# APPENDIX F

## Probable Maximum Flood Study
## Mississippi River at
## Prairie Island, Minnesota

Incorporated into Updated Safety Analysis Report
Revision 4 12/85

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# APPENDIX F

## INTRODUCTION AND SUMMARY DESCRIPTION

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# CHAPTER I - INTRODUCTION

## Scope

This report describes the determination of the probable maximum flood level on the Mississippi River at the proposed Prairie Island Nuclear Generating Plant. The proposed site of the plant is on the line between sections 4 and 5 T. 11 N., R. 15 W. in Goodhue County, Minnesota. It is on the right bank of the Mississippi River, at the outlet of Sturgeon Lake, and about one mile upstream of Lock and Dam No. 3 and about 28 miles southeast of the Twin Cities of Minneapolis and St. Paul

The study area for the probable maximum flood includes the entire Mississippi River drainage above the plant site; about 45,000 square miles. Included in the drainage area are the Mississippi River and two major tributaries, the St. Croix River and the Minnesota River. The drainage area extends into parts of four states: South Dakota, Wisconsin, Minnesota, and Iowa.

## Definition

The term “probable maximum flood,” as used herein, is the hypothetical flood that would result if all the factors that contribute to the generation of the flood were to reach their most critical values that could occur concurrently. The probable maximum flood is derived from hydrometeorological studies and is independent of historical flood frequencies. It is the estimate of the boundary between possible floods and impossible floods. Therefore, it would have a return period approaching infinity and a probability of occurrence, in any particular year, approaching zero.

## Authorization

Authorization to conduct this study was given by the Northern States Power Company, Minneapolis, Minnesota, by contract signed February 19, 1968.

## Data

Data used in the study included U.S. Geological Survey maps and publications on water supply and floods in the study area, U.S. Army Corps of Engineers reports on river hydraulics and storm data, U.S. Weather Bureau reports and technical papers on meteorological data and Technical Bulletins of the University of Minnesota Agricultural Experiment Station on the climate of Minnesota. In addition, soil maps of the basin were obtained from the U.S. Department of Agriculture.

**Investigations**

Determination of the probable maximum flood included studies of the probable maximum precipitation for both spring and summer storms, infiltration rates for various soil conditions, snowfall and snow cover, and historical temperature sequences and snowmelt rates. Unit hydrographs were developed and studies of flood runoff were made for each of the sub-basins comprising the drainage area above the project site.

Relationships of flood discharge to water level were developed for the plant site and used to determine the maximum water level resulting from the passing of the probable maximum flood.

**Report**

A general description of the climate and hydrology of the study area is presented. Specific references are made to historical events which relate to the determination of the probable maximum flood.

Detailed descriptions of the study procedures are discussed. including the maximization of storms, determination of unit hydrographs and infiltration rates, flood routing techniques and development of stage-discharge relationships.

Comparisons of computed and historical hydrological and climatological events are presented as an indication of the degree of reasonable maximization over recorded events.

Exhibits have been prepared showing the study basin, storm isohyets, unit hydrographs for each of the sub-basins, depth-duration curves for the summer and spring storms, the maximum probable flood hydrograph, the stage-discharge relationship, and channel cross-sections at the plant site and 10 miles downstream.

**Acknowledgements**

The assistance of the administrators and engineers of the Northern States Power Company is gratefully acknowledged. Their cooperation and provision of materials used in the study were very helpful.

The assistance of the U.S. Army Corps of Engineers. the U.S. Weather Bureau and the U.S. Geological Survey, who provided valuable hydrological and meteorological information, is greatly appreciated.

Principal participants of the consulting engineering staff were:

| | |
|---|---|
| Project Sponsor | A. P. Guess |
| Chief Hydrologist | R. W. Revell |
| Project Manager | H. E. Schoeller |
| Hydrometeorologist | D. W. Fonken |
| Planning Engineer | L. L. Wang |

The report was reviewed by Dr. R. A. Clark, Professor in the Department of Meteorology, College of Geo-Sciences, Texas A and M University, as a consultant to Harza Engineering Company.

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# CHAPTER II - CLIMATE AND HYDROLOGY OF THE STUDY AREA

## General

Data were taken from reports and technical papers to describe the general climatic and hydrologic conditions of the basin. In particular, the degree of variance from normal conditions of climatic events was studied to determine the range of expected values under reasonable but very rare conditions.

## Reference Data

U.S. Geological Survey maps of the basin at a scale of 1 to 250,000 were obtained from the client. Special purpose maps were also available tn many of the reports on the climate and hydrology of the basin.

Technical bulletins on the “Climate of Minnesota”, published by the University of Minnesota, Agricultural Experiment Station, used extensively in describing the climate of the basin.

## The Study Area

The Mississippi River basin above the plant site has a area of approximately 45,000 square miles and occupies parts of four states; Minnesota, Wisconsin, South Dakota and Iowa. The largest portion of the basin, about 85 percent, lies in Central and Southern Minnesota.

The topography of the basin is characterized by level to rolling prairie land interspersed with areas of glacial moraines whose hills rise from 50 to 300 feet above the surrounding land.

Variations of elevations in the basin are slight; the elevation at the project site is about 680 feet above mean sea level, while the highest elevation in the basin reaches about 2100 feet. The average elevation of the basin is about 1200 feet.

Most of the basin is covered with glacial deposits and the land surface consists of features derived from the several different ice sheets that advanced and then retreated from the area. The principal feature, from the hydrological standpoint, is the numerous lakes that were formed in the surface depressions created by the movement of ice. As the ice retreated, depressions were left which filled with water to form lakes. The streamflow characteristics of the Mississippi and of all its chief tributaries are largely determined by the natural storage provided by these lakes and the many swamps.

## Climate

The study area lies within a zone of marked continental climate characterized by wide and rapid variations in temperature, moderate winter precipitation and usually ample summer rainfall. It has a tendency to extremes in all climatic features although this is moderated somewhat by the large number of bodies of water in the area.

Atmospheric moisture mainly flows into the region along two water vapor streams: a strong southerly flow from the Gulf of Mexico and a comparatively diffuse westerly movement from the Pacific Ocean. Of the two, Gulf moisture is the more important, accounting for most of the precipitation in the study area. During the months when the southerly winds reach Minnesota, May through September, about 65 percent of the annual rainfall is recorded. Because these air masses must travel 1200 to 1500 miles before reaching Minnesota, minor wind changes can account for large variations from normal precipitation.

## Precipitation

Annual normal precipitation over the study area varies from about 30 inches in the southeast to about 20 inches in the northwest. Extremes of annual precipitation recorded at Minneapolis - St. Paul range from 49.7 inches to 10.2 inches. Monthly normal precipitation varies across the study area but reaches a high of about 5.5 inches in June near the center of the area. Minimum normal monthly precipitation is about one-half inch in January and December in the western part of the area. During the 30-year normal period (1931-60) the highest monthly precipitation recorded in the study area was 15.0 inches at Malaca in June. Zero precipitation was recorded at many stations in the area during the normal period. The maximum 24-hour precipitation recorded within the study area was 8.07 inches at Marshall in July 1909.

## Snow

Most winter precipitation occurs as snow, which is stored on the ground until the spring thaw. Normal annual snowfall in the study area varies from about 40 inches in the southwest and west to about 60 inches in the northeast. A maximum annual fall of 107 inches was recorded about one hundred miles to the northeast of the study area, in Cook County, Minnesota. Accumulations of three to four feet of snow within the study area are not unusual. Runoff is most affected by snow conditions. Gradual melting of snow on unfrozen ground may result in much moisture entering the soil and subsoil, but sudden thaws in the spring may cause rapid runoff of the entire winter accumulation of snow, especially with deep frost penetration.

**Temperature**

The study area, lying within the heart of the North American land mass, displays a typically continental climate. It has great extremes in temperature, not only from season to season and month to month, but on a diurnal basis as well. The only nearby water body of sufficient size to modify climate on more than an extremely localized basis is Lake Superior. However, its influence on the study area is restricted essentially to confines of the shoreline due essentially to prevailing westerly winds and also to the abrupt rise of the land from the lakeshore.

Normal average daily temperatures at St. Cloud, which is nearly at the center of the basin, ranged from about 10°F in late January to about 72°F in late July. Normal maximum and minimum daily temperatures for the same station are about 20°F and O°F in January and about 83°F and 59°F in July.

Normal temperatures over the basin for each season of the year are as follows:

| Season | South | North |
|---|---|---|
| Winter (December, January and February) | 18°F | 7°F |
| Spring (March, April and May) | 45°F | 37°F |
| Summer (June, July and August) | 71°F | 64°F |
| Fall (September, October and November) | 49°F | 42°F |

The great extremes of temperature in the basin are apparent from the absolute range of l73°F that has been recorded. The extreme maximum temperature recorded during the total record period was 114°F in July while the extreme minimum recorded was -59°F in January. Extreme maximum and minimum temperatures for each month of the year from St. Cloud, which is centrally located in the basin are shown below. Temperatures given are in degrees Fahrenheit.

| | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Extreme Maximum | 55 | 58 | 81 | 91 | 105 | 102 | 107 | 105 | 106 | 90 | 71 | 63 |
| Extreme Minimum | -42 | -35 | -32 | 2 | 18 | 33 | 41 | 34 | 18 | 6 | -23 | -32 |

**Wind**

Prevailing winds are from the northwest during the winter and early spring, and from the southeast during the summer and latter part of spring. Monthly mean wind speeds vary slightly over the basin. Annual averages are from about 10 to 13 miles per hour with mean monthly variations from about 9 to 15 miles per hour. The highest monthly mean winds are attained in April.

**Hydrology**

The study area is comprised of three major rivers; the Minnesota, St. Croix, and Upper Mississippi, and numerous tributaries. The headwaters of the Mississippi River form the northern boundary of the basin while the Minnesota and St. Croix River Basins form the southwestern and southeastern boundaries. The Minnesota River joins the Mississippi at St. Paul about 45 miles above the project site and the St. Croix enters the Mississippi about 33 miles farther downstream.

**Annual Runoff**

The annual runoff from the rivers and streams throughout the basin is directly affected by the amount of lake or swamp area as evaporation losses reduce the yield. Annual runoff for the basin is approximately 3.9 inches with a range in mean annual runoff from 0.4 to 15.4 inches for smaller watersheds in the basin.

**Floods**

Two types of flooding occur in the basin--open-water flooding and backwater flooding. Flooding while open-water conditions prevail is caused by runoff producing rains, or by melting snow, or by a combination of the two. Flooding because of backwater is usually caused by ice jams. The most serious flooding throughout the basin has been associated with excessive snowmelt and rainfall. Major floods in the main streams occur on the average two to three years out of ten. The time of occurrence of floods shows the greatest frequency in April during the spring thaw. A second peak occurs in June due to thunderstorm type rains. A smaller peak occurs in the fall. Local flash floods occur in the smaller streams in the spring thaw and also in the warmer season from intensive rainfall.

The maximum flood of record (1928-1967) on the Mississippi River at Prescott, Minnesota was 228,000 cubic feet per second (Elev. 693.1 feet) on April 18, 1965. Records for the station at St. Paul indicate that this was probably the maximum flood since 1851. This flood which established record high stages at many stations in the Upper Mississippi Basin resulted from a severe winter and a combination of climatic events that led to a deep snow cover on top of an ice layer. Moderate to heavy rainfall and a return to normal temperatures during April produced rapid melting and extremely high runoff.

## CHAPTER III - PROBABLE MAXIMUM FLOOD DETERMINATION

The probable maximum flood at the proposed plant site was determined by transposing an actual critical spring storm to the drainage basin and maximizing the precipitation for potential moisture. Potential snow cover and a critical temperature sequence were developed for determining snowmelt contribution to flood runoff. Flood runoff at the plant site was determined by developing unit hydrographs for 16 sub-basins, applying rainfall and snowmelt excesses to the unit hydrographs and routing the resultant hydrographs for the sub-basins to the project site.

A probable maximum summer storm over the project area was also studied in detail and the resulting flood at the project site determined. Although the summer storm was much larger than the spring storm, the much lower retention rates under ordinary spring conditions and the snowmelt contribution to runoff resulted in the spring storm producing the more critical flood. Exhibit 1 shows the general location of the study area.

### Probable Maximum Storm

A probable maximum spring storm and a probable maximum summer storm were determined by transposing and maximizing actual recorded storms.

The storms selected were the March 23-27, 1913 storm centered at Bellefontaine, Ohio, (OR1-15, U.S. Army Corps of Engineers, "Storm Rainfall in the United States") and the August 28-31,1941 storm centered at Hayward, Wisconsin, (UMV 1-12). These storms represent near maximum conditions of meteorological events for spring and summer conditions.

Maximization of these storms involved multiplying the observed rainfall values by the ratios of the maximum perceptible water in an air column over the study area to the observed perceptible water in an air column for the actual storm. Under the assumption of a saturated pseudoadiabatic atmosphere, the amount of moisture is a unique function of the ground elevation and surface dewpoint. Perceptible water was thus determined from the inflow barriers to the storm centers and observed and maximum persisting l2-hour dewpoints. Persisting 12-hour dewpoints for the actual storm were obtained from U.S. Weather Bureau data. In accordance with frontal theory, the storm dewpoints were measured in the warm air rather than at the point of rainfall. Maximum persisting 12-hour dewpoints for the study area were taken from <u>The National Atlas of the United States,</u> "Maximum Persisting 12-Hour 1000-MB Dewpoints (°F), Monthly and of Record." For the transposed storms the maximum persisting 12-hour dewpoints were taken from the atlas at a point equally distant from the center of the study area as the point at which the observed dewpoints were from the recorded storm centers. The distances were measured in a direction into the general path of air flow from the Gulf of Mexico.

The original observed storm patterns were superimposed over the study area and the weighted average precipitation over each sub-basin determined by planimetering the areas between isohyetal lines. The precipitation was then adjusted for maximum moisture charge in accordance with the above criteria. Superposition of the observed storm patterns over the study area is justified because the areas are meteorologically homogeneous and no major orographic differences exist between the study area and the observed storm areas. Rotation of the transposed storm patterns was limited to 20 degrees from the observed storm.

The depth-duration relationships for 50,000 square miles from the recorded storms was used to determine rainfall increments for each sub-basin. The rainfall increments were then arranged into a sequence considered to be the most critical that could reasonably occur. The depth-duration curves for the spring and summer storms are shown on Exhibits 4 and 5. Exhibits 2 and 3 show the transposed isohyetal patterns and the maximized precipitation for each storm.

Following the determination of the flood resulting from the spring storm, the isohyetal pattern was reoriented over the study area to find the most critical rainfall pattern. Although an infinite number of orientations is possible, the effect on the resulting flood was found to become negligible with additional orientations.

**Snow Cover**

Snow cover over the basin was taken from the U.S. Weather Bureau, Technical Paper No. 50, Frequency of Maximum Water Equivalent of March Snow Cover in North Central United States.” For the purpose of the maximum probable flood study, maximum water equivalent (inches) for March 16-31 having 1 percent probability was used. Lines of equal snow cover, taken from the report, were superimposed over the basin and the weighted average snow cover for each sub-basin determined by planimetering. Exhibit 6 shows the assumed basin snow cover.

**Temperature Sequence**

For purposes of snowmelt computations, it was necessary to determine a critical temperature sequence that could reasonably be expected to occur while the snow cover was at a maximum. Weather records for the Minneapolis station offered the longest record of observed temperatures centrally located in the basin (54 years) and this record was used to determine a critical temperature sequence. As a large percentage of the total snow cover could be melted in about five days the maximum historical five-day mean daily temperature sequence occurring from April 1 to 15 was selected. This was the period April 2-6, 1921. It was assumed that this temperature sequence could occur at any time between April 1 and April 15 and that it could occur following a period of extremely cold weather such that the snow cover would be at a maximum.

Since temperatures vary considerably over the basin, several stations located throughout the basin were selected and the observed April 2-6, 1921, temperature sequence recorded. These temperatures were assumed to be representative of the sub-basin which they were nearest and were used in the snowmelt computations. Table 1 shows the record five-day temperature sequence used for each sub-basin. Temperatures subsequent to the maximum five-day sequence were assumed to be the same as those recorded in 1921.

**Snowmelt**

Snowmelt for the probable maximum flood study was computed using methods developed by the U.S. Army Corps of Engineers and described in their Manual EM 1110-2-1406, 5 January 1960, “Runoff from Snowmelt.” These methods utilize basic data on temperature, precipitation, wind velocities, insolation, snow albedo, basin exposure and canopy cover, and a convection-condensation melt factor which represents the mean exposure of the basin to wind. Average monthly values of insolation and wind velocity were determined from Minnesota weather records for use in the computations. Insolation of 450 langleys was used throughout while average wind velocities were determined to be 12 miles per hour for the snowmelt period preceding precipitation and 20 miles per hour during precipitation. Snow surface albedo was assumed to be 45 percent at the start of the melting period. Basin exposure was assumed to be high due to the lack of large topographic variations and basin canopy cover was determined for each sub-basin by estimating the percentage of forested area from maps showing forest cover. A mean relative humidity of 70 percent was used for converting air temperatures to dewpoint temperatures during the days of high insolation melt.

**Infiltration and Retention**

Infiltration and initial retention losses were assumed to be extremely low at the start of the runoff period. Documented flood events in the Upper Mississippi Basin indicate that it is not unusual to have very high runoff in the early spring due to surface conditions at this time of year. Commonly, early warm spells will cause melting of a light snow cover with the free water percolating through the soil to fill surface voids and depressions. This is often followed by the return of freezing temperatures that cause ice to form over the ground surface, and a heavy snowpack accumulation. If these conditions are followed by an extremely warm period and rainfall there is almost no loss of free water and runoff is maximized. Since records of frost depth indicate that three to five feet of frozen ground at the end of March are not unusual, retention rates are not likely to increase significantly for some time after melting starts. Initial retention was assumed to be zero in this study and other losses were assumed to be 0.02 inches per hour during the snowmelt period and 0.03 inches per hour during the period following the beginning of rainfall.

**Runoff Sequence**

The most critical sequence of events leading to a major flood would be to have an unusually heavy spring snowfall and low temperatures after a period of intermittent warm spells and sub-freezing temperatures has formed an impervious ground surface and then a period of extremely high temperatures followed by a major storm. This sequence of events is not unusual in the study area and the maximization of rainfall, snow-cover, and temperature would produce a probable maximum flood.

For the purpose of this study, antecedent conditions were assumed to be such that extremely high runoff rates would result from snow melt and precipitation. Snow, water equivalent having a 1 percent probability, was assumed to cover the study area on March 31. On April 1, the maximum historical temperature sequence was started. By the fifth day the high temperatures were below the dewpoint temperatures of the storm and the probable maximum spring precipitation was assumed to begin April 5. Temperatures for the period following the maximum five-day sequence were assumed to be the same as those recorded for the April 7-16, 1921, period.

**Unit Hydrographs**

The study area was divided into 16 sub-basins and unit hydrographs were developed for each, using synthetic methods. Snyder's method, which related basin characteristics to hydrograph shape and peak was used for a first approximation. Computed coefficients of basin lag and unit hydrograph peak were then compared with coefficients for other unit hydrographs for basins in the study area, computed from recorded flood events. Because of the large number of lakes and swamps, basin lag times are considerably longer than other topographic features would indicate. Coefficients of basin lag were, therefore, taken as the average of the coefficients computed from the recorded floods. Unit hydrograph peaks were also increased by 25 percent and basin lag decreased by one-sixth, in accordance with standard Corps of Engineer practice. Exhibit 7 shows the unit hydrographs for each sub-basin.

**Flood Routing**

Snowmelt and rainfall excesses were applied to unit hydrographs and the resulting hydrographs determined for each sub-basin. Sub-basin hydrographs were then routed to the project site, using the modified Wilson method. Hydrograph computation and flood routings were done by computer program. Travel times for flood routing were taken from recorded travel times for large floods. Base flow was then added to the total of the routed hydrographs. Base flow was determined from long-term records of streamflow for nearby stations. The resultant probable maximum flood hydrograph at the project site is shown on Exhibit 8.

## Stage-Discharge Relation

### Determination of Stage

The peak elevation of the probable maximum flood was determined from a stage-discharge relationship developed for the site. The method used was an extension on logarithmic coordinates of the known rating curves for the U.S. Geological Survey Prescott and Winona gages and for the Corps of Engineers headwater gage at Lock and Dam No. 3. The stage scale of these three ratings was adjusted to give approximately a straight line on logarithmic coordinates, which is standard practice for logarithmic rating curves. The curves were then extended as a straight line to the discharge of the probable maximum flood. The stage-discharge relationship at the project site was determined by interpolation between the Prescott and the Lock and Dam No. 3 curves. Exhibit 9 shows the rating curve for the project site plotted to a more convenient stage scale, which accounts for its not being a straight line. This curve indicates a stage of 703.5 feet MSL (1912 adjustment) for the probable maximum flood of 963,000 cubic feet per second.

The various locks and dams along the river have a negligible effect on the stage of a major flood. With all gates open the fall through the dam is generally less than a foot and for the probable maximum flood the embankments at the dams would be submerged. The effect of the dams also is reflected in the river slopes used in the computations.

### Verification of Procedure

Experience of the U.S. Geological Survey and many other organizations has shown that a logarithmic rating curve with the stage scale adjusted to approximate a straight line can be extended a considerable amount with good accuracy if there is no significant change in the downstream channel conditions for the increased flow. These downstream channel conditions were carefully examined before extending the rating curve.

The first step was to plot two water surface profiles, one for 200,000 cubic feet per second and one for 30,000 cubic feet per second, based on the three previously mentioned rating curves. Actually a 10 percent greater flow was used at Winona in plotting the profiles because of the greater drainage area.

Both profiles were close to straight lines, with the slope downstream from Lock and Dam No. 3 being slightly greater than upstream. River valley widths then were measured at 9 cross sections extending from the Prescott gage to Alma, the latter being about 46.5 miles downstream from Prairie Island. The elevation at each cross section for a flow of 200,000 cubic feet per second was estimated from the profile and the valley width at that elevation determined from topographic maps. The average width downstream from Lock and Dam No. 3, which is about one and a half miles downstream from the Prairie Island site, was essentially the same as the average width upstream. The spacing and lift of the various locks in the reach of river under consideration were checked and found to indicate no large variation in river slope.

There are reaches of river shown on maps as lakes. The channel conveyance in these reaches is higher than average. However, it was found that these reaches also had substantially narrower overbank areas so that the variation in total conveyance for a major flood would be greatly reduced.

A flow of 800,000 cubic feet per second was selected solely for the purpose of extending the rating curve by Manning's formula computations. An average value of Manning's "n" of 0. 035 was selected for a flow of 200,000 cubic feet per second, including both channel and overbanks flow. From the average measured width at that flow, weighted for the length of reach represented by each measured width, and known slope and estimated "n" value, the average hydraulic radius was computed. The additional weighted average width for a flow of 800,000 cubic feet per second was determined from topographic maps and estimated stage. An "n" value of 0.045 was selected for the part of the cross-section represented by this additional width. By a process of approximation, different incremental stages were tried until the stage was found that gave the required conveyance for the average river conditions downstream from Prairie Island. When plotted on the Prairie Island extended logarithmic rating curve, this point was found to be on the extended curve. Therefore, it was considered that these computations verified the extended rating curve. The curve then was extended a little farther to the discharge of the probable maximum flood and the corresponding stage read from the curve.

It is not possible to make an exact determination of stage for the probable maximum flood. It is believed, however, that the accuracy of the determination is comparable to the accuracy of the determination of the flood discharge.

**Valley Cross Sections**

The stage-discharge relation for a point on a large river of flat slope, such as in this case, is determined by the channel conditions over a considerable distance downstream. The channel at the site affects the stage-discharge relation only to the extent that it is representative of downstream conditions.

As an independent indication of the stage at the project site that would result from the probable maximum flood, we made additional peak stage studies based on single cross-sections and observed average river slopes.

Our earlier computations were based on maps having 20-foot contour intervals with occasional intermediate spot elevations. At a later date a detailed cross section was surveyed at the project site. This is shown on Exhibit 10 and is based on a field survey made by John W. Gorman, Inc., of Minneapolis, Minnesota. Computations based on the detailed cross-section gave a one-foot lower peak stage for the probable maximum flood than did computations based on the 20-foot contour map at the same cross section. Although this is not conclusive, it is a good indication that stages based on 20-foot contour maps are not too low.

Four determinations of peak stage based on individual cross-sections were made for the peak discharge of 963,000 cubic feet per second. Three were based on the cross-section at the project using different roughness factors and slopes and the other was based on topographic map data at a cross section at River Mile 788.3 a short distance downstream of Red Wing, Minnesota, and about 10 miles downstream from the project site.

The flood plain is wider at the project site than its average width downstream from the project. Therefore, the computed peak stages were substantially lower than the 703.5 feet computed earlier. The cross-section near Red Wing, shown on Exhibit 11, is believed to be much more representative of average channel conditions downstream of the project, during flood stages, than is the cross-section at the project site. Computations at this cross-section, used Manning's “n” values of 0.030 and 0.050 for the channel and overbank areas, respectively. This main channel value is believed to be conservative. The average slope between Lock and Dam No. 3 and Winona was used. These computations, when adjusted for the fall between the project site and the cross-section, gave a peak stage of 702.0 feet M.S.L. (1912 adjustment) at the project site. This is 1.5 feet lower than the 1.5 feet initially computed.

The originally computed peak stage was based on nine valley widths measured from maps and on known ratings for up to about 200,000 cubic feet per second. It is believed to be more accurate than the peak stages based on single cross sections. The latter values were all below 703.5 feet and tend to confirm that this peak stage is adequately conservative.

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# CHAPTER IV - STAGE DETERMINATION

## Introduction

Supplemental information for the probable maximum flood study at the Prairie Island Nuclear Generating Station, Minnesota, is being supplied in response to requests made by the Atomic Energy Commission, Division of Reactor Licensing, and the United States Geological Survey. Computations for the probable maximum flood study were made by Harza Engineering Company. Field surveys were conducted by Northern States Power Company.

Specifically, the request was to determine Manning's roughness factors that would produce a reasonable reconstruction of historical flood profiles and then use these roughness factors as a guide for the probable maximum flood for depths up to the tops of trees. Substantially lower "n" values are permissible above the tops of trees. However, in this study, no adjustments were made to Manning's roughness factors above the tops of trees, owing to lack of conclusive data on tree height. It is certain, however, that a significant percentage of the trees would be overtopped in the probable maximum flood.

The "n" values referred to herein are roughness factors in the Manning's Equation for open channel flow. Cross sections for the study were surveyed or scaled from two-foot and five-foot contour maps. Cross sections derived from maps were spot checked in the field except for the three closest to Winona.

Several factors seriously complicate the selection of "n" values the vicinity of the project site. These include:

1. Lock and Darn No. 3
2. Highway 63 fill and bridges
3. Multiple channels
4. Considerable channel curvature
5. Diagonal railroad embankment across the flood plain
6. Variations in vegetal cover in overbank areas
7. Natural levees along the main channel and tributaries crossing the flood plain
8. Questionable access of river water to parts of the overbank area
9. Lake Pepin (a 22-mile long lake)

**The Procedure**

The various obstructions were incorporated into the river cross sections with every effort being made to make this incorporation reasonable from the standpoint of hydraulics.

Historical flood profiles were reconstituted by backwater computations made by an IBM 1130 computer system using a program prepared by the Hydrologic Engineering Center, Corps of Engineers, Sacramento, California. The effective cross-sections were completely described to the computer and Manning's "n" values for overbanks and channels for each section were read in. The "n" values read in were those that gave a reasonable reproduction of historical flood profiles. Discharge and starting water surface elevations were read into the computer at the first section and the computer carried out computations of water surface elevation for each section in upstream order. Elevations at each succeeding upstream section were determined by the computer by multiplying the average of the slope at each end of the reach by the length of the reach.

**Cross Sections**

In reproducing the historical flood profiles, 5 surveyed cross sections at, and downstream of, Prairie Island were used. In addition to the surveyed cross sections, 9 cross sections were scaled from five-foot contour maps above Lake Pepin and 11 cross sections were scaled from two-foot contour maps below Lake Pepin. All cross sections other than the three farthest downstream were verified by field checks. Among the above scaled cross sections, 4 hypothetical cross sections were used to reproduce the effect of the various obstructions in the flood plain. In areas where hypothetical cross sections were used they were placed between actual cross sections so that they would only represent the modified portion of a given reach. The nearest actual cross sections then were assumed to be repeated at appropriate distances from the hypothetical cross sections so that the effect of the hypothetical cross sections would be hydraulically correct. For trapezoidal shaped obstructions, the nearest actual cross sections generally were repeated 50 feet upstream and downstream.

The plan of the cross sections is shown on Exhibit 12. The surveyed cross sections are shown on Exhibit 13.

**Length of Reaches**

For channels, the length of the reaches between cross sections was measured along the thalweg. For overbank areas, the perpendicular distance was used. No reduction was made for the probable maximum flood.

**Non-Conveyance Areas**

A very important key to the selection of “n” values that reproduced historical floods was the elimination from the cross section of areas that carried no flow during those historical floods. These areas, however, would have essentially full conveyance for the probable maximum flood because the structures that caused slack water during historical floods would be overtopped by many feet during the probable maximum flood.

There were two such non-conveyance areas upstream from Lake Pepin and two downstream from the lake.

The farthest upstream area was that resulting from the transverse part of the right overbank dike at Lock and Dam No. 3. This dike was not overtopped in any historical flood although only sandbagging prevented overtopping in the 1965 flood. Therefore, a length equal to the length of the transverse part of the dike was deducted from Section 15 a short distance downstream from the dam for historical floods. This section was repeated a short distance upstream from the dam but at that point only a small part of the cross section near the angle between the transverse and longitudinal part of the dike was excluded.

Conversations were held with Mr. Dick Buse of the Omaha District of the Corps of Engineers. That district has had extensive experience in determining overbank flow. They consider that downstream from an obstruction the flow expands one foot for each six feet in a downstream direction. For these studies a slightly greater expansion of 10° was assumed. On this basis, 0.42 miles of Section 12 to the left of where it crosses the new highway fill was found to be non-conveying and similarly 0.27 miles of Section 11 also was found to be non-conveying.

Similar adjustments were made below Lock and Dam No. 4 and Lock and Dam No. 5, downstream from Lake Pepin.

**Reconstitution of Historical Flood Profiles**

After making the adjustments for non-conveying areas, the historical floods were reconstituted very closely using the main channel and overbank “n” values shown in Table 2. The 1965 flood profile was reconstituted all the way from Winona to Prairie Island. The 1969 and 1952 flood profiles were reconstituted from the lower end of Lake Pepin to Prairie Island. No attempt was made to verify the 1969 and 1952 floods farther downstream.

At the three dams downstream from Lake Pepin, velocities over the spillways exceeded critical velocities in the 1965 flood. Therefore, the computer program could not carry the backwater curves through the dams. The historical flood profile, however, was reconstituted accurately between dams. For the probable maximum flood, the velocities over the spillways will be well below critical.

Historical and reconstituted flood profiles are shown on Exhibit 14. Computer printouts for the 1965, 1969, 1952 and the probable maximum floods are shown as Exhibits 15, 16, 17, and 18 respectively.

For the reconstitution of 1965 flood profile, the discharge at points between the Prescott and Winona gages was computed. The difference between Prescott flow plus measured inflow and the Winona flow was prorated between Prescott and Winona on the basis of river mile. All flows used in the computations were the flows on the day of peak discharge at Prairie Island.

**Determination of Probable Maximum Flood Profile**

The first step in the determination of the probable maximum flood profile was to make a downward adjustment to the magnitude of the probable maximum flood. This adjustment resulted from elimination of the increase in the peak of the various unit hydrographs for the probable maximum flood, as requested by Mr. Dwight Nunn of the Atomic Energy Commission. This reduced the peak from 963,000 cubic feet per second to 910,300 cubic feet per second.

The flow at various points along the river for the probable maximum flood is somewhat indeterminate. The storm that contributes to the probable maximum flood drops off rapidly in magnitude downstream from Prairie Island, and in fact is only four inches at Prairie Island. Since the downstream snowmelt would be too early to contribute to the peak, it would be reasonable to assume that the flattening of the flood peak would more than balance downstream inflow, at least as far as the mouth of the Chippewa River. This is the reach where the discharge has the greatest effect on Prairie Island stages. In the computations, however, a flow of 910,300 cubic feet per second was used throughout.

The starting elevation at Winona for the probable maximum flood backwater curves was determined by extrapolation of a logarithmic rating curve to be 674 feet M.S.L. (1912 adjustment). To test the significance of starting elevation, the backwater computations were repeated with five-foot higher starting elevation at Winona. The resulting difference was only 0.2 foot at Prairie Island. This indicates that the starting elevation at Winona is not critical.

Identical cross sections were used for the probable maximum flood as were used in reconstituting the historical floods except that no reductions in effective area were made because of upstream obstructions. These obstructions would have a negligible effect on downstream conveyance because they would be overtopped by many feet, generally, at least 20 feet.

In computing the probable maximum flood profile, the “n” values used were identical to those used in reconstituting the historical flood profiles, with the following exceptions:

1. At two cross sections 2B and 3 (River Mite 750.4 and 752.5) downstream from Lake Pepin, the large increase in overbank flooded area for the probable maximum flood is mostly cleared agricultural land. Therefore, conservative reductions of overbank “n”, from 0.085 to 0.075 for two sections were made. This reduction brings these sections into line with other sections below Lake Pepin.

2. At Section 12 (River Mile 791.3), 80 percent of the 0.42 miles in the cross section determined to be non-conveying for historical floods, as explained earlier, is in open water of Upper Lake. For the probable maximum flood, this part of the cross section would have a very low “n” value. Therefore, the composite “n” value for the entire overbank area was reduced from 0.125 to 0.100. This is considered to be a conservative reduction.

3. At Section 11 (River Mile 790.3), 70 percent of the 0.27 miles in the cross section determined to be non-conveying for historical floods is in open water of Upper Lake. Because of the smaller area involved, a smaller reduction in overbank “n”, from 0.075 to 0.065, was made. Considering the large amount of open water at this cross section. the reduction is believed to be conservative.

4. At Section 13 (River Mile 792.8), the high overbank “n” value, 0.125, is believed to be due to the downstream effect of the new and old highway crossings, which would be nearly eliminated for the probable maximum flood. Examination of the aerial photographs of the 1965 flood indicates that the “n” should be no higher than for Sections 14 and 15 (0.085). However, only part of this reduction, to 0.100, was made.

No reductions were made to any of the channel “n” values although a significant reduction would be reasonable.

The net result of the changes enumerated above, and also shown Table 1, was to produce a probable maximum flood elevation at Prairie Island of 704.1 feet M.S.L. (1912 adjustment). The profile for the probable maximum flood is shown on Exhibit 14,

The changes in “n” values that were made for the probable maximum flood are small and supported by sound hydrological logic. Further reductions in overbank “n” and significant reductions in channel “n” values could be supported. Therefore, the probable maximum flood level of 704.1 feet M.S.L. (1912 adjustment) is believed to be conservative.

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## CHAPTER V - CONCLUSION

The probable maximum flood at the project site was determined to be 910,300 cubic feet per second (cfs) and to have a corresponding peak stage of 704.1 feet M.S.L. (1912 adjustment). As explained on page IV-4, the 910,300 cfs represents a requested adjustment from the discharge shown in the probable maximum flood hydrograph (See Exhibit 8). The occurrence of the sequence of events, described in Chapter III, would cause the flood to reach its maximum level about 12 days after the beginning of high temperatures and would remain above a stage of 681.5 feet M.S.L. (1912 adjustment) for about 30 days.

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**TABLE 1 SUB-BASIN RECORD FIVE-DAY TEMPERATURE SEQUENCES**

| Sub Basin | Station | Mean Daily Temperature Sequence, °F | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1 | New Ulm | 57.5 | 63.5 | 69.5 | 64.5 | 53.5 |
| 2 | St. Peter | 56.5 | 63.5 | 71.5 | 69.5 | 59.5 |
| 3 | Brainard | 46.0 | 54.5 | 57.0 | 57.5 | 57.0 |
| 4-5-8 | St. Cloud | 48.5 | 54.0 | 69.0 | 62.0 | 57.5 |
| 6 | Pokagama | 40.5 | 53.5 | 54.0 | 54.0 | 53.5 |
| 7 | New London | 54.0 | 53.5 | 67.5 | 61.0 | 58.5 |
| 10 | Hinkley | 48.0 | 55.5 | 56.5 | 61.5 | 58.0 |
| 11-12a | Minneapolis | 56.0 | 66.0 | 71.5 | 67.0 | 59.5 |
| 13 | Grantsburg | 51.0 | 57.5 | 68.0 | 65.0 | 62.0 |
| Big Stone Lake | Morris | 52.5 | 59.5 | 62.5 | 62.5 | 54.5 |
| Lac Qui Parle - New Ulm | Montivideo | 53.0 | 64.5 | 69.0 | 56.5 | 57.5 |
| Blue Earth | Winnebago | 57.0 | 62.0 | 67.0 | 66.0 | 55.5 |

## TABLE 2 HYDRAULIC CROSS SECTIONS
## MISSISSIPPI RIVER
(Page 1 of 2)

| Section No. | River Mile | Description | Manning's "n" Values Overbank | Manning's "n" Values Channel | Remarks |
|---|---|---|---|---|---|
| 1 | 725.70 | Valley Cross Section at Winona | 0.075 | 0.030 | |
| | 727.30 | D. S. of Lock & Dam 5A | 0.075 | 0.030 | H. |
| | 728.22 | U. S. of Lock & Dam 5A | 0.075 | 0.030 | R. |
| | 730.60 | Valley Cross Section at Minnesota City | 0.075 | 0.030 | |
| | 738.10 | 50 feet D. S. of Lock & Dam 5 | 0.075 | 0.030 | H. |
| | 738.12 | 50 feet U. S. of Lock & Dam 5 | 0.075 | 0.020 | R. |
| 2 | 740.00 | Valley Cross Section at New Buffalo | 0.075 | 0.020 | |
| | 741.40 | Valley Cross Section at Minneiska | 0.075 | 0.030 | |
| 2B | 750.40 | Valley Cross Section at New Chute | 0.085 (0.075)* | 0.040 | |
| 3 | 752.50 | Valley Cross Section at Alma | 0.085 (0.075) | 0.030 | |
| | 753.60 | U. S. of Lock & Dam 4 | 0.075 | 0.025 | H. |
| | 756.50 | Valley Cross Section at Teepeeota Point | 0.075 | 0.030 | |
| 4 | 758.10 | Valley Cross Section at Wabasha | 0.075 | 0.030 | |
| | 760.20 | Wabasha Highway | 0.075 | 0.030 | |
| 5 | 764.60 | Valley Cross Section at Outlet of Lake Pepin | 0.075 | 0.030 | |
| | 766.50 | Valley Cross Section at the Lower end of Lake Pepin | 0.075 | 0.030 | |
| 6 | 771.00 | Valley Cross Section at Lake City | 0.075 | 0.030 | |
| 7 | 779.00 | Valley Cross Section at Lake Frontenac | 0.075 | 0.030 | |
| 8 | 784.80 | Valley Cross Section at Wacouta | 0.075 | 0.030 | |
| 9 | 787.10 | Valley Cross Section at Bay City | 0.075 | 0.030 | |
| 10 | 789.80 | Valley Cross Section at Power Line near Red Wing | 0.110 | 0.040 | S. |

## TABLE 2 HYDRAULIC CROSS SECTIONS MISSISSIPPI RIVER

(Page 2 of 2)

| Section No. | River Mile | Description | Manning's "n" Values Overbank | Manning's "n" Values Channel | Remarks |
|---|---|---|---|---|---|
| 11 | 790.30 | Valley Cross Section at Red Wing | 0.075 (0.065) | 0.040 | |
| 12 | 791.30 | Valley Cross Section near North Channel Bridge | 0.125 (0.100) | 0.030 | S. |
| 13 | 792.80 | Valley Cross Section North of Red Wing | 0.125 (0.100) | 0.040 | |
| 14 | 794.20 | Valley Cross Section at Trenton | 0.085 | 0.030 | S. |
| 15 | 796.40 | Valley Cross Section D. S. of Lock and Dam 3 | 0.085 | 0.030 | S. |
| | 796.90 | Lock & Dam 3 | 0.085 | 0.030 | H. |
| | 796.91 | Valley Cross Section U. S. of Lock and Dam 3 | 0.085 | 0.030 | R. |
| 16 | 798.30 | Valley Cross Section at Prairie Island | 0.075 | 0.030 | S. |

Legend

- * Values in parenthesis were used in PMF study
- S Survey Cross Section
- H Hypothetical Cross Section
- R Repeated Cross Section

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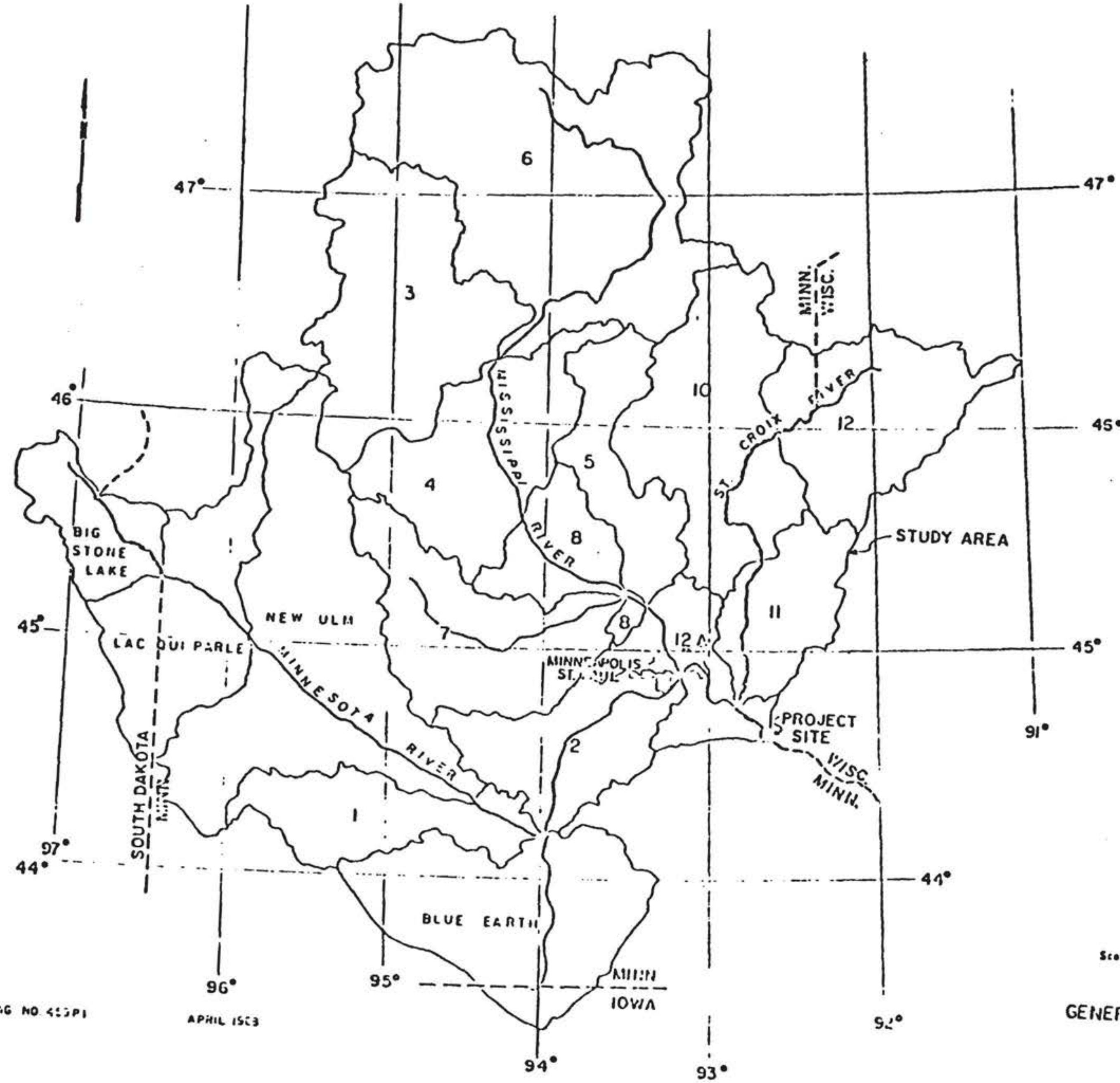
EXHIBIT I

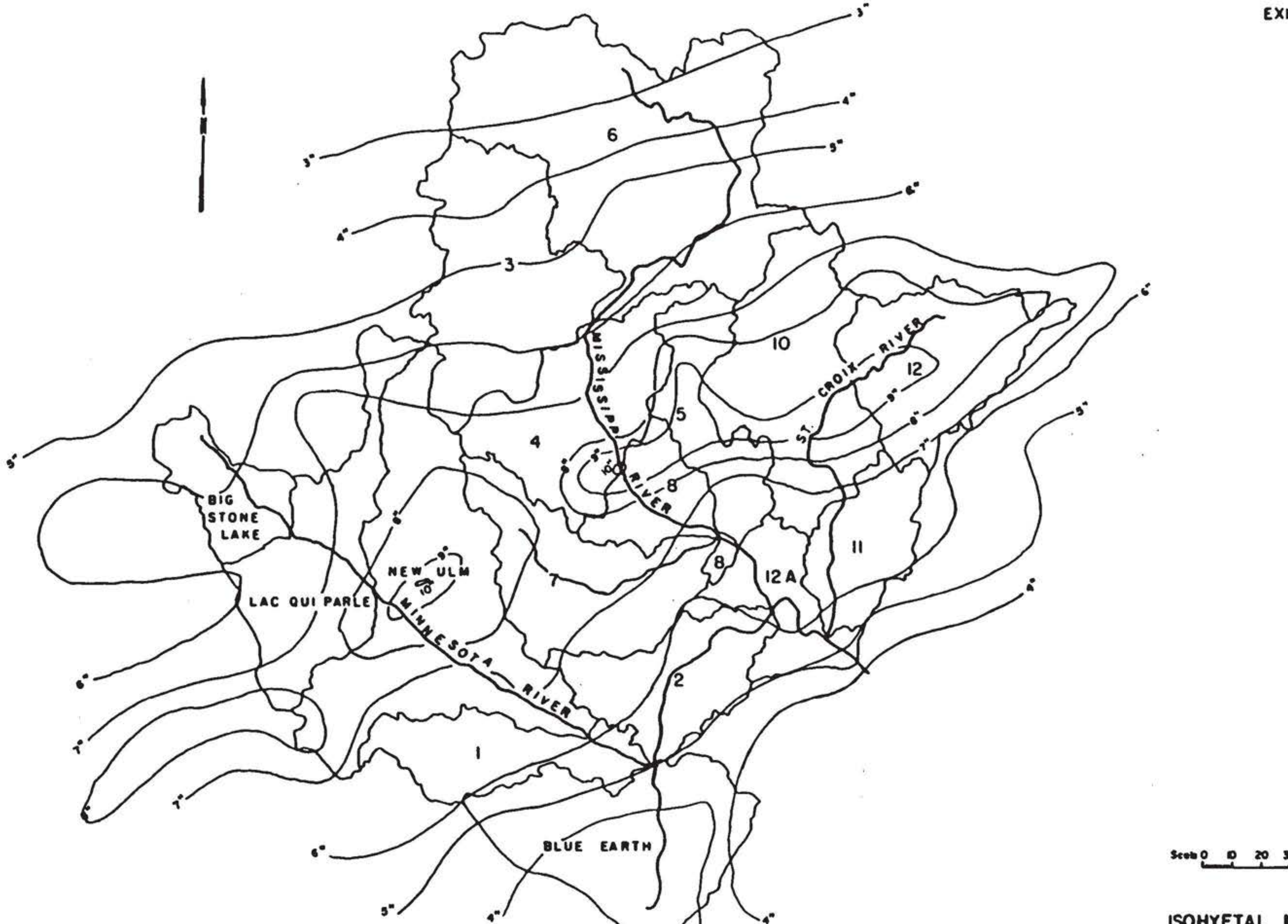



Scale 0 10 20 30 Miles

RZA ENGINEERING COMPANY DWG NO. 453P1

APRIL 1983

GENERAL LOCATION MAP

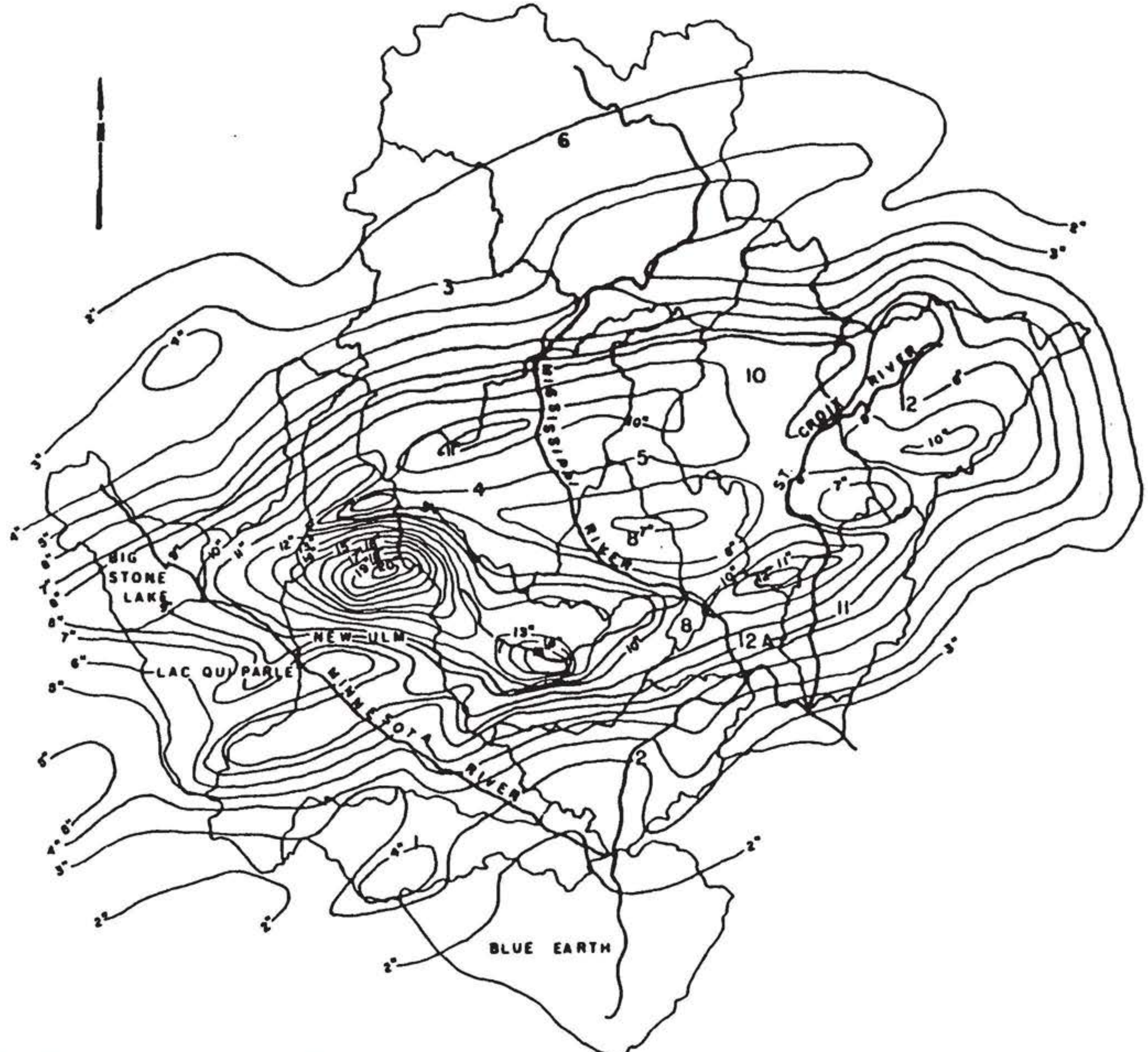



HARZA ENGINEERING COMPANY DWG. NO. 459 P 2

APRIL 1968

ISOHYETAL MAP
SPRING STORM
ORIENTATION I

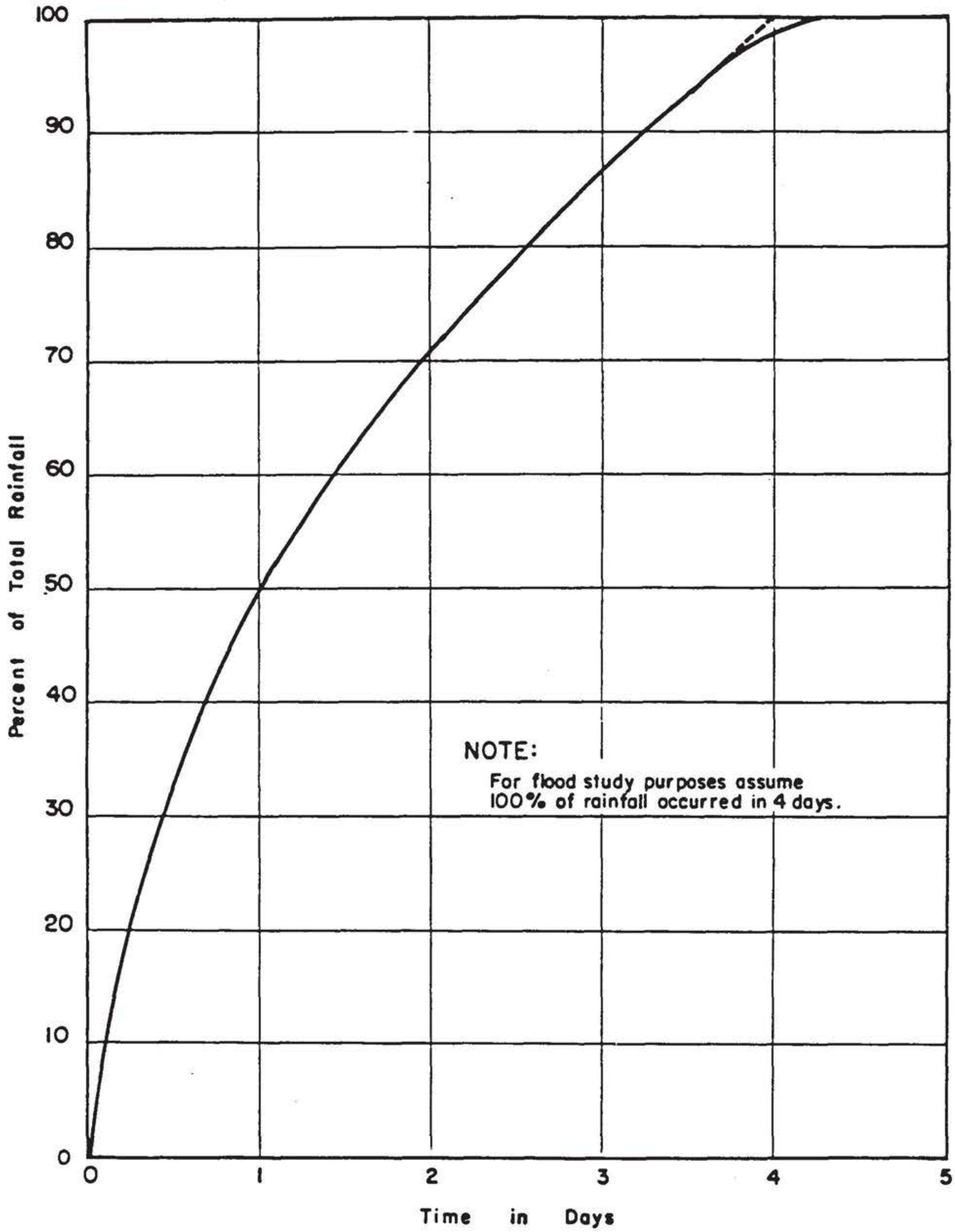
EXHIBIT 3




Scale 0 10 20 30 Miles

ISOHYETAL MAP
SUMMER STORM

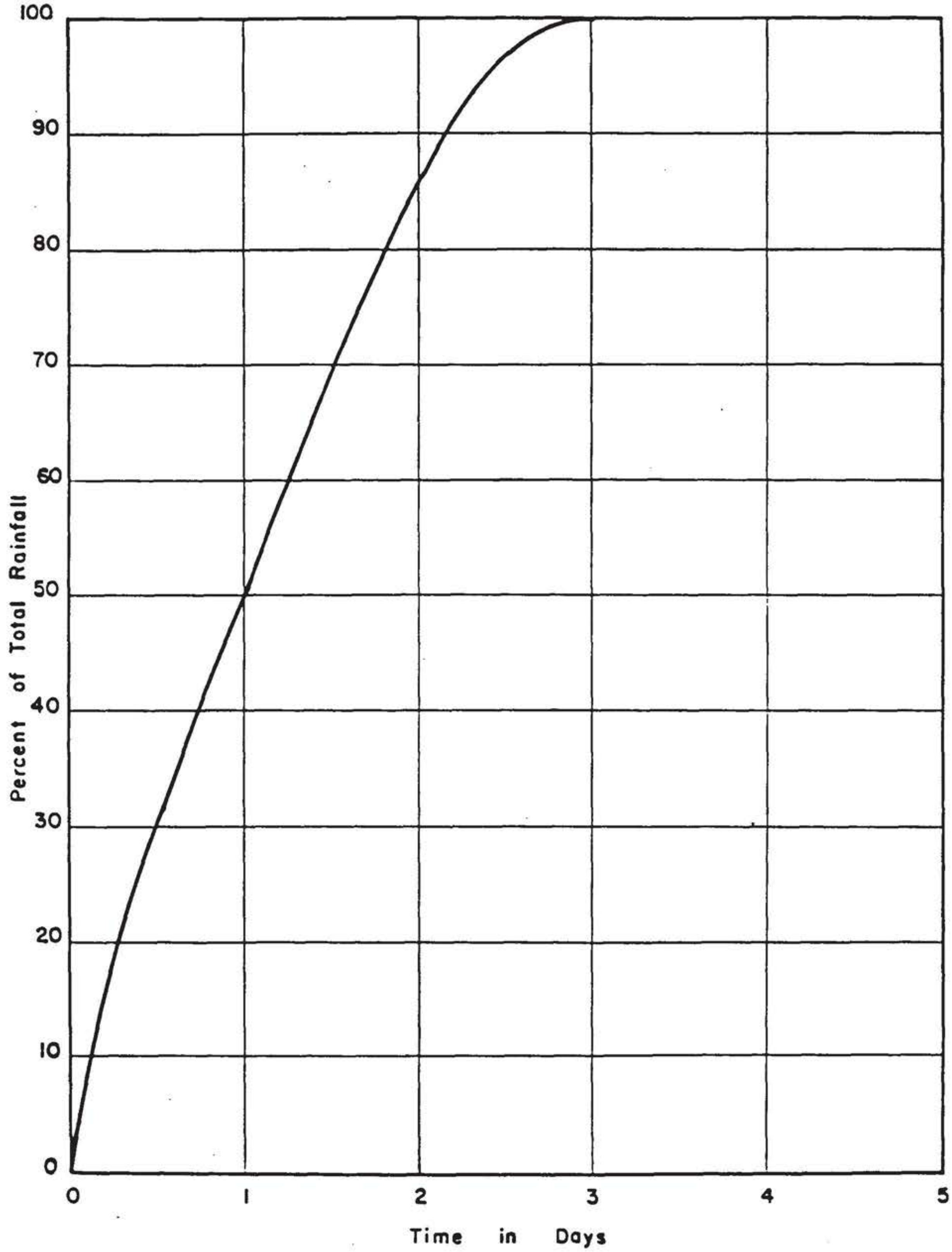
HARZA ENGINEERING COMPANY DWG NO. 459 P 3 APRIL 1968




DEPTH - DURATION CURVE
FOR 50,000 SQ. MI.
SPRING STORM OR I-15

HARZA ENGINEERING COMPANY DWG. NO. 459 P4 MAY 1968

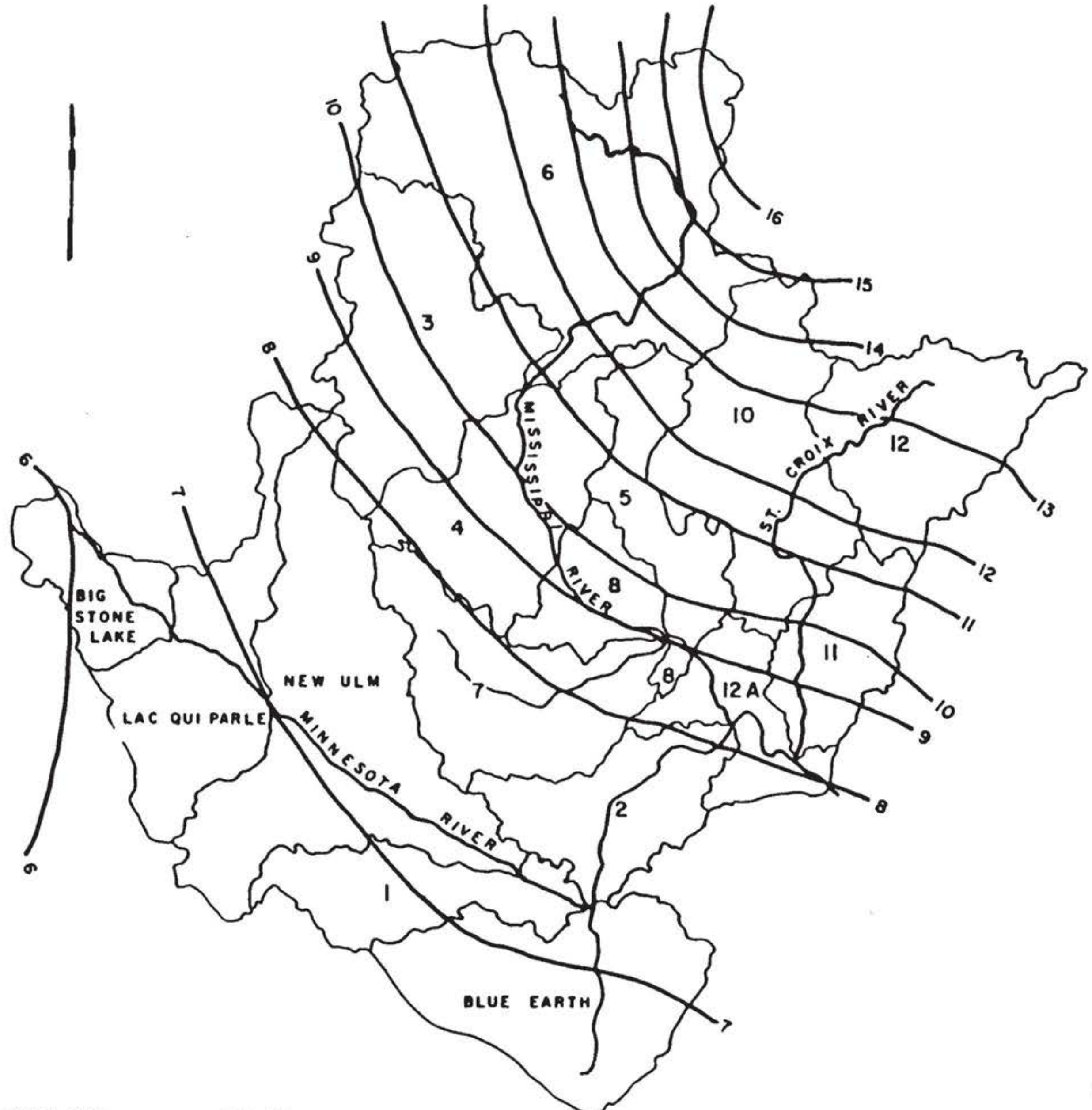
EXHIBIT 5




DEPTH - DURATION CURVE
FOR 50,000 SQ. MI.
SUMMER STORM UMV I-22

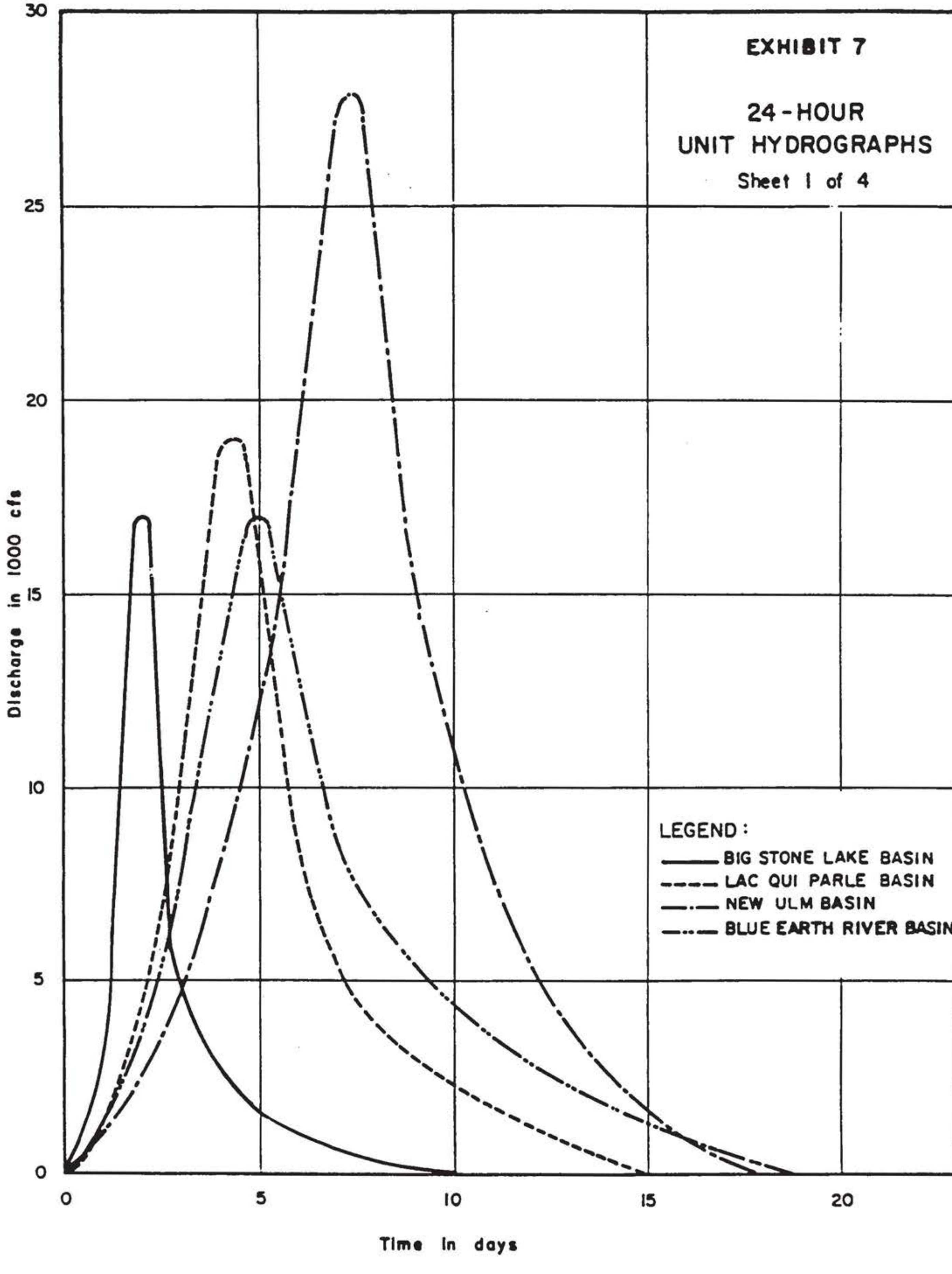
HARZA ENGINEERING COMPANY DWG. NO. 459-P5 MAY 1968

EXHIBIT 6

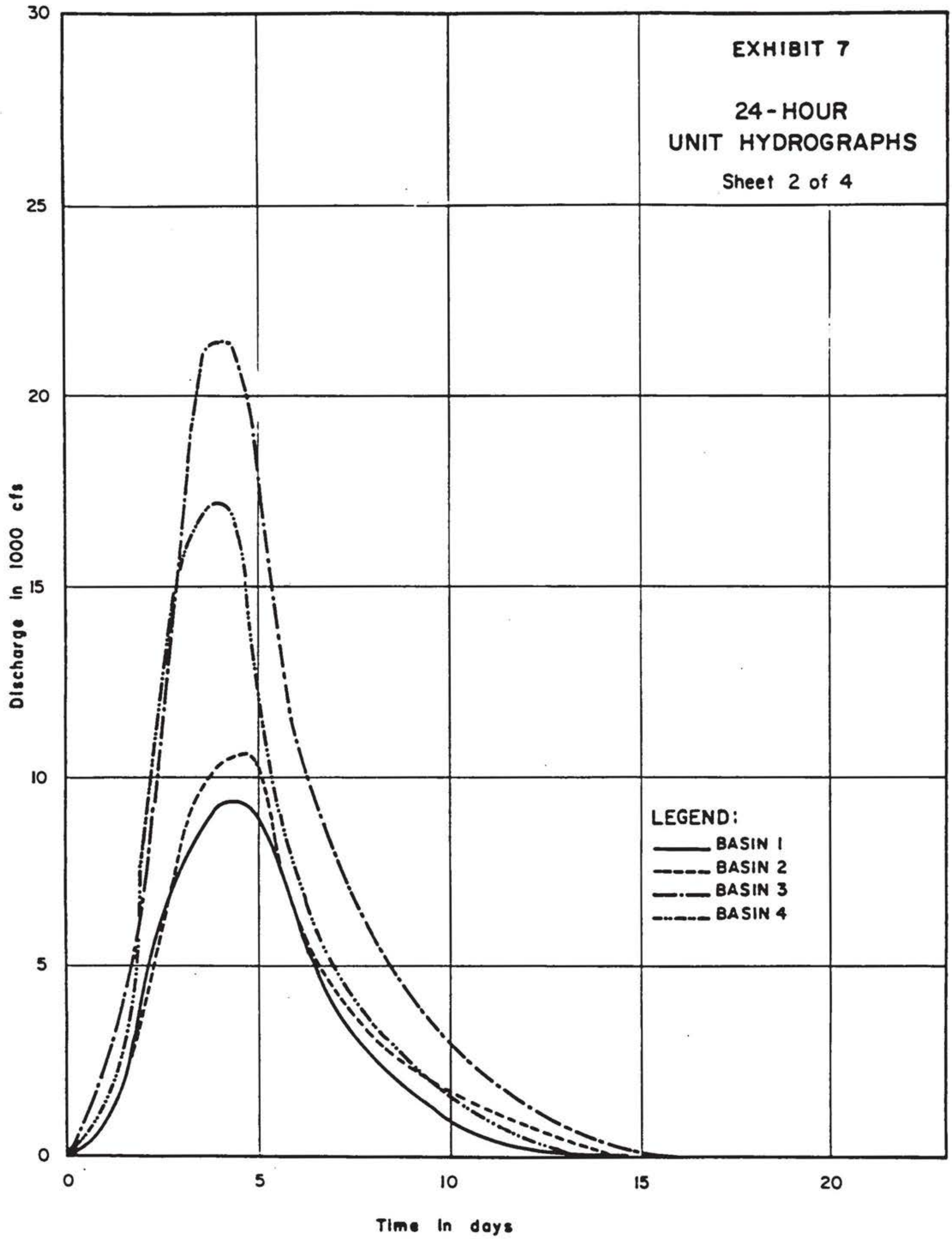



BASIN SNOW COVER
(WATER EQUIVALENT IN INCHES)
1% PROBABILITY, MARCH 16-31

HARZA ENGINEERING COMPANY DWG NO. 459 P6 APRIL 1968




HARZA ENGINEERING COMPANY DWG. NO. 459 P 7 APRIL 1968

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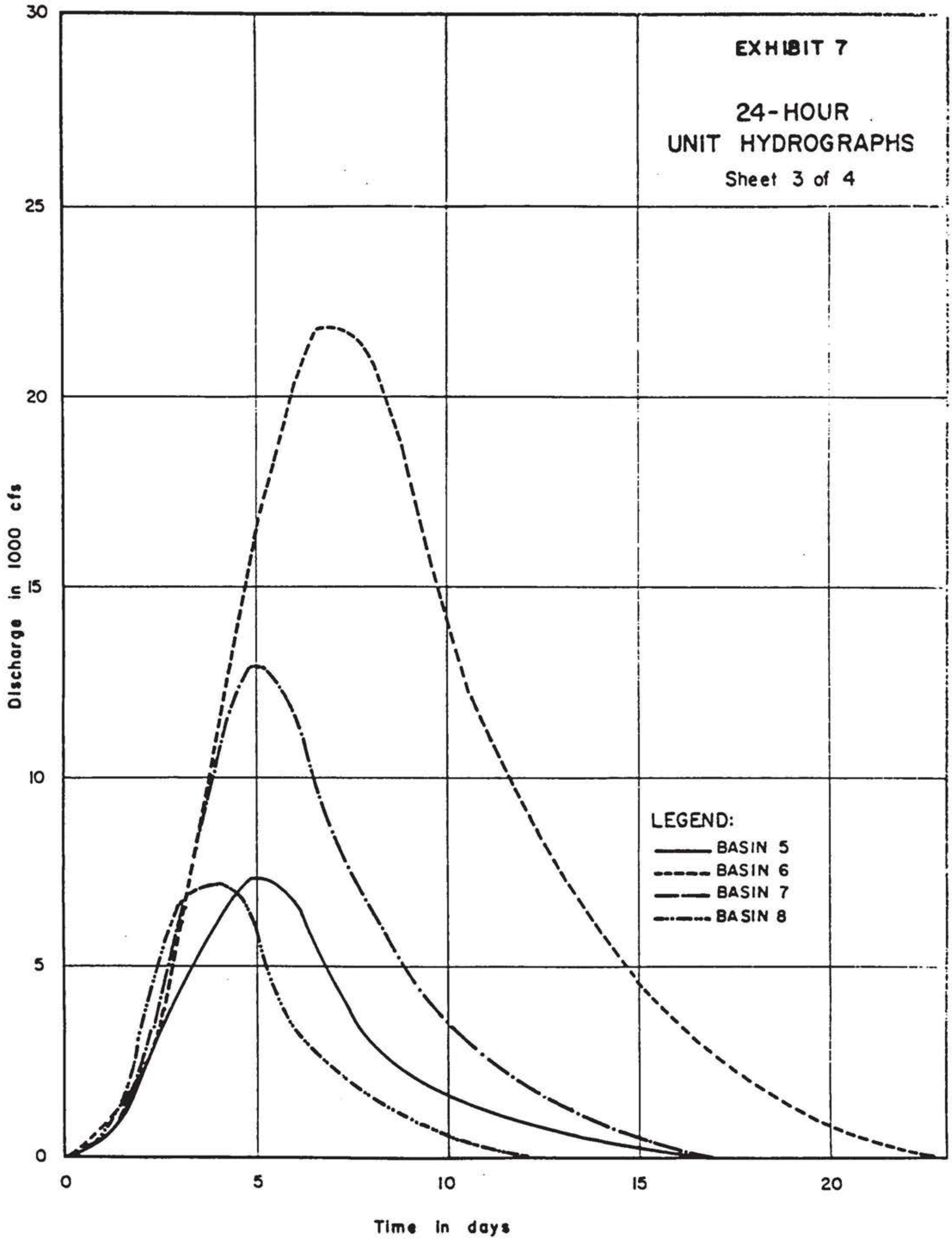


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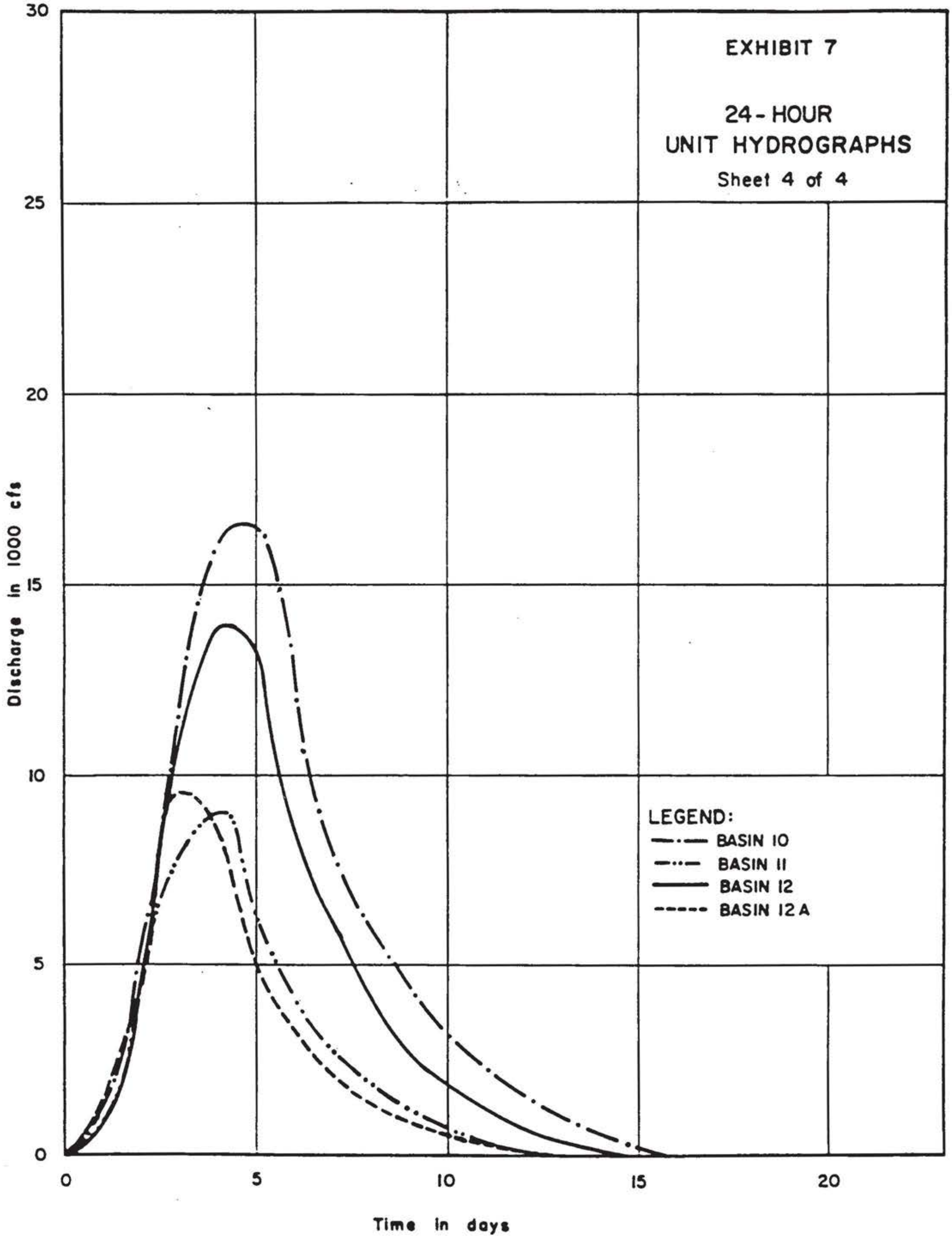


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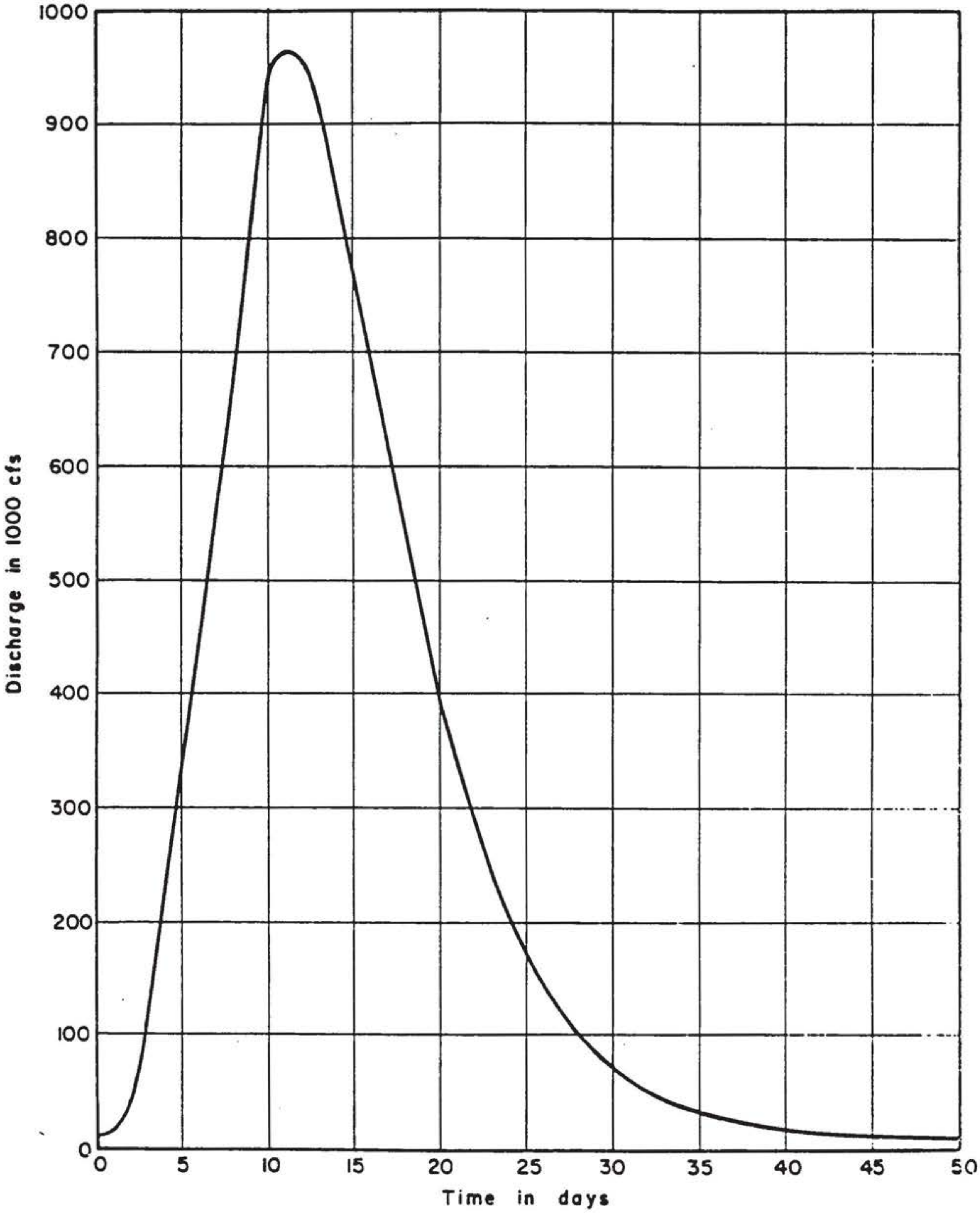
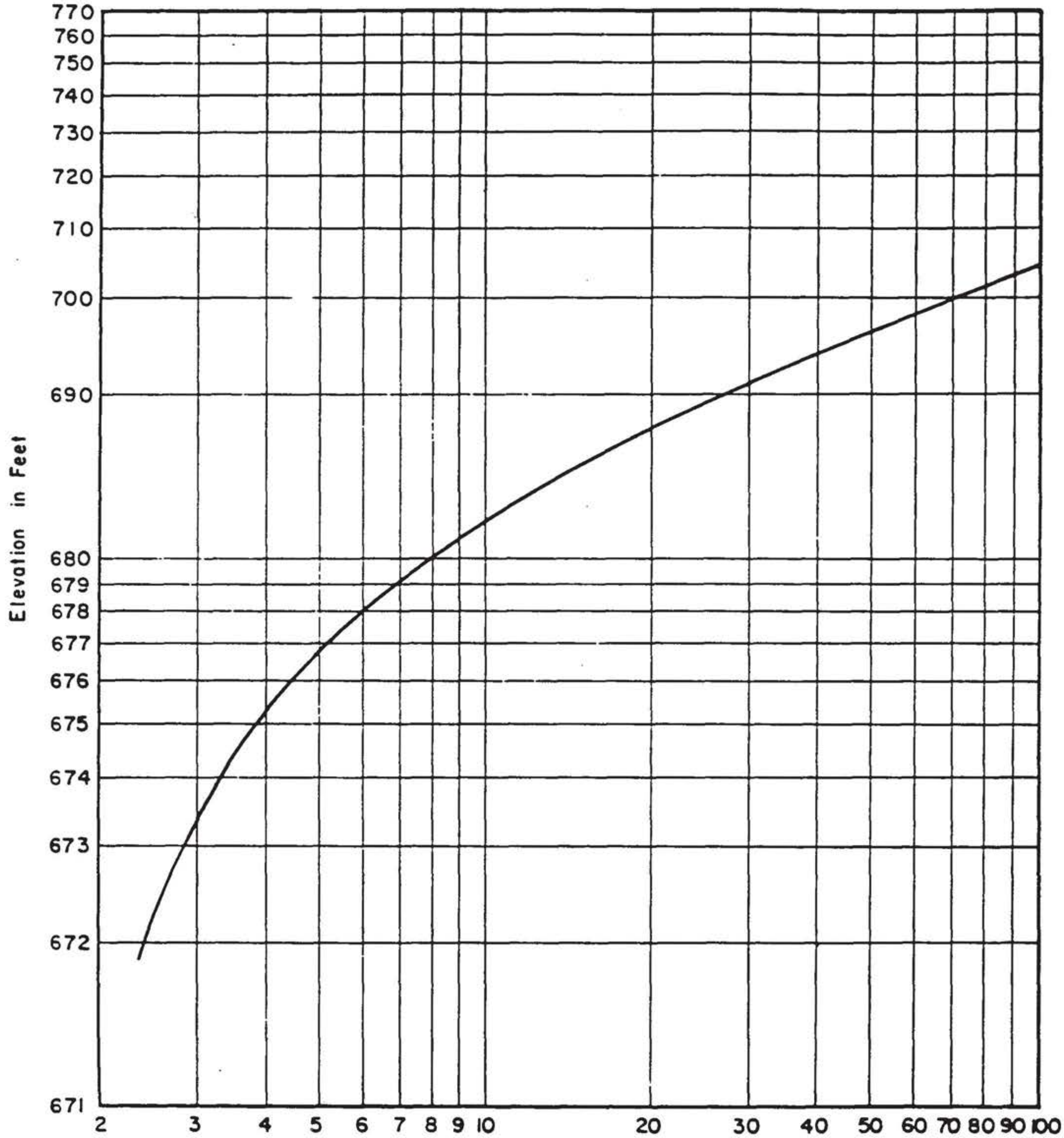



PROBABLE MAXIMUM FLOOD HYDROGRAPH
MISSISSIPPI RIVER AT PRAIRIE ISLAND, MINN.

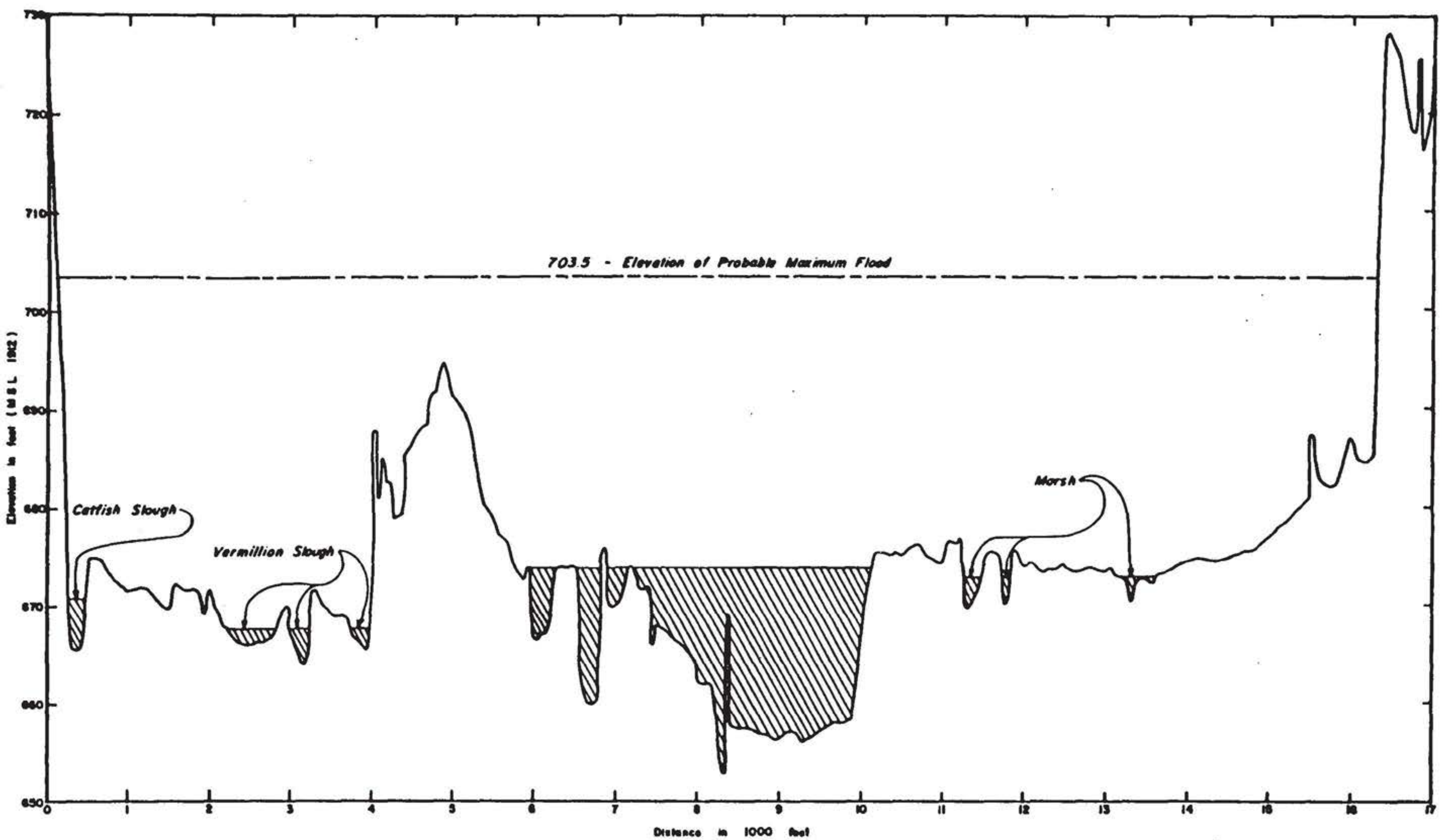
HARZA ENGINEERING COMPANY DWG. NO. 459 P II MAY 1968




DISCHARGE RATING CURVE
MISSISSIPPI RIVER AT PRAIRIE ISLAND, MINN.

HARZA ENGINEERING COMPANY DWG. NO. 459 P12 MAY 1968

EXHIBIT 10

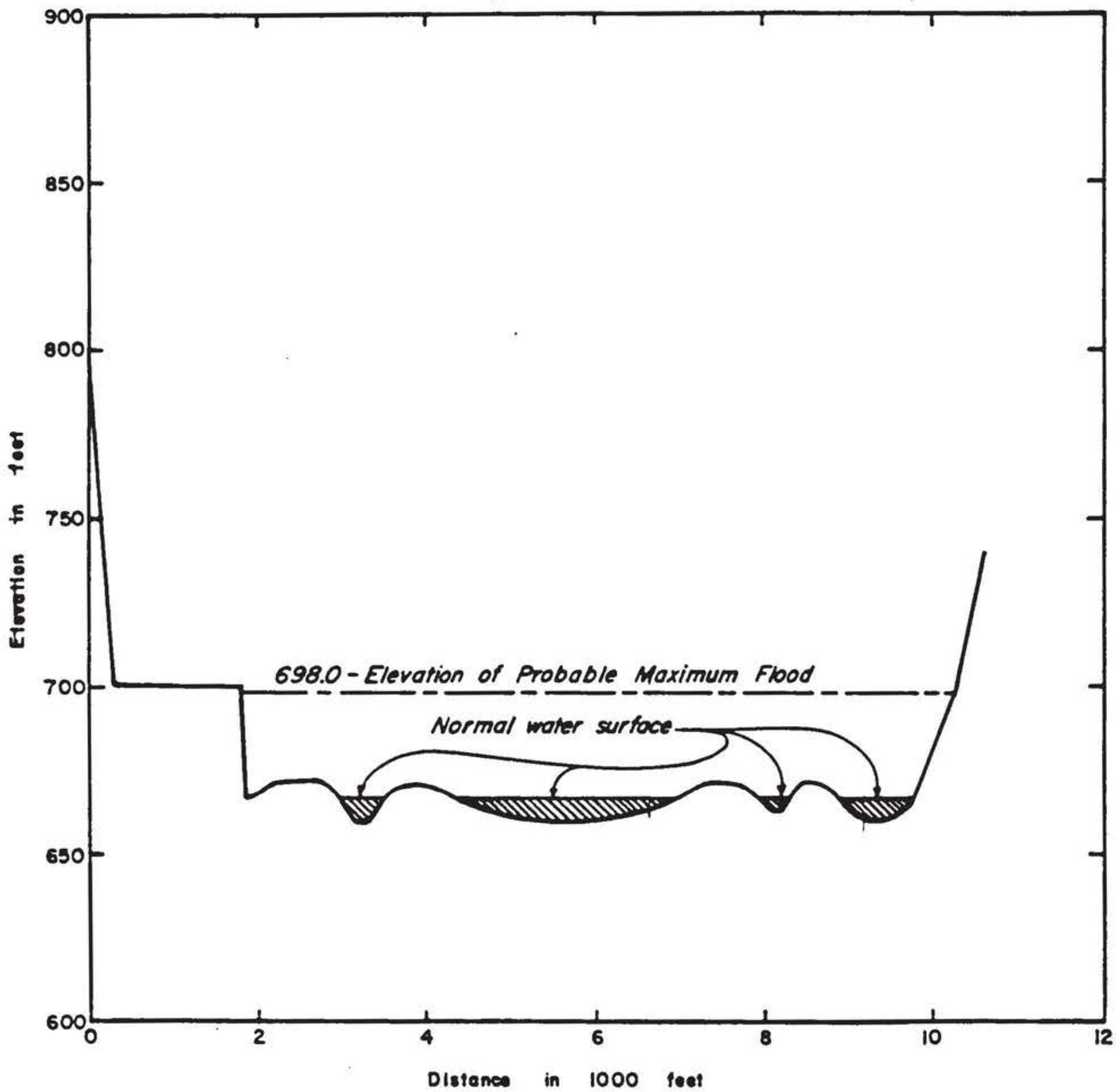



NOTES:
1. Sloughs enter Mississippi River below Lock and Dam No. 3
2. Cross section taken looking upstream

CHANNEL CROSS SECTION
MISSISSIPPI RIVER AT
PRAIRIE ISLAND, MINN.
(MILE 798.5)

HARZA ENGINEERING COMPANY DWG. NO. 459 P13 OCTOBER 1968

EXHIBIT 11



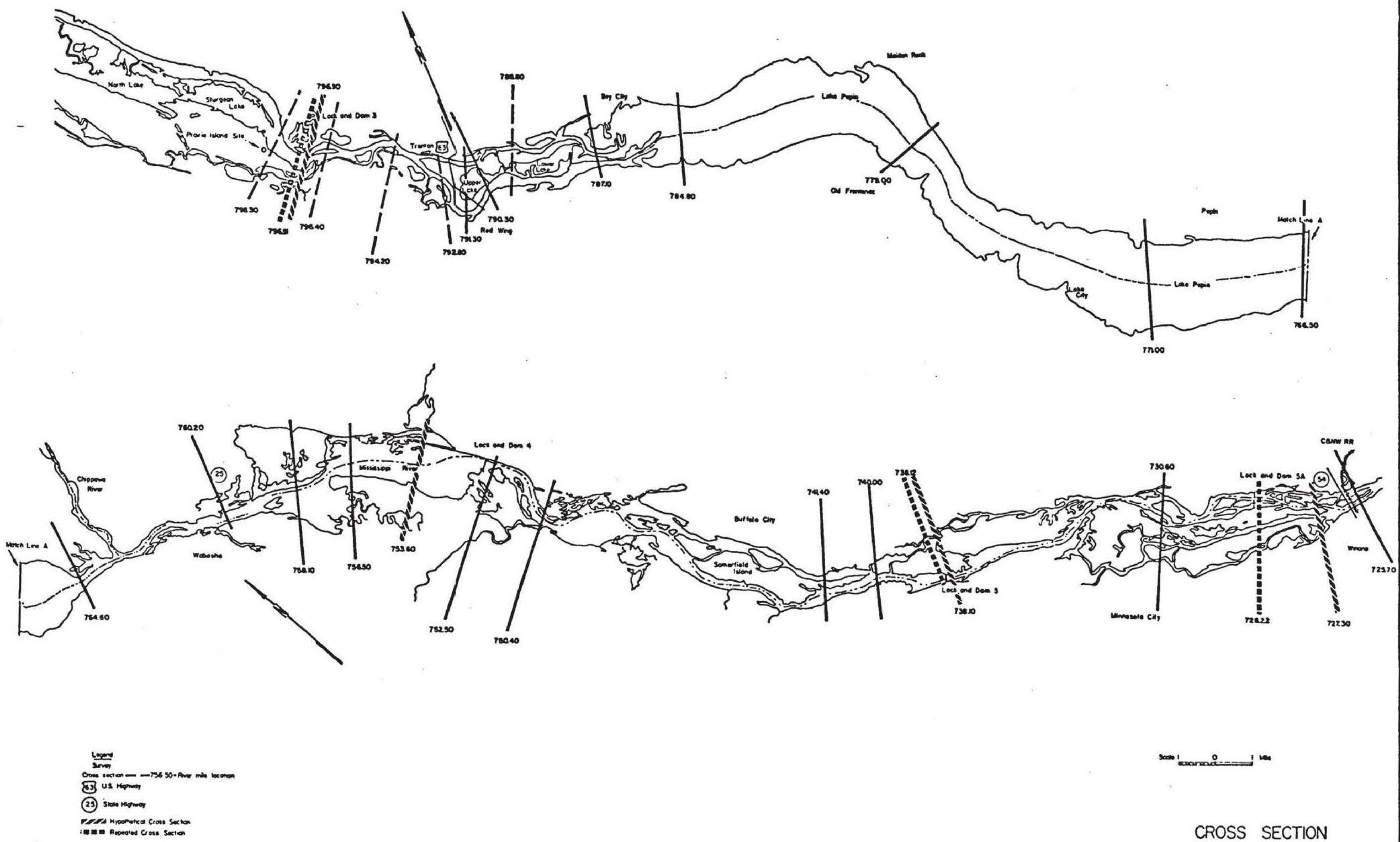

*NOTE:*

*Cross section taken looking upstream*

CHANNEL CROSS SECTION
MISSISSIPPI RIVER NEAR
RED WING, MINN.
(MILE 788.3)

HARZA ENGINEERING COMPANY DWG. NO. 459 P 14 OCTOBER 1968

EXHIBIT 12




CROSS SECTION
LOCATION MAP

HARZA ENGINEERING COMPANY DWG. 459-1 APRIL 1970

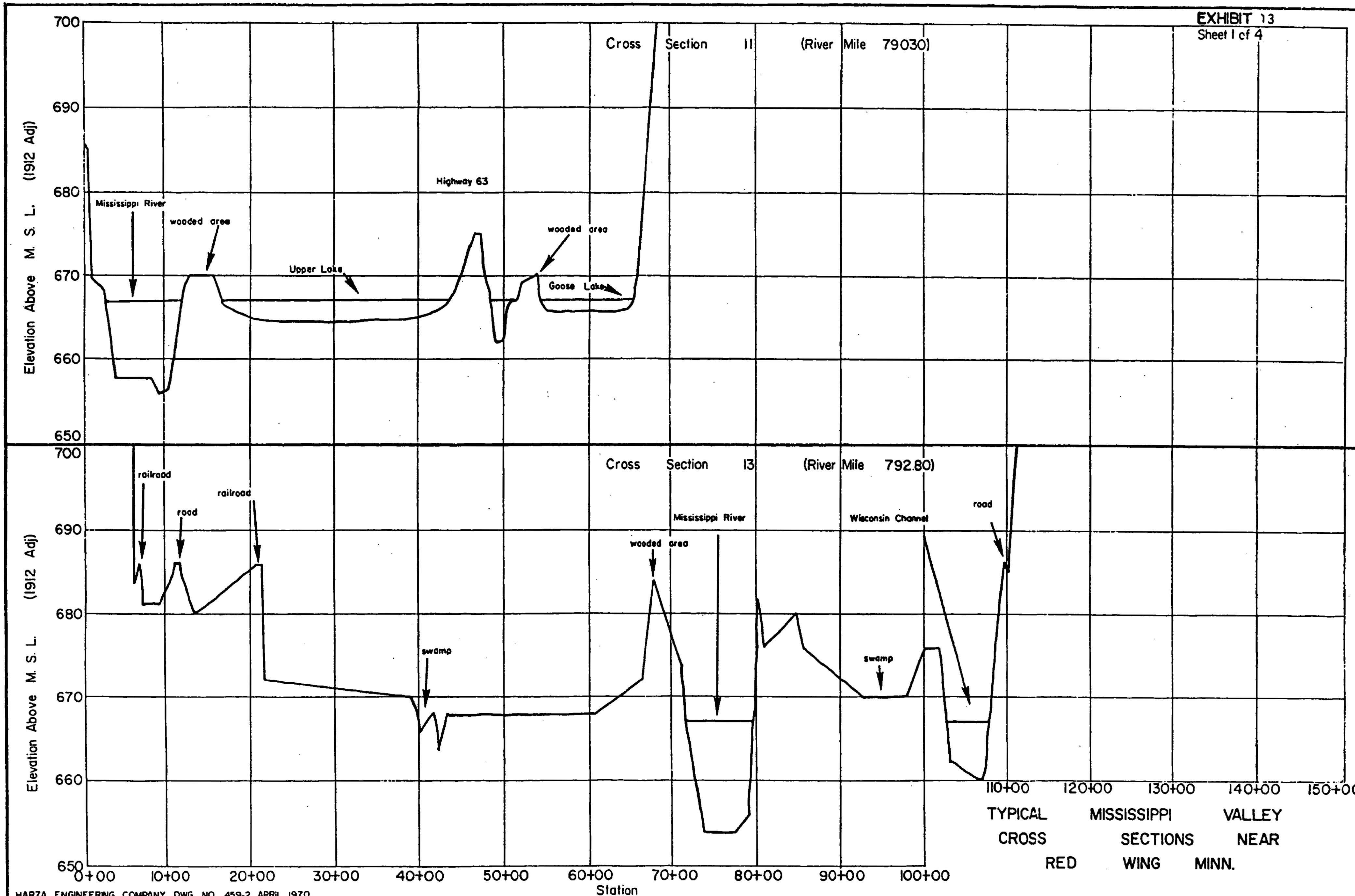
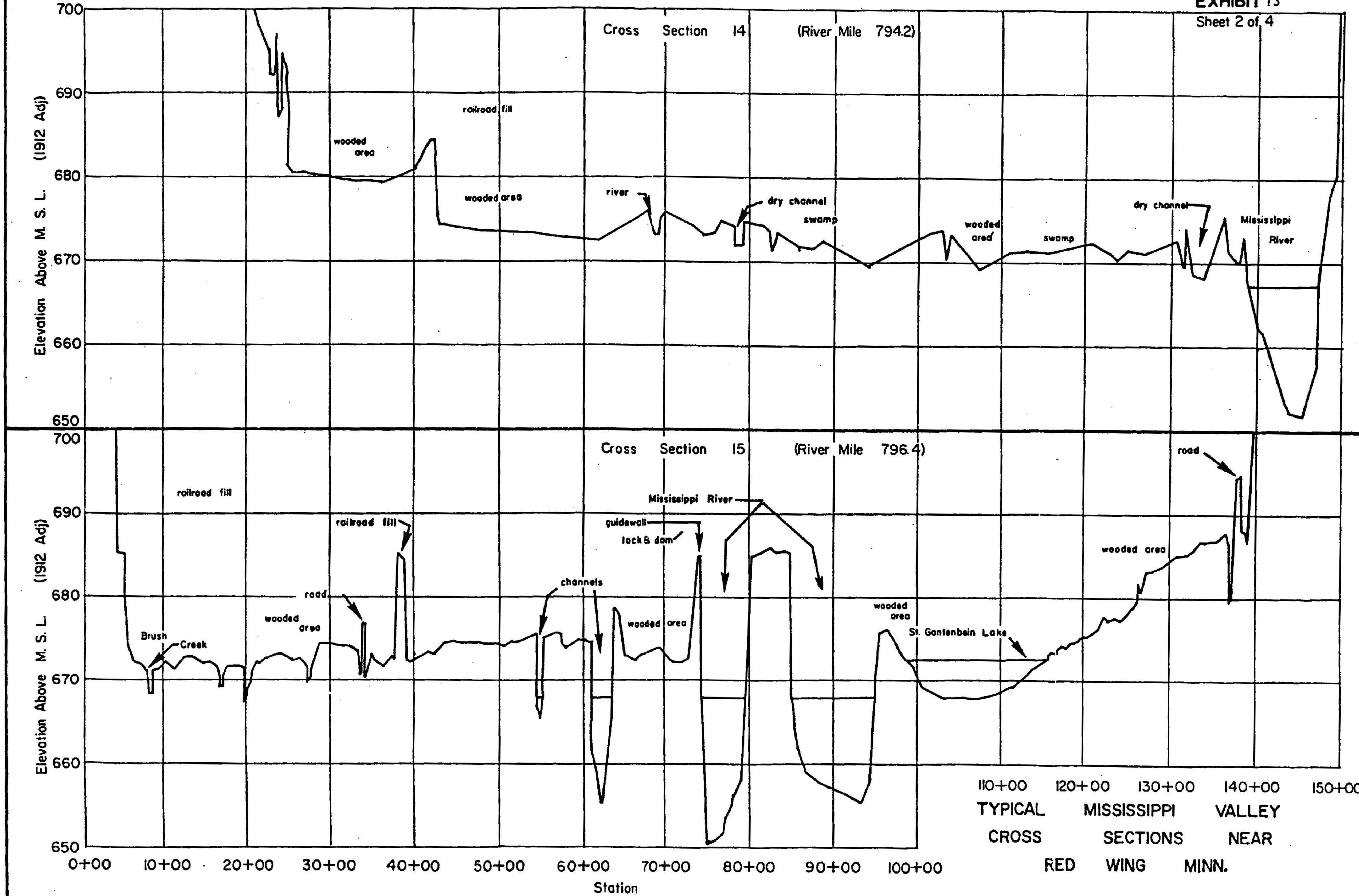
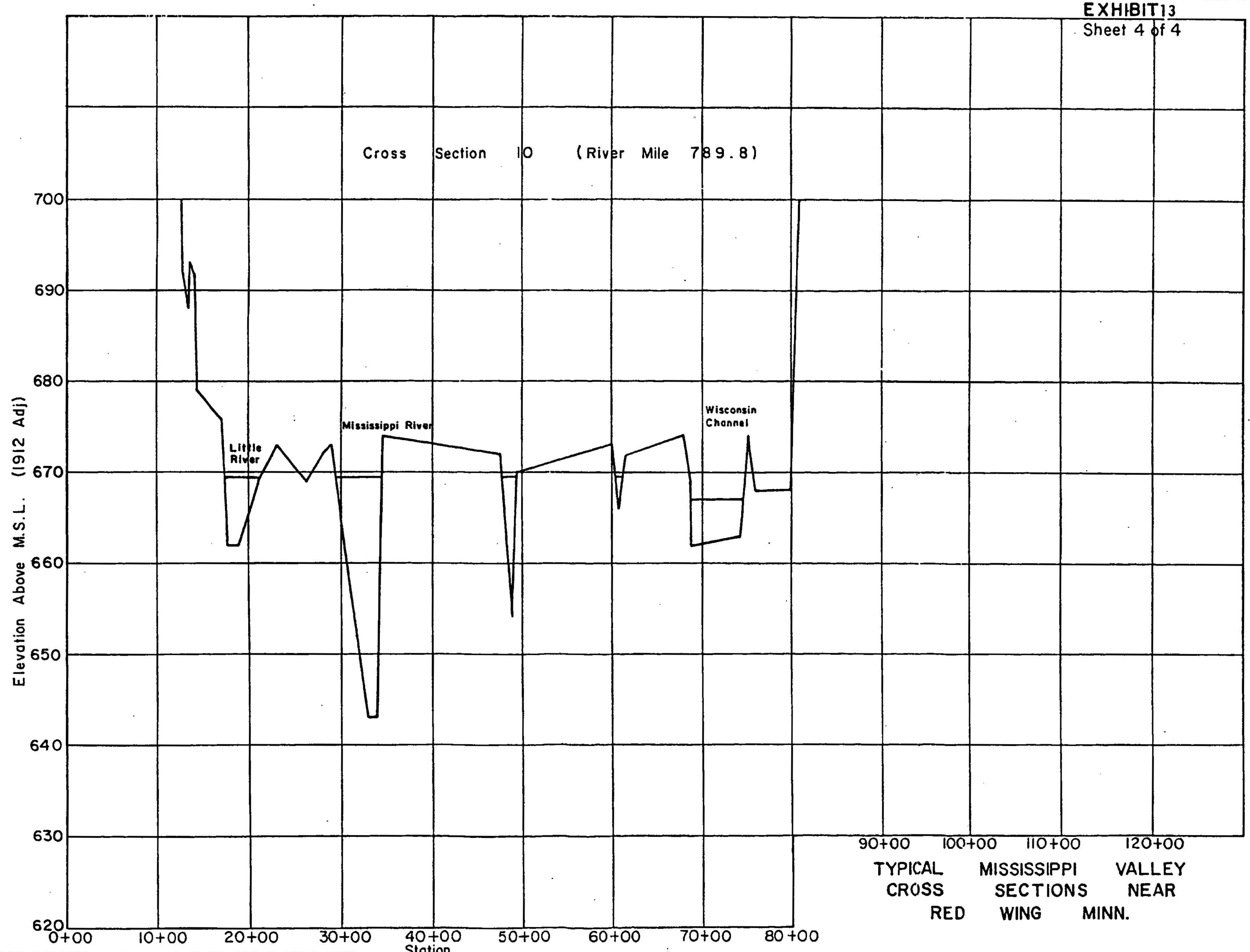


EXHIBIT 13
Sheet 1 of 4
Cross Section 11 (River Mile 79030)
Elevation Above M. S. L. (1912 Adj)
700
690
680
670
660
650
Mississippi River
wooded area
Upper Lake
Highway 63
wooded area
Goose Lake
Cross Section 13 (River Mile 792.80)
railroad
road
railroad
swamp
Mississippi River
wooded area
Wisconsin Channel
swamp
road
0+00
10+00
20+00
30+00
40+00
50+00
60+00
70+00
80+00
90+00
100+00
110+00
120+00
130+00
140+00
150+00
Station
TYPICAL MISSISSIPPI VALLEY
CROSS SECTIONS NEAR
RED WING MINN.
HARZA ENGINEERING COMPANY DWG. NO 459-2 APRIL, 1970




TYPICAL MISSISSIPPI VALLEY CROSS SECTIONS NEAR RED WING MINN.

HARZA ENGINEERING COMPANY DWG. NO. 459-2 APRIL, 1970




TYPICAL CROSS MISSISSIPPI SECTIONS VALLEY NEAR RED WING MINN.

HARZA ENGINEERING COMPANY DWG. NO. 459-2 APRIL, 1970.

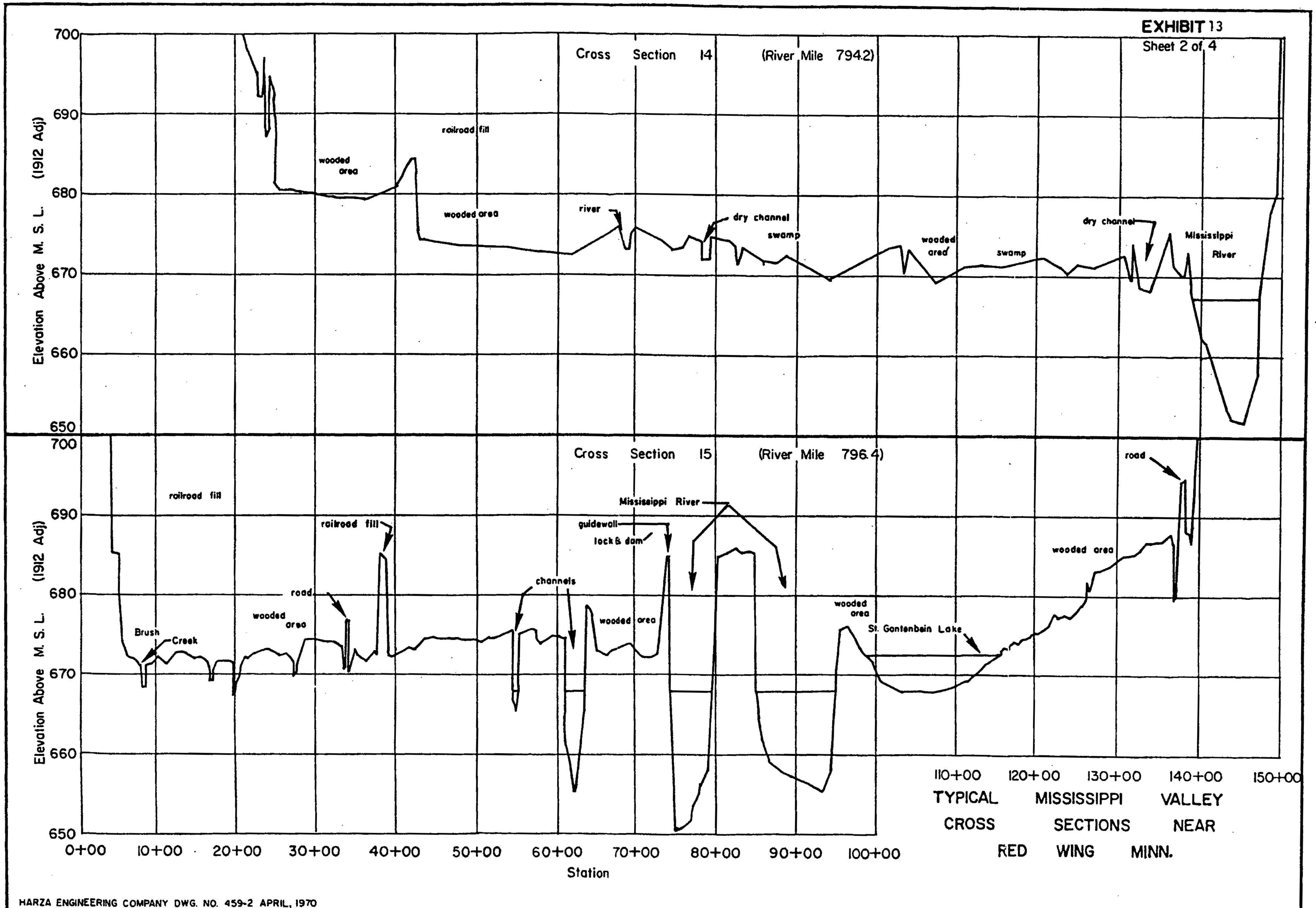
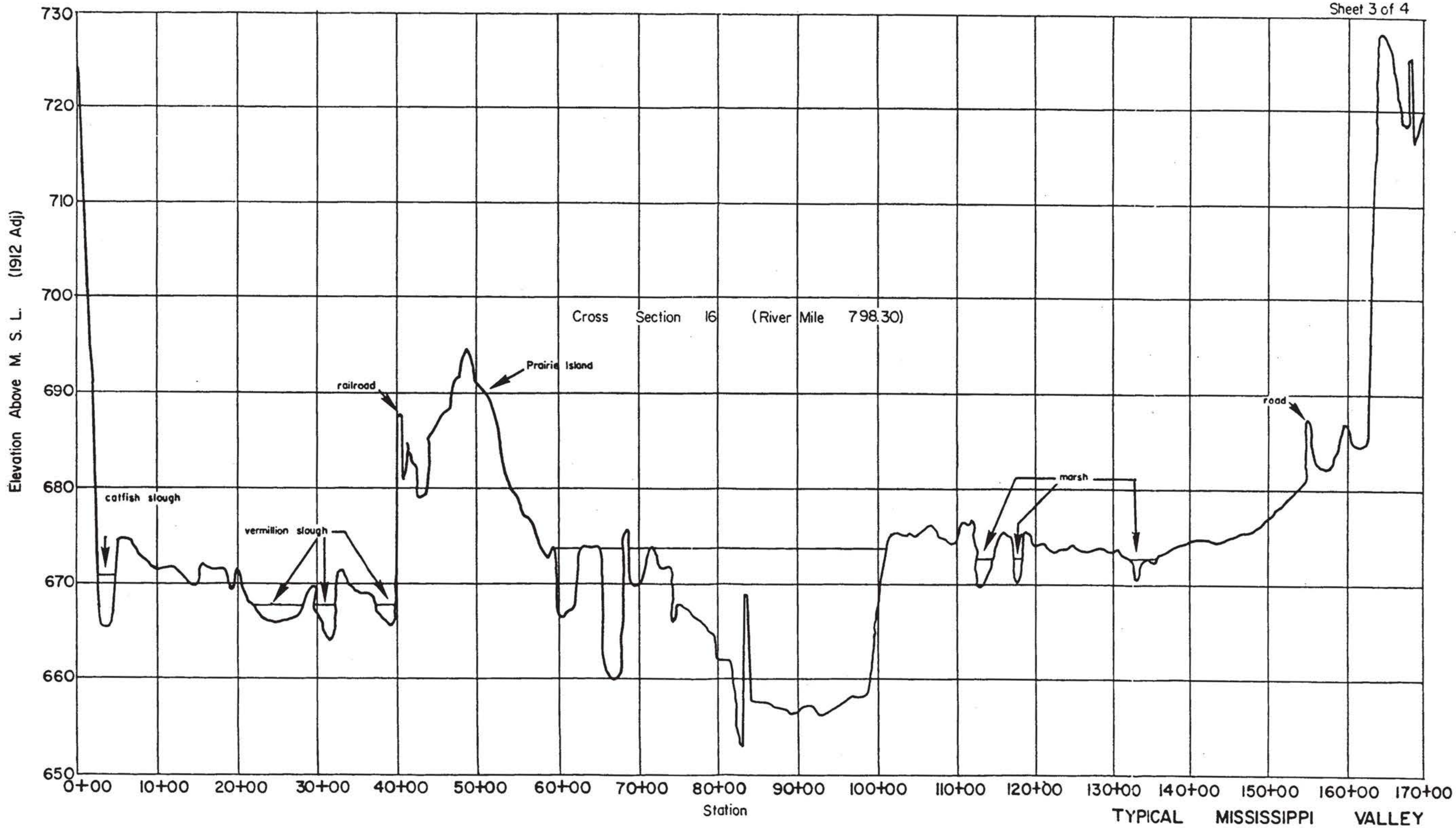


EXHIBIT 13
Sheet 2 of 4
Cross Section 14 (River Mile 794.2)
Elevation Above M. S. L. (1912 Adj)
700
690
680
670
660
650
railroad fill
wooded area
wooded area
river
dry channel
swamp
wooded area
swamp
dry channel
Mississippi River
Cross Section 15 (River Mile 796.4)
railroad fill
railroad fill
road
Brush
Creek
wooded area
channels
wooded area
guidewall
lock & dam
Mississippi River
wooded area
St. Gantenbein Lake
wooded area
road
0+00
10+00
20+00
30+00
40+00
50+00
60+00
70+00
80+00
90+00
100+00
110+00
120+00
130+00
140+00
150+00
Station
TYPICAL MISSISSIPPI VALLEY
CROSS SECTIONS NEAR
RED WING MINN.
HARZA ENGINEERING COMPANY DWG. NO. 459-2 APRIL, 1970




NOTE:
Sloughs enter Mississippi River below Lock and Dam No. 3

TYPICAL MISSISSIPPI VALLEY CROSS SECTIONS NEAR PRAIRIE ISLAND MINN.

HARZA ENGININEERING COMPANY DWG. NO. 459-2 APRIL, 1970

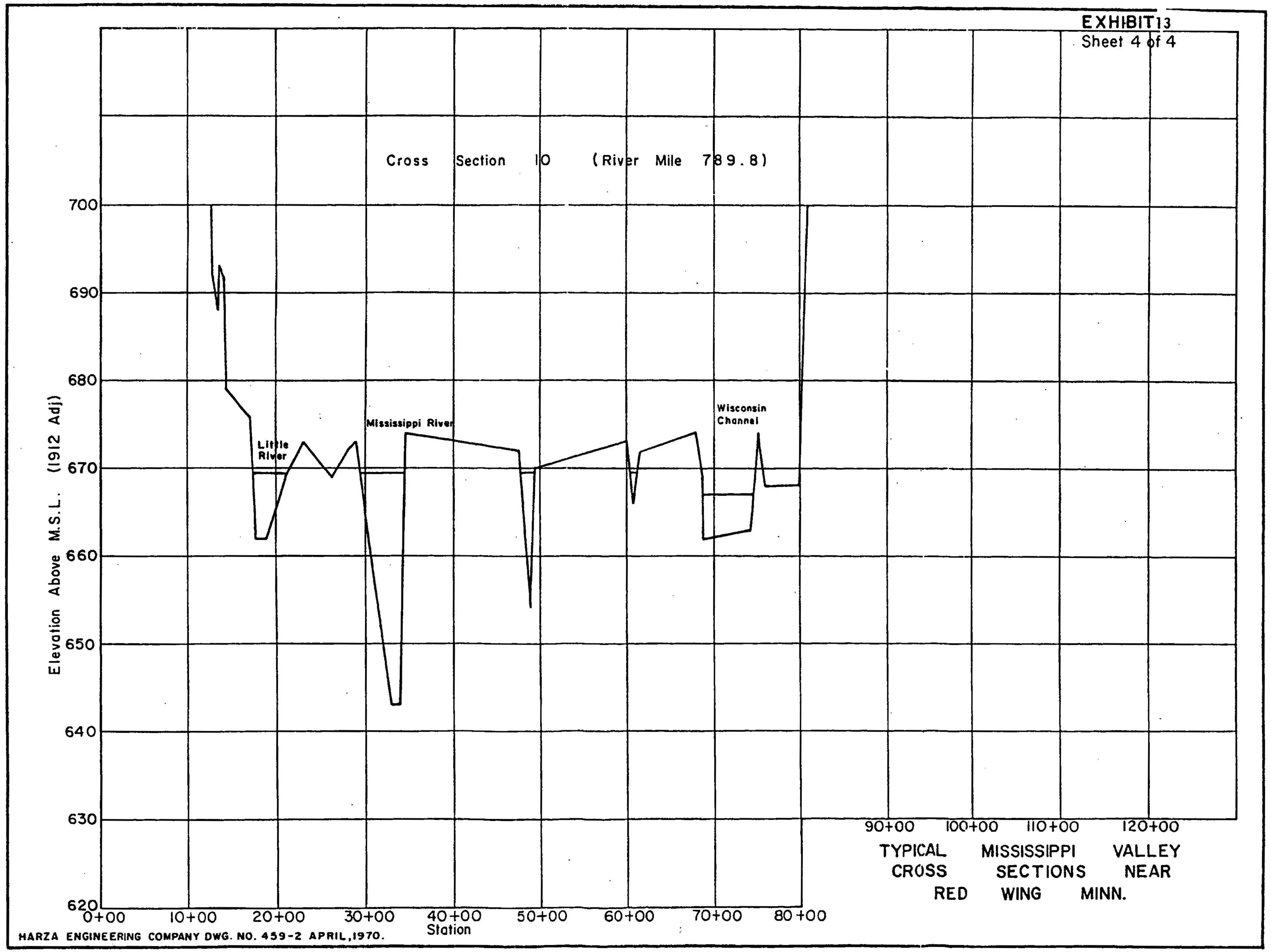
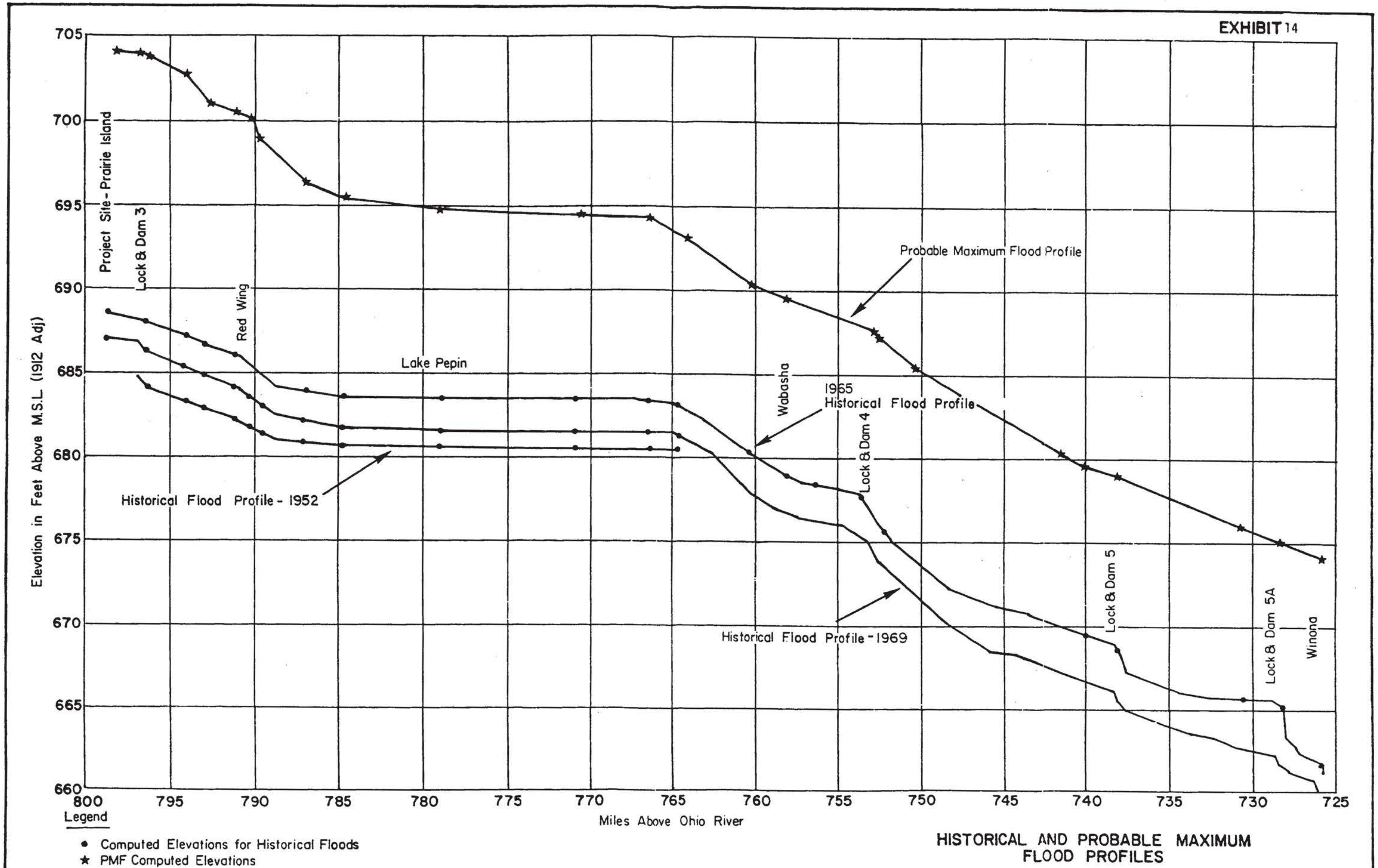


EXHIBIT 13
Sheet 4 of 4
Cross Section 10 (River Mile 789.8)
Elevation Above M.S.L. (1912 Adj)
700
690
680
670
660
650
640
630
620
Little River
Mississippi River
Wisconsin Channel
0+00
10+00
20+00
30+00
40+00
50+00
60+00
70+00
80+00
90+00
100+00
110+00
120+00
Station
TYPICAL MISSISSIPPI VALLEY CROSS SECTIONS NEAR RED WING MINN.
HARZA ENGINEERING COMPANY DWG. NO. 459-2 APRIL, 1970.




HISTORICAL AND PROBABLE MAXIMUM FLOOD PROFILES

HARZA ENGINEERING COMPANY DWG. NO. 459-3 APRIL, 1970

NORTHERN STATES POWER COMPANY --- PROJECT 459
PROBABLE MAXIMUM FLOOD STUDY
REPRODUCE THE HISTORICAL FLOOD TO OBTAIN ROUGHNESS
MISSISSIPPI RIVER NEAR RED WING MINNESOTA
MARCH 19,1970 ---- TEST RUN NO. ---1 *D/S 1965 Flood*

STARTING CONDITIONS

| COEF CONT | COEF EXP | ALL-FRR 2WSEL | *N* LT BK | *N* RT BK | *N* CHAN | INTIAL, VOL-AF | TW AREA ACRES |
|---|---|---|---|---|---|---|---|
| 0.100 | 0.300 | 0.100 | 0.075 | 0.075 | 0.030 | 0. | 0. |

START BY KNOWN W S

| WATER SURFACE EL | DISCHARGE |
|---|---|
| 661.500 | 238000. |

| DISCHARGE | LOB-RL | CH-RL | ROB-RL | LOB-N | CH-N | ROB-N | CRIT.WS.EL. | |
|---|---|---|---|---|---|---|---|---|
| SEC NO | EST WSEL | SLOPE | HL-FRICT | HV | COMP WSEL | VOL-AF | TW-ACRES | KWSEL |
| AREA-LB | V(1)-LB | V-LB | Q-LB | | | | | |
| AREA-CH | V(1)-CH | V-CH | Q-CH | TRIALS-NORMAL | - | DC - | S/A | |
| AREA-RB | V(1)-RB | V-RB | Q-RB | AVG MANNING N- | | SECN | WTN | |
| 238000. | 0. | 0. | 0. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 725.70 | 661.500 | 0.000067 | 0.000 | 0.100 | 661.500 | 0. | 0. | 0.00 |
| 1612. | 0.68 | 0.56 | 905. | | | | | |
| 67400. | 3.42 | 2.81 | 189411. | | 1 | 0 | 0 | |
| 49029. | 1.18 | 0.97 | 47682. | | | 0.000 | 0.000 | |
| 239000. | 12950. | 8900. | 6850. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 727.30 | 662.054 | 0.000025 | 0.412 | 0.050 | 661.967 | 24415. | 1429. | 0.[illegible] |
| 0. | 0.00 | 0.00 | 0. | | | | | |
| 131515. | 3.58 | 1.80 | 238000. | | 2 | 0 | 0 | |
| 0. | 0.00 | 0.00 | 0. | | | 0.030 | 0.029 | |

Note: For the reconstitution of the 1965 flood, Profiles were discontinuous at Dams 4, 5, and 5A, because of supercritical velocities over the spillways.

NORTHERN STATES POWER COMPANY --- PROJECT 459
PROBABLE MAXIMUM FLOOD STUDY
REPRODUCE THE HISTORICAL FLOOD TO OBTAIN ROUGHNESS
MISSISSIPPI RIVER NEAR RED WING MINNESOTA
MARCH 19,1970 ---- TEST RUN NO. --- 2 *1965 Flood*

STARTING CONDITIONS

| COEF CONT | COEF EXP | ALL-ERR 3WSEL | *N* LT BK | *N* RT BK | *N* CHAN | INTIAL. VOL-AF | TW AREA ACRES |
|---|---|---|---|---|---|---|---|
| 0.100 | 0.300 | 0.100 | 0.075 | 0.075 | 0.030 | 0. | 0. |

START BY KNOWN W S

| WATER SURFACE EL | DISCHARGE |
|---|---|
| 665.000 | 239556. |

| DISCHARGE<br>SEC NO | LOB-RL<br>EST WSEL | CH-RL<br>SLOPE | ROB-RL<br>HL-FRICT | LOB-N<br>HV | CH-N<br>COMP WSEL | ROB-N<br>VOL-AF | CRIT.WS.EL.<br>TW-ACRES | <br>KWSEL |
|---|---|---|---|---|---|---|---|---|
| AREA-LB | V(1)-LB | V-LB | Q-LB | | | | | |
| AREA-CH | V(1)-CH | V-CH | Q-CH | TRIALS-NORMAL | | - DC - | S/A | |
| AREA-RB | V(1)-RB | V-RB | Q-RB | AVG MANNING N- | | SECN | WTN | |
| 239556. | 0. | 0. | 0. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 728.22 | 665.000 | 0.000046 | 0.000 | 0.079 | 665.000 | 0. | 0. | 0.000 |
| 0. | 0.00 | 0.00 | 0. | | | | | |
| 106040. | 3.32 | 2.25 | 239556. | | 1 | 0 | 0 | |
| 0. | 0.00 | 0.00 | 0. | | | 0.000 | 0.000 | |
| 240895. | 10600. | 12700. | 11600. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 730.60 | 665.538 | 0.000023 | 0.438 | 0.034 | 665.437 | 40165. | 2584. | 0.000 |
| 16146. | 0.77 | 0.37 | 5999. | | | | | |
| 154521. | 3.15 | 1.51 | 234339. | | 1 | 0 | 0 | |
| 1636. | 0.70 | 0.34 | 556. | | | 0.031 | 0.031 | |
| 245278. | 34050. | 37950. | 37950. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 738.10 | 668.576 | 0.000152 | 3.333 | 0.411 | 668.557 | 135932. | 8675. | 0.002 |
| 2350. | 0.92 | 1.14 | 2681. | | | | | |
| 46824. | 4.18 | 5.17 | 242329. | | 3 | 0 | 0 | |
| 268. | 0.80 | 0.99 | 266. | | | 0.030 | 0.030 | |

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NORTHERN STATES POWER COMPANY ---  PROJECT 459
PROBABLE MAXIMUM FLOOD STUDY
REPRODUCE THE HISTORICAL FLOOD TO OBTAIN ROUGHNESS
MISSISSIPPI RIVER NEAR RED WING MINNESOTA
MARCH 19,1970  ----   TEST RUN NO. --- 5      1965 Flood

STARTING CONDITIONS

   COEF  COEF   ALL-FRR    *N*     *N*     *N*    INTIAL.   TW AREA
   CONT  EXP    3WSEL     LT BK   RT BK   CHAN    VOL-AF     ACRES

  0.100 0.300    0.100   0.075   0.075   0.020        0.         0.

START BY KNOWN W S

WATER SURFACE EL    DISCHARGE

    668.500          245278.


DISCHARGE   LOB-RL     CH-RL  ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
 SEC NO    EST WSEL     SLOPE HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  KWSEL

AREA-LB     V(1)-LB      V-LB     Q-LB
 AREA-CH    V(1)-CH      V-CH     Q-CH    TRIALS-NORMAL  -  DC -   S/A
 AREA-RB    V(1)-RB      V-RB     Q-RB    AVG MANNING N-    SECN   WTN

   245278.       0.         0.        0.   0.075   0.020    0.075    0.000
    738.12  668.500  0.000087    0.000   0.288  668.500      0.       0.      0.000
       56.     0.46      0.43       24.
    56928.     4.59      4.30  245253.                1       0        0
        0.     0.00      0.00        0.                     0.000   0.000

   246395.    9500.    10000.    5500.   0.075   0.020    0.075    0.000
    740.00  669.287  0.000075    0.814   0.263  669.341 13416.     851.      0.000
       67.     0.49      0.42       28.
    59840.     4.75      4.11  246366.                2       0        0
        0.     0.00      0.00        0.                     0.020   0.020

   247218.    7400.     8450.    7400.   0.075   0.030    0.075    0.000
    741.40  669.918  0.000024    0.400   0.029  669.999 39109.    2460.      0.000
      415.     0.81      0.40      167.
    90773.     3.36      1.66  151276.                1       0        0
   130011.     1.48      0.73   95773.                      0.047   0.032

   252510.   46500.    47500.   47500.   0.085   0.040    0.085    0.000
    750.40  673.752  0.000134    3.766   0.091  673.722232636.  19427.      0.000
    43963.     0.45      0.52   23205.
    89753.     2.19      2.54  228327.                3       0        0
      965.     0.87      1.01      976.                     0.044   0.040

   253745.   11600.    11100.    9000.   0.085   0.030    0.085    0.000
    752.50  675.306  0.000170    1.722   0.283  675.310264482.  22687.      0.000
    83230.     1.01      1.32  110492.
    25456.     4.28      5.58  142193.                3       0        0
     1278.     0.63      0.82     1058.                     0.054   0.042
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        NORTHERN STATES POWER COMPANY ---  PROJECT 459
        PROBABLE MAXIMUM FLOOD STUDY
        REPRODUCE THE HISTORICAL FLOOD TO OBTAIN ROUGHNESS
        MISSISSIPPI RIVER NEAR RED WING MINNESOTA
        MARCH 19,1970  ----   TEST RUN NO. --- 4

   STARTING CONDITIONS

        COEF  COEF  ALL-ERR   *N*    *N*    *N*   INTIAL,  TW AREA
        CONT  EXP   3WSEL    LT BK  RT BK  CHAN  VOL-AF     ACRES

       0.100 0.300    0.100  0.075  0.075  0.025      0.        0.

   START BY KNOWN W S

   WATER SURFACE EL    DISCHARGE

        677.550        253921.


DISCHARGE   LOB-RL     CH-RL  ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
 SEC NO    EST WSEL    SLOPE HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  KWSEL

AREA-LB    V(1)-LB      V-LB    Q-LB
 ' "A-CH   V(1)-CH      V-CH    Q-CH   TRIALS-NORMAL  -  DC -  S/A
   A-RB    V(1)-RB      V-RB    Q-RB   AVG MANNING N-     SECN  WIN

   253921.       0.         0.      0.  0.075  0.025   0.075    0.000
    753.60  677.550  0.000020   0.000  0.057  677.550     0.       0.     0.000
        0.     0.00      0.00      0.
   132034.     4.22      1.92 253580.                1      0      0
      935.     0.89      0.40    340.                   0.000  0.000

   255509.   15200.    15250.  17400.  0.075  0.030   0.075    0.000
    756.50  678.250  0.000076   0.738  0.110  678.251 40758.   2394.     0.000
     7682.     1.06      0.93   7171.
    91969.     3.09      2.69 248254.                3      0      0
      199.     0.47      0.41     82.                   0.031  0.031

   257038.    7900.     8450.   7900.  0.075  0.030   0.075    0.000
    758.10  678.854  0.000055   0.540  0.052  678.854 67538.   4177.     0.000
      485.     0.67      0.50    245.
    65388.     3.08      2.29 150087.                3      0      0
   118650.     1.20      0.89 106704.                   0.048  0.037

   257900.   10000.    11050.  14200.  0.075  0.030   0.075    0.000
    760.20  680.290  0.000191   1.545  0.200  680.296111792.   7213.     0.000
        0.     0.00      0.00      0.
    28805.     3.41      4.72 136196.                3      0      0
    79212.     1.11      1.53 121703.                   0.051  0.042

   259700.   22200.    23200.  25400.  0.075  0.030   0.075    0.000
    764.60  683.199  0.000048   2.859  0.085  683.282189219. 12278.     0.000
     1138.     0.82      0.57    653.
    64282.     3.99      2.77 178623.                1      0      0
   100336.     1.15      0.80  80423.                   0.044  0.042
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NORTHERN STATES POWER COMPANY --- PROJECT 459
REPRODUCE HISTORICAL FLOOD
BASED ON THE ASSUMED MANNING ROUGHNESS
MISSISSIPPI RIVER NEAR RED WING MINNESOTA
MARCH 14,1970 ---- TEST RUN NO. --- 5

*1965 Flood u/s of River Mile 759*
*Discharge varies*

STARTING CONDITIONS

| COEF CONT | COEF EXP | ALL-FRS JWSEL | *N* LT BK | *N* RT BK | *N* CHAN | INTIAL. VOL-AF | TW AREA ACRES |
|---|---|---|---|---|---|---|---|
| 0.100 | 0.300 | 0.100 | 0.075 | 0.075 | 0.030 | 0. | 0. |

START BY KNOWN W S

| WATER SURFACE EL | DISCHARGE |
|---|---|
| 683.000 | 259700. |

| DISCHARGE | LOB-RL- | CH-RL | ROB-RL | LOB-N | CH-N | ROB-N | CRIT.WS.EL. | |
|---|---|---|---|---|---|---|---|---|
| SEC NO | EST WSEL | SLOPE | HL-FRICT | HV | COMP WSEL | VOL-AF | TW-ACRES | KWSEL |
| AREA-LB | V(1)-LB | V-LB | Q-LB | | | | | |
| AREA-CH | V(1)-CH | V-CH | Q-CH | | TRIALS-NORMAL - | DC - | S/A | |
| AREA-RB | V(1)-RB | V-RB | Q-RB | | AVG MANNING N- | SECN | WTN | |
| 259700. | 0. | 0. | 0. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 764.60 | 683.000 | 0.000049 | 0.000 | 0.087 | 683.000 | 0. | 0. | 0.000 |
| 1111. | 0.81 | 0.57 | 639. | | | | | |
| 63725. | 3.97 | 2.81 | 179107. | | 1 | 0 | 0 | |
| 99003. | 1.14 | 0.80 | 79953. | | | 0.000 | 0.000 | |
| 206789. | 9200. | 10000. | 13400. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 766.50 | 683.420 | 0.000001 | 0.258 | 0.007 | 683.347 | 54396. | 2261. | 0.000 |
| 87. | 0.28 | 0.03 | 3. | | | | | |
| 302623. | 5.17 | 0.68 | 206213. | | 2 | 0 | 0 | |
| 3350. | 1.28 | 0.17 | 572. | | | 0.030 | 0.030 | |
| 209435. | 22400. | 23800. | 20700. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 771.00 | 683.379 | 0.000000 | 0.026 | 0.002 | 683.379 | 279800. | 8615. | 0.000 |
| 1269. | 1.02 | 0.07 | 92. | | | | | |
| 495101. | 5.91 | 0.41 | 207172. | | 3 | 0 | 0 | |
| 27392. | 1.11 | 0.07 | 2170. | | | 0.030 | 0.030 | |
| 214139. | 46400. | 47200. | 36400. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 779.00 | 683.426 | 0.000001 | 0.042 | 0.007 | 683.418 | 681737. | 19490. | 0.000 |
| 6000. | 1.11 | 0.13 | 822. | | | | | |
| 301288. | 5.73 | 0.70 | 213124. | | 1 | 0 | 0 | |
| 2051. | 0.75 | 0.09 | 191. | | | 0.030 | 0.030 | |
| 217549. | 31700. | 30600. | 41200. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 784.80 | 683.461 | 0.000008 | 0.151 | 0.020 | 683.560 | 858386. | 25608. | 0.000 |
| 6685. | 1.13 | 0.32 | 2183. | | | | | |
| 185191. | 4.02 | 1.16 | 215314. | | 1 | 0 | 0 | |
| 406. | 0.42 | 0.12 | 50. | | | 0.030 | 0.030 | |
| 218907. | 12100. | 12100. | 13200. | 0.075 | 0.030 | -1.000 | 0.000 | |
| 787.10 | 683.776 | 0.000026 | 0.228 | 0.038 | 683.776 | 906358. | 28040. | 0.000 |
| 426. | 0.79 | 0.40 | 174. | | | | | |
| 20948. | 3.91 | 2.03 | 40701. | | 3 | 0 | 0 | |
| 121553. | 2.82 | 1.46 | 178025. | | | -0.807 | -0.060 | |
| 220420. | 14200. | 14200. | 14200. | 0.110 | 0.040 | -1.000 | 0.000 | |
| 789.80 | 684.719 | 0.000112 | 0.989 | 0.101 | 684.722 | 947084. | 30455. | 0.000 |
| 20697. | 1.53 | 1.62 | 33723. | | | | | |
| 16574. | 3.67 | 3.89 | 64539. | | 3 | 0 | 0 | |
| 70563. | 1.63 | 1.73 | 122156. | | | -0.525 | -0.110 | |

```
DISCHARGE    LOB-RL      CH-RL  ROB-RL  LOB-N     CH-N  ROB-N  CRIT.WS.EL.
 SEC NO    EST WSEL      SLOPE HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  KWSEL

AREA-LB     V(1)-LB      V-LB     Q-LB
 AREA-CH     V(1)-CH      V-CH     Q-CH   TRIALS-NORMAL  -  DC -   S/A
 AREA-RB     V(1)-RB      V-RB     Q-RB   AVG MANNING N-     SECN  WTN

   220783.     3200.     2600.    5800.  0.075   0.040  -1.000    0.000
    790.30   685.088  0.000077    0.446  0.084  685.186758420. 31126.    0.000
      379.      0.74      0.65     248.
    28406.      3.06      2.70   76729.               2       0       0
    67908.      2.40      2.11  143804.                 -0.637 -0.127

   221371.     5800.     5280.    2050.  0.125   0.030  -1.000    0.000
    791.30   685.505  0.000217    0.495  0.230  685.579964657. 31493.    0.000
    14359.      0.64      0.95   13657.
    13453.      3.72      5.48   73796.               1       0       0
    47631.      1.90      2.81  133916.                 -0.587 -0.138

   222253.     3050.     7940.    3330.  0.125   0.040  -1.000    0.000
    792.80   686.533  0.000094    0.770  0.063  686.534975461. 32178.    0.000
    82436.      0.76      0.74   61071.
    29527.      2.82      2.75   81339.               3       0       0
    43913.      1.86      1.81   79842.                 -0.310 -0.144

   223076.    11600.     7400.    6300.  0.085   0.030   0.085    0.000
    794.20   687.253  0.000058    0.745  0.099  687.254******* 34935.    0.000
   157251.      1.03      0.78  123957.
    76265.      4.87      3.72   97831.               3       0       0
     2319.      0.72      0.55    1286.                  0.060 -0.131

   224370.     9500.    11600.    8900.  0.085   0.030  -1.000    0.000
    796.40   687.767  0.000035    0.473  0.063  687.767******* 37225.    0.000
    47005.      2.55      1.52   71915.
    28167.      4.58      2.74   77384.               3       0       0
    50438.      2.48      1.48   75070.                 -0.296 -0.141

   219474.     1850.     2650.    1050.  0.085   0.030   0.085    0.000
    796.90   687.854  0.000189    0.191  0.110  687.925******* 37536.    0.000
    50407.      1.05      1.45   73189.
    10494.      3.55      4.89   51402.               1       0       0
    69900.      0.99      1.37   94881.                  0.072 -0.139

   219474.       50.       50.      50.  0.085   0.030   0.085    0.000
    796.90   687.916  0.000083    0.006  0.072  687.973******* 37546.    0.000
    54095.      1.05      0.96   52096.
    32075.      3.34      3.05   98083.               2       0       0
    71553.      1.05      0.96   69294.                  0.060 -0.139
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DISCHARGE   LOB-RL     CH-RL   ROB-RL  LOB-N    CH-N   ROB-N  CRIT.WS.EL.
 SEC NO    EST WSEL     SLOPE HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  KWSEL

AREA-LB    V(1)-LB      V-LB     Q-LB
 AREA-CH    V(1)-CH      V-CH     Q-CH   TRIALS-NORMAL  -  DC -  S/A
 AREA-RB    V(1)-RB      V-RB     Q-RB   AVG MANNING N-    SECN  WTN

    220297.     6100.     7390.    4230.  0.075   0.030   0.075    0.[illegible]
     798.30   688.355  0.000012    0.325  0.022  688.355******* 39271.     [illegible]
     72208.      1.35      0.48   35198.
    109449.      3.92      1.40  154212.                 3      0      0
     78246.      1.10      0.39   30886.                    0.043 -[illegible]
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NORTHERN STATES POWER COMPANY ---  PROJECT 459
REPRODUCE HISTORICAL FLOOD
BASED ON THE ASSUMED MANNING ROUGHNESS
MISSISSIPPI RIVER NEAR RED WING MINNESOTA
MARCH 16,1970  ----  TEST RUN NO. --- FINAL

TARTING CONDITIONS

  COEF  COEF  ALL-ERR   *N*    *N*    *N*   INTIAL,  TW AREA
  CONT  EXP   3WSEL    LT BK  RT BK  CHAN  VOL-AF    ACRES

 0.100 0.300   0.100  0.075  0.075  0.030     0.       0.

START BY KNOWN W S

WATER SURFACE EL   DISCHARGE

   681.100          199000.    1969 Flood

 DISCHARGE   LOB-RL     CH-RL  ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
  SEC NO   EST WSEL     SLOPE HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  WSEL

AREA-LB    V(1)-LB      V-LB    Q-LB
 AREA-CH   V(1)-CH      V-CH    Q-CH   TRIALS-NORMAL  -  DC -  S/A
 AREA-RB   V(1)-RB      V-RB    Q-RB   AVG MANNING N-    SECN  WTH

    199000.       0.        0.       0.   0.075   0.030   0.075    0.000
     764.60  681.100  0.000041   0.000  0.066  681.100     0.       0.     0.000
       816.     0.72      0.46    381.
     58404.     3.75      2.42 141450.                  1      0       0
     85723.     1.03      0.67  57169.                      0.000  0.000

    199000.    9200.    10000.  10400.   0.075   0.030   0.075    0.000
     766.50  681.447  0.000002   0.218  0.007  681.383 49995.   2269.    0.000
        15.     0.15      0.02      0.
    284671.     4.91      0.69 198481.                  2      0       0
      2956.     1.23      0.17    516.                      0.030  0.030

    199000.   22400.    23800.  20200.   0.075   0.030   0.075    0.000
     771.00  681.419  0.000000   0.030  0.002  681.419262957.  8587.     0.000
      1044.     0.95      0.06     72.
    471580.     5.72      0.41 197203.                  3      0       0
     23349.     1.01      0.07   1723.                      0.030  0.030

    199000.   46600.    42200.  36400.   0.075   0.030   0.075    [illegible]
     779.00  681.472  0.000001   0.044  0.007  681.460643550. 19606.    [illegible]
      5073.     1.01      0.12    645.
    286337.     5.54      0.69 198234.                  1      0       0
      1297.     0.73      0.09    119.                      0.030  0.030

    199000.   31700.    30600.  41200.   0.075   0.030   0.075    [illegible]
     784.80  681.563  0.000009   0.166  0.020  681.617800554. 25665.    [illegible]
      5712.     1.02      0.31   1795.
    170906.     3.80      1.15 197190.                  2      0       0
       168.     0.25      0.07     13.                      0.030  0.030

    199000.   12100.    12100.  13200.   0.075   0.030  -1.000    0.000
     787.10  681.867  0.000031   0.264  0.040  681.968851902. 27391.    [illegible]
       334.     0.72      0.40    136.
     10331.     3.69      2.07  37959.                  3      0       0
    107744.     2.66      1.49 160903.                     -0.802 -0.060
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DISCHARGE   LOB-RL     CH-RL  ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
 SEC NO   EST WSEL      SLOPE HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  KWSEL

AREA-LB    V(1)-LB      V-LB    Q-LB
AREA-CH    V(1)-CH      V-CH    Q-CH   TRIALS-NORMAL  -  DC -  S/A
AREA-RB    V(1)-RB      V-RB    Q-RB   AVG MANNING N-     SECN  WTN

   199000.    14200.    14200.  14200.  0.110   0.040  -1.000    0.000
    789.80   682.919  0.000123   1.190  0.205  682.925888141. 30301.     0.000
    18030.      1.45      1.61  29072.
    15638.      3.53      3.92  61576.                3      0      0
    62252.      1.56      1.74 105950.                  -0.517 -0.108

   199000.     3200.     2600.   5800.  0.075   0.040  -1.000    0.000
    790.30   683.432  0.000084   0.486  0.087  683.432898313. 30909.     0.000
      300.      0.60      0.62    189.
    26419.      2.91      2.67  70721.                3      0      0
    61572.      2.26      2.08 128089.                  -0.629 -0.125

   199000.     5800.     5280.   2050.  0.125   0.030  -1.000    0.000
    791.30   683.867  0.000241   0.547  0.234  683.874903953. 31333.     0.000
    12427.      0.59      0.92  11495.
    12401.      3.52      5.47  67871.                1      0      0
    42119.      1.82      2.84 119632.                  -0.583 -0.137

   199000.     3050.     7940.   3330.  0.125   0.040  -1.000    0.000
    792.80   684.909  0.000101   0.851  0.067  684.909913596. 31995.     0.000
    73867.      0.71      0.72  53359.
    26212.      2.81      2.83  74344.                3      0      0
    39071.      1.81      1.82  71296.                  -0.309 -0.142

   199000.    11600.     7400.   6300.  0.085   0.030   0.085    0.000
    794.20   685.670  0.000062   0.787  0.104  685.671949248. 34722.     0.000
   139054.      0.95      0.75 105366.
    24919.      4.70      3.71  92692.                3      0      0
     1834.      0.64      0.51    941.                   0.059 -0.120

   199000.     9500.    11600.   8900.  0.085   0.030  -1.000    0.000
    796.40   686.217  0.000036   0.497  0.059  686.218980612. 36971.     0.000
    41856.      2.54      1.53  64225.
    27103.      4.31      2.60  70572.                3      0      0
    44272.      2.40      1.45  64201.                  -0.284 -0.139

   199000.     1850.     2650.   1050.  0.085   0.030   0.035    0.000
    796.90   686.363  0.000231   0.225  0.100  686.415994834. 37280.     0.000
    45310.      0.98      1.49  67694.
     9844.      3.02      4.60  45305.                2      0      0
    59159.      0.95      1.45  86000.                   0.072 -0.137

   199000.       50.       50.     50.  0.085   0.030   0.035    0.000
    796.99   686.369  0.000093   0.008  0.078  686.447984980. 37292.     0.000
    48347.      0.97      0.94  45886.
    29311.      3.24      3.14  92138.                1      0      0
    62558.      1.00      0.97  60975.                   0.059 -0.137
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DISCHARGE   LOB-RL     CH-RL  ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
 SEC NO    EST WSEL     SLOPE HL-FRICT  HV COMP WSEL  VOL-AF  [illegible]  [illegible]

AREA-LB     V(1)-LB      V-LB    Q-LB
 AREA-CH     V(1)-CH      V-CH    Q-CH   TRIALS-NORMAL  -  DC - [illegible]
 AREA-RB     V(1)-RB      V-RB    Q-RB   AVG MANNING N-     SECN [illegible]

   199000.     6100.      7390.    4230.   0.075    0.030    0.075    [illegible]
    798.30   686.874  0.000013    0.364   0.022  686.974[illegible]  [illegible]    [illegible]
    65738.      1.29      0.47   31381.
   102194.      3.75      1.38  141610.                  3        0        0
    69143.      1.01      0.37   26007.                      0.043 [illegible]
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NORTHERN STATES POWER COMPANY ---  PROJECT 459
REPRODUCE HISTORICAL FLOOD
BASED ON THE ASSUMED MANNING ROUGHNESS
MISSISSIPPI RIVER NEAR RED WING MINNESOTA
MARCH 16,1970  ----   TEST RUN NO. --- FINAL 1982

STARTING CONDITIONS

     COEF  COEF   ALL-ERR   *N*    *N*    *N*    INITAL,   TW AREA
     CONT  EXP    3WSEL    LT BK  RT BK  CHAN   VOL-AF     ACRES

    0.100 0.300    0.100  0.075  0.075  0.030       0.        0.

START BY KNOWN W S

WATER SURFACE EL    DISCHARGE

      680.200        155000.


DISCHARGE   LOB-RL    CH-RL   ROB-RL  LOB-N    CH-N   ROB-N  CRIT.WS.EL.
 SEC NO    EST WSEL   SLOPE  HL-FRICT  HV  COMP WSEL VOL-AF  TW-ACRES  KWSEL

AREA-LB   V(1)-LB     V-LB     Q-LB
 AREA-CH   V(1)-CH     V-CH     Q-CH    TRIALS-NORMAL  -  DC -   S/A
 AREA-RB   V(1)-RB     V-RB     Q-RB    AVG MANNING N-    SECN   WTR

   155000.      0.        0.        0.   0.075   0.030   0.075    0.000
    764.60  680.200  0.000030    0.000  0.046  680.200     0.       0.      0.000
      680.     0.69      0.37     258.
    55684.     3.64      2.00  111954.                 1       0       0
    78733.     0.98      0.54   42786.                     0.000   0.000

   155000.    9200.    10000.   10400.   0.075   0.030   0.075    0.000
    766.50  680.498  0.000001    0.157  0.004  680.403 47903.   2263.      0.000
        1.     0.07      0.00       0.
   276035.     4.81      0.56  154608.                 1       0       0
     2790.     1.20      0.14     391.                     0.030   0.030

   155000.   22400.    23800.   20200.   0.075   0.030   0.075    0.000
    771.00  680.427  0.000000    0.020  0.001  680.427254720.  8574.      0.000
      937.     0.91      0.05      50.
   455677.     5.62      0.33  153741.                 3       0       0
    21313.     0.95      0.05    1207.                     0.030   0.030

   155000.   46400.    42200.   36400.   0.075   0.030   0.075    0.000
    779.00  680.462  0.000001    0.029  0.004  680.454626639.  19319.     0.000
     4609.     0.96      0.09     454.
   278615.     5.44      0.55  154468.                 1       0       0
     1049.     0.71      0.07      76.                     0.030   0.030

   155000.   31700.    30600.   41200.   0.075   0.030   0.075    0.000
    784.80  680.486  0.000006    0.119  0.013  680.566783265.  25296.     0.000
     5168.     0.97      0.25    1301.
   161394.     3.67      0.95  153695.                 1       0       0
       49.     0.12      0.03       1.                     0.030   0.030

   155000.   12100.    12100.   13200.   0.075   0.030  -1.000    0.000
    787.10  680.754  0.000023    0.198  0.028  680.795823959.  27718.     0.000
      286.     0.69      0.33      96.
    17329.     3.55      1.73   30077.                 3       0       0
    99696.     2.56      1.25  124825.                    -0.799  -0.059
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DISCHARGE    LOB-RL     CH-RL   ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
 SEC NO     EST WSEL    SLOPE  HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  EWSEL

AREA-LB     V(1)-LB     V-LB     Q-LB
 AREA-CH    V(1)-CH     V-CH     Q-CH    TRIALS-NORMAL  -  DC -  S/A
 AREA-RB    V(1)-RB     V-RB     Q-RB    AVG MANNING N-     SECN  WTN

   155000.    14200.    14200.   14200.   0.110   0.040  -1.000    0.000
    789.80   681.564  0.000095    0.846   0.078  681.566857256. 30175.     0.000
    16037.      1.38      1.35   21711.
    14933.      3.42      3.34   49923.                3       0       0
    56002.      1.52      1.48   83364.                  -0.509  -0.107

   155000.     3200.     2600.    5800.   0.075   0.030  -1.000    0.000
    790.30   681.845  0.000039    0.311   0.061  681.896866457. 30792.     [illegible]
      233.      0.63      0.39      92.
    24515.      3.70      2.32   57107.                2       0       0
    55531.      2.79      1.76   97799.                  -0.619  -0.124

   155000.     5800.     5280.    2050.   0.085   0.030  -1.000    0.000
    791.30   682.141  0.000187    0.384   0.166  682.207671492. 31151.     0.000
    10401.      0.79      1.08   11289.
    11266.      3.30      4.52   50993.                1       0       0
    36199.      1.87      2.56   92717.                  -0.582  -0.135

   155000.     3050.     7940.    3330.   0.085   0.030  -1.000    0.000
    792.80   682.951  0.000055    0.617   0.052  682.951879949. 31799.     0.000
    62059.      0.98      0.73   45508.
    24533.      3.41      2.53   62197.                3       0       0
    33330.      1.91      1.41   47298.                  -0.268  -0.140

   155000.    11600.     7400.    6300.   0.085   0.030   0.085    0.000
    794.70   683.459  0.000059    0.540   0.097  683.460909886. 34440.     0.000
   113693.      0.85      0.66   75044.
    23040.      4.46      3.44   79454.                3       0       0
     1164.      0.55      0.42     500.                   0.056  -0.129

   155000.     9500.    11600.    8900.   0.085   0.030  -1.000    0.000
    796.40   684.033  0.000031    0.460   0.049  683.974936431. 36573.     0.000
    36568.      2.50      1.40   51482.
    24433.      4.16      2.34   57180.                1       0       0
    36409.      2.26      1.27   46336.                  -0.259  -0.136
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NORTHERN STATES POWER COMPANY --- PROJECT 459
PROBABLE MAXIMUM FLOOD STUDY
BASED ON THE ASSUMED MANNING ROUGHNESS
MISSISSIPPI RIVER NEAR RED WING MINNESOTA
APRIL 8, 1970 ---- TEST RUN NO. ---

STARTING CONDITIONS

| COEF CONT | COEF EXP | ALL-FOR 3WSEL | *N* LT BK | *N* RT BK | *N* CHAN | INITIAL VOL-AF | TW AREA ACRES |
|---|---|---|---|---|---|---|---|
| 0.100 | 0.300 | 0.100 | 0.075 | 0.075 | 0.030 | 0. | 0. |

START BY KNOWN W S

| WATER SURFACE EL | DISCHARGE |
|---|---|
| 674.000 | 910300. |

| DISCHARGE<br>SEC NO<br>AREA-LB<br>AREA-CH<br>AREA-RB | LOB-RL<br>EST WSEL<br>V(1)-LB<br>V(1)-CH<br>V(1)-RB | CH-RL<br>SLOPE<br>V-LB<br>V-CH<br>V-RB | ROB-RL<br>HL-FRICT<br>Q-LB<br>Q-CH<br>Q-RB | LOB-N<br>HV<br><br>TRIALS-NORMAL<br>AVG MANNING N- | CH-N<br>COMP WSEL | ROB-N<br>VOL-AF<br><br>- DC -<br>SECN | CRIT.WS.EL.<br>TW-ACRES<br><br>S/A<br>WTN | <br>[illegible] |
|---|---|---|---|---|---|---|---|---|
| 910300. | 0. | 0. | 0. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 725.70 | 674.000 | 0.000095 | 0.000 | 0.223 | 674.000 | 0. | 0. | 0.000 |
| 140975. | 1.51 | 1.48 | 208765. | | | | | |
| 113650. | 4.85 | 4.75 | 539971. | | 1 | 0 | 0 | |
| 93656. | 1.76 | 1.72 | 161562. | | | 0.000 | 0.000 | |
| 910300. | 17700. | 13650. | 11600. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 728.30 | 675.100 | 0.000049 | 1.035 | 0.165 | 675.100123331. | | 5497. | 0.000 |
| 146804. | 1.30 | 0.92 | 135085. | | | | | |
| 220735. | 4.98 | 3.51 | 775214. | | 3 | 0 | 0 | |
| 0. | 0.00 | 0.00 | 0. | | | 0.036 | 0.035 | |
| 910300. | 50. | 50. | 50. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 728.31 | 675.048 | 0.000348 | 0.009 | 0.335 | 674.991123676. | | 5516. | 0.000 |
| 113762. | 1.27 | 2.37 | 270187. | | | | | |
| 120309. | 2.85 | 5.32 | 640112. | | 2 | 0 | 0 | |
| 0. | 0.00 | 0.00 | 0. | | | 0.043 | 0.036 | |
| 910300. | 50. | 50. | 50. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 728.32 | 675.130 | 0.000051 | 0.010 | 0.151 | 675.203124017. | | 5534. | 0.000 |
| 118381. | 1.28 | 0.92 | 109103. | | | | | |
| 242101. | 4.60 | 3.30 | 801196. | | 2 | 0 | 0 | |
| 0. | 0.00 | 0.00 | 0. | | | 0.035 | 0.036 | |
| 910300. | 10600. | 12700. | 11600. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 730.60 | 675.889 | 0.000060 | 0.704 | 0.171 | 675.893216531. | | 9489. | 0.000 |
| 47136. | 1.27 | 0.99 | 41770. | | | | | |
| 253897. | 4.39 | 3.40 | 864445. | | 3 | 0 | 0 | |
| 5095. | 1.03 | 0.80 | 4083. | | | 0.032 | 0.034 | |
| 910300. | 35050. | 38950. | 38950. | 0.075 | 0.030 | 0.075 | 0.000 | |
| 738.10 | 678.914 | 0.000096 | 3.054 | 0.210 | 678.920502637. | | 21632. | 0.000 |
| 0. | 0.00 | 0.00 | 0. | | | | | |
| 131953. | 4.51 | 4.44 | 586394. | | 3 | 0 | 0 | |
| 211161. | 1.55 | 1.53 | 323905. | | | 0.046 | 0.041 | |

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DISCHARGE   LOB-RL     CH-RL   ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
 SEC NO   EST WSEL     SLOPE HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  KWSEL

AREA-LB    V(1)-LB     V-LB     Q-LB
 AREA-CH    V(1)-CH     V-CH     Q-CH   TRIALS-NORMAL  -  DC -   S/A
 AREA-RB    V(1)-RB     V-RB     Q-RB   AVG MANNING N-     SECN  WTN

  910300.      50.      50.      50.  0.075   0.020   0.075    0.000
   738.11  678.918 0.000098    0.004  0.334  678.839503009. 21648.    0.000
       0.     0.00     0.00       0.
  102967.     5.73     5.67 584322.                1       0       0
  211200.     1.55     1.54 325977.                    0.039   0.041

  910300.      50.      50.      50.  0.075   0.020   0.075    0.000
   738.12  678.922 0.000058    0.003  0.298  678.582503385. 21665.    0.000
       0.     0.00     0.00       0.
  129345.     6.69     5.09 659357.                1       0       0
  211248.     1.55     1.18 250942.                    0.035   0.041

  910300.    9500.   10000.    5500.  0.075   0.020   0.075    0.000
   740.00  679.496 0.000080    0.577  0.353  679.422557729. 23957.    0.000
    1012.     0.61     0.55     559.
   97612.     6.58     5.89 575790.                2       0       0
  235167.     1.58     1.42 333949.                    0.040   0.041

  910300.    7400.    8450.    7400.  0.075   0.030   0.075    0.000
   741.40  680.250 0.000072    0.614  0.159  680.250670380. 26563.    0.000
    1682.     1.01     0.86    1460.
  143775.     4.56     3.89 559587.                3       0       0
  224080.     1.83     1.55 349252.                    0.047   0.041

  910300.   46500.   47500.   47500.  0.075   0.040   0.075    0.000
   750.40  685.365 0.000145    5.153  0.177  685.390******* 45816.    0.000
  188408.     1.17     1.41 267188.
  162337.     3.25     3.93 638675.                3       0       0
    2923.     1.30     1.57    4436.                   0.050   0.044

  910300.   11600.   11100.    9000.  0.075   0.030   0.075    0.000
   752.50  687.030 0.000157    1.722  0.293  687.032******* 50954.    0.000
  273303.     1.41     1.78 486519.
   66966.     4.90     6.15 412477.                3       0       0
    7719.     1.16     1.45   11252.                   0.054   0.045

  910300.    1580.    1580.    1580.  0.075   0.030   0.075    0.000
   752.80  687.535 0.000466    0.493  0.284  687.536******* 51514.    0.000
  180942.     1.26     2.74 496050.
   73488.     2.59     5.60 411599.                3       0       0
    1715.     0.71     1.54    2649.                   0.054   0.045

  910300.      50.      50.      50.  0.075   0.030   0.075    0.000
   752.81  687.551 0.000071    0.013  0.214  687.626******* 51634.    0.000
  115872.     1.12     0.95 110719.
  201637.     4.66     3.95 797282.                1       0       0
    2077.     1.30     1.10    2758.                   0.035   0.045
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DISCHARGE   LOB-RL     CH-RL  ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
 SEC NO    EST WSEL     SLOPE HL-FRICT  HV COMP WSEL VOL-AF  TW-ACRES  ELEV.

AREA-LB    V(1)-LB      V-LB     Q-LB
 AREA-CH    V(1)-CH      V-CH     Q-CH   TRIALS-NORMAL  -  DC -  S/A
 AREA-RB    V(1)-RB      V-RB     Q-RB   AVG MANNING N.    SECN  WTN

   910300.    24200.    27950.  24300.   0.075   0.030   0.075    0.000
    758.10   689.315  0.000046   1.649  0.133  689.364******* 60553.     0.000
     1598.      1.00      0.68   1098.
   308357.      4.31      2.93 905245.                   3      0      0
     5620.      1.03      0.70   3956.                      0.030  0.043

   910300.    10000.    11050.  14700.   0.075   0.030   0.075    0.000
    760.20   690.107  0.000098   0.870  0.186  690.198******* 64493.     0.000
    20608.      1.20      1.19  36484.
   138599.      4.20      4.17 579285.                   2      0      0
   184706.      1.60      1.59 394529.                      0.046  0.043

   910300.    22200.    23200.  25400.   0.075   0.030   0.075    0.000
    764.60   693.000  0.000147   2.952  0.387  693.009******* 71947.     0.000
     2740.      1.30      1.58   4350.
    91727.      5.06      6.15 564407.                   3      0      0
   172591.      1.63      1.97 341542.                      0.047  0.043

   910300.     9200.    10000.  10400.   0.075   0.030   0.075    0.000
    746.50   694.213  0.000013   0.804  0.079  694.152******* 74252.     0.000
     1010.      0.72      0.26    270.
   400841.      6.17      2.26 907271.                   1      0      0
     4887.      1.54      0.56   2758.                      0.030  0.043

   910300.    22400.    23800.  20200.   0.075   0.030   0.075    0.000
    771.00   694.415  0.000004   0.209  0.030  694.415******* 80665.     0.000
     2502.      1.42      0.29    731.
   627531.      6.92      1.42 892295.                   3      0      0
    51333.      1.64      0.33  17312.                      0.030  0.042

   910300.    46400.    42200.  36400.   0.075   0.030   0.075    0.000
    779.00   694.787  0.000011   0.335  0.082  694.714******* 91725.     0.000
    12539.      1.58      0.54   6779.
   388161.      6.78      2.31 900408.                   1      0      0
     6879.      1.28      0.44   3032.                      0.030  0.040

   910300.    31700.    30600.  41200.   0.075   0.030   0.075    0.000
    784.80   695.395  0.000036   0.732  0.155  695.395******* 97957.     0.000
    13017.      1.68      1.01  13179.
   280661.      5.30      3.19 895621.                   3      0      0
     2329.      1.07      0.64   1499.                      0.030  0.039
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 DISCHARGE   LOB-RL     CH-RL  ROB-RL  LOB-N    CH-N  ROB-N  CRIT.WS.EL.
  SEC NO   EST WSEL     SLOPE HL-FRICT  HV COMP WSEL VOL-AF TW-ACRES  KWSEL

AREA-LB     V(1)-LB      V-LB     Q-LB
 AREA-CH     V(1)-CH      V-CH     Q-CH   TRIALS-NORMAL  -  DC -  S/A
 AREA-RB     V(1)-RB      V-RB     Q-RB   AVG MANNING N-     SECN  WIN

    910300.   12100.    12100.  13200.   0.075   0.030  -1.000   0.000
     787.10  696.148  0.000087   0.804   0.229  696.148*******100411.     0.000
       987.     1.11      1.04   1032.
     31183.     5.26      4.92 153481.                   3      0      0
    211144.     3.82      3.57 755785.                  -0.825  0.004

    910300.   14200.    14200.  14200.   0.110   0.040  -1.000   0.000
     789.80  698.775  0.000303   2.775   0.418  698.791*******107860.     0.00?
     42891.     2.13      3.71 159396.
     23883.     4.68      8.15 194787.                   3      0      0
    135562.     2.35      4.10 556115.                  -0.583 -0.019

    910300.    3200.     2600.   5800.   0.065   0.040  -1.000   0.000
     793.30  700.026  0.000110   1.049   0.250  700.026*******103650.     0.000
      1352.     1.61      1.69   2295.
     46331.     4.24      4.46 207008.                   3      0      0
    180949.     3.67      3.87 700996.                  -0.760 -0.030

    910300.    5800.     5280.   2050.   0.100   0.030  -1.000   0.000
     791.30  700.337  0.000076   0.241   0.187  700.337*******104177.     0.000
     32572.     1.29      1.13  36941.
     23096.     5.33      4.65 107587.                   3      0      0
    228438.     3.83      3.35 765771.                  -0.833 -0.036

    910300.    3050.     7940.   3330.   0.100   0.040  -1.000   0.000
     752.80  700.877  0.000213   0.669   0.244  700.966*******105039.     0.000
    172248.     1.40      2.04 353032.
     46171.     4.11      6.00 277222.                   2      0      0
     87396.     2.19      3.20 280044.                  -0.256 -0.039

    910300.   11600.     7400.   6300.   0.085   0.030   0.085   0.000
     794.20  702.668  0.000123   1.723   0.274  702.669*******107873.     0.000
    337633.     1.65      1.83 620346.
     39368.     6.38      7.08 278788.                   3      0      0
      7206.     1.39      1.54  11164.                   0.068 -0.036

    910300.    9500.    11600.   8900.   0.085   0.030  -1.000   0.000
     796.40  703.727  0.000066   0.939   0.166  703.727*******110823.     0.000
    175371.     2.40      1.98 348826.
     45488.     6.09      5.04 229325.                   3      0      0
    119569.     3.35      2.77 332148.                  -0.324 -0.043
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DISCHARGE   LOB-RL     CH-RL   ROB-RL  LOB-N    CH-N   ROB-N   CRIT.WS.EL.
 SEC NO    EST WSEL    SLOPE HL-FRICT  HV COMP WSEL VOL-AF  TW-ACRES  KWSEL

AREA-LB    V(1)-LB      V-LB     Q-LB
 AREA-CH    V(1)-CH      V-CH     Q-CH   TRIALS-NORMAL  -  DC -  S/A
 AREA-RB    V(1)-RB      V-RB     Q-RB   AVG MANNING N-    SECN  WTN

   910300.     1850.     2650.    1050.   0.085   0.030   0.085    0.000
    796.90   703.904  0.000049    0.129   0.105  703.924*******111439.     0.000
    95695.      1.70      1.19  114359.
   191659.      4.41      3.10  594280.                 1       0       0
   166544.      1.72      1.21  201659.                    0.049 -0.043

   910300.       50.       50.      50.   0.085   0.030   0.085    0.000
    796.91   703.907  0.000024    0.001   0.081  703.952*******111457.     0.000
    95719.      1.70      0.83   80070.
   270121.      5.24      2.57  696626.                 1       0       0
   153093.      1.77      0.87  133603.                    0.042 -0.043

   910300.     6100.     7390.    4230.   0.075   0.030   0.075    0.000
    798.30   704.124  0.000029    0.176   0.097  704.117*******113654.     0.000
   150775.      1.97      1.07  162151.
   186720.      5.60      3.05  570772.                 1       0       0
   175578.      1.85      1.01  177375.                    0.046 -0.041
```