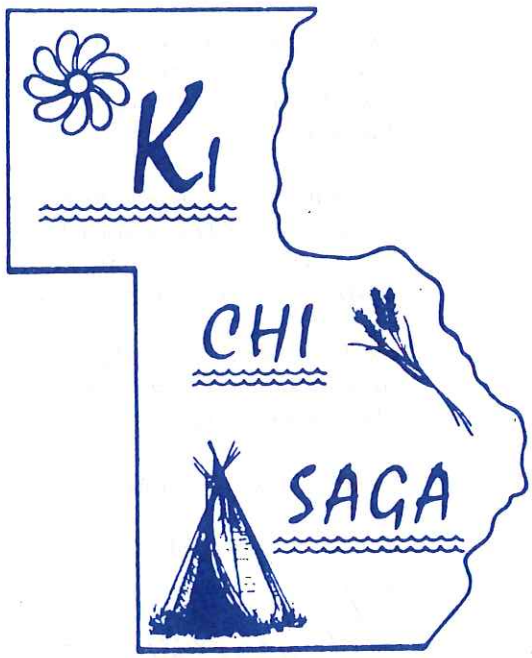
1987
EMERGENCY MANAGEMENT PLAN

CHISAGO LAKES OUTLET PROJECT



CHISAGO COUNTY BOARD

JULY 1987

Wenck Associates, Inc.

Wenck Associates, Inc.

Consulting Engineers
(612) 475-0858

September 10, 1987

Honorable Chairman and County Board of Commissioners
Chisago County Courthouse
Center City, Minnesota 55012

Re: Chisago Lakes Outlet Project

Dear Chairman Vande Kamp and members of the County Board of Commissioners:

Wenck Associates, Inc. is pleased to transmit herewith the "1987 Emergency Management Plan" for the Chisago Lakes Outlet Project. The hydrologic analysis requested by the County is included as Appendix B.

Although the Minnesota Department of Natural Resources has directed that this plan should be in force only for the current year, we believe that the present form of the plan will with little, if any, modification fulfill the needs for a long-term management plan.

If has been our pleasure to serve and work with you on this project. We hope that the plan and the outlet project will serve the County well in the coming years.

Respectfully submitted,

WENCK ASSOCIATES, INC.

Norman C. Wenck, P.E.
President

NCW/cmk
Enclosure

832 Twelve Oaks Center
15500 Wayzata Blvd.
Wayzata, MN 55391

1987 EMERGENCY MANAGEMENT PLAN

CHISAGO LAKES OUTLET PROJECT

CHISAGO COUNTY BOARD

JULY 1987

Prepared by

WENCK ASSOCIATES, INC.
15500 Wayzata Boulevard
Suite 832
Wayzata, Minnesota 55391

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Registered Professional Engineer under the laws of the State of Minnesota.

John B. Erdmann

John B. Erdmann Minn. Reg. No 14241

REVISED SEPTEMBER 1987

PREFACE

This Emergency Management Plan for the Chisago Lakes Outlet Project includes a set of operating rules for control gates at the Chisago and Green Lake outlets and an associated on-going monitoring plan. Related studies are included as appendices. This plan will be effective until December 31, 1987, and it is anticipated to form the basis for a long-term management plan thereafter.

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CHISAGO LAKES OUTLET PROJECT

I. INTRODUCTION

A. Background and Purpose

The Chisago Lakes Outlet Project was undertaken in 1986 to provide an outlet from the Chisago Chain of Lakes to Green Lake, and from Green Lake to the Sunrise River, in order to alleviate extremely high lake levels. (See Figure 1.) In the past Green Lake was landlocked, and the Chisago Chain of Lakes was virtually landlocked. A separate project in 1986 improved an existing outlet from the Chisago Chain through Wallmark Lake. Previously this outlet barely functioned.

Appendix A contains historical lake level data and illustrates the unusually high levels occurring in recent years. In 1986 the levels of both Green Lake and the Chisago Chain reached substantially above the Natural Ordinary High Water (NOHW) established for each. Table 1 gives the NOHW's along with the outlet elevations allowed by the Minnesota Department of Natural Resources and the design outflow rates for the project. The outflow rates are equivalent to a lake level drawdown rate of approximately two inches per week on all the lakes when both the Chisago and Green outlets are operating. A hydrologic investigation concerning lake levels and downstream flows is included as Appendix B.

The Chisago Lakes Outlet Project includes several control gates, as described in Table 2. In the County Road 24 drop structure serving the Chisago Chain, a pair of gates controls the activation of the low weir used for temporary drawdown, while another gate controls the outlet itself (see Figure 2). Similarly, a gate in the Lake Ellen drop structure serving Green Lake controls that outlet. Green Lake has no temporary drawdown elevation and, hence, no low weir requiring additional control.

Note that the Chisago-Wallmark outlet's weir elevation is the same as that of the permanent, or high, weir of the Chisago outlet at County Road 24. The Chisago-Wallmark outlet flows at an equivalent drawdown rate of 0.4 inch

per week when the Chisago Chain of Lakes stands at its NOHW. Unlike the Green and Chisago outlets, the Chisago-Wallmark outlet has no control gates and thus flows freely whenever the lake exceeds the weir level.

It is the existence of the control gates at the Chisago and Green outlets that necessitates a management plan for the Chisago Lakes Outlet Project. Monitoring, discussed in Section II, and operating rules, discussed in Section III, are the primary components of the management plan. In addition to these, Subsections B and C below outline a procedure for revising the plan and note a special consideration for winter outflow.

B. Procedure for Revision

Should it become necessary to revise the management plan, the procedure would be as follows: (1) the County, consulting as appropriate with the Lake Improvement District and others, would develop the proposed revision in draft form; (2) the County would submit the proposed revision to the Minnesota Department of Natural Resources for review and, possibly, for permit modifications; and (3) the County would satisfy any further DNR requirements necessary for DNR approval of the revision. Following approval, the revision would become part of the plan.

C. Winter Outflow

Appendix C provides a safety plan as required by the DNR for winter outflow, in the remote event that this should ever be required.

II. MONITORING

Sound management of the lake outlets will require initial monitoring of hydraulic characteristics and on-going hydrologic monitoring. This monitoring will be carried out by the County.

A. Initial Hydraulic Monitoring

The aim of the initial hydraulic monitoring is to determine: (1) the control gate settings for the Chisago and Green outlets that are required for limiting outflow to the design rates when the lakes are at higher elevations; (2) the relationship between lake elevation and outflow rate (rating curve) at lower elevations; and (3) the adequacy of natural flowage paths downstream from Swamp Lake.

Appendix D outlines the initial monitoring plan in greater detail. The initial monitoring was conducted during April - June 1987, and the results are in Appendix E. Due to the absence of flow from the Chisago outlet by the time of its completion in June 1987, control gate settings and rating curve data are not available at this time for that outlet.

B. On-Going Hydrologic Monitoring

The on-going hydrologic monitoring will include lake levels and snow accumulation, as described below.

1. Lake Levels

The levels of Chisago, Green, and Swamp Lakes will be monitored on an on-going basis. The frequency of monitoring will depend on outflow conditions. During periods of outflow the affected lakes should generally be monitored weekly. If a period of outflow is interrupted by the closure of one or both outlets, then the affected lakes may be monitored more frequently during the period of interruption. (Section III outlines certain situations when an interruption of outflow could occur. Note, however, that the Chisago-Wallmark outlet would continue to flow even if outflow were interrupted at the Chisago outlet at County Road 24.)

If it is desired to exercise the late-winter drawdown option with the Chisago outlet (see Section III), then the level of Chisago Lake must be monitored in the late-winter period. This monitoring should be coordinated with the late-winter snow monitoring described in the following subsection. A reasonable schedule would be to obtain both types of data in mid-February, late February, and mid-March.

At all other times the frequency of lake level monitoring would be wholly discretionary.

2. Snow

High spring lake levels caused by snowmelt can be estimated in advance on the basis of late-winter snow accumulation. For example, suppose that in late February the water equivalent of accumulated snow is 6 inches, or 0.5 feet, while the elevation of Chisago Lake (and hence the Chisago Chain of Lakes) is 899.2. Assuming essentially 100% of the accumulated snow will run off into the lakes, the contributing watershed of 8520 acres will produce a total runoff volume of 4260 acre-feet by the end of snowmelt. Based on a total lake area of 3900 acres (at elevation 899.2), this runoff would cause a 1.1-foot rise in lake level. Therefore, if there were no outflow, the estimated high spring lake level would be 899.2 + 1.1 = 900.3.

The above scheme is incorporated into the following definition of the "potential level" for the Chisago Chain:

$$\text{"Potential level"} = L + f \cdot S,$$

where L = the actual lake level measured in late winter, f = 0.18, and S = the water equivalent in inches of accumulated snow (as measured at the same time as the lake level). The factor f in this definition is the ratio of watershed area to lake area, the ratio then being divided by 12 to convert inches to feet.

The National Weather Service regularly monitors the water equivalent of accumulated snow at first-order weather stations, including Minneapolis and St. Cloud. Unlike rainfall, snow accumulation in Minnesota tends to be fairly uniform over large areas because snow storms here are generally large-scale weather systems.

In light of the above, arrangements have been pursued whereby the required snow data may be obtained from the National Weather Service.

An empirical relationship with the first-order station values could then be used to estimate the water equivalent of accumulated snow for the Chisago Chain of Lakes watershed. Based on an analysis of historical data mapped in the Weather Bureau's "Frequency of Maximum Water Equivalent of March Snow Cover in the North Central United States" (TP50), multiplying factors are $W_m = 0.58$ for Minneapolis and $W_s = 0.54$ for St. Cloud. The formula for the estimated Chisago watershed snow-water content is:

$$S = W_m \cdot S_m + W_s \cdot S_s$$

where S = the estimated water equivalent of accumulated snow for the Chisago watershed; S_m, S_s = the Minneapolis and and St. Cloud values, respectively, of the water equivalent of accumulated snow ; and W_m, W_s = the respective multiplying factors.

If actual snow-water content data become available from the Chisago Lakes watershed, then these data should be used to determine S in lieu of the above methodology.

III. OPERATING RULES

Below are the operating rules for the Chisago low weir, Chisago outlet, and Green outlet control gates.

A. Chisago Low Weir

1. Usual Position of Low Weir Control Gates

The usual position of the low weir control gates is fully closed.

2. Opening of Low Weir Control Gates

If Chisago Lake's "potential level" exceeds the NOHW during March 1 - April 30, and Green Lake is below its NOHW, then the low weir control gates may be opened at the earliest feasible time. ("Potential level" = $L + f \cdot S$, where L = actual lake level, f = 0.18, and S = water content in inches of accumulated snow; see Section II for further explanation.) The gates must again be closed: (i) when the lake level retreats by an amount equal to the excess of the potential level over the NOHW if this occurs before April 30, or (ii) otherwise on April 30. For example, suppose that on March 1 the actual lake level is 899.0 but the potential level is 900.7, which exceeds the NOHW by 0.5 foot. Then in this case the low weir gates could be opened until the lake level retreats 0.5 foot below the starting level of 899.0 (i.e., until the lake achieves a level of 898.5), provided this occurs by April 30.

B. Chisago Outlet

1. Usual Position of Chisago Outlet Control Gate

The usual position of the Chisago outlet control gate is as follows:

a. During Late Winter Through Fall

During late winter through fall (that is, from March 1 until the formation of ice on the lakes), the usual position of the Chisago outlet control gate is fully open when the lake level is below 900.0; for higher lake levels the position is set for up to the design outflow rate. However, the gate may be maintained closed if desired when the lake level is below 899.2

b. During Early and Mid-Winter

During early and mid-winter (that is, the period from ice formation until the end of February), the usual position of the Chisago outlet control gate is fully closed.

2. Closing of Chisago Outlet Control Gate

The Chisago outlet control gate must be closed if Green Lake exceeds its NOHW (892.5). The gate may be opened again to its usual position whenever Green Lake is below its NOHW. (Note that the Chisago-Wallmark outlet will continue to flow even if outflow at the Chisago outlet is interrupted.)

C. Green Outlet

1. Usual Position of Green Outlet Control Gate

The usual position of the Green outlet control gate is as follows:

a. During Late Winter Through Fall

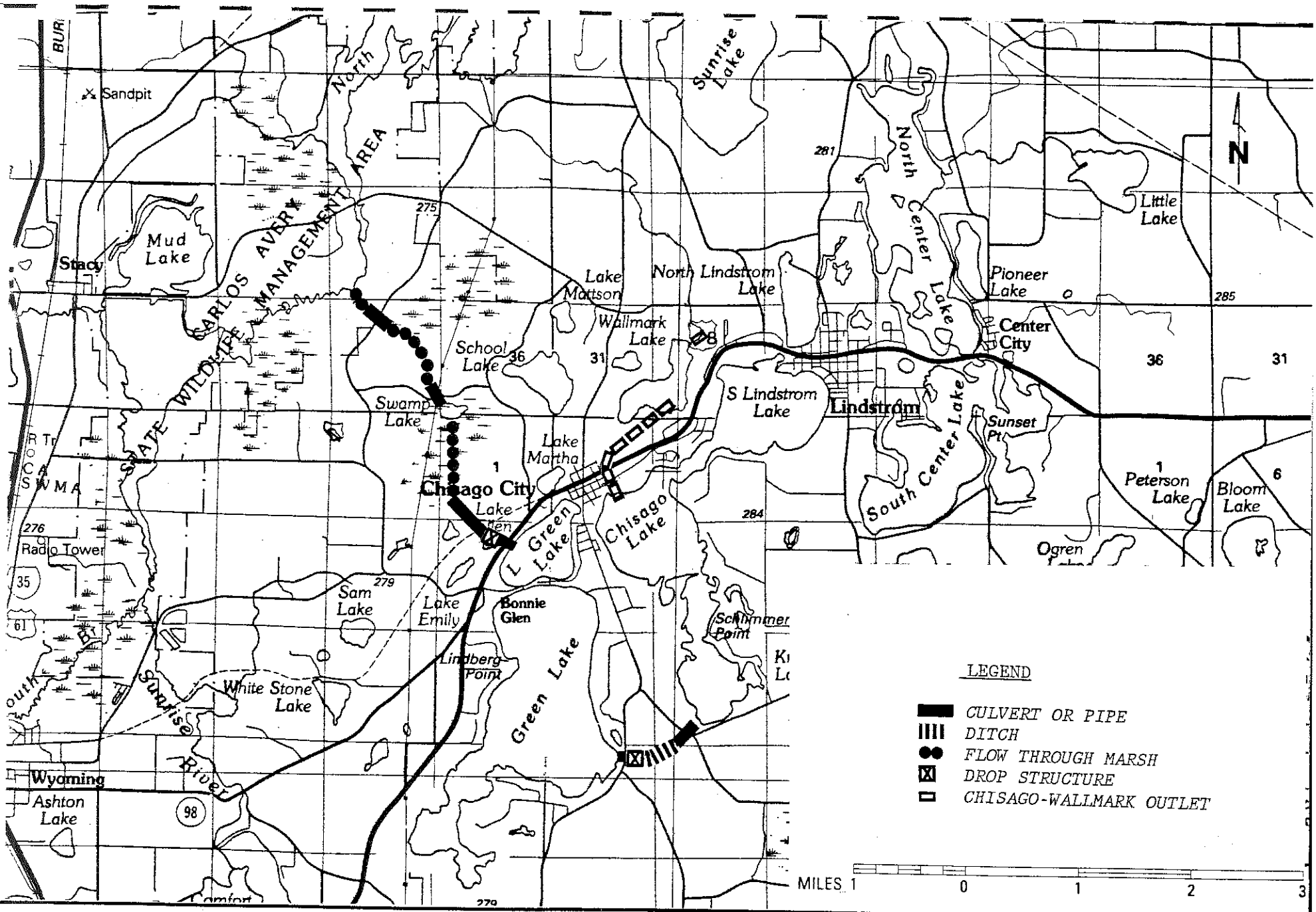
During late winter through fall (that is, from March 1 until the formation of ice on the lakes), the usual position of the Green outlet control gate is fully open when the lake level is below 891.5; for higher lake levels the position is set for up to the design outflow rate. However, the gate may be maintained closed if desired when the lake level is below 891.0.

b. During Early and Mid-Winter

During early and mid-winter (that is, the period from ice formation until the end of February), the usual position of the Green outlet control gate is fully closed.

2. Closing of Green Outlet Control Gate

If Swamp Lake reaches a "high" level (defined as 882.7), then the Green outlet control gate must be closed until both of the following occur: (i) the County investigates whether any flow obstructions exist at County Road 80 or downstream, and if so, removes them, and (ii) the level of Swamp Lake retreats to 881.6. After (i) and (ii) occur, the gate may be opened again to its usual position.



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CHISAGO LAKES OUTLET PROJECT

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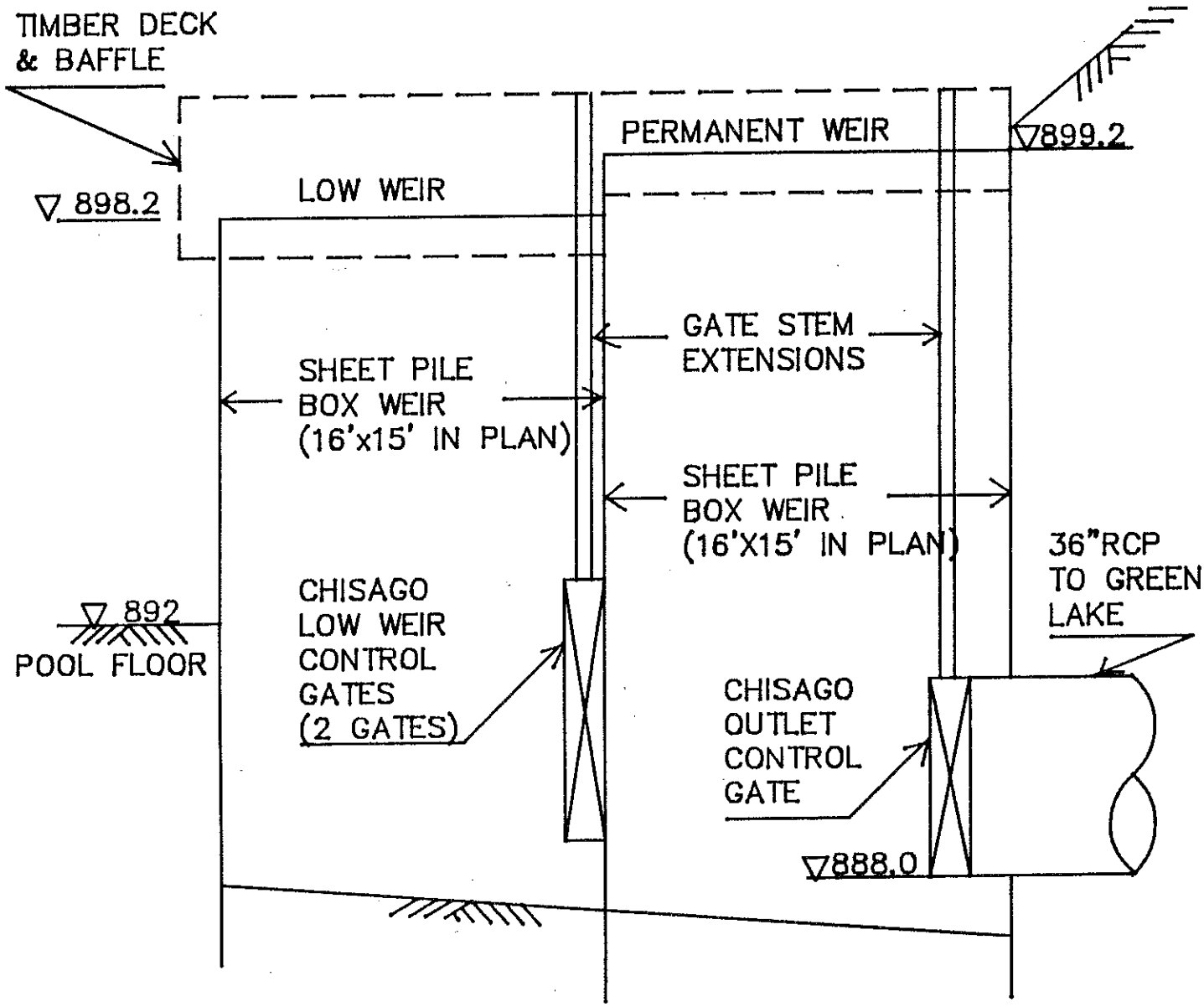

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Co. Rd. 24 Drop Structure - Profile (N.T.S.)	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	2

TABLE 1

BASIC ELEVATION AND OUTFLOW DATA
CHISAGO LAKES OUTLET PROJECT

	Chisago	Green
Natural Ordinary High Water	900.2	892.5
Permanent Outlet (High Weir) Elevation	899.2	891.0
Low Weir Elevation	898.2	--
Design Outflow Rate (cubic feet per second)	48	72

NOTE: Elevations established by Minnesota Department of Natural Resources; design outflow rate determined by project design.

TABLE 2

CONTROL GATES
CHISAGO LAKES OUTLET PROJECT

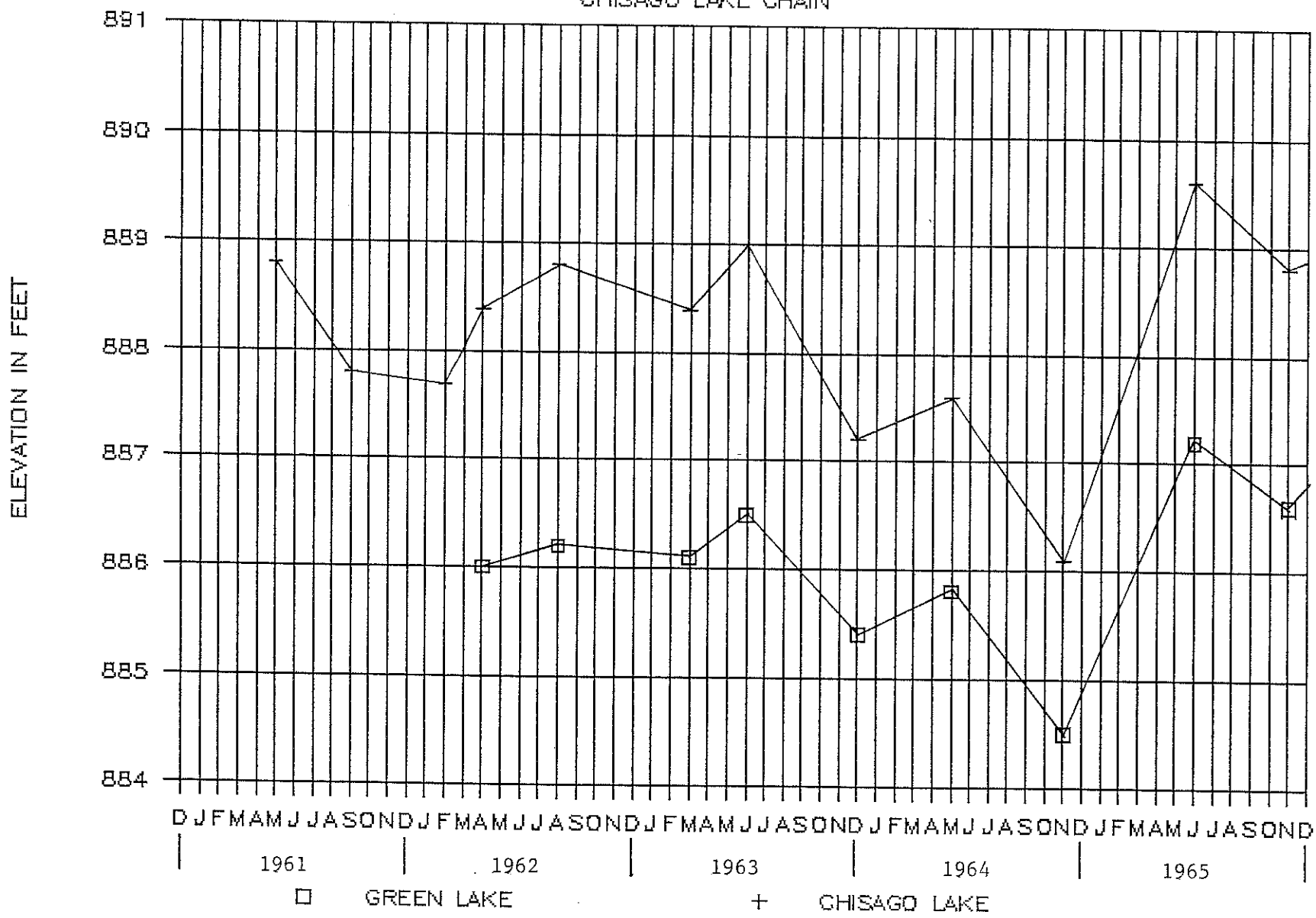
Control Gate	Location	Description	Purpose
Chisago Low Weir	County Rd. 24 Drop Structure	2 gates, each 4 ft x 4 ft	To activate low weir to effect temporary drawdown.
Chisago Outlet	County Rd. 24 Drop Structure	1 gate, 3 ft x 3 ft	To ensure against downstream damage by limiting outflow to design rate and, if ever necessary, by stopping outflow.
Green Outlet	Lake Ellen Drop Structure	1 gate, 4 ft x 4 ft	To ensure against downstream damage by limiting outflow to design rate and, if ever necessary, by stopping outflow.

APPENDIX A

HISTORICAL LAKE LEVEL DATA

LAKE LEVELS

CHISAGO LAKE CHAIN



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HISTORICAL LAKE LEVEL DATA - CHISAGO AND GREEN LAKES

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15500 Wayzata Blvd.
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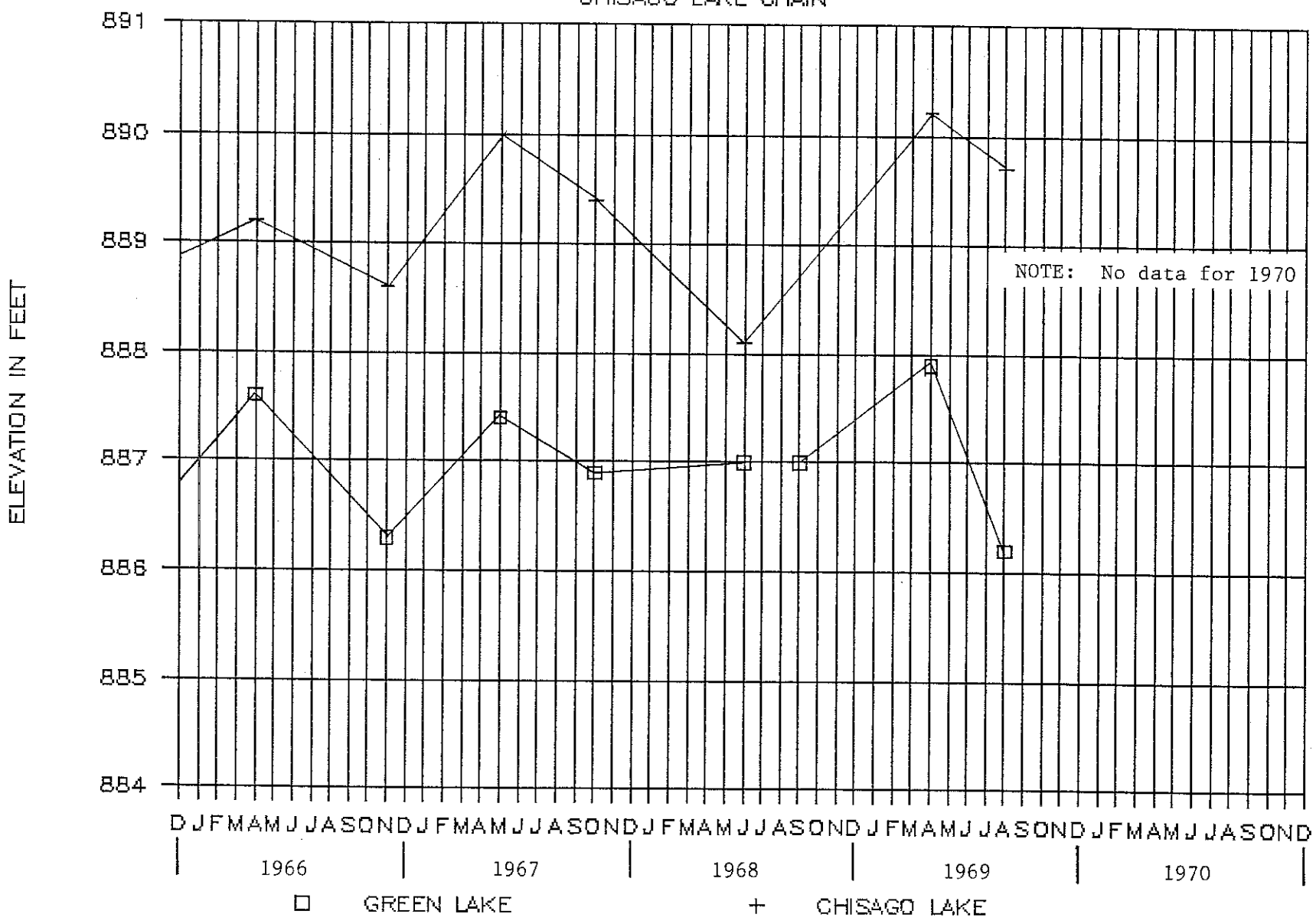
LAKE LEVELS

CHISAGO LAKE CHAIN



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HISTORICAL LAKE LEVEL DATA - CHISAGO AND GREEN LAKES

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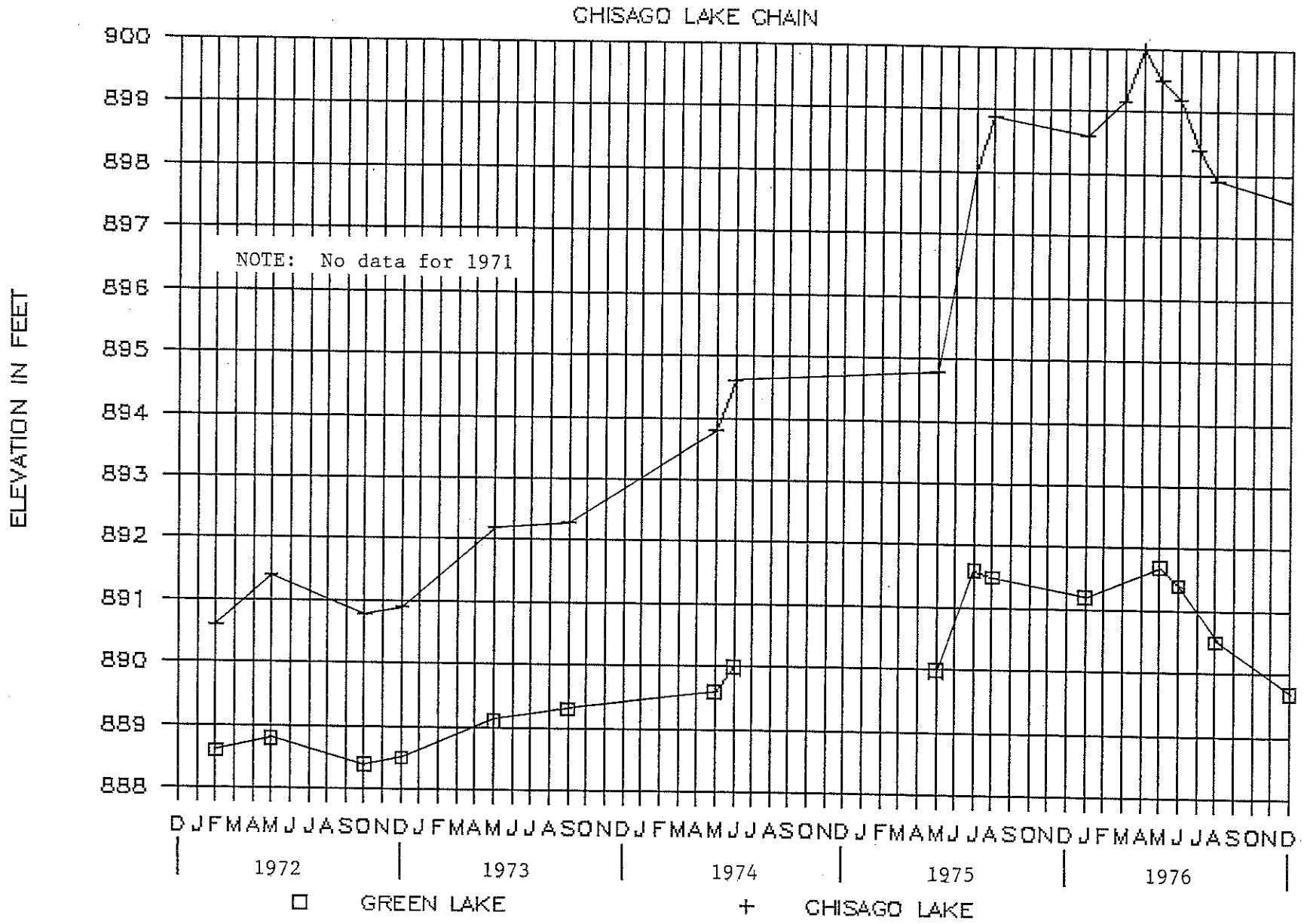
LAKE LEVELS



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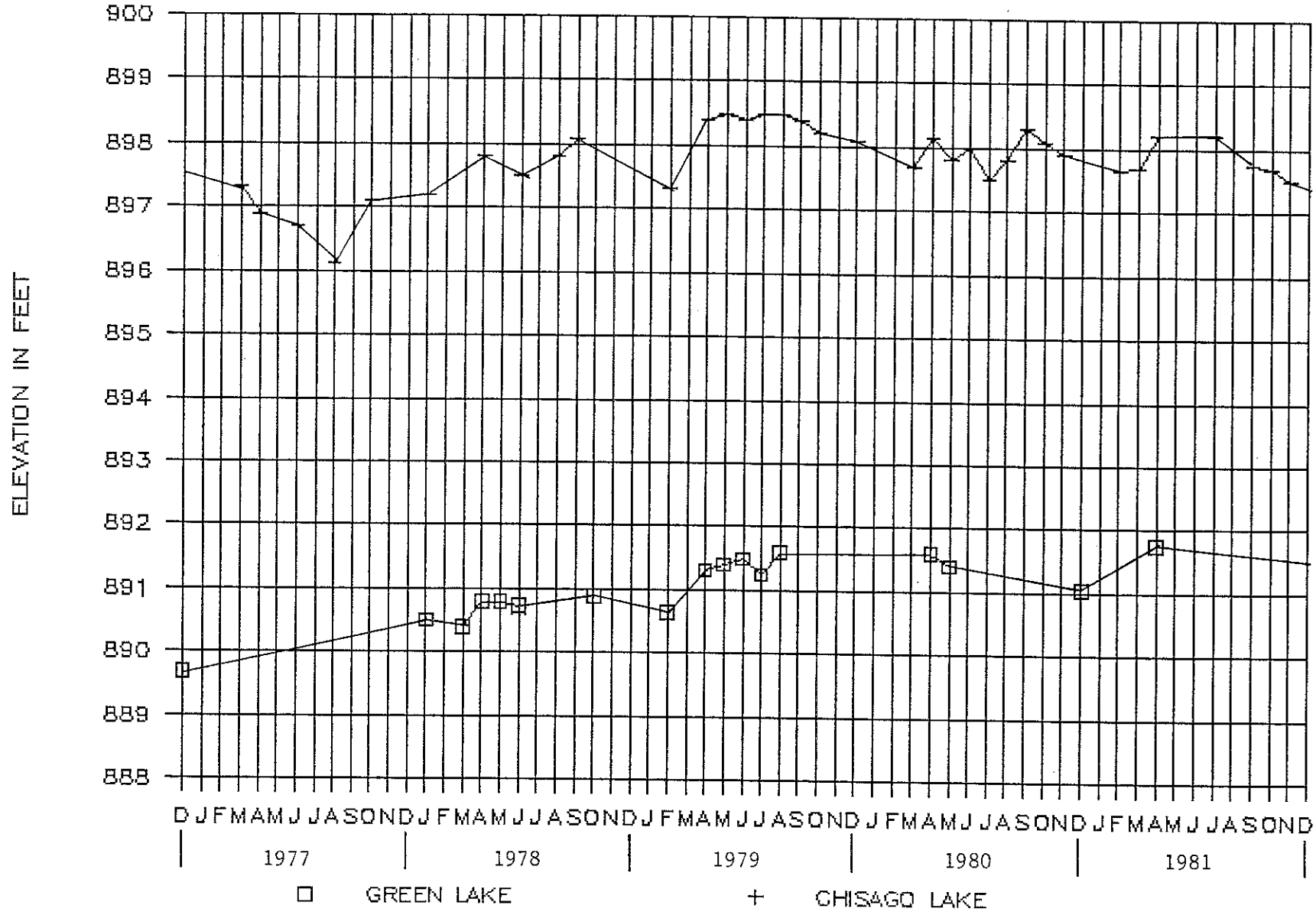
HISTORICAL LAKE LEVEL DATA - CHISAGO AND GREEN LAKES	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	A-3

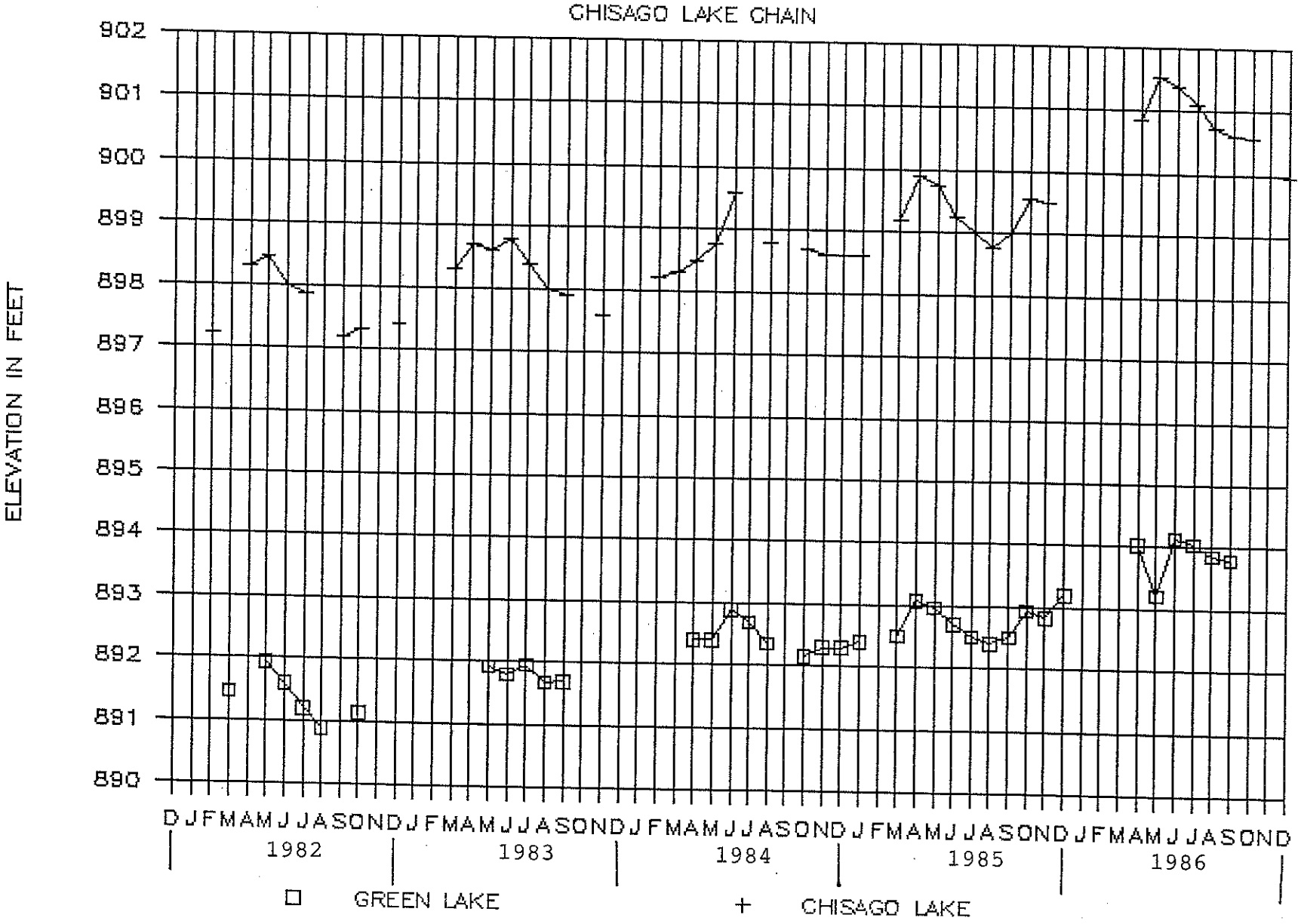
LAKE LEVELS

CHISAGO LAKE CHAIN



CHISAGO COUNTY BOARD	Consulting Engineers	OCT '86
HISTORICAL LAKE LEVEL DATA - CHISAGO AND GREEN LAKES	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	A-4

LAKE LEVELS



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HISTORICAL LAKE LEVEL DATA - CHISAGO AND GREEN LAKES	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	A-5

APPENDIX B

HYDROLOGIC INVESTIGATION

HYDROLOGIC ANALYSIS
CHISAGO LAKES OUTLET PROJECT

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HYDROLOGIC ANALYSIS

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INTRODUCTION

A hydrologic analysis was undertaken in order to compare the effects of outflow from the Chisago Lakes Outlet Project with pre-existing flows due to storm runoff from the immediately downstream drainage area. The outlet project includes a connection from Chisago Lake - and hence the entire upper Chisago Chain of Lakes - to Green Lake, and an outlet from Green Lake via Little Green Lake and Lake Ellen to a downstream drainage path tributary to the Sunrise River.

The study area is the drainage area between Ivywood Trail and Karmel Avenue which is naturally tributary to the culvert under County Road 19 between these two roads (see Figure I). The "Upper Area" comprises the local watershed of Swamp Lake, whose outlet is a set of culverts (formerly one culvert) under County Road 80. The "Lower Area" is the drainage area downstream from County Road 80 and extending to the County Road 19 culvert and to a newly provided second outlet culvert under Ivywood Trail. The study area covers portions of sections 25, 26, 35 and 36 of Township 34 N, Range 21 W, section 30 of Township 34 N, Range 20 W, and sections 1, 2, 11 and 12 of Township 33 N, Range 21 W.

Two separate lines of analysis were followed. One was based on the historical lake level record, covering a period of approximately 25 years, and yielded lake outflow statistics. (Note that the "study area" for the lake level and outflow analysis is implicitly entire the Chisago Lakes watershed.) The other estimated peak storm runoff flows in the Upper and Lower Areas of the previously described downstream drainage area, based on the hydrologic characteristics there. This report concludes with a summary comparison of the results of these two lines of investigation.

LAKE LEVEL AND OUTFLOW ANALYSIS

The historical lake level record for Chisago and Green Lakes, as provided by the County Surveyor, is presented graphically in Appendix A of the Chisago

Lakes Outlet Project Management Plan. The period of record for Green Lake is April 1962 through September 1986 and totals 24.5 years; the record is slightly longer for Chisago Lake. The monitoring has been on an irregular basis. Missing data were interpolated as monthly values where necessary. Also, a single lake level was selected to represent each month of the record in a few cases where multiple data were available. The lengthy data gap including the years 1970-71 does not affect the present analysis as the levels then were obviously well below the high levels which are the only ones critical to the analysis.

In order to estimate lake outflow statistics, the historical lake level record was adjusted in such a manner as to reflect approximately what the situation would have been if the outlet project had been in place throughout the period of record. Two basic assumptions were made.

First, it was assumed that those portions of the historical record representing lake levels below the outlet control elevation remain essentially unaffected by the outlet. In other words, only those portions of the record having levels exceeding the outlet control are adjusted.

The second basic assumption was that any effects that the outlet project has on the overall balance of all <u>other</u> inflow and outflow processes can be considered negligible. For example, during a period when the lakes were high enough for outflow to have occurred, the outlet project would of course have caused lower lake levels than those recorded, and this in turn would have resulted in somewhat less water surface area. So total evaporation would have been slightly less due to the reduced surface area. But the assumption is that this kind of change is very small compared with the direct effect of the lake outlet flow.

On this basis the adjusted water balance for a lake or lake-chain can be expressed as

$$\frac{dS'}{dt} = (I - O) - Q \qquad (1)$$

in which S' = adjusted lake storage, t = time, (I - O) = pre-existing net

overall balance of inflows minus outflows, and Q = outlet flow. But the historical water balance is described by

$$\frac{dS}{dt} = I - O \qquad (2)$$

where S = historical lake storage, thus

$$\frac{dS'}{dt} = \frac{dS}{dt} - Q \qquad (3)$$

Assuming further that the water surface area can be considered approximately constant for outflow periods, then equation (3) can be rewritten as

$$A \frac{dE'}{dt} = A \frac{dE}{dt} - Q \qquad (4)$$

in which A = water surface area and E', E = water surface elevation for adjusted and historical conditions, respectively. The area A was taken as 4,000 acres for the Chisago Chain and 2,000 acres for Green and Little Green Lakes, these areas typifying high lake level conditions corresponding to significant outflow.

In discretized form equation (4) is

$$A \frac{E'_2 - E'_1}{t_2 - t_1} = A \frac{E_2 - E_1}{t_2 - t_1} - \frac{1}{2}(Q_1 + Q_2) \qquad (5)$$

in which the subscripts 1 and 2 refer to the beginning and end of a time interval, respectively. The unknowns in equation (5) are E'_2 and Q_2. Rating curves relating E' and Q were previously developed for both outlets and are reproduced in Figures II and III. (Note that in this analysis the Chisago outlet was assumed to operate via the permanent weir only, and not the low weir.) So the adjustment procedure entailed searching for the value of E'_2 which, together with its corresponding value of Q_2 determined by the rating curve, satisfies equation (5).

The procedure just as described above was used to adjust the Chisago Lake level record. For Green Lake, however, a further complication was introduced by the occurrence of outflow from Chisago Lake. Fortunately, though, from

the standpoint of the Green Lake analysis, the flows from Chisago Lake were known quantities. So, to account for them, they merely needed to be added to the right-hand side of equation (5).

The primary results of the above analysis appear in Figures IV-A through IV-C, depicting the adjusted portions of the lake level record, and Figures V-A through V-C, showing the outlet flows. The annual maximum levels for the period of record appear in Figures VI (Chisago Lake) and VII (Green Lake).

Annual maximum lake levels were analyzed statistically to yield the frequency curves presented in Figures VIII (Chisago) and IX (Green). In these figures the results based on the adjusted lake level record are plotted together with the historically based results.

Further statistical analysis was undertaken for the outflow from Green Lake. First, the whole outflow record was used to generate the flow-frequency curve shown in Figure X. This curve indicates, for example, that for 80% of the time there would be no outflow from Green Lake, while outflows exceeding 35 cubic feet per second (cfs) would occur less than 0.5% of the time, or less than 2 days per year on average.

Secondly, the annual maximum outflow rates were analyzed to yield the curve in Figure XI relating the annual maximum outflow to return period. This curve indicates that the maximum outflows corresponding to return periods of 10 and 25 years, respectively, are 35 and 67 cfs. Since the outlet is designed for a controlled maximum flowrate of 72 cfs, this maximum defines the statistical flows for all longer return periods, including 50 and 100 years as shown in Figure XI.

DOWNSTREAM STORM RUNOFF ANALYSIS

The Hydrology Guide for Minnesota (U.S. Dept. of Agriculture, Soil Conservation Service, St. Paul, Minnesota) gives procedures for calculating runoff and peak discharge resulting from storms of various return periods and durations. These procedures were followed to analyze storms of 24-hour duration and return periods of 10, 25, 50 and 100 years for the Upper and Lower portions of the downstream area.

Table I lists basic hydrologic characteristics of the Upper and Lower Areas for this analysis.

Determining the times of concentration required extrapolation beyond the range of standard curves in the Hydrology Guide. Confirmation of these values was sought through a graphic inspection of the outlet project's initial hydraulic monitoring data (Figure XII). Variations in outflow rate from the Lake Ellen drop structure translated downstream to County Road 80 in about 24 hours and to County Road 19 in approximately an additional 36 hours. Based on the drainage pattern, these times should be reasonable estimates of the times of concentration, and thus they confirm the values of the latter used in the analysis.

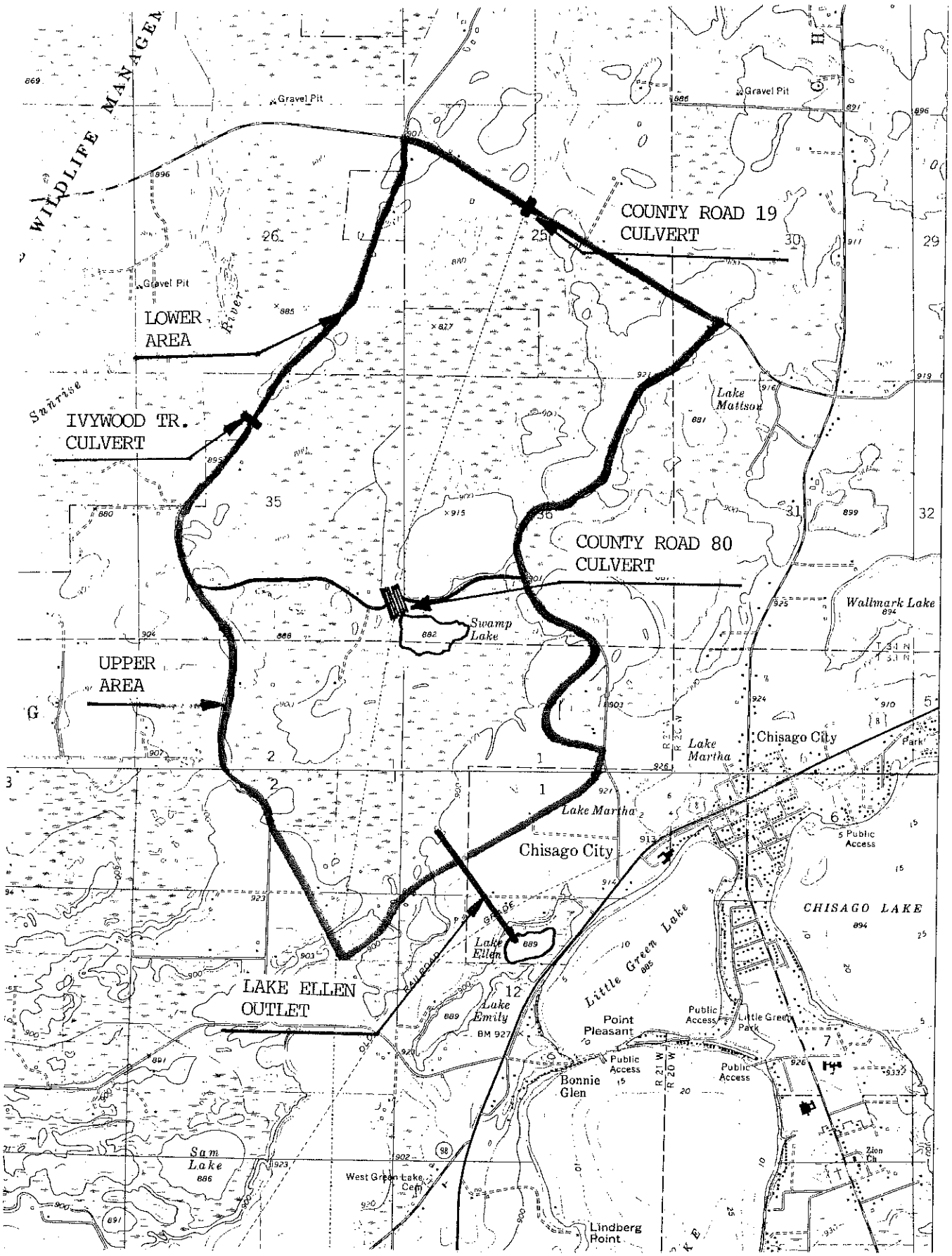
The results of the storm runoff analysis appear in Table II. For example, the calculated 25-year-return-period peak runoff flows are 76 and 86 cfs, respectively, for the Upper and Lower Areas. These peak flowrates describe arrival of locally originating runoff in the vicinity of the upstream end of the culverts draining each of the areas, and not flow through the culverts themselves. So in particular, the Lower Area's peak flow and runoff volume in Table II do not include any contributions from the Upper Area. The volumes for the two areas can simply be added to arrive at the total runoff volume for the study area, but the peak flowrates cannot be handled so simply. Instead, the Upper Area runoff arriving at County Road 80 must be "routed" through Swamp Lake in order to determine the flowrate through the culverts under County Road 80 and, hence, into the Lower Area. However, insufficient topographic data exist for the Swamp Lake vicinity for a meaningful routing analysis. (An analysis was tried on the basis of the U.S. Geological Survey topographic map, but the results appeared to be unreasonable so the analysis was set aside.)

Figure XIII presents the peak storm runoff flowrates from Table II in graphical form.

SUMMARY COMPARISON

Extreme storm runoff flows and Green Lake outflows are plotted together versus return period in Figure XIV. For any given return period, the extreme lake outflow is substantially less than the 24-hour-storm peak runoff flows for both the Upper and Lower Areas.

Another comparison can be made between long-term average flows. According to the Hydrology Guide, average annual runoff in the study area vicinity is 6.3 inches. Taken over the Upper and Lower Areas' total extent of 2,067 acres, this runoff figure implies a long-term average outflow of 1.5 cfs for pre-existing conditions. The Green Lake outflow frequency data depicted in Figure X correspond to a long-term average flow of 1.9 cfs. Hence this comparison shows that the long-term outflow from the study area will be slightly more than doubled by the outlet project.



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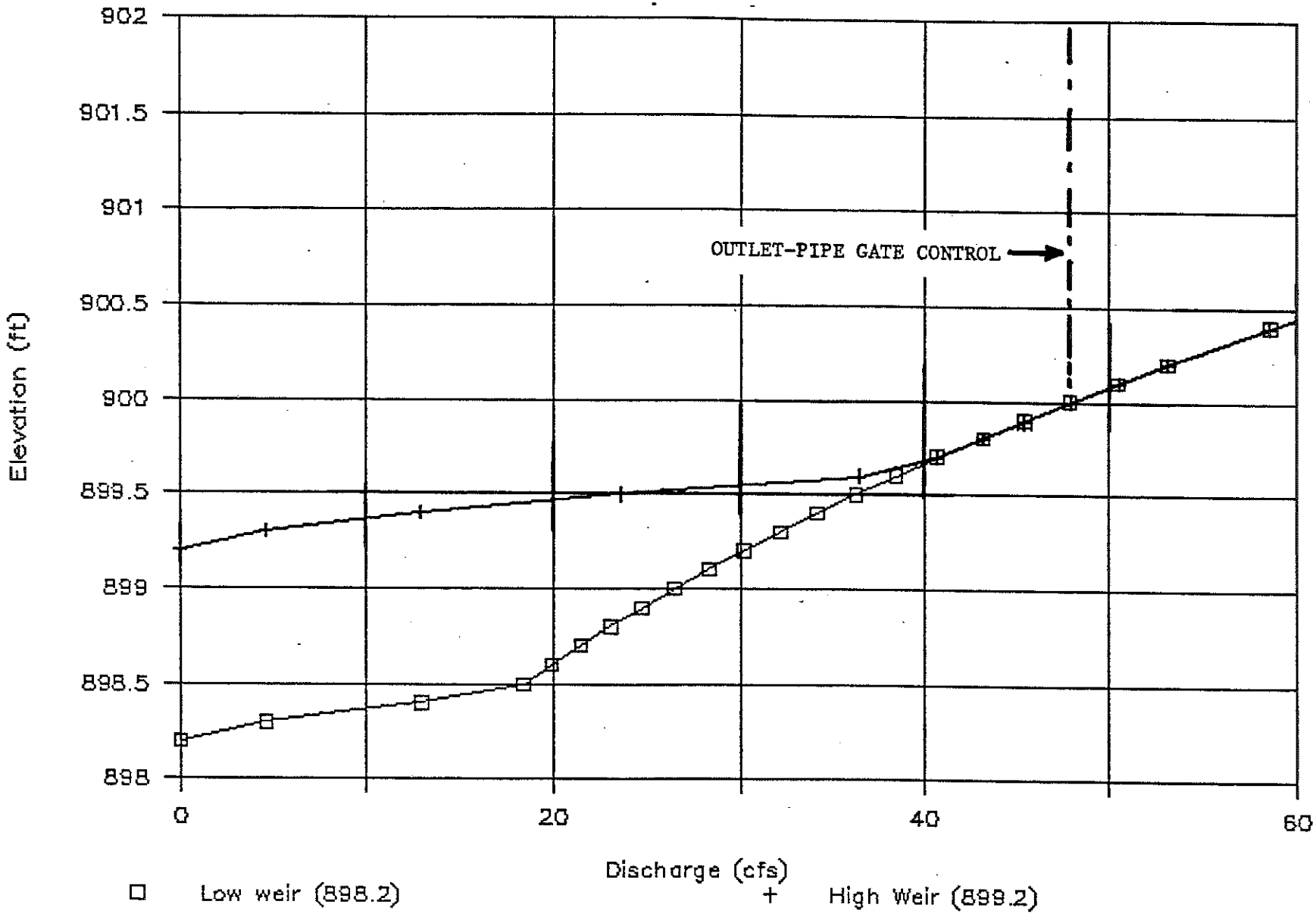
Study Area			I



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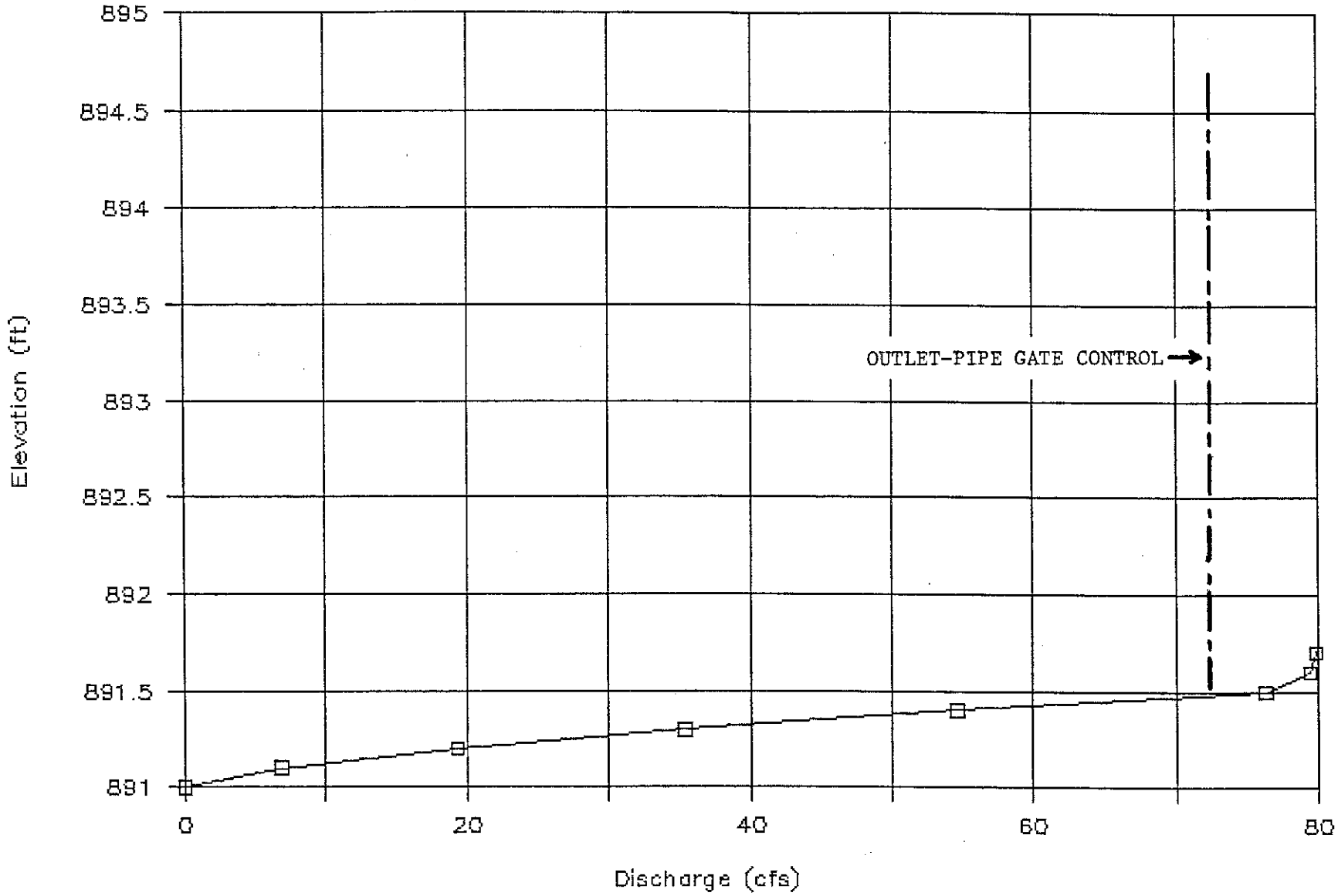
Chisago Lake Outlet Discharge Rating Curve	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	II



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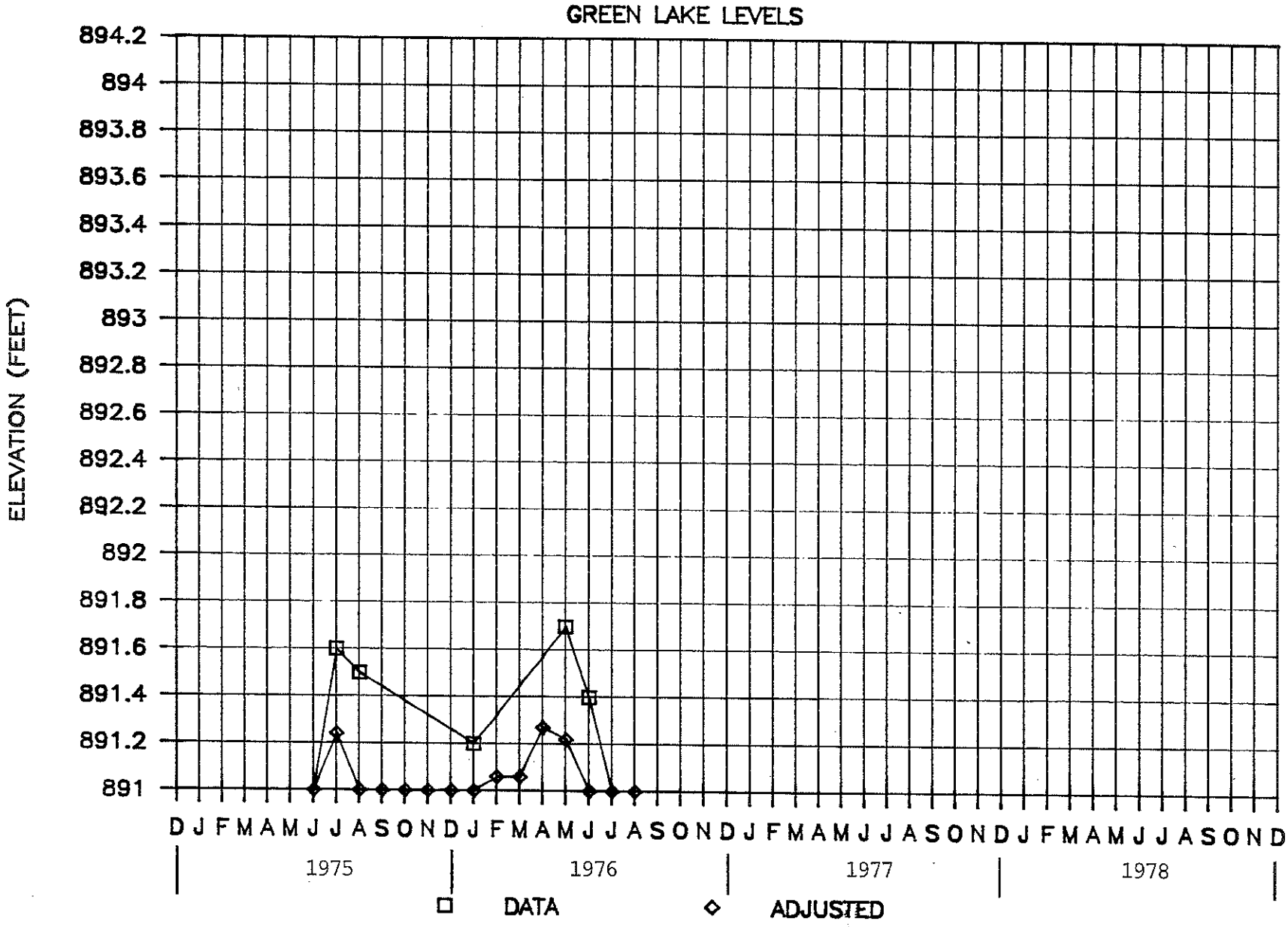
Green Lake Outlet Discharge Rating Curve	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	III

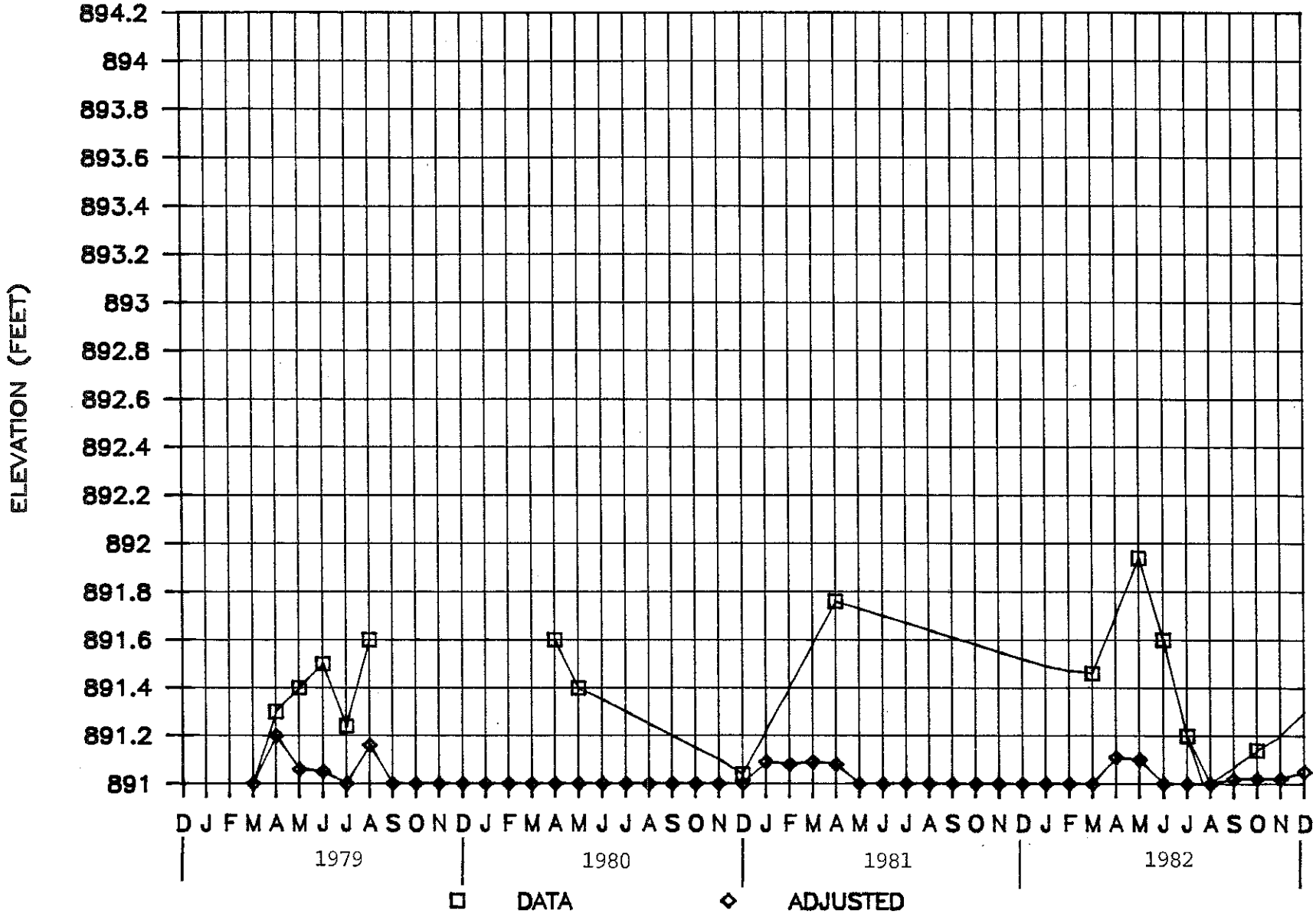
CHISAGO COUNTY



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Green Lake Levels with Outlet Adjustments (1975-78)	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	IV-A

CHISAGO COUNTY

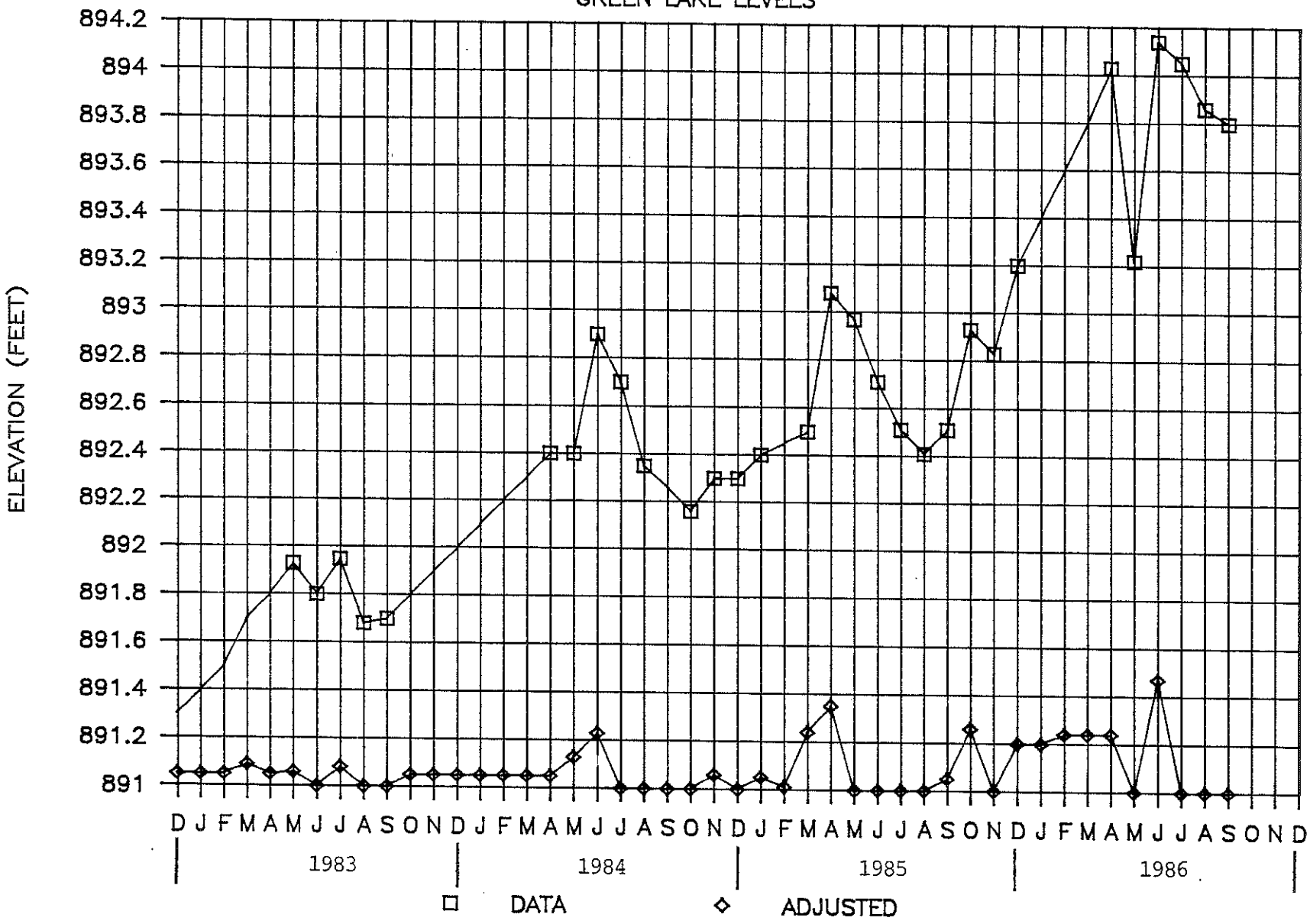
GREEN LAKE LEVELS



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Green Lake Levels with Outlet Adjustments (1979-82)	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	IV-B

CHISAGO COUNTY

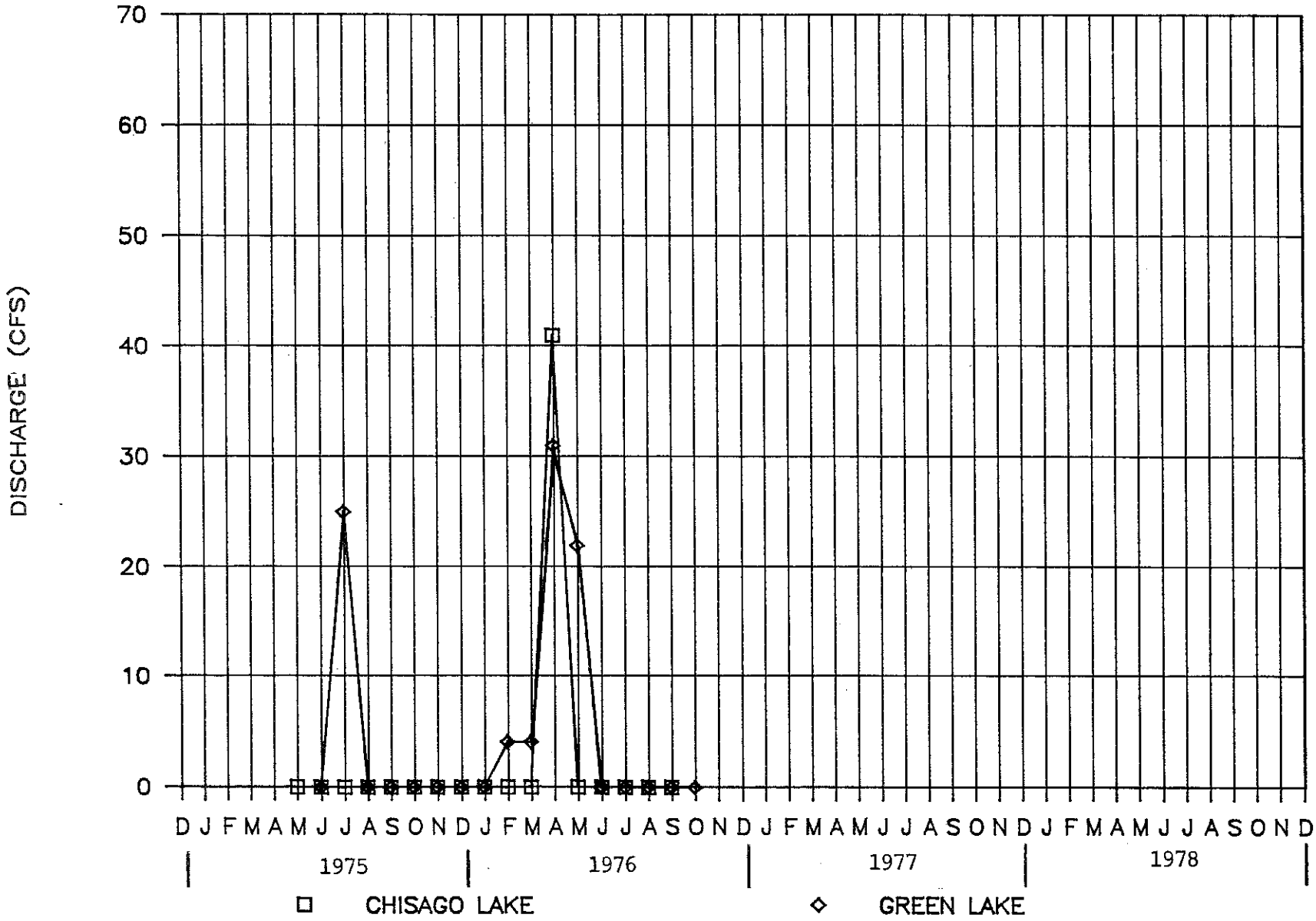
GREEN LAKE LEVELS



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Green Lake Levels with Outlet Adjustments (1983-86)	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	IV-C

CHISAGO COUNTY

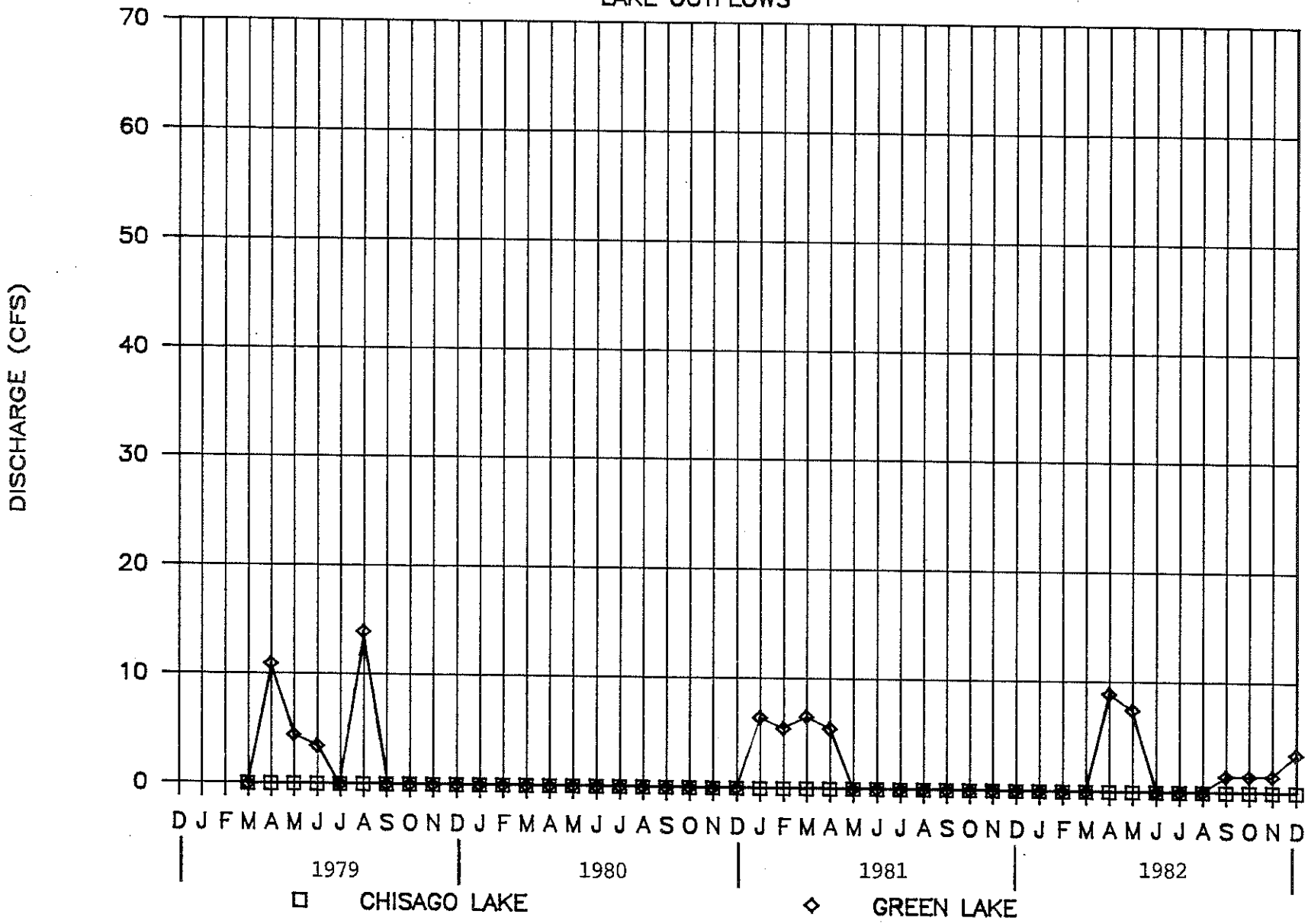
LAKE OUTFLOWS



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Lake Outflows for Adjusted Record (1975-78)	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	V-A

CHISAGO COUNTY

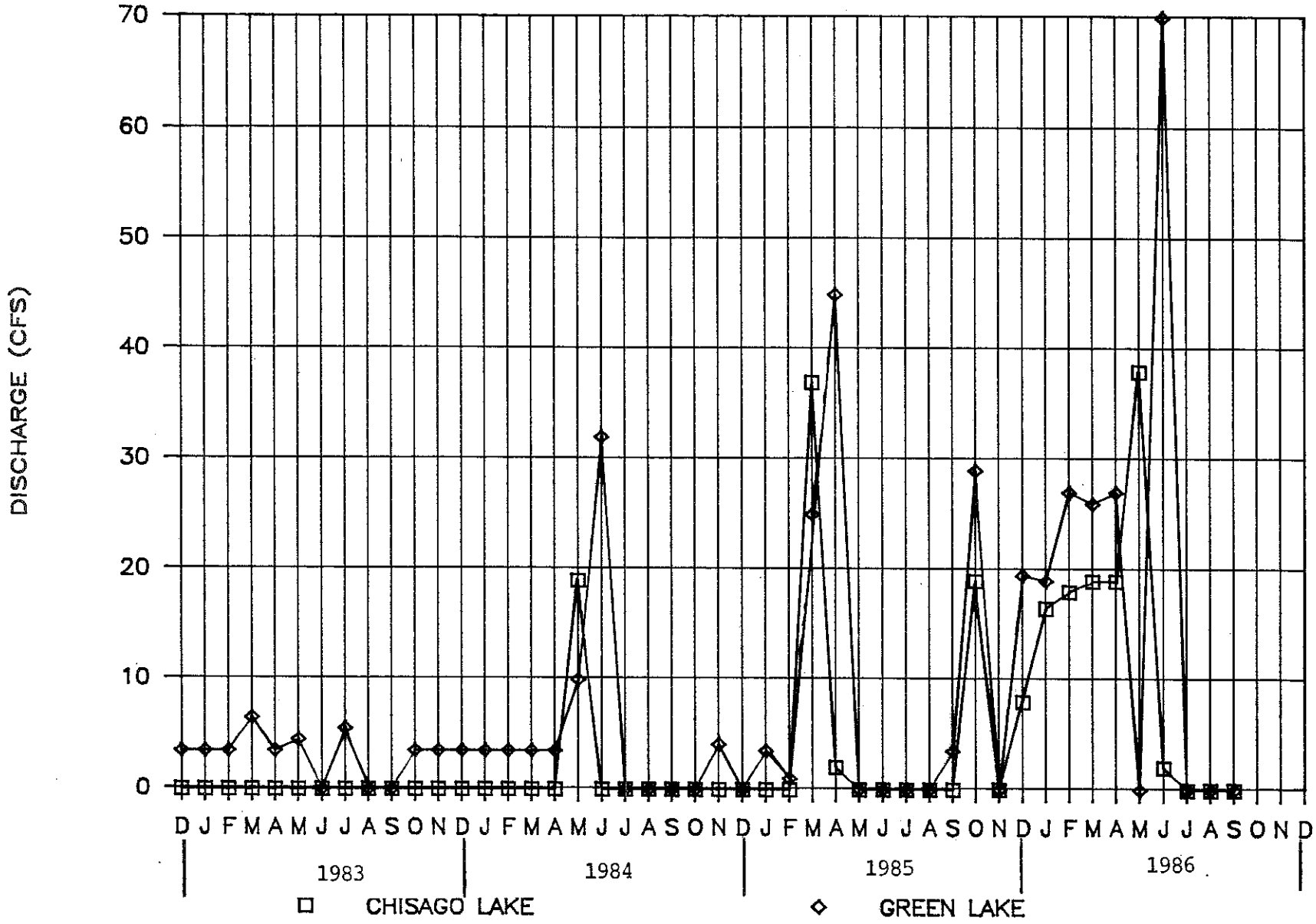
LAKE OUTFLOWS



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Lake Outflows for Adjusted Record (1979-82)	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	V-B

CHISAGO COUNTY

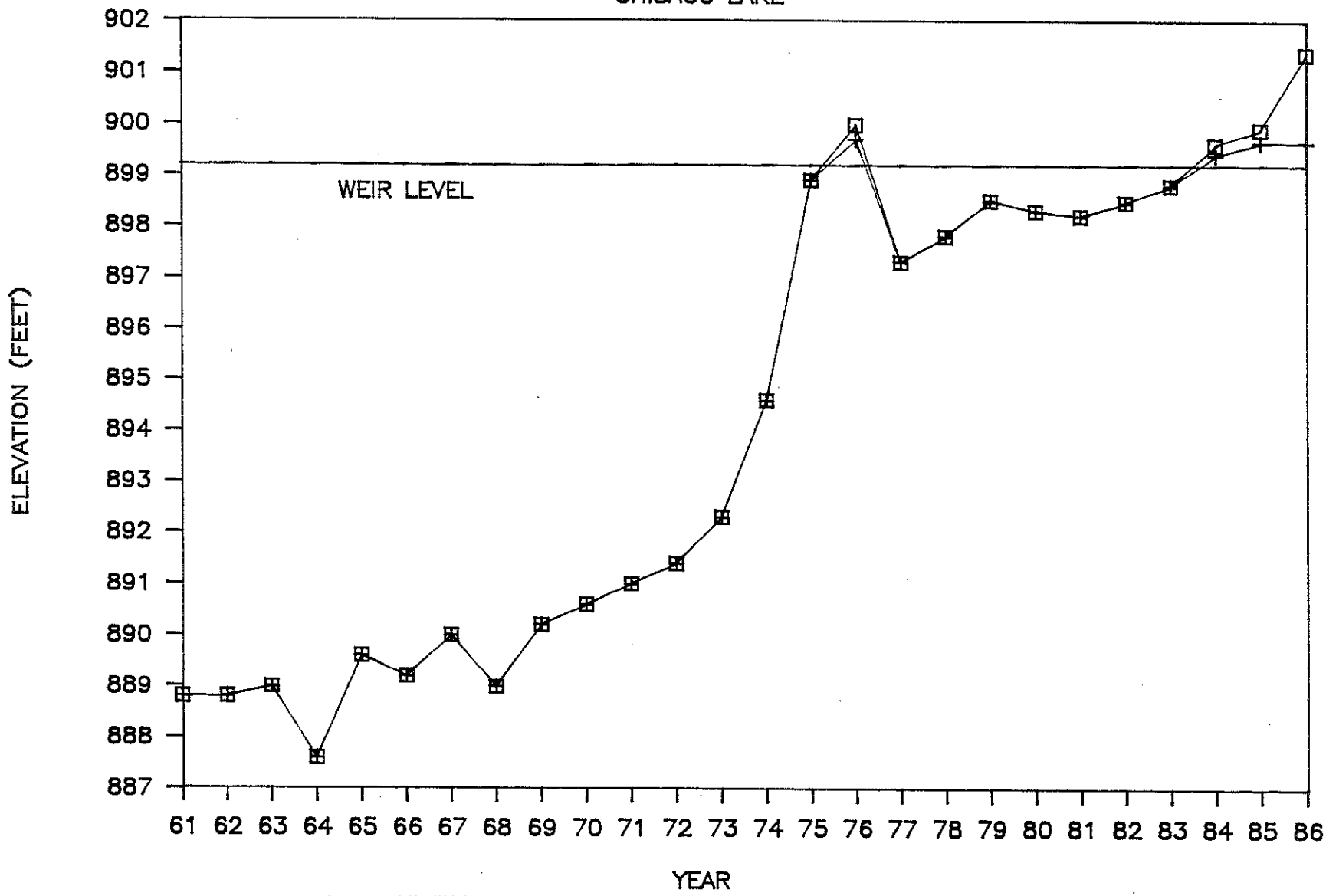
LAKE OUTFLOWS



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Lake Outflows for Adjusted Record (1983-86)	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	V-C

ANNUAL MAXIMUM LAKE LEVELS

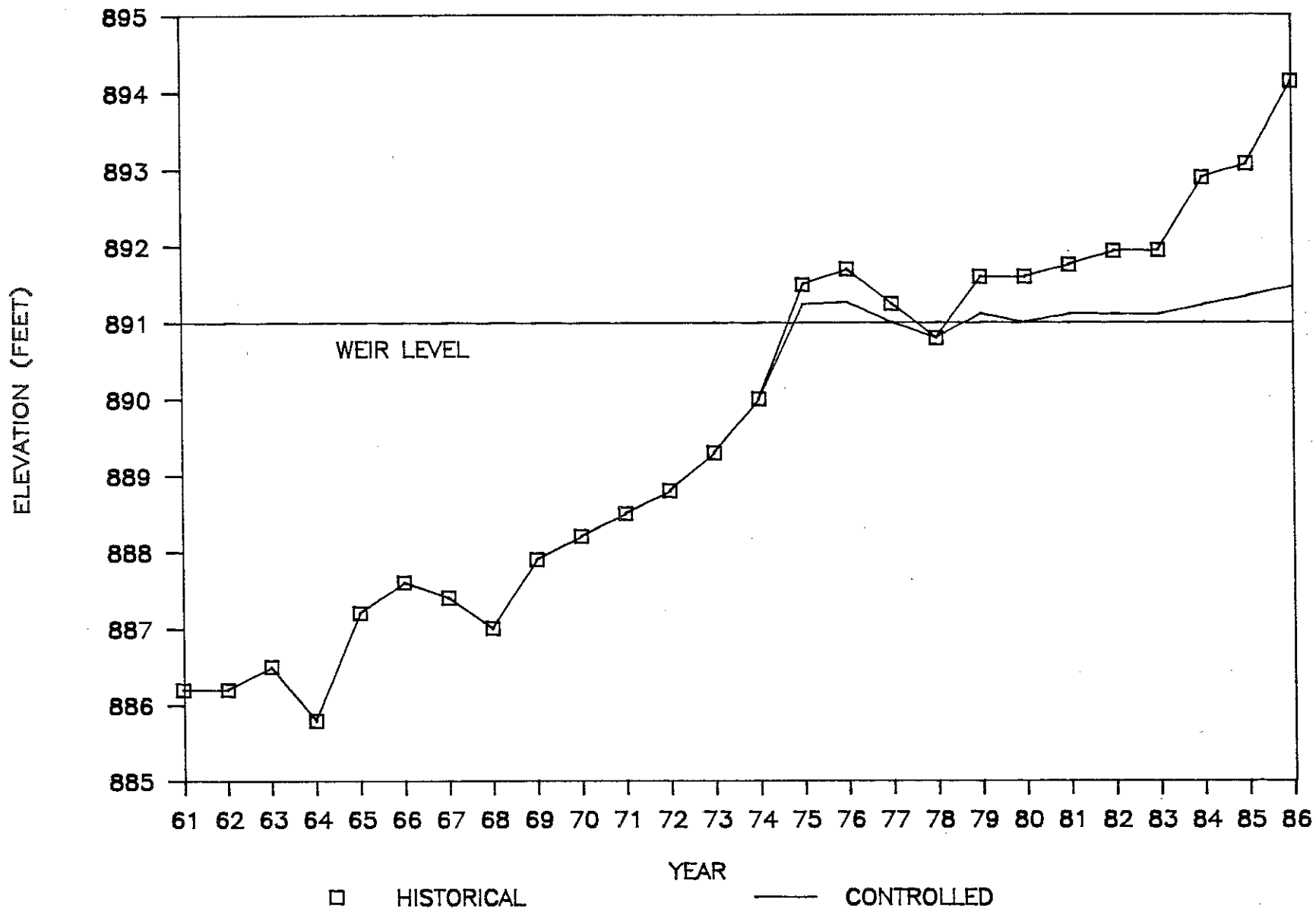
CHISAGO LAKE



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Chisago Lake Annual Maximum Levels	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	VI

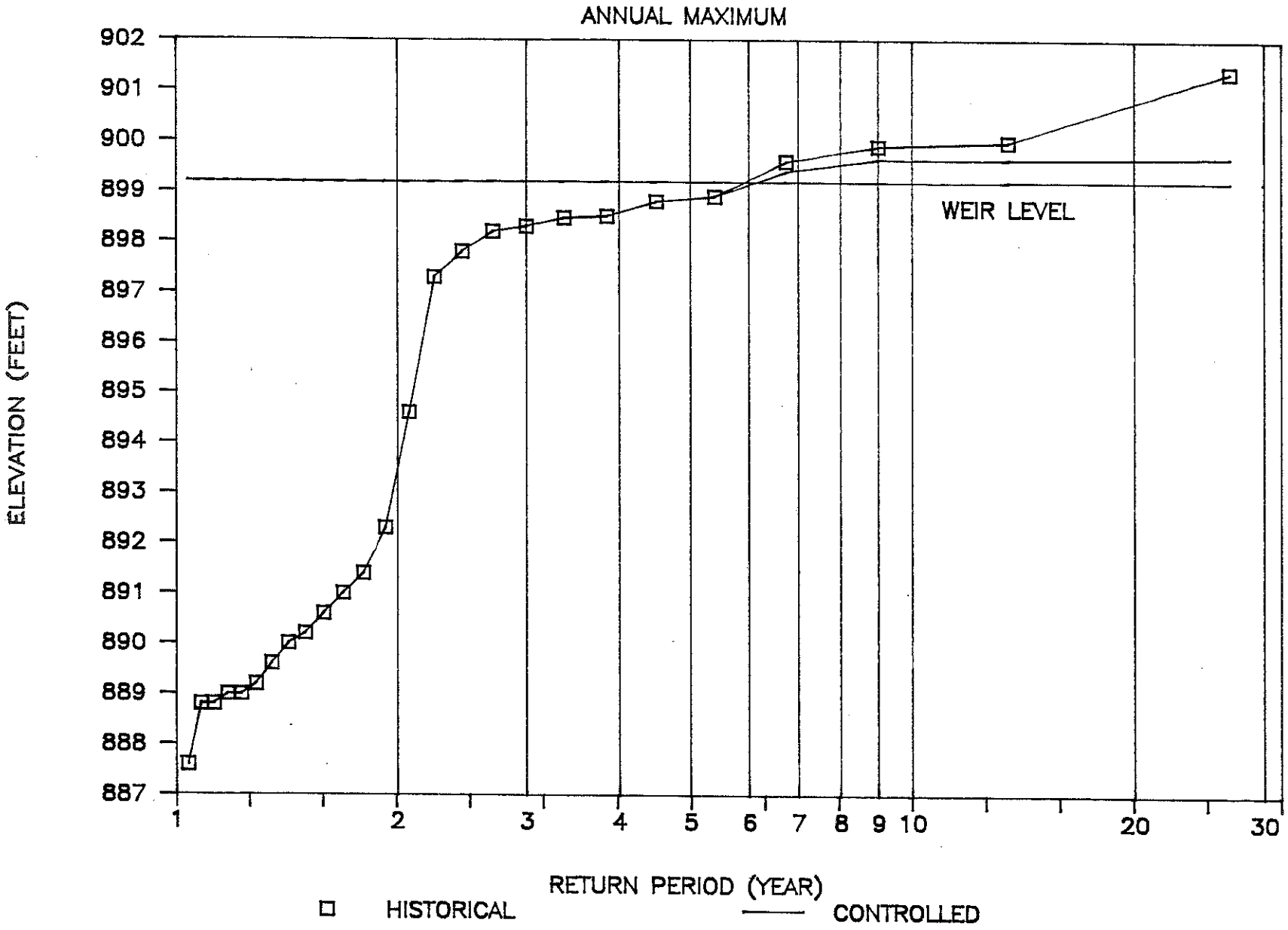
ANNUAL MAXIMUM LAKE LEVELS

GREEN LAKE



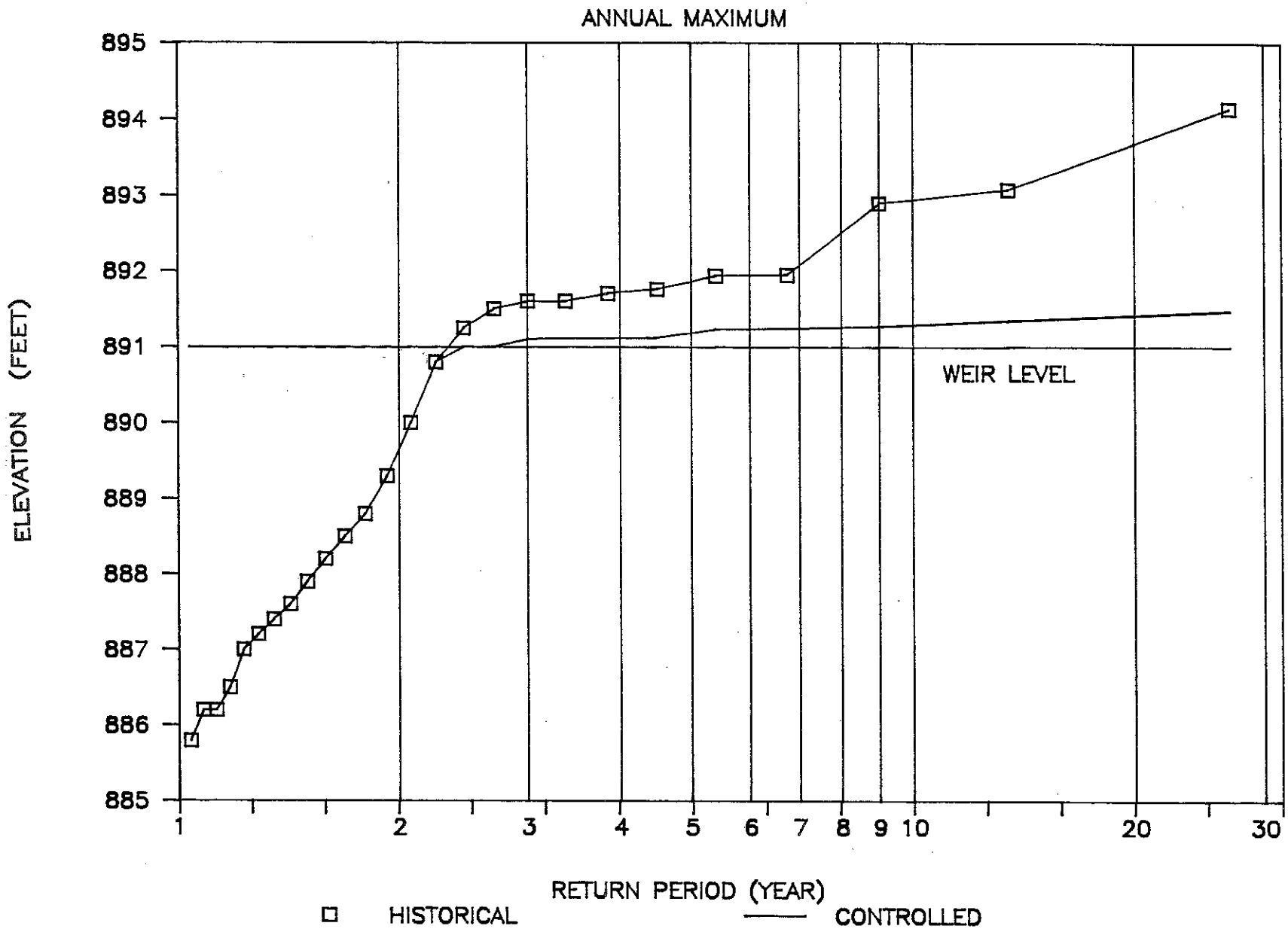
CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Green Lake Annual Maximum Levels	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	VII

CHISAGO LAKE LEVEL FREQUENCY



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Chisago Lake Level Frequency	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	VIII

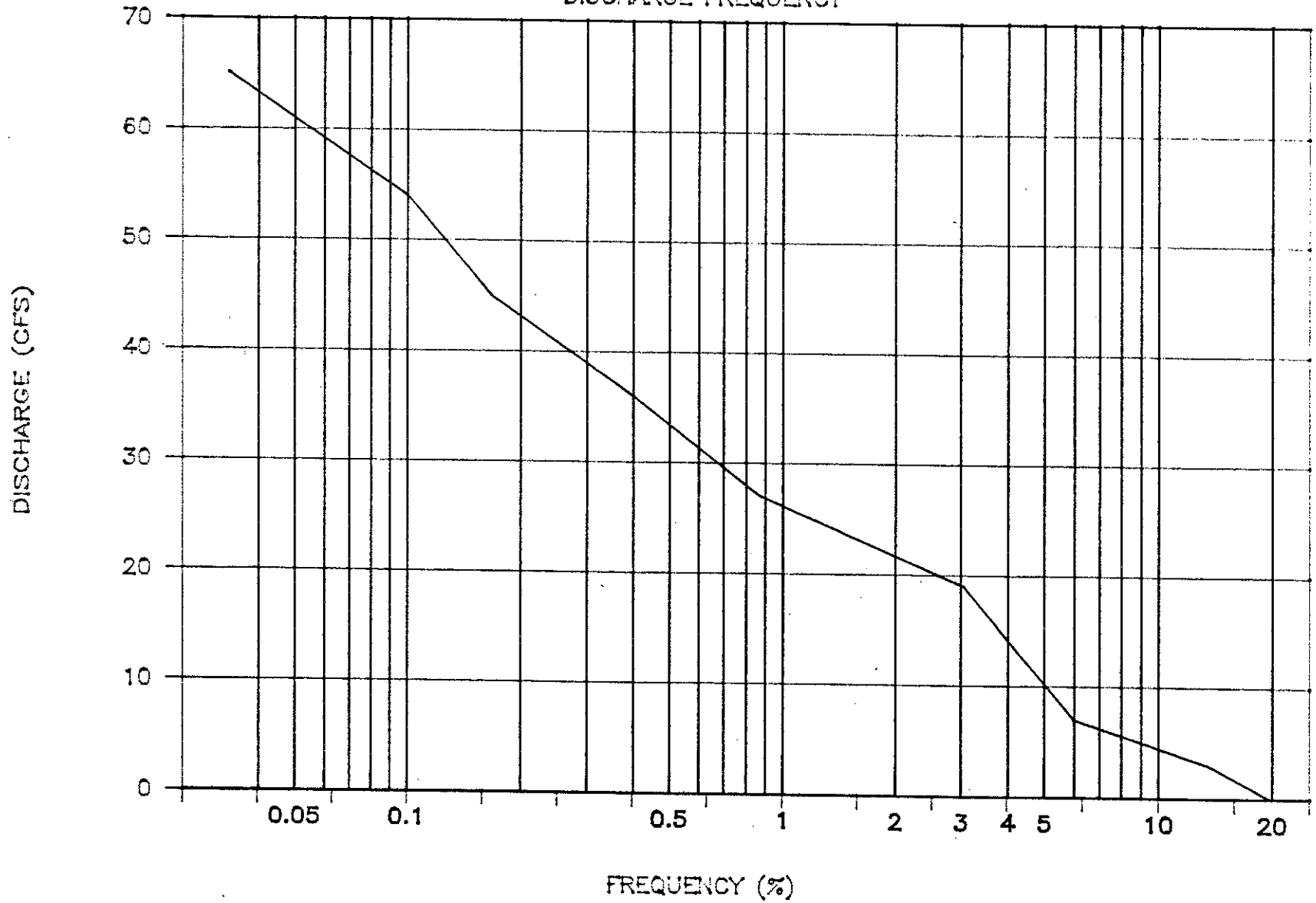
GREEN LAKE LEVEL FREQUENCY



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Green Lake Level Frequency	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	IX

GREEN LAKE

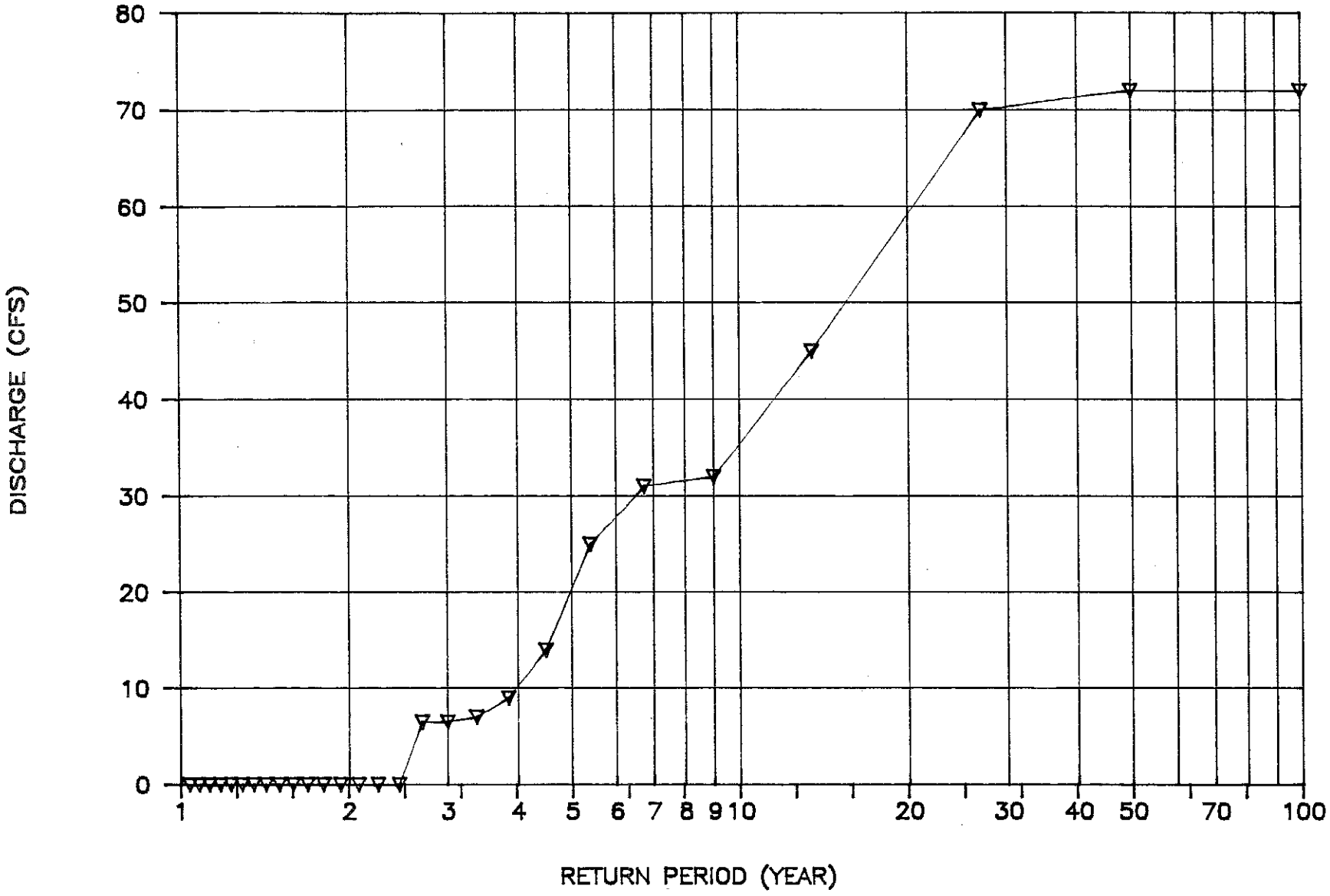
DISCHARGE FREQUENCY



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Green Lake Outflow Frequency Curve	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	X

GREEN LAKE OUTFLOW FREQUENCY

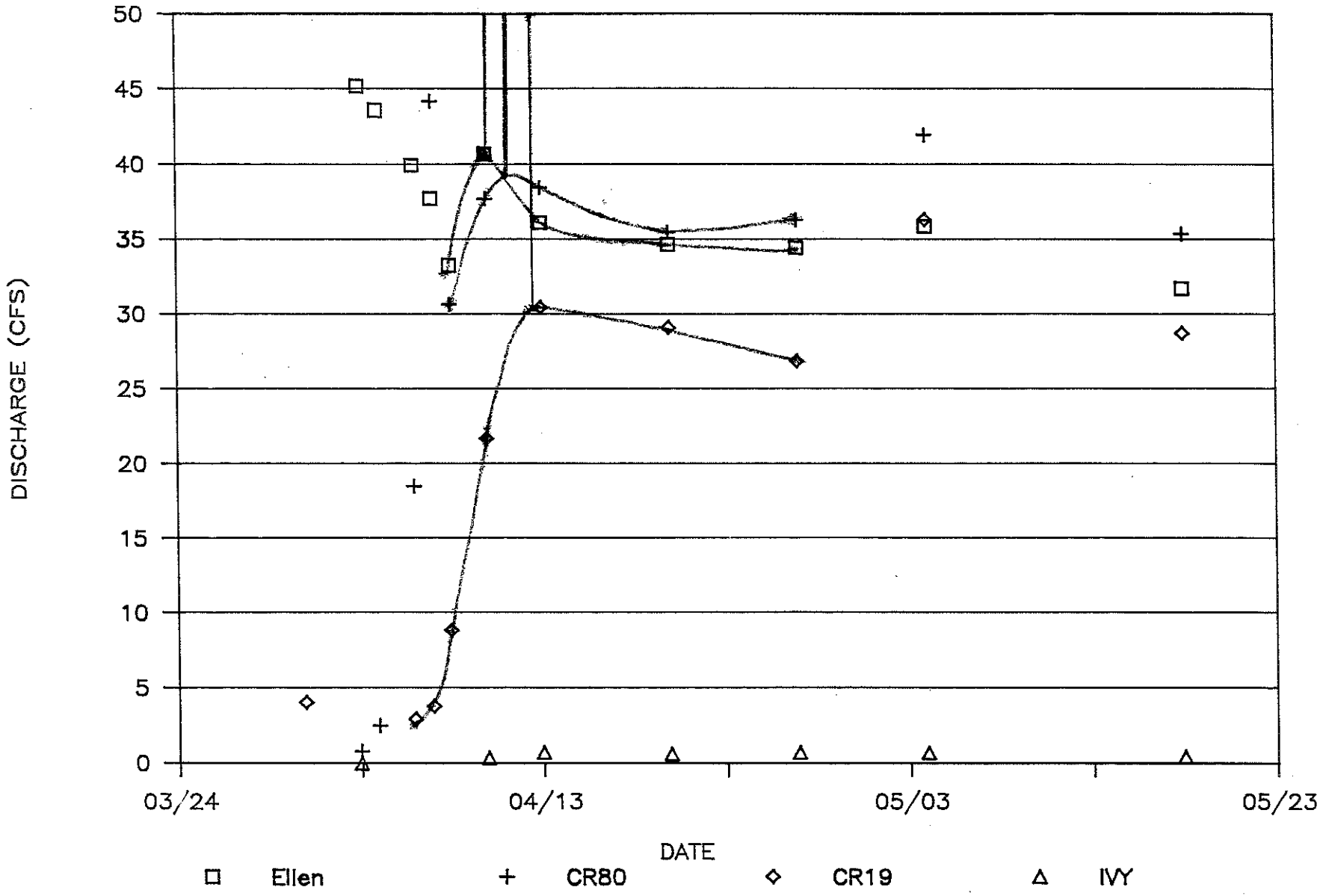
ANNUAL MAXIMUM



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Green Lake Annual Maximum Outflow Frequency	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	XI

CHISAGO COUNTY

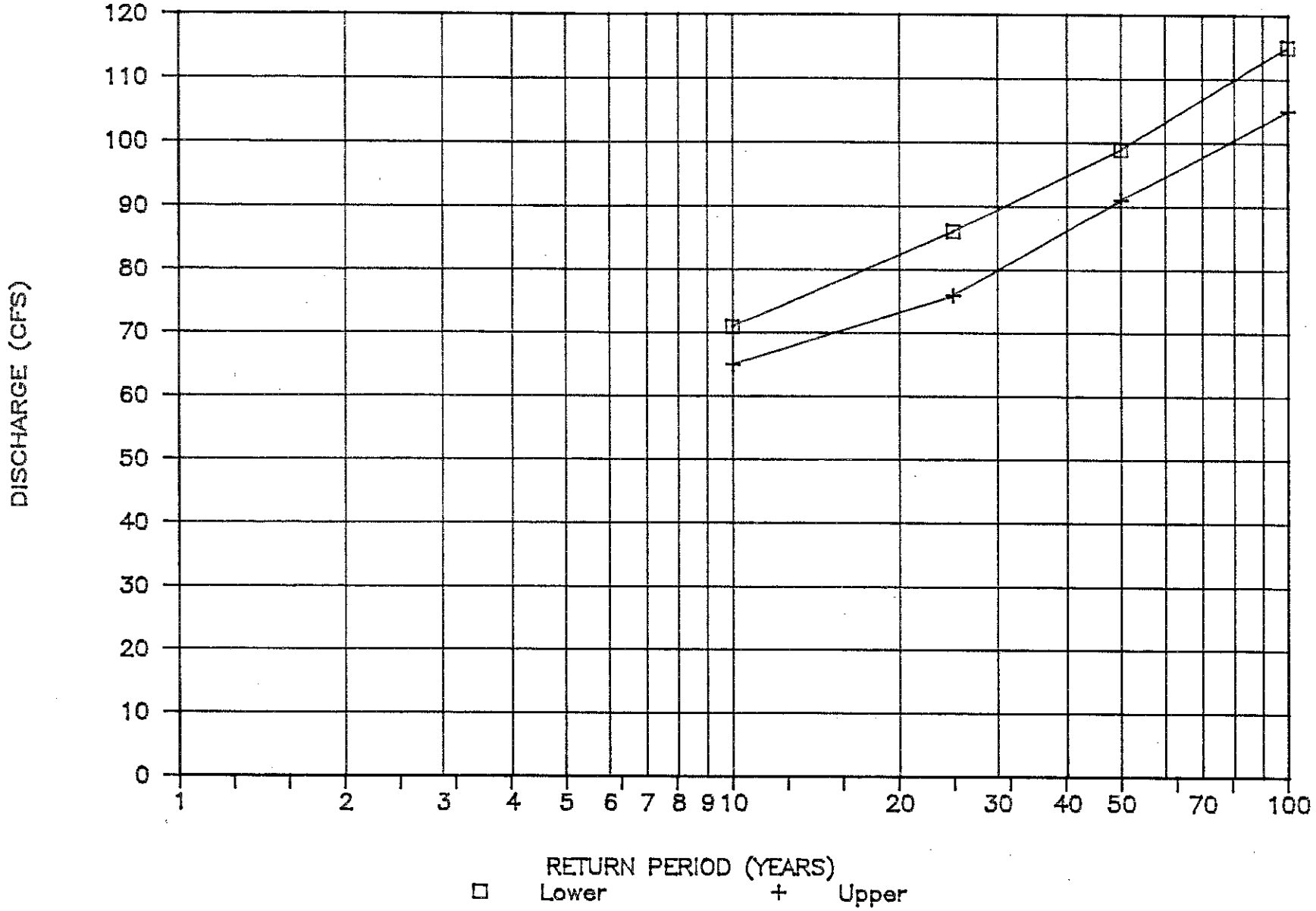
DOWNSTREAM HYDROGRAPHS



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Downstream Flows in Early 1987	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	XII

FLOOD FREQUENCY

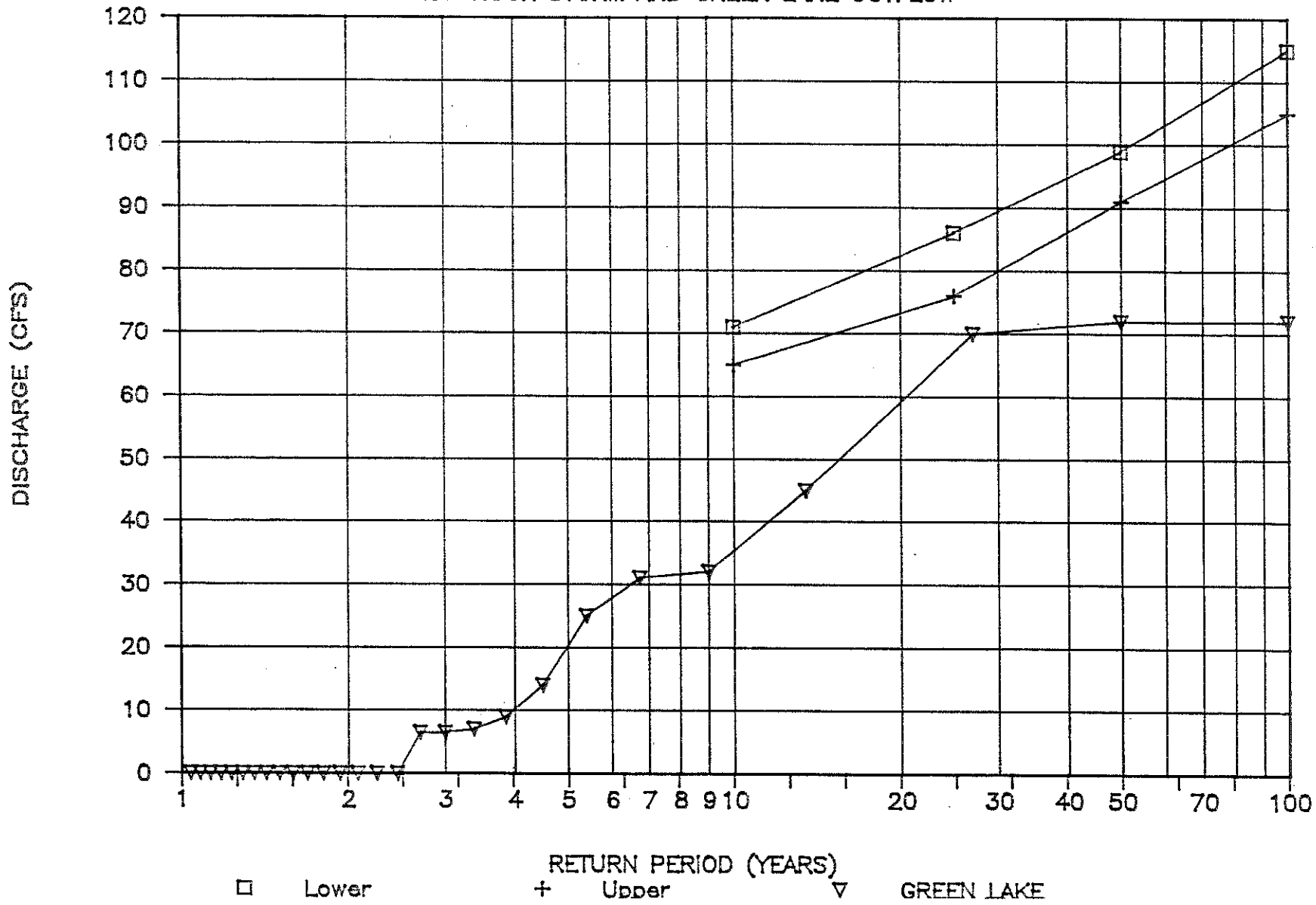
24-HOUR STORM



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
Downstream Flood Frequency Curves	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	XIII

FREQUENCY OF ANNUAL MAXIMUM FLOWS

24-HOUR STORM AND GREEN LAKE OUTFLOW



CHISAGO COUNTY BOARD	Consulting Engineers	JUL 87
High-Flow Frequency Comparison	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	XIV

TABLE I

HYDROLOGIC CHARACTERISTICS OF STUDY AREA

Characteristic	Upper Area	Lower Area
Area (sq. miles)	1.38	1.85
Maximum Elevation	890	878
Outlet Elevation (typical water surface)	882	873
Length (ft)	7,000	8,000
Average Slope (%)	0.11	0.0625
SCS Soil Group	C	C
Soil Cover Complex	Swamp	Swamp
SCS Curve Number	85	85
Time of Concentration (hr)	23	37
Wetland Correction Factor (for peak discharge)	0.67	0.67

TABLE II

STORM RUNOFF RESULTS

Return Period (years)	Rainfall (inches)	Runoff (inches)	Runoff Volume (cubic ft)	Peak Discharge (cubic ft per sec)
		UPPER AREA		
10	4.1	2.55	8.2×10^6	65
25	4.7	3.09	9.9×10^6	76
50	5.2	3.56	$11,4 \times 10^6$	91
100	5.8	4.12	13.2×10^6	105
		LOWER AREA		
10	4.1	2.55	11.0×10^6	71
25	4.7	3.09	13.3×10^6	86
50	5.2	3.56	15.3×10^6	99
100	5.8	4.12	17.7×10^6	115

APPENDIX C

WINTER OUTFLOW SAFETY PLAN

STATE OF
MINNESOTA
DEPARTMENT OF NATURAL RESOURCES

BOX , 500 LAFAYETTE ROAD • ST. PAUL, MINNESOTA • 55146

DNR INFORMATION
(612) 296-6157

RE[illegible] BY
WENCK ASSOCIATES INC.

DEC 29 1986

December 23, 1986

Mr. John B. Erdmann, P.E.
Wenck Associates, Inc.
832 Twelve Oaks Center
Wayzata, MN 55391

Dear Mr. Erdmann:

It appears that your Winter Outflow Safety Plan meets the minimum marking standards set forth in the Commissioner's Order on aeration systems. The Chisago County Sheriff's Department has picked up 25 - "Thin Ice" signs from us for use on the project.

Sincerely,

Kim A. Elverum
Boat and Water Safery Coordinator

KAE/de

Cc: Dave Leuthe, DNR/Cambridge-Waters
Dave Ford, DNR/St. Paul-Waters
Chisago Co. Sheriff's Department

Wenck Associates, Inc.

Consulting Engineers
(612) 475-0858

December 16, 1986

Mr. Douglas J. Weiszhaar, P.E.
Chisago County Engineer
Chisago County Highway Department
Box 326
Center City, Minnesota 55012

Re: Winter Outflow Safety Plan
Chisago Lakes Outlet Project

Dear Doug:

Enclosed is the Winter Outflow Safety Plan as requested. As I explained on the telephone, copies are also being transmitted directly to the DNR to expedite review and approval.

Let me know if you have any questions on this.

Respectfully submitted,

WENCK ASSOCIATES, INC.

John B. Erdmann, P.E.

JBE/msw

Enclosure

cc: David Leuthe, DNR (Cambridge)
David Ford, DNR (St. Paul)
Kim Elverum, DNR (St. Paul)

832 Twelve Oaks Center
15500 Wayzata Blvd.
Wayzata, MN 55391

WINTER OUTFLOW SAFETY PLAN
CHISAGO LAKES OUTLET PROJECT
DECEMBER 1986

A. Purpose

The purpose of the Winter Outflow Safety plan is to prevent accidents which could potentially occur as a result of open water created by flow through the Chisago Lakes Outlet Project during its first winter of operation. There are four particular areas of concern: (1) the outfall vicinity in Green Lake from the Chisago-Green outlet, (2) the narrows between Green and Little Green Lakes, (3) the area in Little Green Lake near the Highway 8 crossing into Lake Ellen, and (4) all of Lake Ellen itself. Figure 1 shows the location of the outfall in Green Lake from the Chisago-Green outlet. Figure 2 shows the other three locations. In all of these areas there will most likely be a region of open water and/or thin ice. This poses a potential hazard to snowmobilers, ice fishermen, children and others who venture onto the lake ice for any purpose.

B. Guidelines

The Minnesota Department of Natural Resources has official safety requirements for lake aeration systems, which also may create open water or thin ice. The DNR transmitted these safety requirements to Chisago County to be used as guidelines for the Winter Outflow Safety Plan. The DNR requirements are contained in Commissioner's Order 2194 and related sign specifications.

C. Marking

As outlined below, Green Lake, Little Green Lake and Lake Ellen will be marked with specified signs at public access and other commonly used access locations and at the four particular areas of concern.

1. Public Access Locations

Figure 3 shows the typical sign which will be posted on the shorelines of Green Lake, Little Green Lake and Lake Ellen at each public access point and other areas commonly used by the public for access to the lake.

2. Particular Areas of Concern

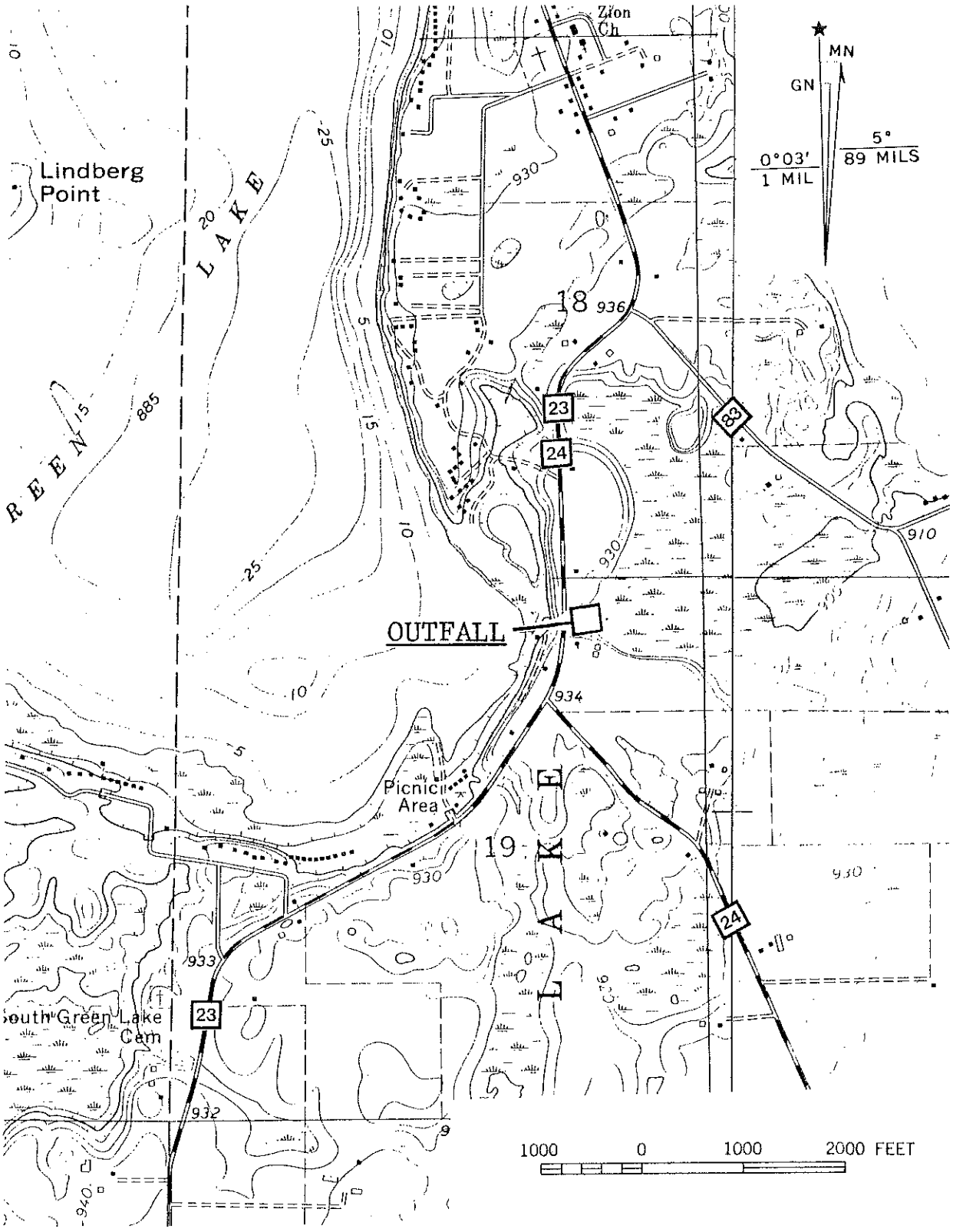
Figure 4 shows the typical "thin ice" sign which will be posted around the perimeter of the four particular areas of concern where the flowing water significantly affects the ice. For each area, the signs will be installed at a height of from four to six feet in a rectangular pattern at each corner of the area. At least two additional signs will be posted between the corner signs on any side exceeding 100 feet in length.

To the extent that the County deems it prudent and feasible, fencing will be placed around the affected areas.

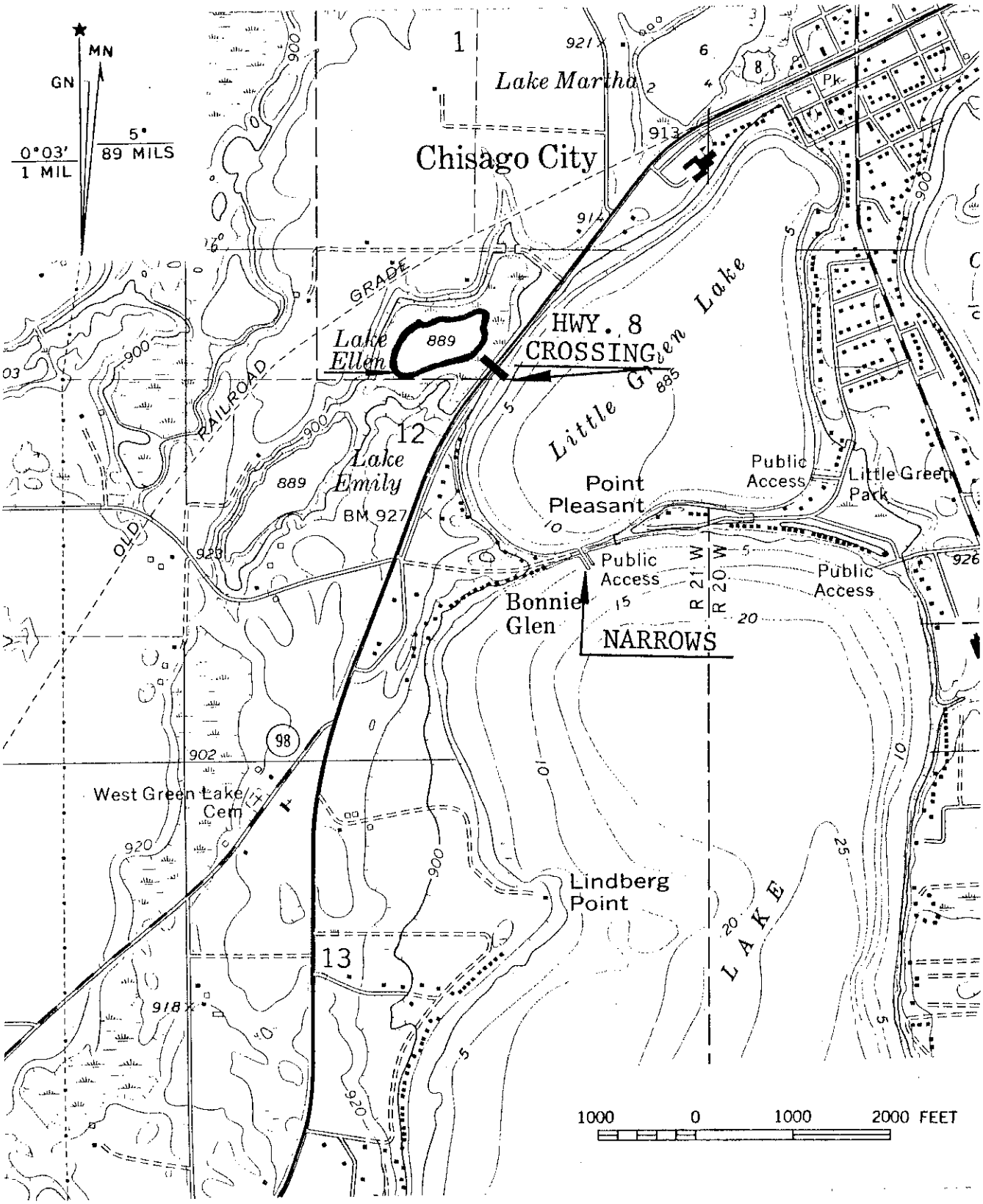
In order to facilitate retrieval of signs and any fencing used on the lake, these may be installed using wooden posts set into the ice.

D. Publication of Notice

Between 5 and 20 days prior to commencement of winter flow through the Chisago Lakes Outlet Project, notice will be published at least two times in area newspapers including the Chisago County Press, Lindstrom and the East Central Minnesota Post Review, North Branch. The notice will include the locations of the outfall in Green Lake, the narrows, the Highway 8 crossing, and Lake Ellen, and the date of commencement of operation.



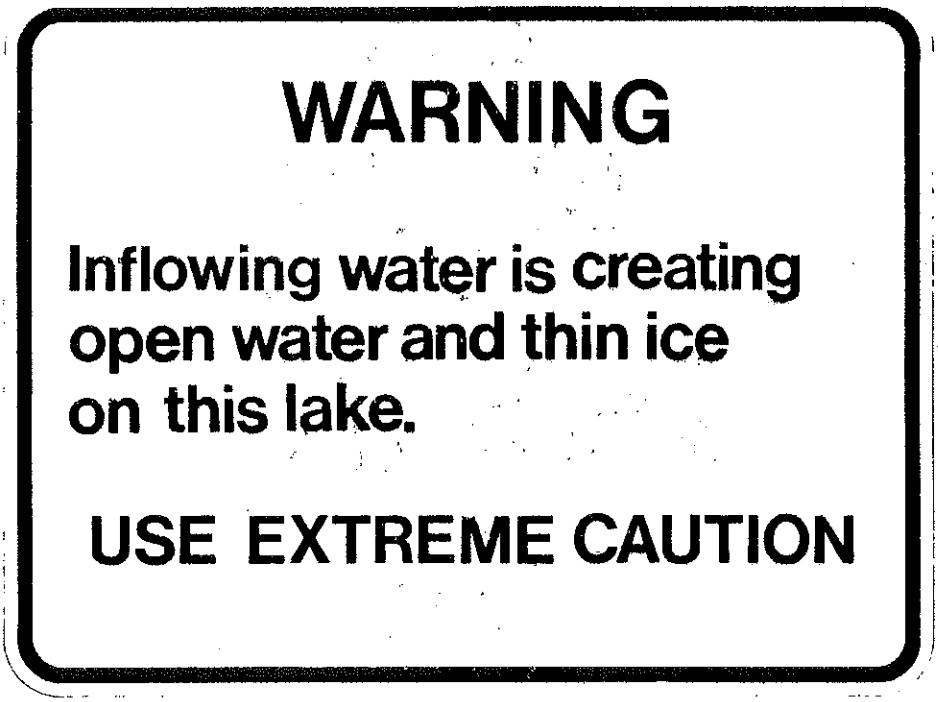
CHISAGO COUNTY BOARD	Consulting Engineers	DEC. '86
Location of Chisago-Green Outfall in Green Lake	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	1



CHISAGO COUNTY BOARD	Consulting Engineers	Dec. 86
Location of Ellen, Hwy. 8 Crossing & Narrows	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	2

Minnesota Department of Natural Resources

Sign Typical
Bureau of Engineering



Sign: WARNING	Notes:
Color: BL./OR.	Wording modified for lake outlet system.
Material: ■ Al. ☐ W.R. ☐ Cd.Bd. ☐ Decal	
Size: ☐ 12"x 18" ■ other 18"x 24"	
Mounting Post: ☐ metal ■ wood	
Reflectorized: ☐ no ■ yes	
File/ID. no. NR 8-348 Date 5/84	

CHISAGO COUNTY BOARD	Consulting Engineers	DEC. '86
Typical Public Access Warning Sign	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	3

Minnesota Department of Natural Resources

Sign Typical
Bureau of Engineering

Sign: Thin Ice	Notes:
Color: BL., OR. / WH.	To be used on all Fisheries operations where open water may be created.
Material: ■ Al. ☐ W.R. ☐ Cd.Bd. ☐ Decal	Sign can be applied to a wood support.
Size: ☐ 12"x 18" ■ other 14"x 18"	
Mounting Post: ☐ metal ■ wood	
Reflectorized ☐ no ■ yes	Specified by Minn. Water Safety Law NR 204 (e) (6) (8)
File/ID. no. NR 8-345 Date 5/84	

CHISAGO COUNTY BOARD	Consulting Engineers	DEC. '86
Typical Thin Ice Sign	Wenck Associates, Inc. Twelve Oaks Center 15500 Wayzata Blvd. Wayzata, MN 55391	4

APPENDIX D

INITIAL HYDRAULIC MONITORING PLAN

INITIAL HYDRAULIC MONITORING PLAN
CHISAGO LAKES OUTLET PROJECT

The aim of the initial hydraulic monitoring is to determine: (1) the control gate settings for the Chisago and Green outlets that are required for limiting outflow to the design rates when the lakes are at higher elevations; (2) the relationship between lake elevation and outflow rate (rating curve) at lower elevations; and (3) the adequacy of natural flowage paths downstream from Swamp Lake. The first two items require water level and flow measurements taken over several months at Chisago Lake and Green Lake and their respective outlets. The third item entails measurements during the first month of operation at several downstream locations.

A. Control Gate Settings and Rating Curves

1. Stations

For Chisago Lake and Green Lake level measurements, stations will be selected to be consistent with past lake level data obtained by the County Surveyor and other agencies. (This means that measurements of the lake levels per se will not be in the vicinity of the drop structures, where water levels will be slightly lower than in the lakes themselves.) Water levels will also be measured at a representative station established near each drop structure (but not so near as to be affected by local drawdown approaching the weirs).

Any newly established water level stations will be surveyed, so that all measurements can be conveniently made from a bench mark of known elevation above sea level (National Geodetic Vertical Datum of 1929).

For flow measurements, stations will be established: (1) in the new ditch connecting Chisago Lake with the County Road 24 drop structure, and (2) at the outlet end of the pipeline from the Lake Ellen drop structure.

2. Schedule

Monitoring of each lake and its outlet will begin as soon as the outlet begins operating. The monitoring will continue once every two weeks during the initial 10 weeks of operation. Following that period, monitoring will be monthly until the outflow at the structure is less than 20 cubic feet per second (cfs). Monitoring at certain times may be omitted if the lake has risen to a previously achieved level at which monitoring was already performed.

3. Procedure

The design outflow rates are 48 cfs for the Chisago outlet and 72 cfs for the Green outlet. At higher lake levels the outlet control gates must be set partially closed in order to limit outflow to the design rate. The monitoring procedure at such times is aimed at determining the proper gate setting. At lower lake levels the control gates are fully open but the outflow is less than the design rate. The monitoring procedure then aims simply to determine the outflow rate and lake level concurrently.

In both cases the outflow rate (discharge) must be measured. This will be accomplished using a current meter, wading rod and tag line, following procedures established by the U.S. Geological Survey.

Also in both cases, water levels will be measured: (1) at least once on the day of monitoring for the lake corresponding to the outlet monitored, and (2) immediately before and after each discharge measurement at the station established near the drop structure.

a. Control Gate Settings

The proper setting of an outlet control gate will be determined by trial and error according to the following procedure: (1) measure the outflow for the existing condition (with water level measurements near the drop structure before and after); (2) verify the outlet control gate setting for the existing condition (it should be exactly as set on the previous occasion); (3) adjust the gate setting to a "guesstimated" position that should

approximately ensure the design outflow rate; (4) measure the outflow for the new setting after waiting for steady flow to be established (as verified by repeated water level measurements near the drop structure beforehand and at least one water level measurement afterwards); (5) repeat steps 3 and 4 until the design rate is achieved within acceptable accuracy (5 - 10%), or until the gate is fully open and the outflow is less than the design rate.

b. Rating Curves

To determine rating-curve data at lower lake levels when the outlet control gate is fully open, the procedure is: (1) measure the existing outflow (with water level measurements near the drop structure before and after); and (2) verify that the outlet control gate is fully open.

The gate setting should always be exactly as set on the previous occasion. If it is not, the control-gate-setting procedure might have to be followed. In addition, the cause of any change in setting must be determined and corrected.

c. Special Procedure for Chisago Outlet

A special procedure must be followed at the Chisago outlet because there are two weirs there. The procedure is: (1) perform the appropriate monitoring (i.e., either control gate setting or rating curve) for the weir in operation at the time; (2) change the low weir control gates to the opposite setting (i.e., if initially closed, then change to fully open, and vice versa); (3) wait until steady flow is again established, verifying this by repeated water level measurements near the drop structure (the waiting time should be less than one hour); (4) perform the appropriate monitoring for the new condition; and (5) return the low weir control gates to the initial setting.

4. Documentation

The complete monitoring results will be tabulated and incorporated into the Management Plan as Appendix E.

B. Downstream Flowage

1. Stations

Monitoring stations will be established at: (1) Swamp Lake outlet, at County Road 80; (2) Ivywood Trail crossing, a new flowage path; and (3) County Road 19 crossing located about one half mile east of Ivywood Trail, the previously existing flowage path for the Swamp Lake outflow (plus some additional drainage). A bench mark for water level measurements will be established at each station.

2. Schedule

Monitoring at all three stations will be daily for the first five days of operation of the Green outlet. Thereafter, monitoring will continue weekly for three more weeks.

3. Procedure

On each day of monitoring, the flow will be measured once at each station, with water level measurements immediately before and after. The discharge will be measured using a current meter, wading rod and tag line, following procedures established by the U.S. Geological Survey.

4. Assessment

The adequacy of flowage paths downstream from Swamp Lake will be assessed during the initial month of operation of the Green outlet. For example, if the flow data suggest an obstruction affecting either the Ivywood or the County Road 19 paths, then this would be further investigated. If necessary, further actions (e.g., beaver dam removal, private culvert replacement, etc.) would be recommended at that time.

APPENDIX E

INITIAL HYDRAULIC MONITORING RESULTS

INITIAL HYDRAULIC MONITORING RESULTS
CHISAGO LAKES OUTLET PROJECT

INTRODUCTION

The initial hydraulic monitoring plan was developed in 1986 on the premise that both the Lake Ellen and County Road 24 drop structures would begin operation under extremely high lake level conditions. However, when the Lake Ellen structure began operating on April 3, 1987, the elevation of Green Lake was 892.95, or more than one foot lower than the maximum level attained in 1986. And completion of the County Road 24 structure in the summer of 1987 came after the Chisago Chain of Lakes had retreated below the outlet weir elevation. As a result, no hydraulic monitoring was performed for the latter structure, and monitoring of the Lake Ellen outlet was somewhat limited. Outflow from Green Lake did afford the opportunity for substantial monitoring of downstream flows.

CONTROL GATE SETTINGS

Table E-1 documents the initial adjustment of the Lake Ellen outlet gate on April 3, 1987. It was decided that initial operation should be at 36 cubic feet per second (cfs), or one-half the design flowrate of 72 cfs. The final gate setting was 75 turns from fully closed. Information from the manufacturer indicates that a total of 576 turns would be required to open the gate fully. The setting remained at 75 turns throughout the period of flow. In the future, if Green Lake elevations significantly higher than 892.95 should occur, then the gate would need to be set at a smaller number of turns to achieve the same flowrate. The required setting would need to be found by trial, as done here initially, using actual discharge measurements. The same sort of procedure will also need to be followed in the future at the County Road 24 drop structure when significant flow occurs there.

RATING CURVES

Discharge rating curves based on hydraulic calculations were previously developed for the two drop structures. These curves have not been updated since at one structure no measurements were possible, while at the other only one or two measurements were made at regimes significantly below the initial setting.

DOWNSTREAM FLOWS

Table E-2 summarizes downstream flow measurements along with elevations of Green Lake for April through mid-June 1987. It is apparent from the data that the major portion of the Lake Ellen outflow followed the pre-existing pathway to the culvert under County Road 19, due to established drainage patterns.

The Green Lake elevation data in Table E-2 confirm the design flowrate basis, which is a lake lowering rate of 2 inches per week. That lowering rate corresponds to design flowrates of 48 cfs from Chisago to Green Lake and 72 cfs out of Green Lake occurring simultaneously -- and thus to a net outflow rate from Green Lake of 24 cfs. The initial Green Lake outflow rate of 36 cfs then corresponds to a lowering rate of 3 inches per week. The actual elevation change from April 3 to May 4 was 1.19 feet, or 14.3 inches, which implies an average lowering rate of 3.2 inches per week.

TABLE E-1

INITIAL ADJUSTMENT OF LAKE ELLEN OUTLET

APRIL 3, 1987

Time	Outlet Gate Setting (turns from fully closed)	Discharge (cubic feet per second)
10:05	100	41.1
11:00	80	32.6
12:00	88	42.4
14:45	88	45.2*
16:30	75	38.7

*Cleaned out trash rack at end of outlet pipe

NOTE: Green Lake Elevation 892.95.

TABLE E-2

DOWNSTREAM FLOWS AND GREEN LAKE LEVELS

Date	Discharge in Cubic Feet per Second				Green Lake Elevation
	L. Ellen Outlet	Co. Rd. 80	Ivywood Tr.	Co. Rd. 19	
3/31/87	--	--	--	4.04 (11:45)*	--
4/03/87	38.7 (16:30)	0.79 (17:00)	<0.1 (--)	--	892.95 (--)
4/04/87	43.6 (9:45)	2.51 (11:45)	<0.1 (--)	--	--
4/06/87	39.9 (8:45)	18.5 (10:00)	<0.1 (--)	2.92 (11:15)	892.82
4/07/87	37.7 (8:45)	--	<0.1 (--)	3.80 (11:00)	--
4/08/87	37.3 (9:40)	30.6 (11:30)	0.03 (13:00)	8.81 (13:30)	892.71 (--)
4/10/87	40.7 (8:30)	37.7 (9:45)	0.36 (10:30)	21.7 (11:00)	892.68 (7:45)
4/13/87	36.1 (8:45)	38.4 (9:45)	0.72 (10:45)	30.4 (11:45)	892.57 (8:15)
4/20/87	34.7 (9:30)	35.5 (10:15)	0.62 (11:15)	29.1 (12:00)	892.32 (--)
4/27/87	34.4 (9:00)	36.3 (10:00)	0.72 (10:45)	26.9 (11:45)	891.98 (8:00)
5/04/87	35.9 (9:30)	--	0.71 (11:00)	36.3 (11:50)	891.76 (9:00)
5/18/87	31.7 (9:30)	35.4 (10:30)	0.44 (11:30)	28.7 (12:00)	891.16 (9:15)
6/01/87	6.29 (10:00)	9.76 (11:00)	0.32 (12:00)	10.5 (12:45)	891.00 (9:30)
6/15/87	0.14 (--)	1.49 (--)	0.11 (--)	4.68 (--)	890.79 (--)

*Time in parentheses.

NOTE: DNR's Green Lake level gage in Chisago City has datum (zero) of 883.44 (per County Surveyor, April 7, 1987).