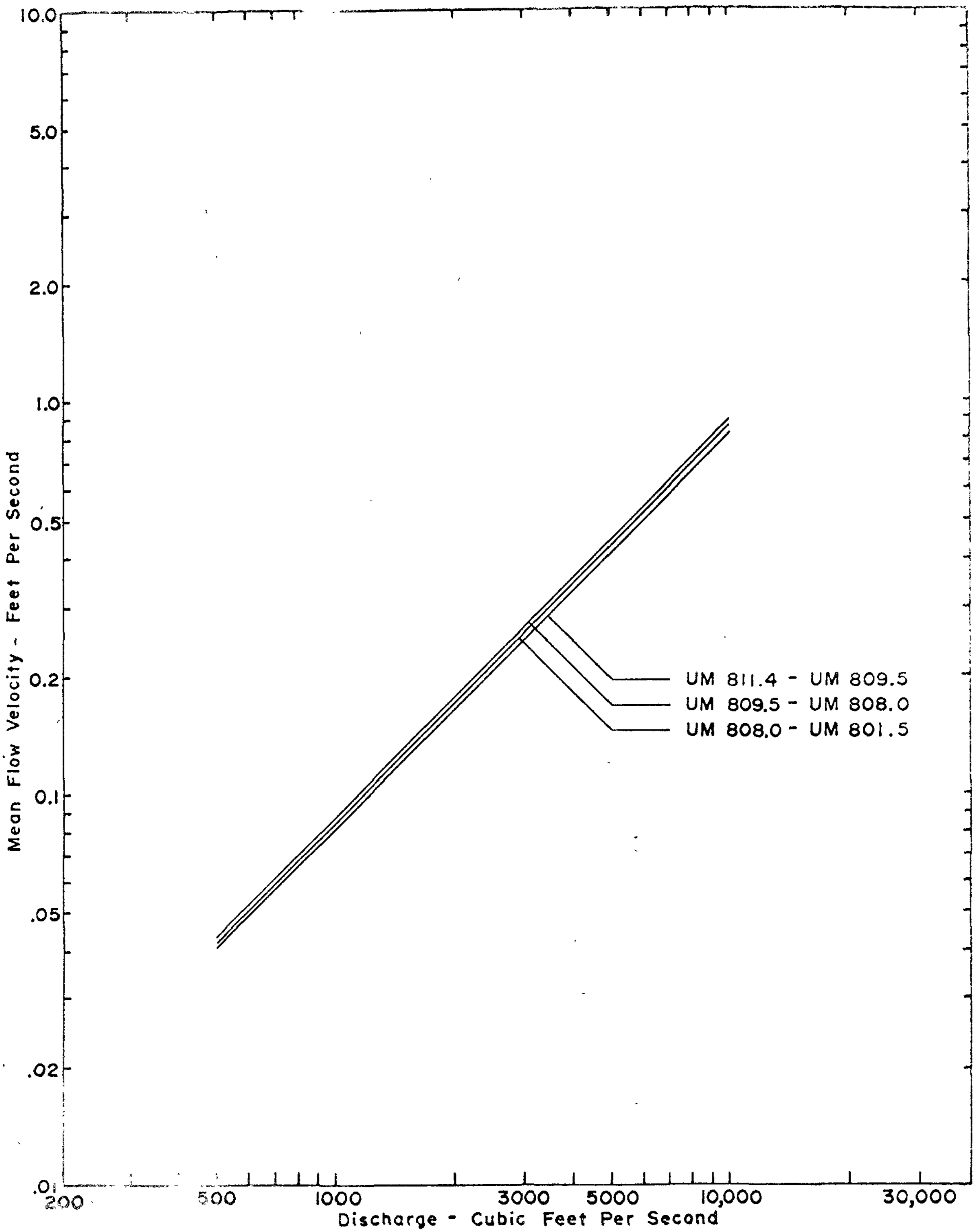
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-6



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 811.4 - 801.5

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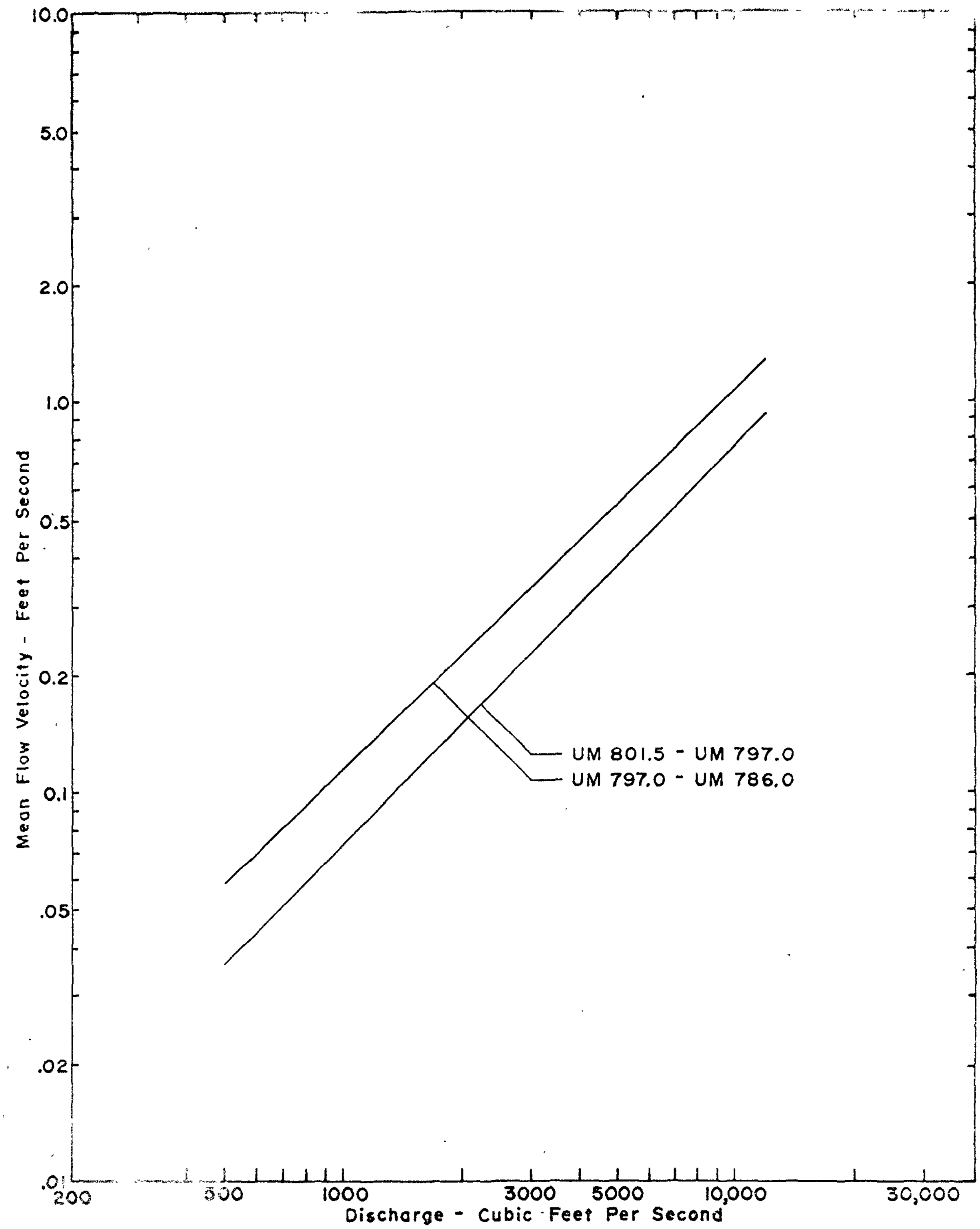
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-7



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
MISSISSIPPI RIVER
RIVER MILE 801.5-786.0

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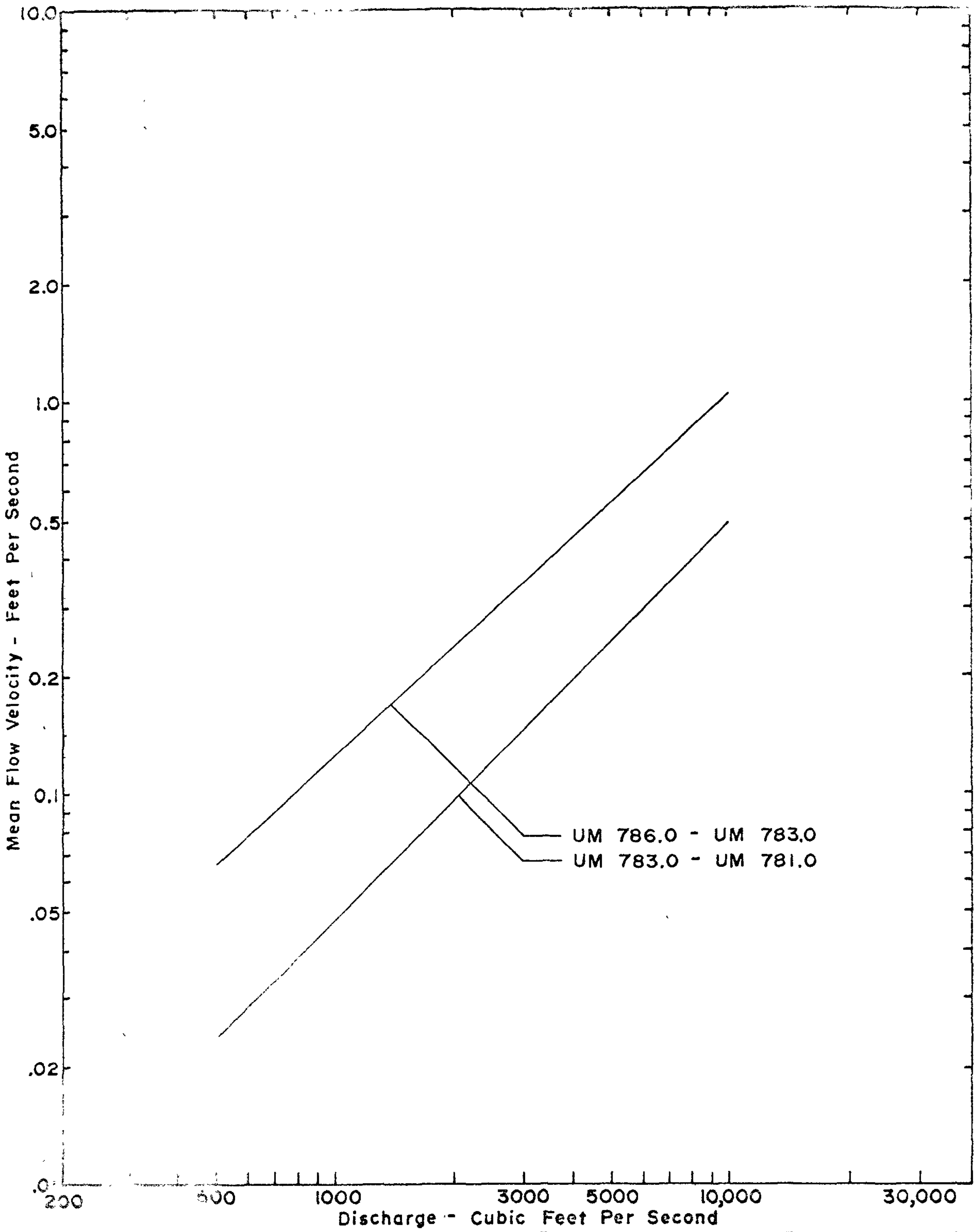
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-3



NOTE

Calculations based on the assumption that 20% of the area (or volume) is effective in transporting the water mass downstream.

TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS

MISSISSIPPI RIVER

RIVER MILE 786.0-781.0

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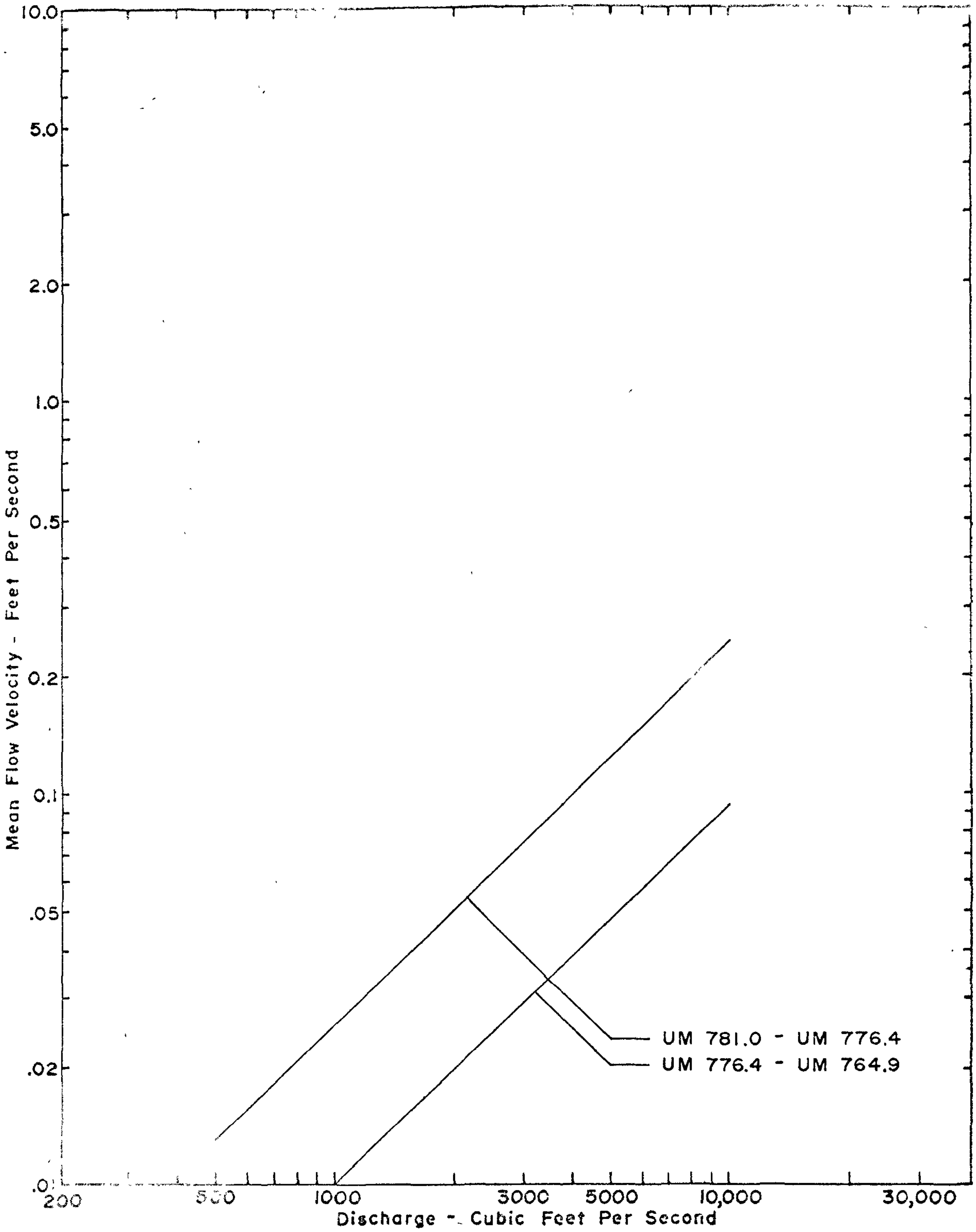
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-9



NOTE

Calculations based on the assumption that 40% of UM 781.0 - UM 776.4 and 60% of UM 776.4 - UM 764.9 areas (or volumes) are effective in transporting the water mass downstream.

TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS

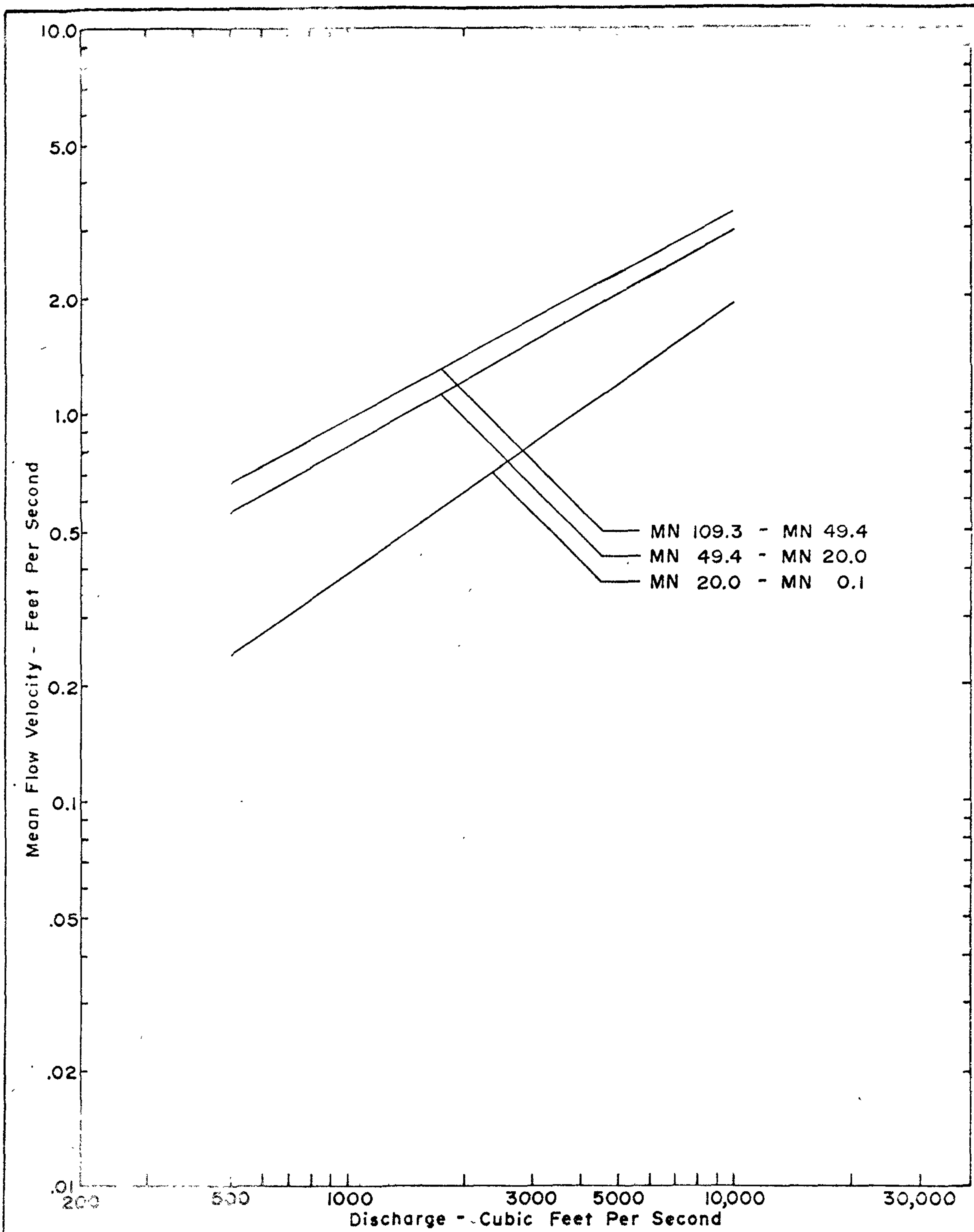
MISSISSIPPI RIVER

RIVER MILE 781.0-764.9

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.

REGION V — CHICAGO, ILLINOIS

FIGURE IV-10



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS

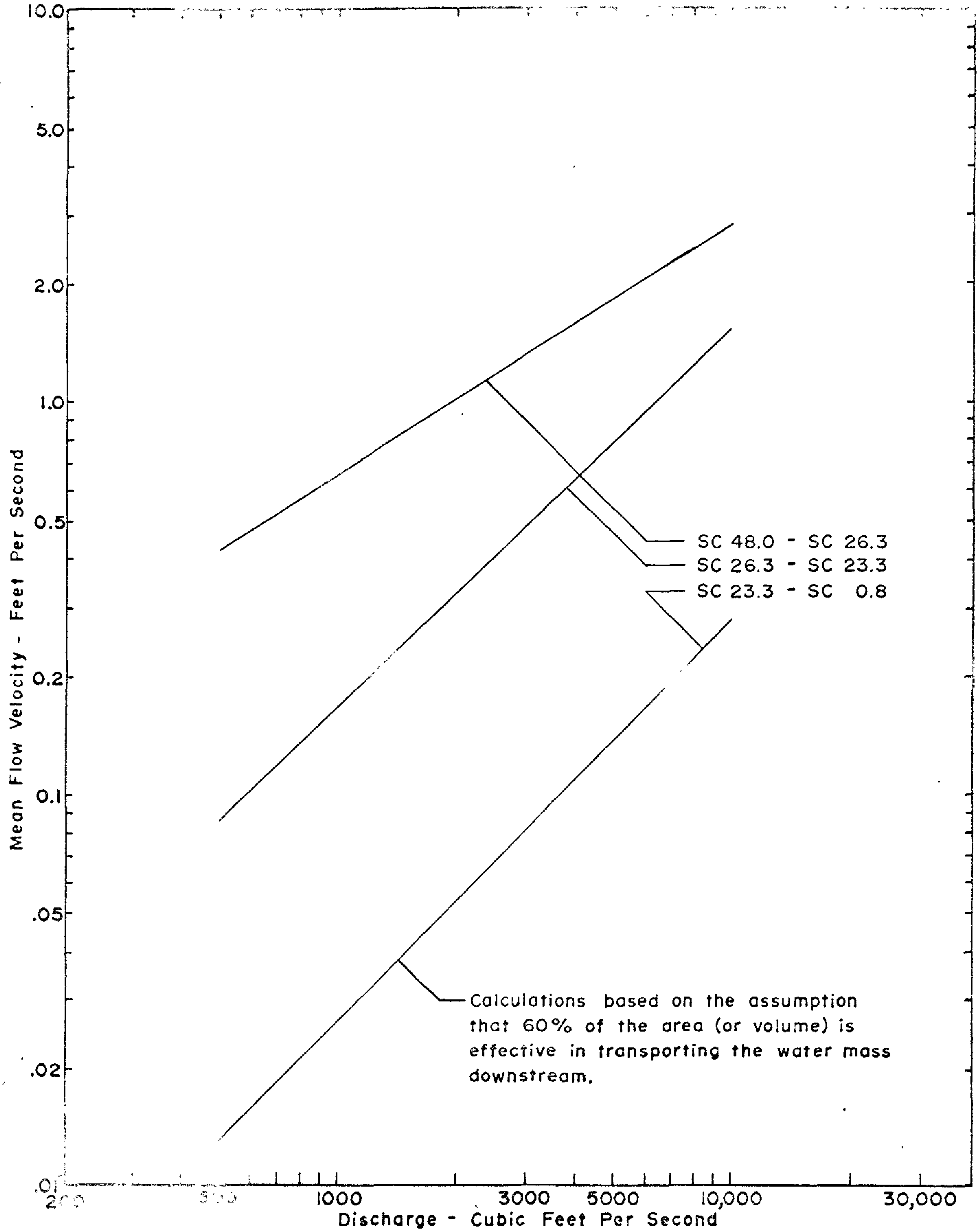
MINNESOTA RIVER

RIVER MILE 109.3 - 0.1

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.

REGION V CHICAGO, ILLINOIS

FIGURE IV-11



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

DISCHARGE - VELOCITY RELATIONSHIPS
ST. CROIX RIVER
RIVER MILE 48.0 - 0.8

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE IV-12

CHAPTER V

RANGE OF DAILY DISCHARGES

INTRODUCTION

The general conditions of flow occurring on the Mississippi, Minnesota and St. Croix Rivers during the period of the Project's routine and intensive surveys are presented in this Chapter. One gaging station on each of these three rivers has been selected to represent the condition of flow. Daily discharges are catagorized into low, medium and high ranges in keeping with the discharge history of the respective stations.

OBJECT

The range of daily discharges are provided in order that water quality data may be grouped according to the discharge range for general interpretation.

GENERAL INFORMATION

The range of discharge conditions for the selected gaging stations are given by the following Figures:

V-1. Minnesota River near Carver, Minnesota

V-2. Mississippi River at St. Paul, Minnesota

V-3. St. Croix River at St. Croix Falls, Wisconsin

A description of these stations and the daily discharge records from which the ranges presented here are derived may be found in this Project's report on Hydrographs.

The Carver gage is located just above that stretch of the Minnesota River which has been studied most carefully by this Project. It therefore provides the most single useful record on that stream and will reflect the general stream flow conditions of the entire stretch under study.

The St. Paul gage provides the most useful record of the Mississippi River because of its location just above that stretch of stream into which considerable waste is being discharged. This record may be applied to the entire stretch of the Mississippi River within the Project study area unless Minnesota or St. Croix River flows are not within or very nearly within the same relative range of flow.

The St. Croix Falls gage is located at the upstream end of the Project study area and reflects accurately the St. Croix River conditions. The Apple River, which flows into the St. Croix River 23 miles below St. Croix Falls does not alter the flow regime of the St. Croix River and therefore the range of flow derived from the St. Croix Falls record may be applied below the confluence of the Apple River.

The flows defining the low, medium and high ranges were selected by examining the U. S. Geological Survey compilation of the discharge records through 1950 (Water Supply Paper 1308) of the three stations used here. Although these records do not correspond to those used by this Project for mean monthly and low flow analysis, they provide a simple and effective means of selecting appropriate ranges of flow. Low flows include the highest minimum daily discharge and the lowest yearly mean discharge. Medium flows include the mean discharge for the period of record but do not include either the highest or lowest yearly mean discharges. High flows include the lowest maximum daily discharge and the highest yearly mean discharge.

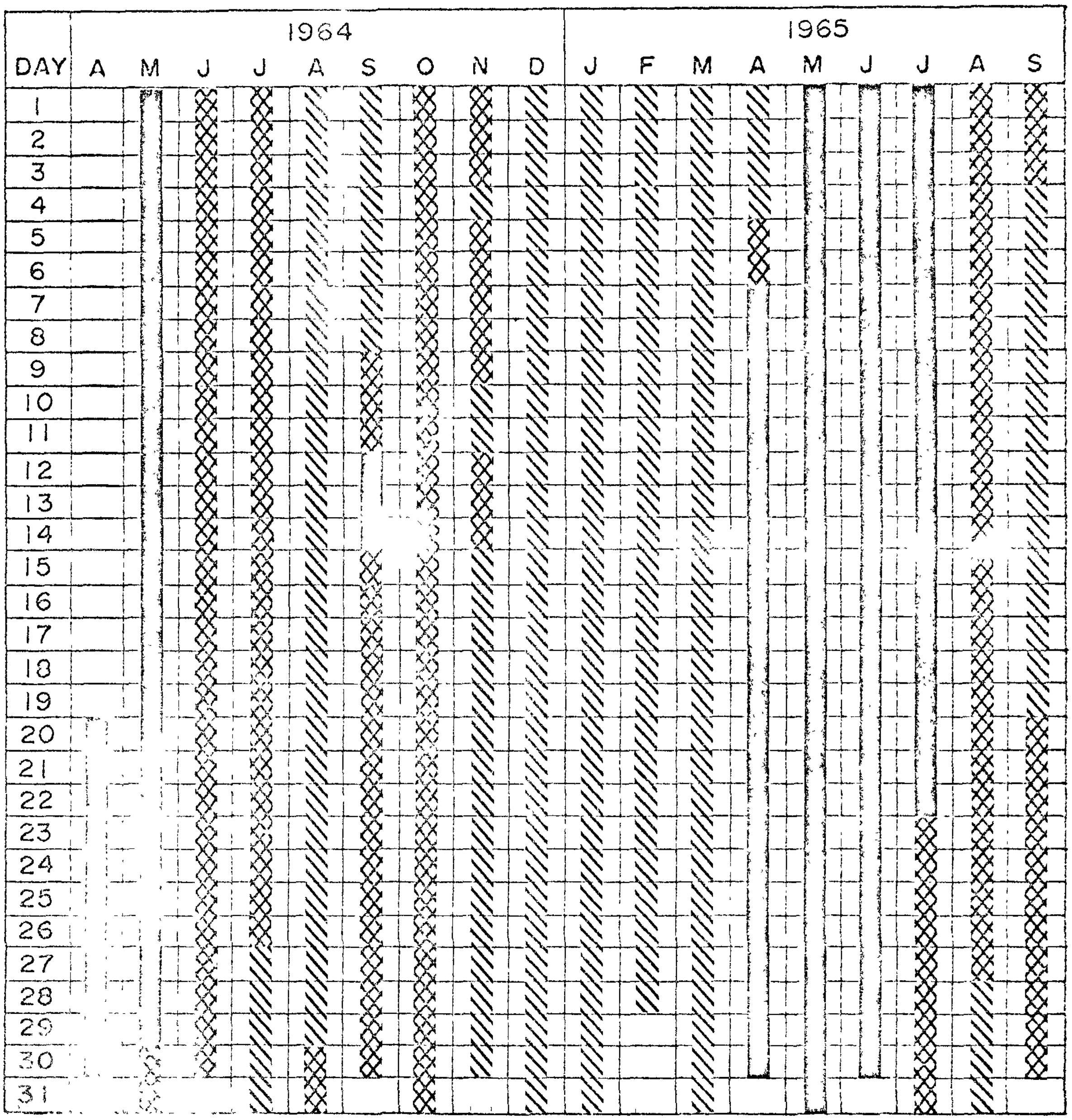
Selection of representative discharges for the ranges of flow at the three stations was based upon the mean and daily discharges presented in Table V-1.

MINNESOTA RIVER

BASED ON DISCHARGE

GAGE NEAR

CARVER MINNESOTA



RANGE [illegible] FLOW

5000 Cubic Feet Per Second or Greater

[illegible]000 to 4999 Cubic Feet Per Second

[illegible] Cubic Feet Per Second or Less

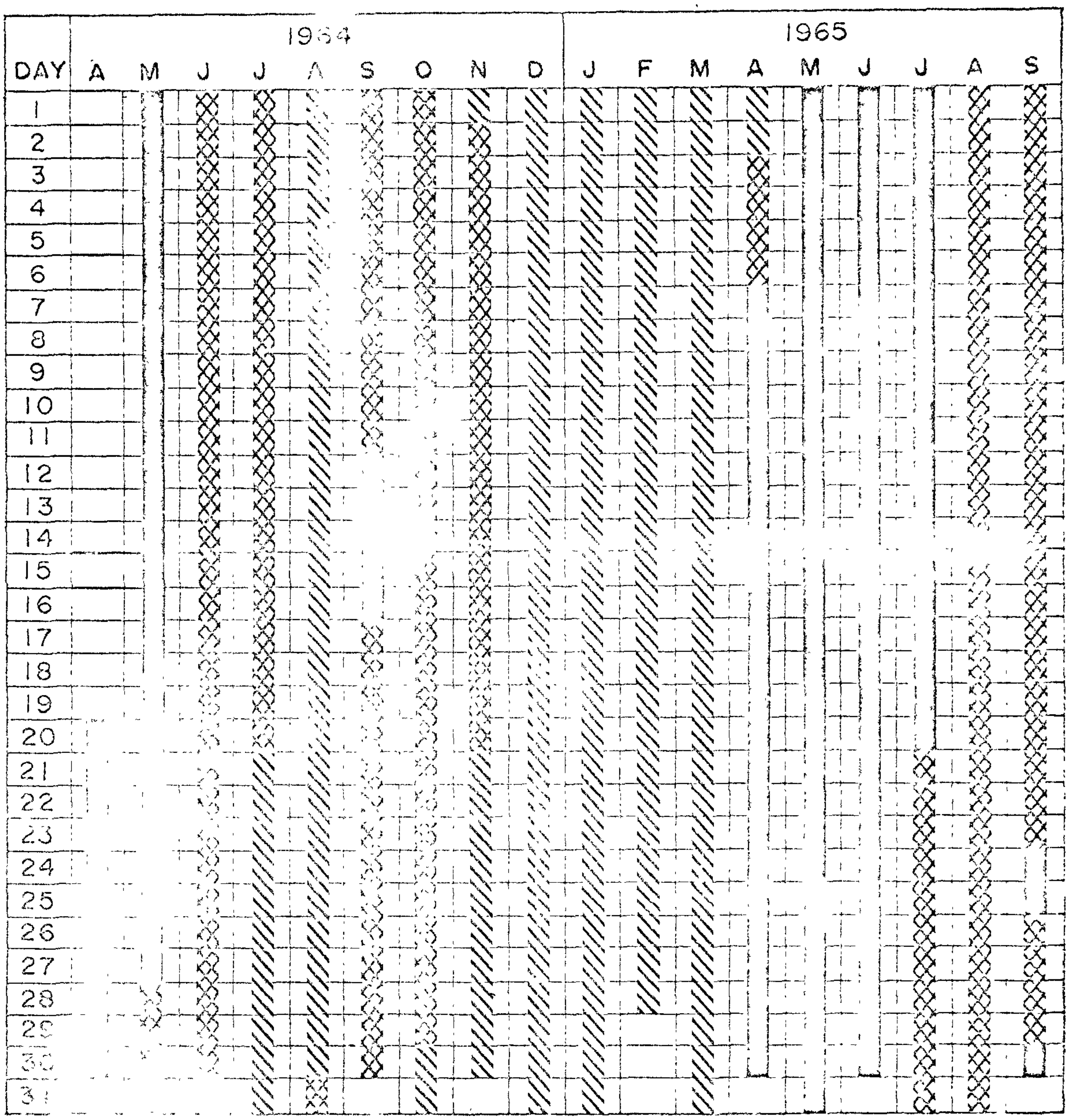
TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

RANGE OF DAILY DISCHARGES FOR PERIOD OF WATER QUALITY SURVEY

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE V-1

MISSISSIPPI RIVER
BASED ON DISCHARGE
GAGE AT
ST. PAUL, MINNESOTA



RANGE OF FLOW

15,000 Cubic Feet Per Second or Greater

5,000 to 14,999 Cubic Feet Per Second

[illegible]99 Cubic Feet Per Second or Less

TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

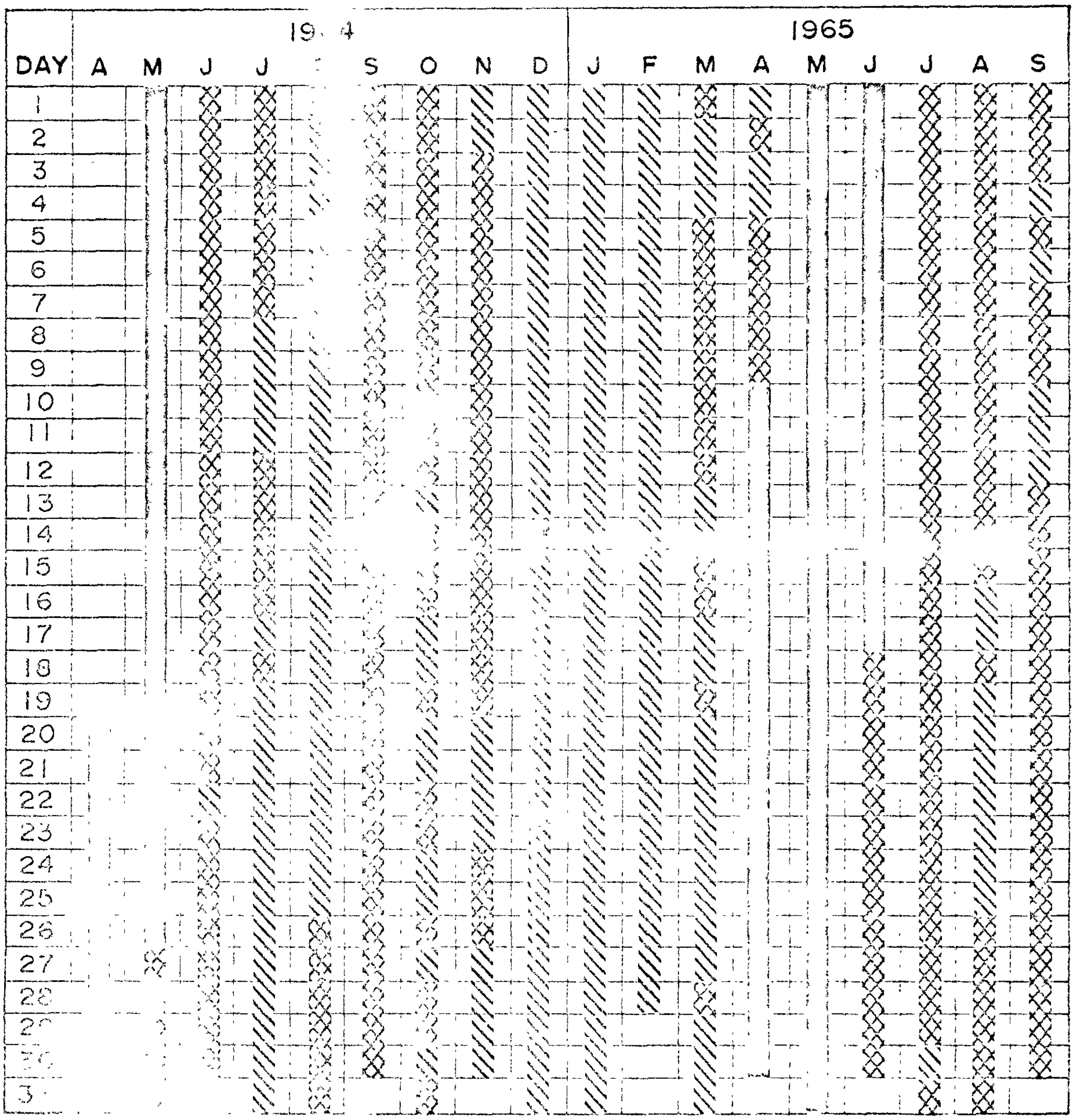
RANGE OF DAILY DISCHARGES FOR PERIOD OF WATER QUALITY SURVEY

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN

REGION V CHICAGO, ILLINOIS

FIGURE V-2

ST. CROIX RIVER
BASED ON DISCHARGE
GAGE AT
ST. CROIX FALLS, WISCONSIN



RANGE OF ...

600[illegible] Cubic Feet Per Second or Greater

[illegible] to 5999 Cubic Feet Per Second

[illegible] Cubic Feet Per Second or Less

TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

RANGE OF DAILY DISCHARGES FOR PERIOD OF WATER QUALITY SURVEY

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.

CHICAGO, ILLINOIS

FIGURE V-3

TABLE V-1

	MISSISSIPPI RIVER AT ST. PAUL	MINNESOTA RIVER NEAR CARVER	ST. CROIX RIVER AT ST. CROIX FALLS
Maximum - daily discharges for the period of record prior to W.Y. 1951	107,000 cfs	64,100 cfs	54,900 cfs
Lowest maximum daily discharge for a year prior to W.Y. 1951	9,640 cfs	4,010 cfs	6,140 cfs
Highest Yearly Mean prior to W.Y. 1951	18,200 cfs	5,602 cfs	6,221 cfs
Mean - Annual Discharge for period of record prior to W.Y. 1951	9,442 cfs	3,044 cfs	3,838 cfs
Lowest Yearly Mean prior to W.Y. 1951	1,935 cfs	729 cfs	1,754 cfs
Highest Minimum Daily Discharge for a year prior to W.Y. 1951	4,730 cfs	650 cfs	1,350 cfs
Minimum Daily Discharge for period of record prior to W.Y. 1951	632 cfs	79 cfs	75 cfs

CHAPTER VI

LOW FLOW FREQUENCY

INTRODUCTION

Low flow frequency curves, based on average daily flows during winter and summer months for the 25-year period of record from Water Year 1940 through 1964, are presented. A family of curves describing 1, 7, 15, 30 and 60 consecutive day periods of low flow are provided for each of five gaging stations. These stations were selected to provide adequate representation of the segments of the Mississippi, Minnesota and St. Croix Rivers within the Project's study area.

OBJECT

These curves may be used to predict the minimum average flow for 1, 7, 15, 30 or 60 consecutive days during either the winter or summer months which is likely to occur in any given span of time up to 26 years.

GENERAL INFORMATION

A family of low flow frequency curves for the winter months of December, January and February and the summer months of July, August and September for each of the selected gaging stations are presented in the following Figures:

VI-1. Mississippi River at Lock & Dam #1 - winter months

VI-2. Mississippi River at Lock & Dam #1 - summer months

VI-3. Minnesota River near Carver, Minnesota - winter months

VI-4. Minnesota River near Carver, Minnesota - summer months

VI-5. Mississippi River at St. Paul, Minnesota - winter months

VI-6. Mississippi River at St. Paul, Minnesota - summer months

VI-7. St. Croix River at Stillwater, Minnesota - winter months

VI-8. St. Croix River at Stillwater, Minnesota - summer months

VI-9. Mississippi River at Lock & Dam #3 - winter months

VI-10. Mississippi River at Lock & Dam #3 - summer months

The chapter "Hydrographs" includes a discussion of each of these stations as well as general comments concerning their selection. The segment of stream to which the flows may be applied as well as the source and reliability of the record are also provided.

The 25-year period of record, used in the computation of the average low flow for the consecutive day periods, was selected after scrutiny of each stream's hydrologic history. The information was obtained largely through consultation with personnel of the U. S. Army Corps of Engineers, U. S. Geological Survey, Minnesota Department of Conservation and the Northern States Power Company. The following general conditions applicable to the Mississippi, Minnesota and St. Croix Rivers were most relevant in selecting Water Years 1940 through 1964:

1. Major dam construction was completed about 1938.

2. There have been no significant changes in storage capacity during that period.

3. Operating procedures for the numerous locks, dams, power plants and reservoirs have remained relatively constant.

The amount of storage capacity made possible by the erection of dams and the operation of these dams is of particular importance where low flow frequency analyses are to be made. With the possible exception of Lake Pepin and Lake St. Croix, there is little storage capacity in the river systems of the Project's study area. Furthermore, upstream reservoirs are not operated to their fullest potential to modify either high or low

flows. For various reasons upstream reservoir levels have been maintained within certain limits. On the St. Croix and Apple Rivers, the Northern States Power Company operates hydroelectric plants under approximately "run-of-the-river" conditions.

The governing philosophies of the agencies that operate the locks, dams, power plants and reservoir affecting the study area have remained relatively unchanged since 1939. The existence of these facilities and their operation do alter the natural hydrology. However, since neither the facilities nor methods of operation changed during the period of record and as long as these conditions do not change, the low flow frequency curves derived from this period are certainly valid and can be used to predict expected low flows for similar intervals in the future.

METHOD OF COMPUTATION

All computations required to plot these frequency curves were performed by a digital computor. The program was written, checked and executed by the Project's Data Processing Unit.

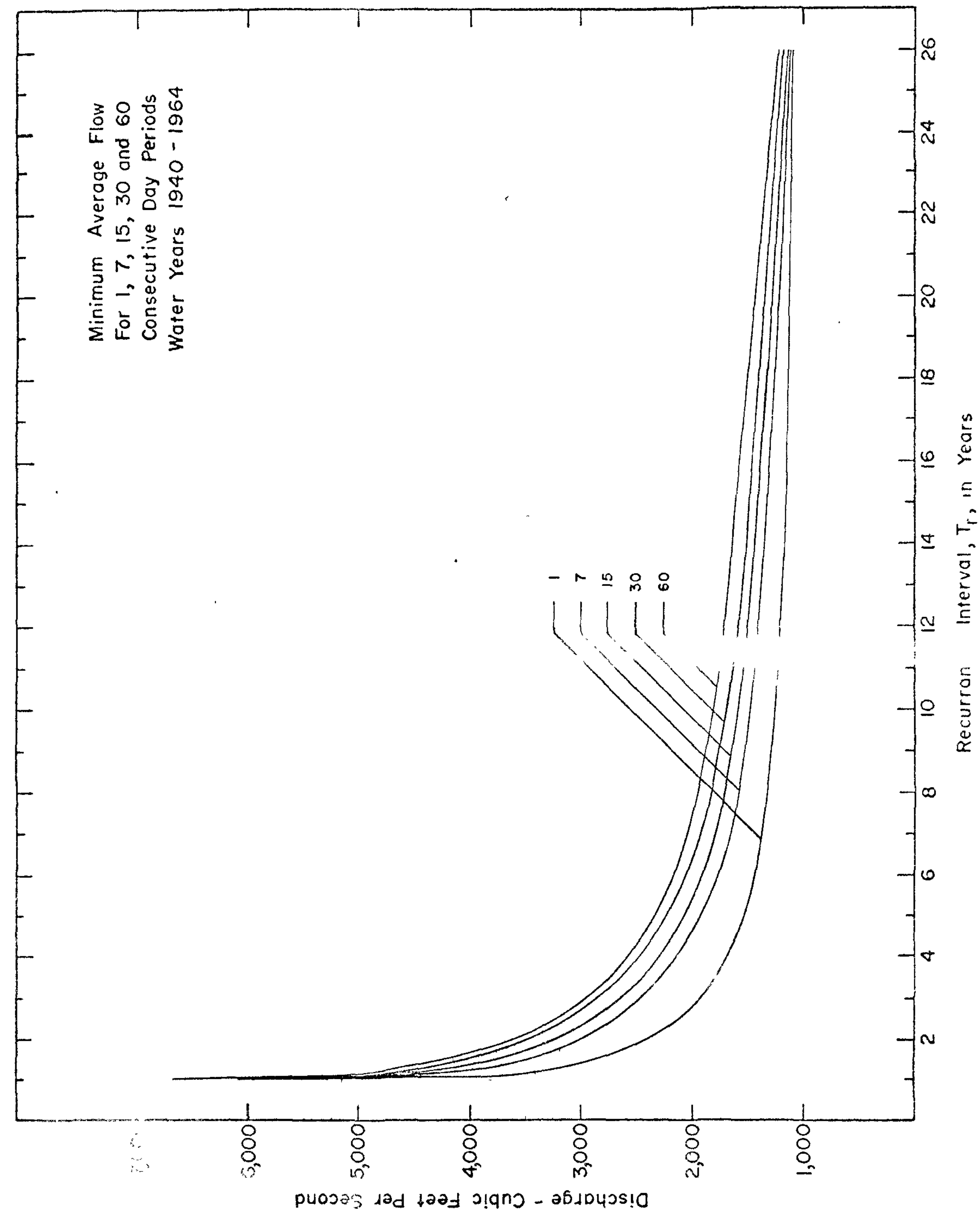
The procedure described below was carried out for winter and summer months at every gaging station. The average daily discharges for every year were arrayed, and the lowest average daily discharge was selected. Every consecutive 7-day average was computed and the lowest selected. The minimum average flow for the 15, 30 and 60 consecutive day periods was calculated in the same way. The minimum average flows for the consecutive day periods were then arrayed in ascending order and their recurrence interval calculated from the formula:

$$Tr = \frac{n + 1}{m}$$

where:

Tr = recurrance interval in years
n = number of years of record
m = rank of the event (m = 1 for the lowest flow in the array)

After plotting flow vs. recurrance interval, the lines of best fit were drawn. This resulted in one family of curves for the winter months and a similar set for the summer months at each of the selected gaging stations.



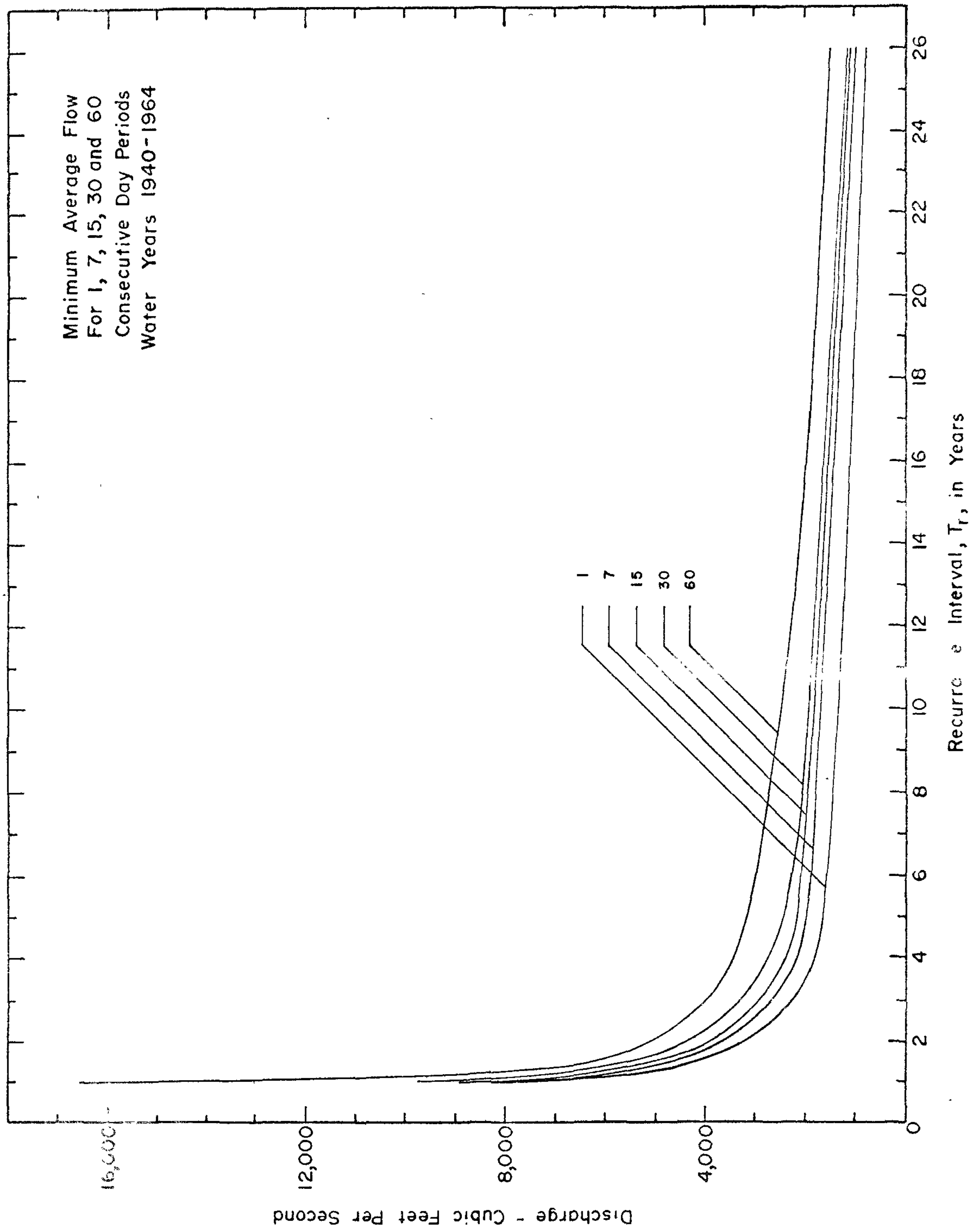
TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

LOW FLOW FREQUENCY
DECEMBER, JANUARY, FEBRUARY
MISSISSIPPI RIVER AT
LOCK AND DAM NUMBER 1

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.

REGION V CHICAGO, ILLINOIS

FIGURE VI-1



TWIN CITIES UPPER MISSISSIPPI
RIVER PROJECT

LOW FLOW FREQUENCY
JULY, AUGUST, SEPTEMBER
MISSISSIPPI RIVER AT
LOCK AND DAM NUMBER 1

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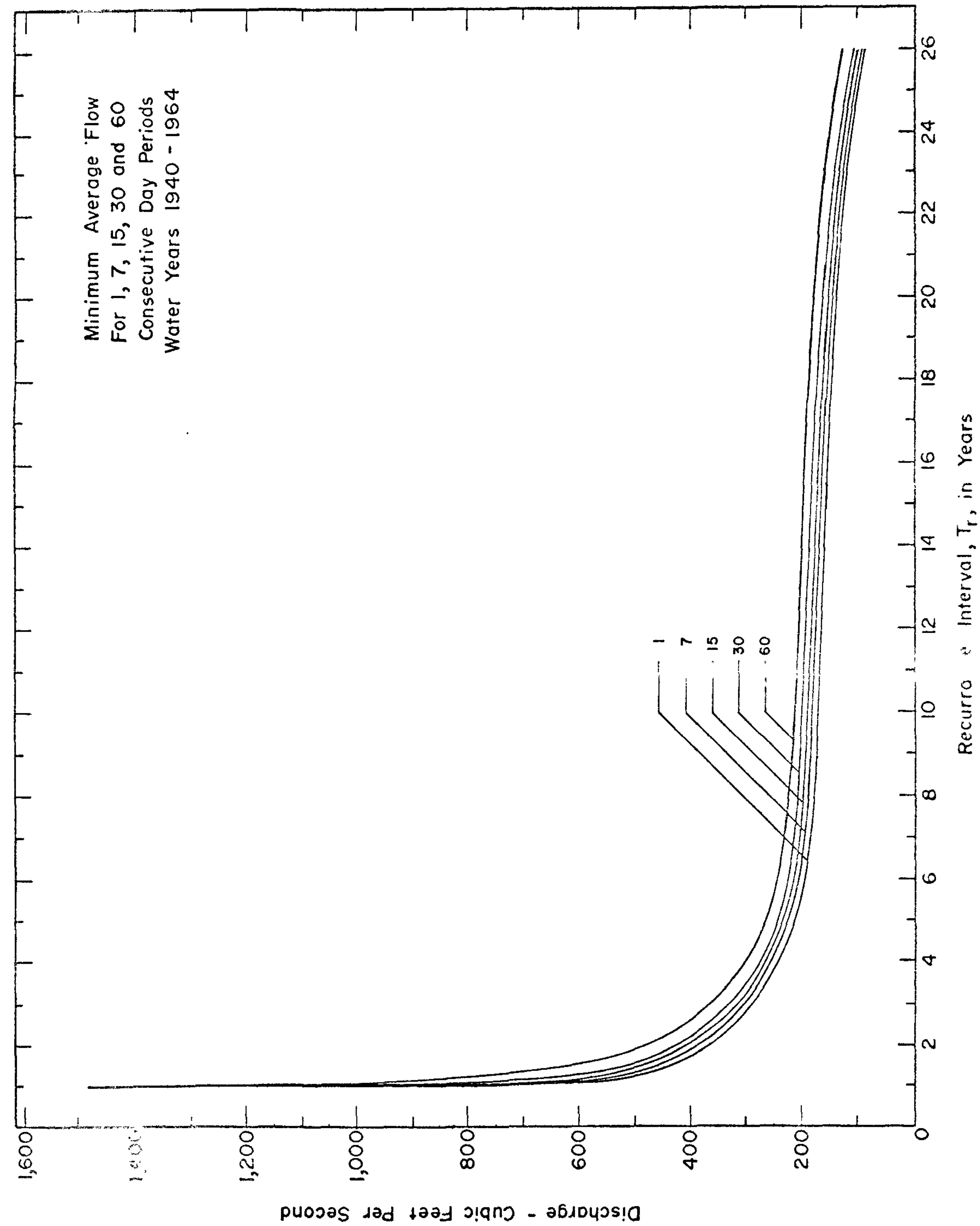
FEDERAL WATER POLLUTION CONTROL
ADMIN.

REGION V CHICAGO, ILLINOIS

FIGURE VI-2

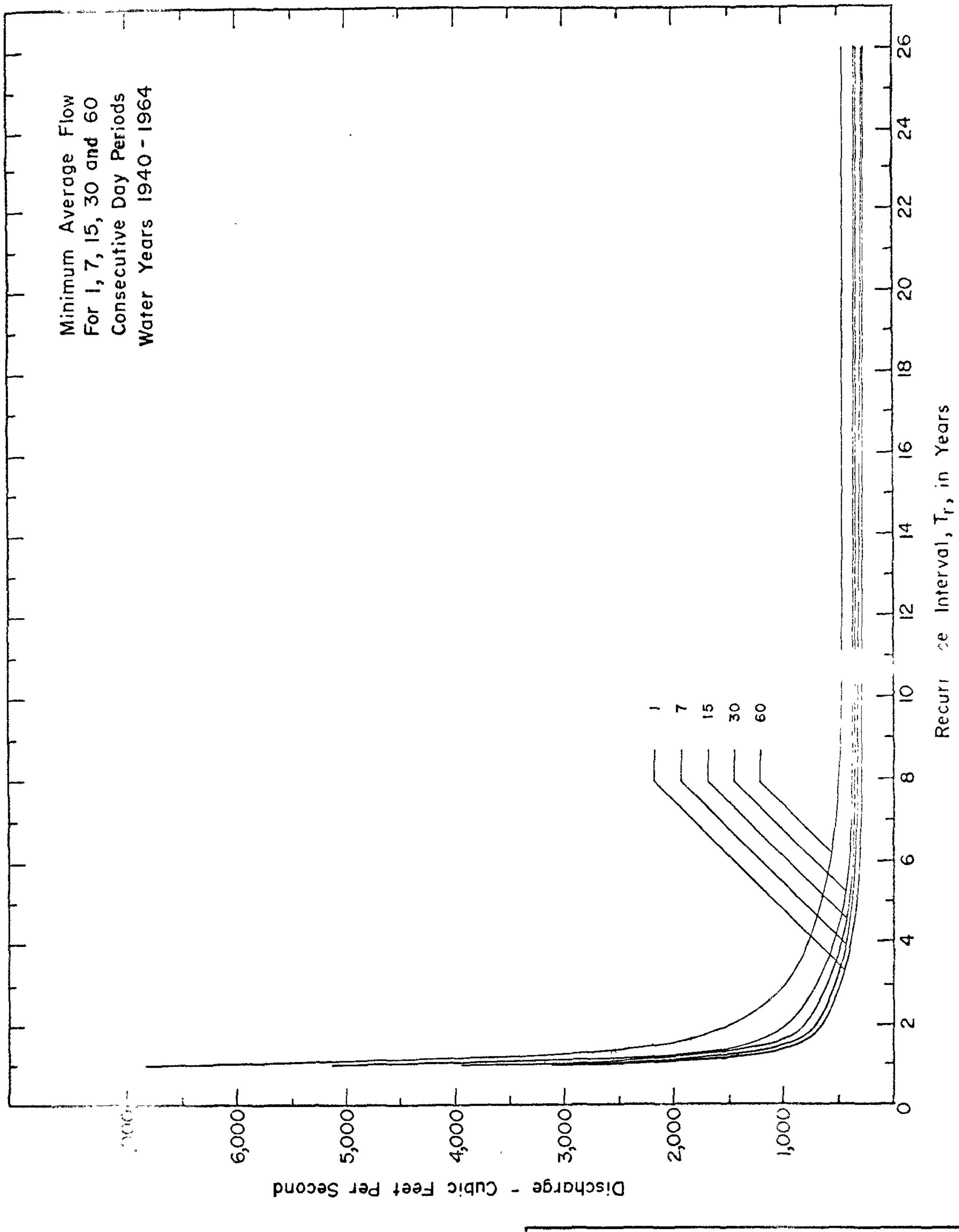


TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

LOW FLOW FREQUENCY
DECEMBER, JANUARY, FEBRUARY
MINNESOTA RIVER NEAR
CARVER, MINNESOTA

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE VI-3



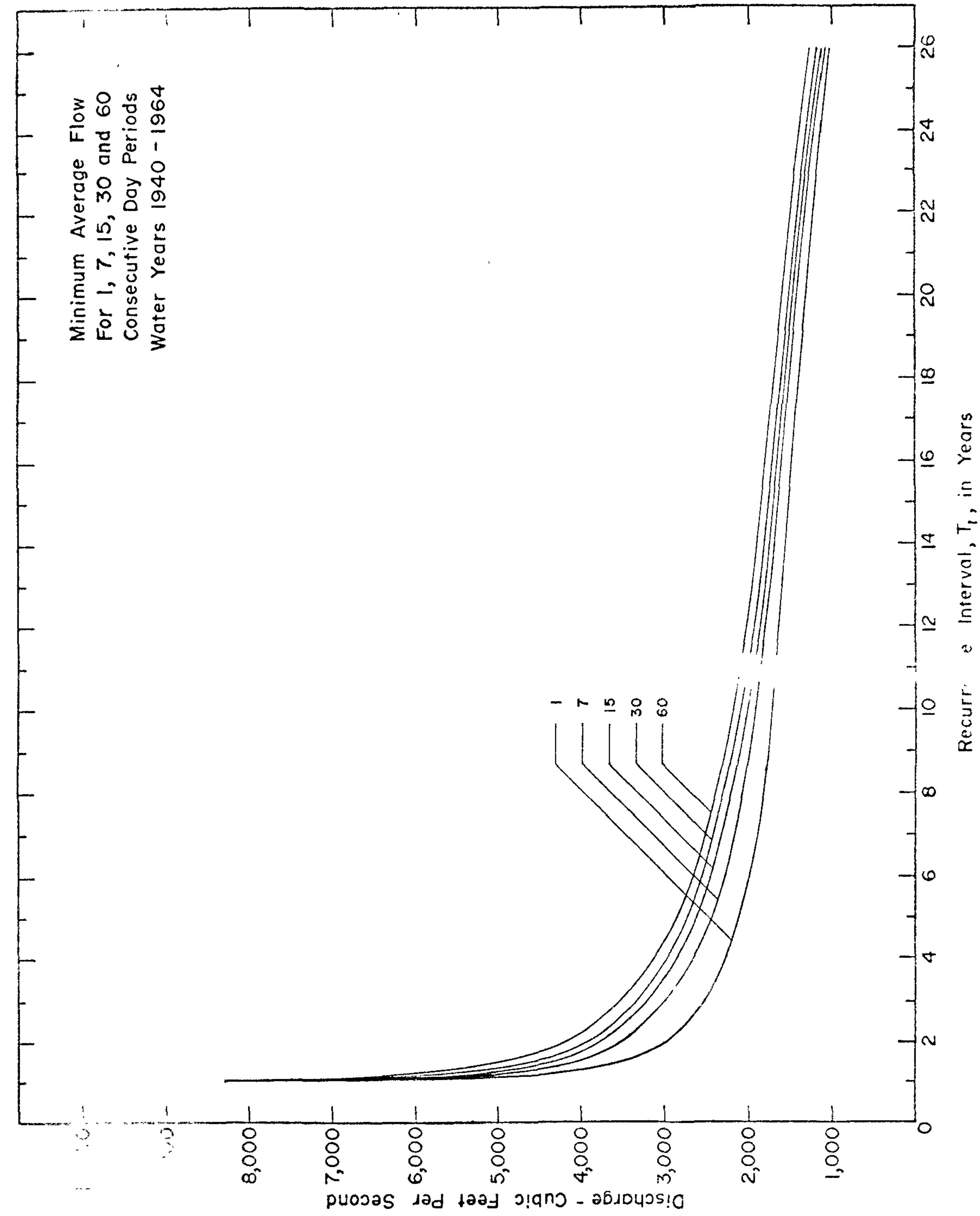
TWIN CITIES UPPER MISSISSIPPI
RIVER PROJECT

LOW FLOW FREQUENCY
JULY, AUGUST, SEPTEMBER
MINNESOTA RIVER NEAR
CARVER, MINNESOTA

DEPT. OF HEALTH, EDUCATION, & WELFARE
FEDERAL WATER POLLUTION CONTROL
ADMIN

REGION V CHICAGO, ILLINOIS

FIGURE VI-4



TWIN CITIES UPPER MISSISSIPPI
RIVER PROJECT

LOW FLOW FREQUENCY
DECEMBER, JANUARY, FEBRUARY
MISSISSIPPI RIVER AT
ST. P[illegible] MINNESOTA

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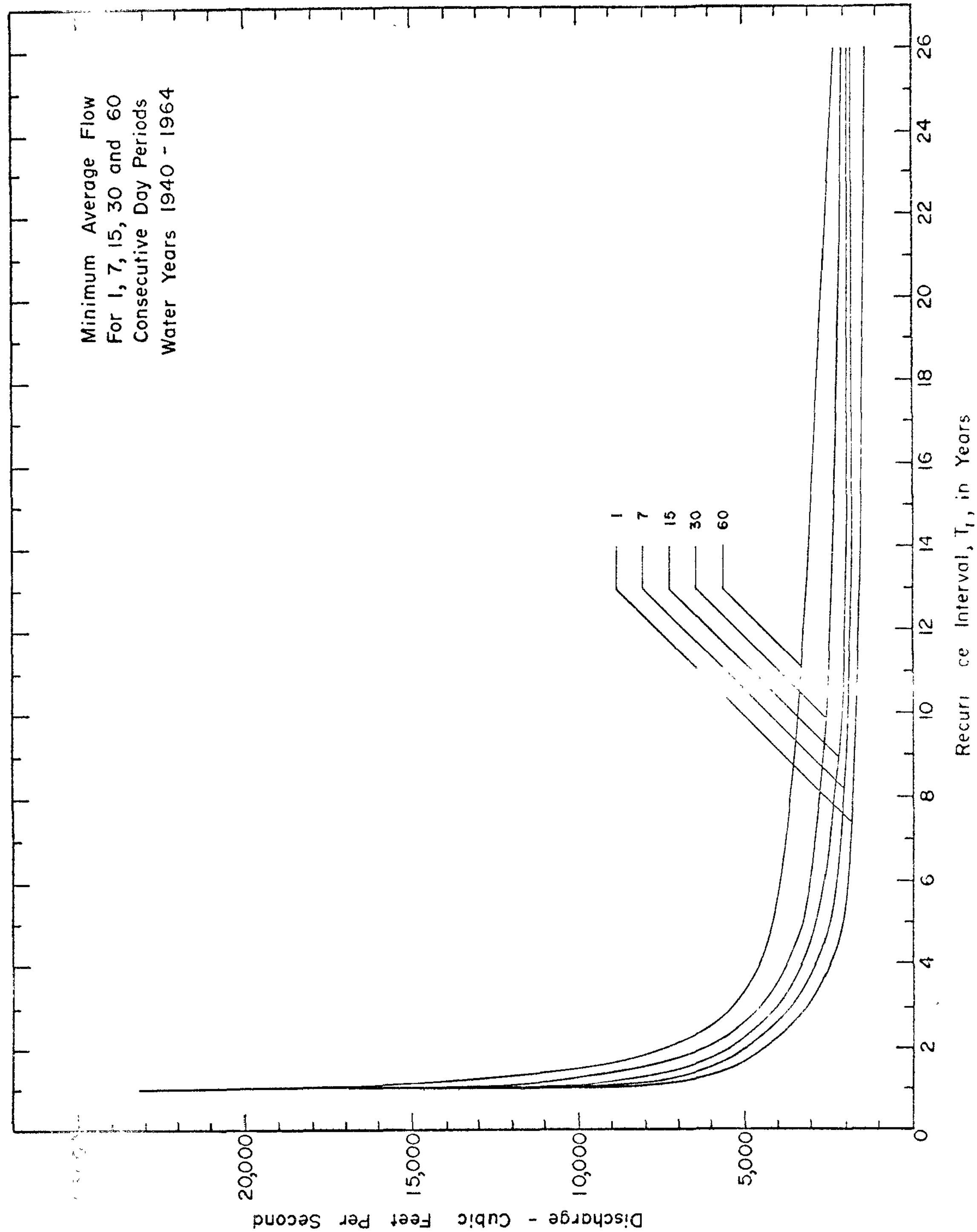
FEDERAL WATER POLLUTION CONTROL
ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE VI-5



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

LOW FLOW FREQUENCY
JULY, AUGUST, SEPTEMBER
MISSISSIPPI RIVER AT
ST. PAUL, MINNESOTA

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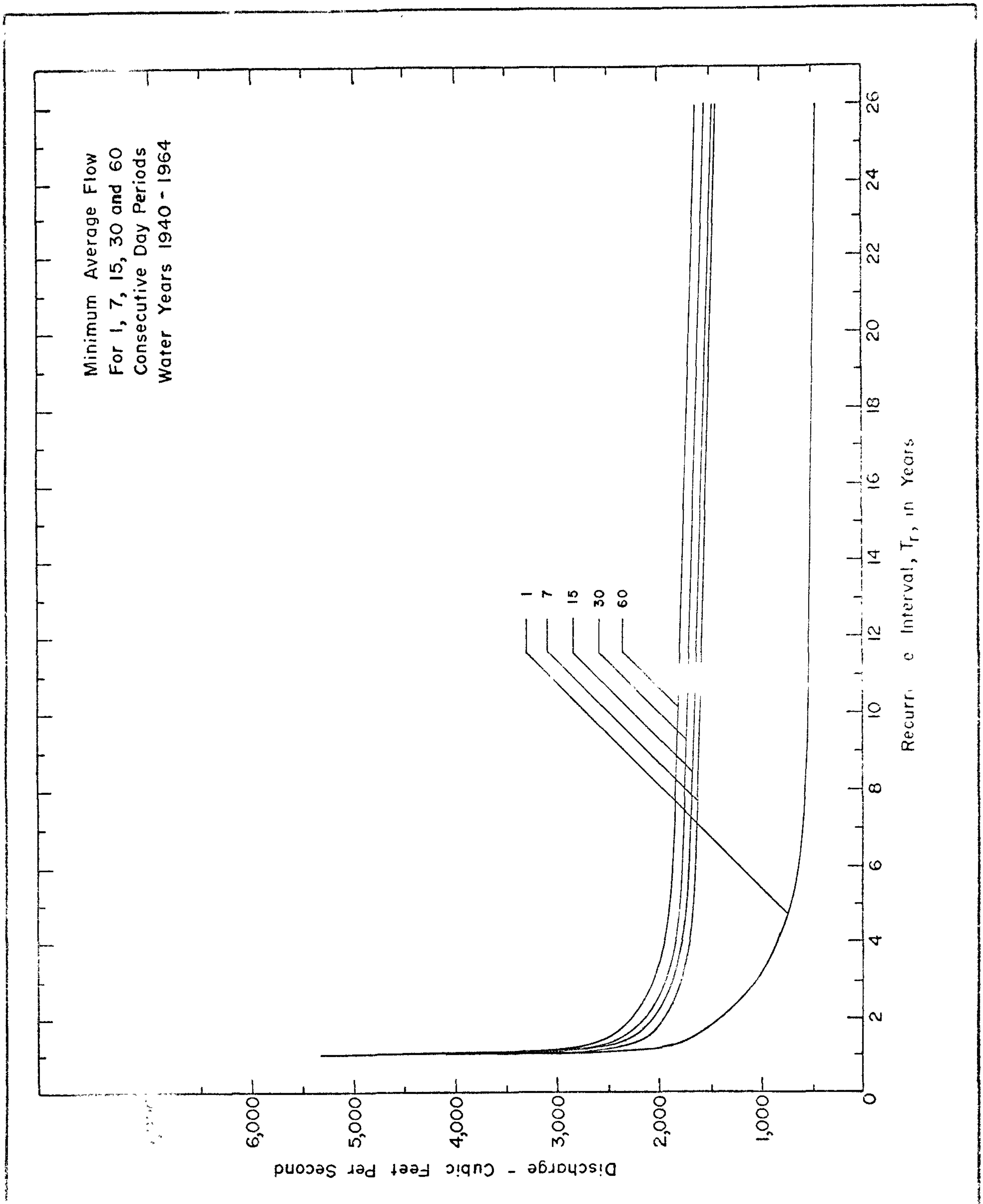
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V — CHICAGO ILLINOIS

FIGURE VI-6



TWIN CITIES UPPER MISSISSIPPI
RIVER PROJECT

LOW FLOW FREQUENCY
DECEMBER, JANUARY, FEBRUARY
ST. CROIX RIVER AT
STILLWATER, MINNESOTA

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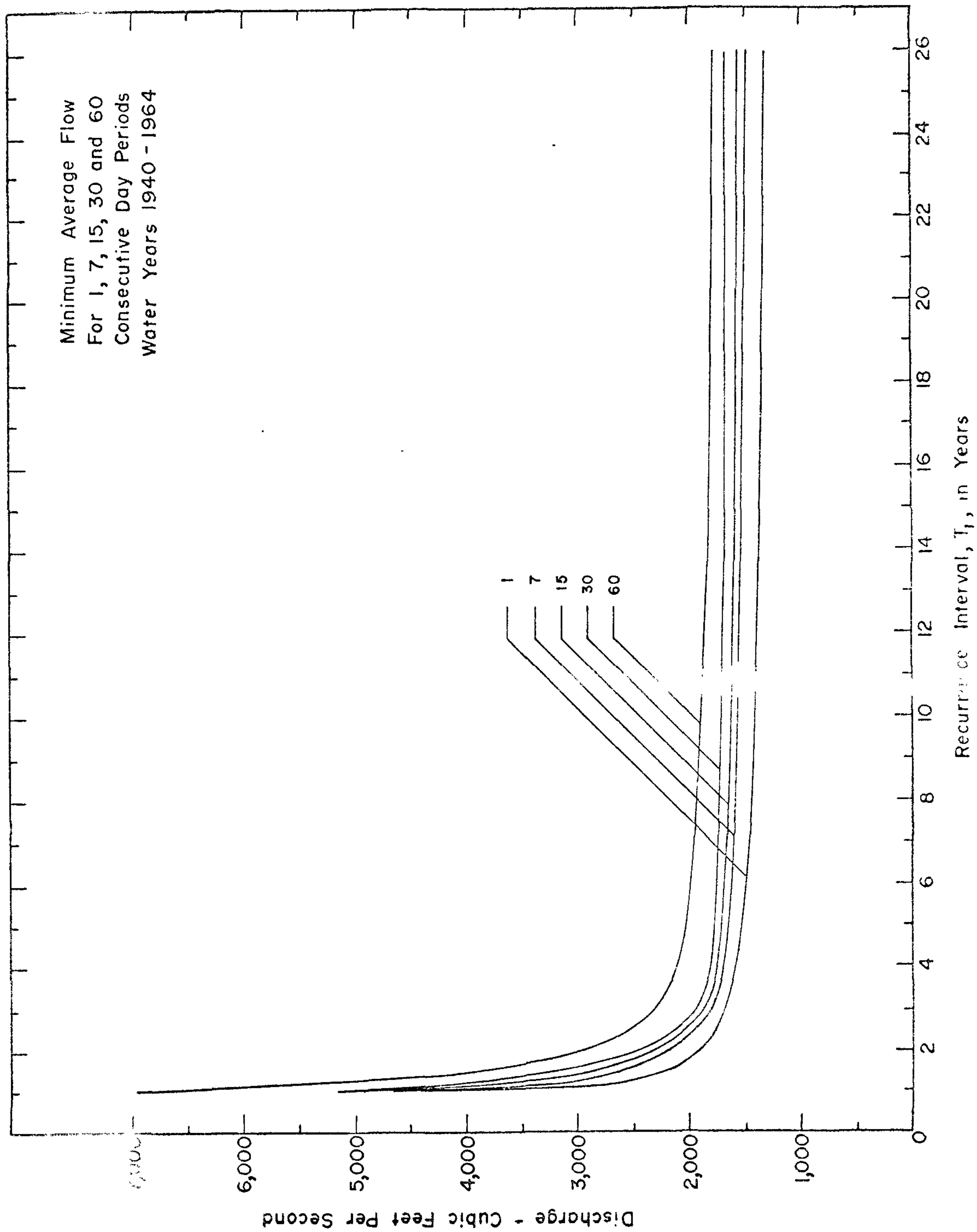
FEDERAL WATER POLLUTION CONTROL
ADMIN.
REGION V CHICAGO ILLINOIS

FIGURE VI-7



TWIN CITIES UPPER MISSISSIPPI RIVER PROJECT

LOW FLOW FREQUENCY
JULY, AUGUST, SEPTEMBER
ST. CR[illegible]X RIVER AT
STILL[illegible]ER, [illegible]

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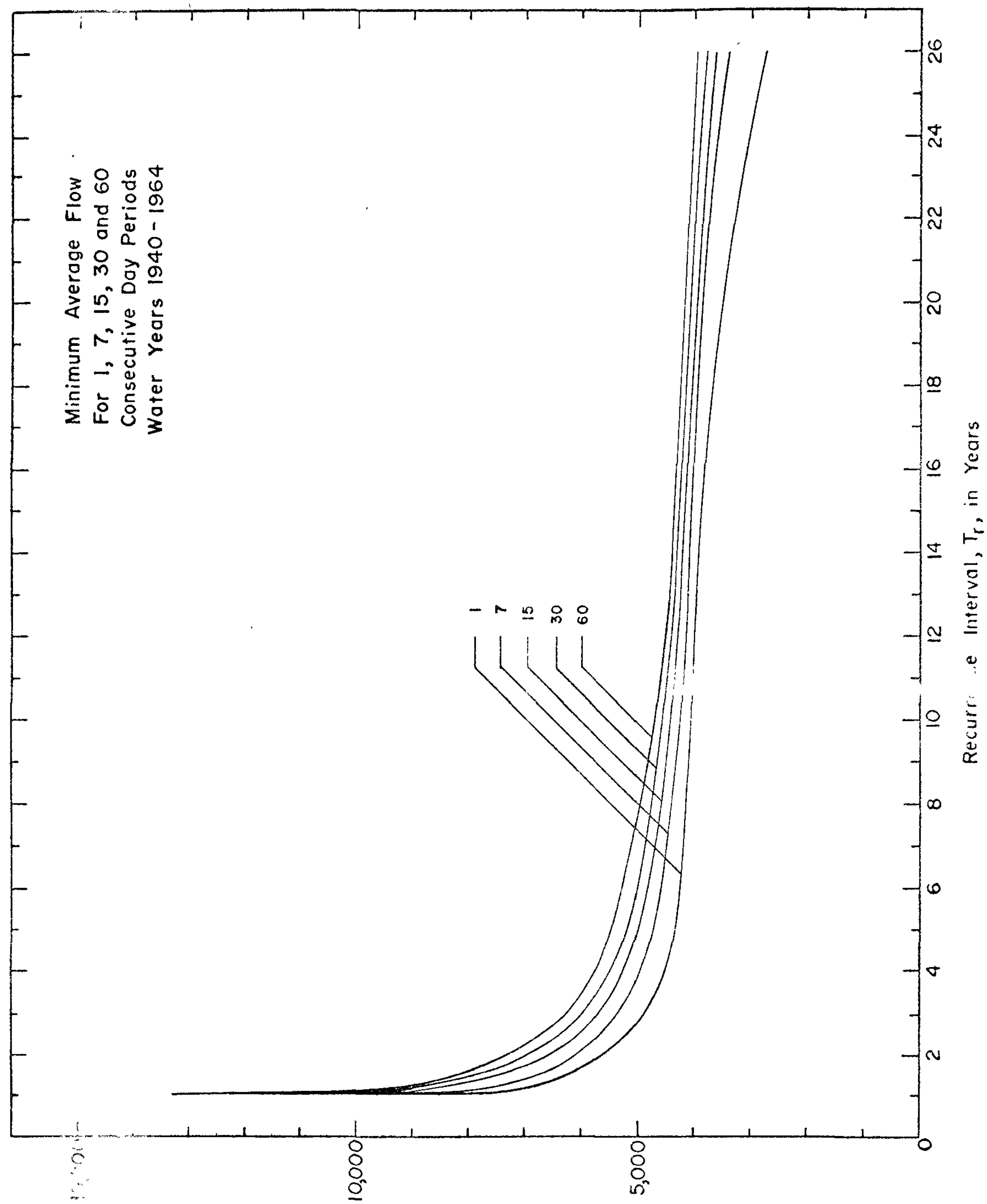
FEDERAL WATER POLLUTION CONTROL ADMIN.
REGION V
[illegible] ILLINOIS

FIGURE VI-8



TWIN CITIES UPPER MISSISSIPPI
RIVER PROJECT

LOW FLOW FREQUENCY
DECEMBER, JANUARY, FEBRUARY
MISSISSIPPI RIVER AT
LOCK AN' DAM NUMBER 3

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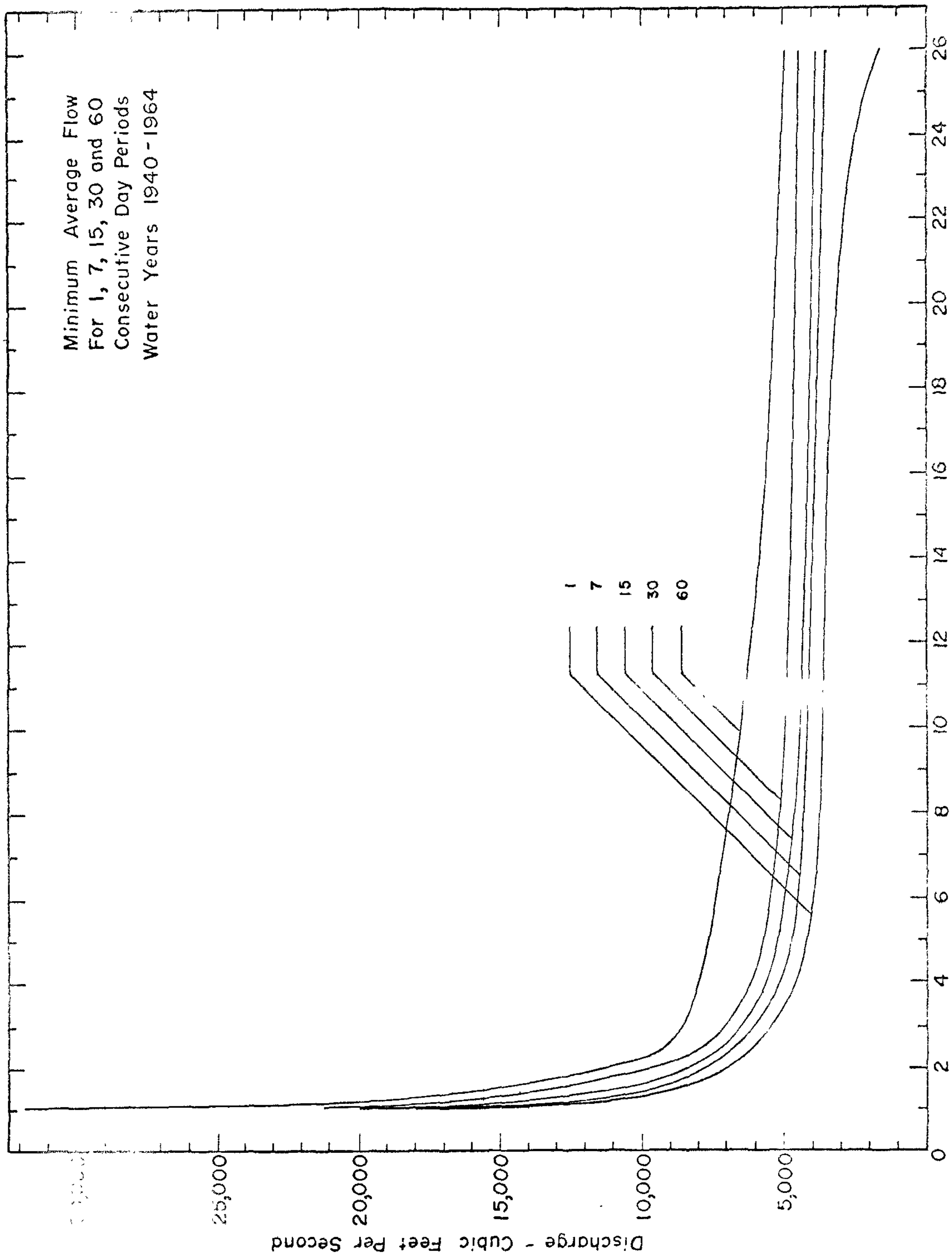
FEDERAL WATER POLLUTION CONTROL
ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE VI-9



TWIN CITIES UPPER MISSISSIPPI
RIVER PROJECT

LOW FLOW FREQUENCY
JULY, AUGUST, SEPTEMBER
MISSISSIPPI RIVER AT
LOCK AND DAM NUMBER 3

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FEDERAL WATER POLLUTION CONTROL
ADMIN.
REGION V CHICAGO, ILLINOIS

FIGURE VI-10

APPENDIX "III-A"

MEAN MONTHLY DISCHARGES
MISSISSIPPI RIVER - LOCK & DAM #1

YEAR	MONTH											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1940	2,900	2,200	1,800	1,200	1,300	1,600	10,300	8,500	4,500	1,900	2,000	1,900
1941	3,900	3,500	2,900	2,600	2,700	3,000	25,200	11,200	15,000	6,200	4,000	10,200
1942	10,200	6,400	4,500	3,900	4,400	6,100	6,900	16,200	13,000	5,400	5,800	9,600
1943	7,200	6,000	4,700	4,900	4,600	5,300	24,700	13,900	29,900	14,000	7,100	5,200
1944	4,700	5,500	4,600	4,900	5,000	5,000	11,500	22,800	30,700	20,900	13,100	7,600
1945	7,100	7,000	5,000	5,200	5,700	18,200	20,500	11,800	11,100	7,000	6,500	7,300
1946	7,300	5,000	4,400	3,800	3,600	14,000	14,500	8,400	13,000	15,600	4,000	4,500
1947	10,000	8,500	5,600	5,600	4,800	5,100	21,300	20,600	15,800	6,400	3,800	3,900
1948	4,000	4,000	3,800	3,300	3,500	8,100	24,500	16,600	4,700	3,500	3,800	2,700
1949	2,600	3,200	2,700	2,700	3,200	5,300	10,900	6,200	4,800	5,900	5,100	3,700
1950	5,100	4,700	3,900	3,700	3,700	5,100	25,100	40,300	17,400	7,100	5,600	5,300
1951	5,400	3,800	4,300	4,600	4,700	5,200	27,100	19,500	12,200	11,200	6,400	13,000
1952	11,200	12,400	9,700	7,200	6,100	6,400	42,000	15,500	8,200	20,600	16,600	9,600
1953	5,000	4,900	4,400	4,300	4,700	9,000	18,000	17,200	24,400	17,200	23,000	9,800
1954	6,400	6,500	5,500	5,800	5,800	7,800	16,500	24,600	15,300	12,100	5,100	5,500
1955	5,600	4,800	4,100	3,800	3,600	4,500	14,000	5,500	5,600	8,100	8,900	5,200
1956	4,100	3,300	3,700	3,000	2,700	3,200	21,300	10,300	7,500	3,800	9,200	3,600
1957	2,700	4,600	3,000	2,500	2,300	6,200	13,300	11,300	19,900	18,100	9,900	12,000
1958	7,800	7,000	5,100	4,300	3,900	5,500	8,100	4,300	4,900	4,500	2,600	4,300
1959	2,900	3,400	2,400	1,800	1,600	2,400	3,500	7,800	10,000	5,500	2,400	4,000
1960	3,800	3,300	3,400	3,200	2,800	3,200	13,200	12,900	7,700	3,700	2,300	3,500
1961	2,400	2,500	2,200	1,900	2,000	3,300	4,800	9,000	3,700	2,000	1,300	1,700
1962	2,300	2,700	2,200	2,200	2,100	3,500	15,400	16,300	16,700	12,200	7,900	6,600
1963	5,400	5,100	3,800	3,500	3,000	5,300	10,900	10,600	15,600	3,800	5,000	3,700
1964	2,800	2,800	2,400	2,600	2,600	3,100	12,800	16,700	5,300	4,500	2,500	8,900
Total	132,800	123,100	100,100	92,500	90,400	145,400	416,300	358,000	316,900	221,200	163,900	153,300
Mean	5,300	4,900	4,000	3,700	3,600	5,800	16,700	14,300	12,700	8,800	6,600	6,100
Max.	11,200	12,400	9,700	7,200	6,100	18,200	42,000	40,300	30,700	20,900	23,000	13,000
Min.	2,300	2,200	1,800	1,200	1,300	1,600	4,800	4,300	3,700	1,900	1,300	1,700

MEAN MONTHLY DISCHARGES
MISSISSIPPI RIVER AT ST. PAUL

YEAR	MONTH											
	Oct.	Nov.	Lec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1940	3,130	2,438	1,963	1,182	1,380	1,757	13,460	9,702	6,189	2,354	2,369	2,653
1941	4,085	4,050	3,664	3,518	3,239	6,997	34,820	15,780	19,550	8,790	4,472	10,750
1942	11,490	8,875	5,810	4,644	5,307	7,981	10,710	21,170	20,610	9,817	9,024	15,510
1943	11,890	7,812	5,745	5,659	5,444	8,814	36,890	19,000	44,190	22,890	13,460	10,560
1944	6,460	6,954	6,862	5,987	7,301	9,462	18,760	43,730	47,750	27,960	14,590	9,208
1945	7,846	7,822	5,635	5,691	6,438	26,160	29,330	17,410	24,400	11,860	10,050	9,116
1946	8,207	5,492	4,839	4,147	4,337	23,760	25,350	12,110	18,460	19,590	5,626	5,980
1947	12,610	12,160	8,171	6,670	5,669	7,330	32,930	34,460	23,390	18,990	6,216	5,217
1948	5,098	5,062	4,743	3,946	4,206	16,870	36,850	21,520	6,255	4,815	6,074	4,064
1949	3,401	4,064	3,400	3,246	3,626	12,130	29,100	9,978	6,981	7,280	6,890	4,805
1950	5,465	5,064	4,249	3,883	3,965	6,671	32,550	45,350	20,070	8,515	6,479	5,946
1951	6,078	4,125	4,617	4,887	4,928	6,832	54,500	36,320	17,060	21,710	10,060	18,110
1952	14,060	14,320	13,020	8,640	7,910	10,340	78,450	31,540	13,800	30,830	20,580	10,510
1953	5,588	5,504	4,700	4,607	5,168	14,020	24,510	26,600	36,670	28,750	33,384	12,520
1954	7,206	7,460	6,435	6,249	6,708	11,980	19,970	29,170	21,040	15,680	6,590	6,527
1955	7,482	6.128	4,703	4,385	4,035	7,671	17,580	7,862	7,253	12,010	9,599	6,133
1956	4,735	3,668	3,976	3,295	2,978	3,927	24,650	13,020	13,190	7,532	12,320	4,527
1957	3,052	5,133	3,636	2,725	2,552	7,045	15,760	13,690	27,610	36,540	17,390	16,870
1958	11,290	10,460	7,353	5,500	4,648	7,789	13,630	7,171	7,027	5,777	3,073	4,654
1959	3,080	3,550	2,663	2,049	1,770	2,898	4,438	8,820	11,900	6,741	3,005	5,008
1960	4,936	4,539	4,421	4,774	3,461	4,174	29,950	26,820	16,710	7,721	3,090	4,973
1961	3,782	3,293	2,806	2,372	2,439	7,474	11,840	14,680	7,419	3 741	3,763	2,477
1962	3,104	3,939	2,923	2,648	2,520	4,219	40,110	27,350	28,320	24,380	15,210	10,850
1963	7,907	6,715	4,617	4,038	3,537	7,352	14 290	13,860	21,550	10,020	10,570	5,503
1964	4,505	4,039	3,165	3,024	3,074	3,949	14,920	23,930	7,963	5,936	3,167	11,850
Total	166,487	152,666	124,116	107,766	106,640	227,602	665,348	531,043	475,357	360,229	237,051	204,321
Mean	6,659	6,107	4,965	4,311	4,266	9,104	26,614	21,242	19,014	14,409	9,482	8,173
Max.	14,060	14,320	13,020	8,640	7,910	26,160	78,450	45,350	47,750	36,540	33,384	18,110
Min.	3,052	2,438	1,963	1,182	1,380	1,757	4,438	7,171	6,189	2,354	2,369	2,477

MEAN MONTHLY DISCHARGES
MISSISSIPPI RIVER - LOCK & DAM #3

YEAR	MONTH											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1940	5,900	5,600	4,600	3,700	4,300	5,000	21,500	17,900	11,300	4,700	5,200	4,700
1941	7,100	8,000	7,100	6,900	6,200	10,500	51,400	22,300	27,800	12,800	7,100	25,100
1942	20,100	15,900	10,200	7,600	8,100	12,400	17,300	31,800	30,400	15,400	13,100	22,000
1943	16,300	12,100	8,700	9,400	8,700	13,300	50,600	26,500	61,800	31.800	18,900	14,300
1944	10,000	11,900	10,700	9,100	10,400	13,100	28,400	62,300	70,500	40,100	20,200	14,300
1945	12,700	12,700	9,400	9,500	10,000	40,200	44,700	25,700	38,400	20,100	16,700	16,000
1946	14,000	10,400	9,500	7,500	7,900	34,800	35,500	17,900	32,900	31,500	8,800	10,800
1947	19,600	20,200	12,800	10,800	9,100	12,300	46,500	46,400	30,500	22,600	8,800	8,400
1948	7,600	8,900	8,300	7,000	7,200	22,500	53,300	28,400	9,800	7,700	9,400	5,900
1949	5,600	7,000	5,800	5,500	6,000	16,700	38,500	17,100	9,400	11,700	9,200	6,700
1950	10,300	8,400	7,000	6,200	6,700	11,500	54,000	70,300	27,200	12,700	9,100	8,400
1951	10,000	7,400	8,000	7,900	8,000	11,000	71,900	44,400	25,800	34,800	15,700	31,900
1952	22,300	24,400	18,300	13,700	12,800	15,400	100,100	40,300	19,300	49,400	29,500	16,800
1953	9,200	9,300	8,500	8,200	9,000	21,200	38,200	39,700	51,800	40,000	46,100	16,700
1954	10,900	12,000	10,800	10,000	10,900	17,100	30,100	47,900	34,500	28,100	11,500	13,100
1955	13,900	11,400	8,600	7,700	7,200	12,600	31,900	12,300	12,000	18,000	19,000	10,700
1956	9,500	9,000	8,600	7,200	6,800	8,000	43,100	19,900	19,700	12,300	18,200	8,100
1957	6,600	10,000	7,500	5,900	5,500	12,200	25,700	20,100	33,400	48,400	21,700	23,200
1958	15,400	16,100	10,800	8,600	7,900	12,300	21,800	12,000	12,600	15,400	6,400	9,500
1959	6,400	7,800	5,100	4,500	4,300	6,300	8,300	15,800	17,600	10,600	6,400	9,800
1960	9,800	8,100	7,700	8,100	6,300	7,300	39,300	35,300	24,300	11,100	6,400	10,300
1961	7,200	7,000	5,800	4,800	4,700	12,000	20,300	27,400	11,600	6,700	6,200	5,500
1962	6,500	8,200	6,000	5,300	5,300	8,800	50,500	38,900	37,300	26,300	19,000	16,500
1963	12,400	10,100	7,600	6,400	6,000	11,900	21,300	21,800	27,600	12,500	13,500	8,600
1964	7,300	6,800	5,500	5,100	5,300	6,900	23,100	39,900	12,100	8,500	5,900	17,100
Total	276,600	268,700	212,900	186,600	184,600	355,300	967,800	782,300	689,600	533,200	352,000	334,400
Mean	11,100	10,700	8,500	7,500	7,400	14,200	38,700	31,300	27,600	21,300	14,100	13,400
Max.	22,300	24,400	18,300	13,700	12,800	40,200	100,100	70,300	70,500	49,400	46,100	31,900
Min.	5,600	5,600	4,600	3,700	4,300	5,000	8,300	12,000	9,400	4,700	5,200	4,700

MEAN MONTHLY DISCHARGES
MINNESOTA RIVER NEAR CARVER

YEAR	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1940	209	211	202	111	130	322	2,840	1,145	1,347	498	506	770
1941	302	660	705	828	561	4,252	9,630	3,748	5,012	2,413	675	695
1942	1,162	2,254	1,233	747	921	1,940	3,250	4,991	6,289	3,826	3,090	4,831
1943	4,007	1,503	960	702	770	4,123	11,500	5,411	15,040	7,561	6,413	5.109
1944	1,490	1,690	2,003	911	2,150	4,255	8,259	20,630	17,260	5,491	1,684	1,386
1945	841	763	529	359	575	8,428	6,940	4,739	12,400	4,337	3,204	1,186
1946	879	623	384	314	759	10,310	9,019	3,738	5,655	3,830	1,453	1,741
1947	2,718	3,192	2,316	982	788	2,569	12,990	12,680	7,560	11,500	2,002	1,040
1948	593	889	947	503	798	9,794	11,220	5,191	1,708	1,386	2,394	963
1949	469	565	488	484	441	7,623	16,990	2,991	1,161	874	727	382
1950	332	329	265	208	224	2,056	7,711	6,130	2,819	1,264	617	356
1951	337	271	221	227	206	1,571	30,390	13,780	5,688	9,172	3,558	4,609
1952	2,545	1,790	2,886	1,392	1,759	3,934	36,860	11,480	4,882	9,146	3,493	1,369
1953	684	558	337	309	500	4,448	6,710	10,590	13,080	10,490	10,980	2,579
1954	763	750	753	437	839	4,156	4,483	4,973	5,479	2,871	1,062	958
1955	1,068	924	604	487	367	3,067	3,055	1,654	1,131	3,598	1,010	589
1956	373	326	246	245	241	698	3,852	1,656	5,141	3,037	2,754	880
1957	405	576	520	298	262	1,420	2,968	2,359	10,790	12,270	4,994	3,776
1958	2,795	3,053	2,151	1,125	733	2,400	5,700	3,035	2,214	1,265	560	364
1959	288	289	215	206	197	582	926	923	2,064	1,058	676	942
1960	1,032	1,136	1,068	1,399	588	1,037	16,930	13,010	6,622	3,815	920	1,474
1961	1,241	798	642	445	459	4,127	6,431	4,942	3,060	1,703	2,344	818
1962	861	1,219	662	485	410	1,088	24,760	10,330	7,903	12,230	5,979	4,350
1963	2,431	1,508	779	543	507	2,533	3,608	3,849	5,545	5,929	5,184	1,783
1964	1,573	1,170	713	451	502	813	4,037	8,455	2,400	1,309	656	3,131
Total	29,398	27,047	21,829	14,198	15,737	87,546	251,059	162,430	152,250	120,873	66,935	46,081
Mean	1,176	1,082	873	568	629	3,502	10,042	6,497	6,090	4,834	2,677	1,843
Max.	4,007	3,192	2,886	1,399	1,759	10,310	36,860	20,630	17,260	12,270	10,980	5,109
Min.	209	211	202	111	130	322	926	923	1,131	498	506	356

MEAN MONTHLY DISCHARGES
ST. CROIX RIVER AT STILLWATER, MINNESOTA
ST. CROIX RIVER AT ST. CROIX FALLS PLUS APPLE RIVER NEAR SOMERSET

YEAR	MONTH											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1940	2,074	2,093	1,869	1,586	1,751	2,011	7,123	7,545	3,307	1,690	1,985	1,700
1941	1,806	3,446	2,450	2,335	2,153	2,193	17,049	4,854	6,911	2,655	1,950	15,183
1942	8,304	6,041	3,643	2,478	2,365	4,295	6,397	11,113	8,401	4,484	2,931	4,889
1943	3,679	3,298	2,956	2,288	2,410	2,979	13,610	7,873	17,344	5,426	4,029	2,991
1944	2,911	3,425	2,368	2,091	2,401	2,817	9,480	17,085	20,453	8,360	4,191	3,793
1945	3,400	3,373	2,498	2,327	2,321	14,989	13,971	5,310	12,619	6,335	4,550	6,784
1946	4,507	3,721	2,936	2,916	2,754	9,978	7,568	4,566	14,042	7,153	2,491	3,012
1947	4,866	6,998	3,553	2,864	2,401	2,981	13,556	9,225	5,997	2,228	2,224	2,315
1948	2,341	2,779	2,524	2,118	1,962	5,532	15,128	4,559	2,359	1,995	1,834	1,705
1949	1,742	2,339	2,041	1,897	1,935	3,988	7,692	7,435	2,471	3,839	2,502	2,142
1950	3,962	2,490	2,123	1,878	2,067	2,982	21,541	22,677	3,856	2,850	1,977	1,928
1951	3,178	2,567	2,432	2,241	2,167	2,811	19,586	6,707	8,801	10,050	4,119	12,283
1952	7,765	9,148	5,064	3,362	3,274	3,283	23,395	5,492	5,786	12,494	6,228	4,621
1953	2,968	2,821	2,940	2,688	2,726	7,714	13,070	13,904	13,624	6,917	10,478	3,220
1954	2,876	3,405	3,524	2,783	3,025	3,570	11,302	17,810	13,623	10,918	4,251	5,633
1955	6,412	4,548	3,322	2,911	2,829	3,596	13,445	4,035	4,234	4,429	8,659	4,452
1956	4,118	4,378	3,399	2,959	2,782	2,918	17,674	6,380	5,038	3,900	4,618	2,848
1957	2,840	3,716	2,831	2,267	2,217	4,320	9,357	5,314	9,554	7,585	3,125	6,063
1958	3,428	4,306	2,953	2,447	2,414	3,301	6,477	3,486	4,225	9,259	2,631	4,311
1959	2,736	3,287	2,104	1,869	1,807	2,299	3,232	5,907	5,311	3,047	2,386	3,856
1960	3,980	2,947	2,531	2,705	2,236	2,444	9,672	8,581	5,295	2,684	2,458	4,201
1961	2,778	2,945	2,635	1,985	1,935	3,347	7,658	11,993	3,556	2,374	2,851	2,252
1962	2,439	3,307	2,352	2,051	2,010	2,683	11,051	13,186	5,444	3,244	2,875	4,271
1963	2,935	2,572	2,148	1,961	1,815	3,134	5,773	6,779	5,486	1,806	2,158	2,073
1964	2,174	2,196	1,899	1,751	1,720	2,117	7,123	13,247	3,090	2,163	1,960	3,987
Total	90,219	92,146	69,095	58,758	57,477	102,282	291,930	225,063	190,827	127,885	89,461	110,513
Mean	3,609	3,686	2,764	2,350	2,299	4,091	11,677	9,003	7,633	5,115	3,578	4,421
Max.	8,304	9,148	5,064	3,362	3,274	14,989	23,395	22,677	20,453	12,494	10,478	15,183
Min.	1,742	2,093	1,869	1,586	1,720	2,011	3,232	3,486	2,359	1,690	1,834	1,700