APPENDIX G

PROBABLE MAXIMUM FLOOD

MISSISSIPPI AT MONTICELLO

MINNESOTA

MAY 26, 1969

APPENDIX G

PROBABLE MAXIMUM FLOOD
MISSISSIPPI RIVER AT MONTICELLO, MINNESOTA

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Northern States Power Company
Monticello Generating Plant
Probable Maximum Flood Study

Chapter I

INTRODUCTION

Scope

This report describes the determination of the probable maximum flood level on the Mississippi River at the Monticello Nuclear Generating Plant. The plant site is on the right bank of the Mississippi River, about 3.5 miles upstream of Monticello and about 70 river miles northwest of Minneapolis-St. Paul.

The study area for the probable maximum flood includes the Mississippi River drainage above the plant site; about 13,900 square miles.

Hydrologic and meteorologic data developed by Harza for the Prairie Island nuclear generating plant site have been used extensively to develop the probable maximum flood for the Monticello site whose drainage area lies entirely within the boundaries of the northern portion of the Prairie Island drainage area.

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 and hydrological 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 Purchase Order M-79613 dated May 1, 1969.

Data

Data used in the study included U. S. Geological Survey maps, Northern States Power Co. detailed topographic maps for the area near the site 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.

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	K. E. Sorensen
Project Manager	L. L. Wang
Chief Hydrologist	R. W. Revell
Overall Report Responsibility	J. C. Ringenoldus
Civil Engineer	A. A. Mueller

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

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. 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 24,000 with a 10-foot contour interval were used in the study. In addition, detailed topographic maps near the project site were obtained from the Client. Special purpose maps were also available in 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, were used extensively in describing the climate of the basin.

The Study Area

The Mississippi River basin above the plant site has a drainage area of approximately 13,900 square miles and lies entirely in the state of 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.

Elevations in the basin range from 900 to 2100-feet, msl. The elevation at the project site is about 930 feet above mean sea level, and 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, meager 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 ranges from about 28 inches in the east to about 24 inches in the west. Extremes of annual precipitation recorded at Minneapolis - St. Paul range from 49.7 inches to 10.2 inches. Monthly normal precipitation also ranges widely across the study area but reaches a high of about 5.5 inches in June in the southern portion of the area. Minimum normal monthly precipitation is about one-half inch in January and December in the western part of the area. The maximum 24-hour precipitation recorded was 8.07 inches at Marshall, which is near the study area, in July 1909. 91-034

Snow

Most winter precipitation occurs as snow, which largely is stored on the ground until the spring thaw. Normal annual snowfall in the study area averages about 50 inches. 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 sub soil, 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 L · - 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 approximately 25 miles upstream of the plant site, range 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 0°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	Temperature
Winter (December, January and February)	7°F
Spring (March, April and May)	37°F
Summer (June, July, and August)	64°F
Fall (September, October, and November)	42°F

The great extremes of temperature in the area are apparent from the absolute range of 173°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 are shown below. Temperatures given are in degrees Fahrenheit.

MONTICELLO

	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 variation from about 9 to 15 miles per hour. The highest monthly mean winds are attained in April.

Hydrology

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. Then long-term mean annual runoff for the basin is approximately 5.0 inches with a range in mean annual runoff from 1.22 to 8.93 inches.

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. The time of occurrence of floods shows the greatest frequency in April during the spring thaw. A second peak occurs in June due to thunderstorms. 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 locally-intensive rainfall.

The maximum flood of record on the Mississippi River at the plant site was 51,000 cubic feet per second (elevation 916.2 feet) in April, 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.

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Chapter III

PROBABLE MAXIMUM FLOOD DETERMINATION

The probable maximum flood at the 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 four 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, (OR 1-15, U. S. Army Corps of Engineers, "Storm Rainfall in the United States") and the August 28-31, 1941 storm centered at Hayward, Wisconsin (UMV 1-22). 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 precipitable water in an air column over the study area to the observed precipitable water in an air column for the actual storm. Under the assumption of a saturated pseudo-adiabatic atmosphere, the amount of moisture is a unique function of the ground elevation and surface dewpoint. Precipitable water was thus determined from the inflow barriers to the storm centers and observed and maximum persisting 12-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 the National Atlas of the United States, "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 15,000 square miles from the recorded storms were 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 resulting 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 re-oriented 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 probable maximum flood study, maximum water equivalent (inches) for March 16-31 having one 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 near 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 III-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.

TABLE III-1

Sub-Basin	Station	Mean Daily Temperature Sequence 1	2	3	4	5
3	Brainard	46.0	54.5	57.0	57.5	57.0
4-8a	St. Cloud	48.5	54.0	69.0	62.0	57.5
6	Pokagama	40.5	53.5	54.0	54.0	53.5

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, and 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 canaopy 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 purposes 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 one 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 four major sub-basins and synthetic unit hydrographs were developed for each using Snyder's method, which is derived from the various physical basin characteristics. The equations which Snyder developed are:

1) $t_p = C_t (LL_{ca})^{0.3}$ time to peak

2) $q_p = C_p \times \frac{640}{T_p}$ peak rate of discharge

3) $T = 3 + (t_p \div 8)$ duration of unit hydrograph

Where: t_p = Lag time from center of rainfall period to peak of unit hydrograph in hours

L = Length of river to the most remote portion of the basin, in miles

L_{ca} = Distance along the water course to the geographical center of gravity of the drainage basin

q_p = Peak rate of discharge, in cubic feet per second per square mile

T = Duration of unit hydrograph in days

C_t and C_p are constants

The constants C_t and C_p are critical values in determining the basin lag and the peak discharge. Data exists at several gaging stations in Minnesota on the Mississippi and Minnesota rivers, so unit hydrographs could be constructed based on actual data. After these unit hydrographs were developed, known values were applied to Snyder's equations and a range of values for C_t and C_p were determined. The average value of C_t was 8.0 and the average value of C_p was 0.75. These two values were then used in Snyder's equations to develop synthetic unit hydrographs for the sub-basins used in the study.

Unit hydrograph peaks were increased by 25 percent and basin lag decreased by one-sixth in accordance with standard Corps of Engineers practice. Exhibit 7 shows the unit hydrographs for each sub-basin.

Flood Routing

Snowmelt and rainfall excesses were applied to the unit hydrographs and the resulting hydrographs were determined for each sub-basin. Sub-basin hydrographs were then routed to the project site by computer program using the modified Wilson method -- the equation used in the method is:

$$O_2 = O_1 + K(I_1 + I_2 - 2O_1)$$

where $K = \dfrac{t}{2T + t}$

O_1, O_2 = Instantaneous discharge or outflow from a basin

I_1, I_2 = Instantaneous discharge or inflow to a basin

t = Routing interval - 24 hours for this study

T = Travel time - hours

Travel time T for flood routing were taken from Corps of Engineers recorded travel times for large floods. Base flow was determined from long-term USGS records for the stream gage at Elk River, Minnesota with a drainage area of 14,500 square miles. Examination of the records indicated that for the months of March - April, a base flow of 5000 cfs was reasonable. The base flow of 5000 cfs was then added to the total of the routed flood hydrographs. The resultant probable maximum flood hydrograph is shown on Exhibit 9.

Chapter IV

STAGE DISCHARGE RELATIONSHIP

The stage-discharge curve at the nuclear plant site was extended above the range of historical experience by means of hydraulic computations based on the river channel downstream. This was done by a series of backwater computations based on a range of discharges. The backwater computation procedure takes into account channel conditions over a reach of river and tends to converge on the true stage at the upstream end of the reach even though the starting elevation at the downstream end of the reach cannot be established. Selection of an adequately long reach of river for analysis will provide the correct upstream stage regardless of errors in starting elevation.

Procedure

River profiles were derived by the "Standard Step Method" of backwater calculations, using an electronic computer. The term "backwater," as applied in the discussion of natural channel (mild slope) hydraulics, generally refers to a depth of flow, or water surface elevation, which is greater than normal depth because of a downstream control such as a dam or channel condition.

Since the depth of flow is greater than normal under these conditions, the cross-sectional area is greater than normal, and the velocity is less than normal. Normal velocity corresponds to a rate of head loss equal to channel gradient, so the rate of head loss must be less than the channel gradient. Thus, the water surface slope is less than the bed slope.

This slope-reduction caused by a downstream depth greater than normal extends with diminishing effect upstream from the control until the "backwater profile" becomes coincident with the normal depth profile.

The standard step method utilizes the Manning formula in a computational procedure designed to take into account the effects of gradually varied flow. As utilized in computations for a natural channel, this procedure includes effects of downstream channel conditions and constrictions in the determination of the water surface elevation at upstream points. The Bernoulli equation of conservation of energy is successively applied for channel reach segments using the Manning formula for determination of head losses.

Computer Program

Backwater computations were made on 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 left overbank, right overbank and channel for each section were read in. 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 assuming a water surface elevation equal to that of the last section raised by the product of the slope and the distance between sections. Computations were made of average slope, velocity, discharge in left and right overbank as well as the channel, velocity head, eddy loss due to expansion or contraction, energy gradient, and water surface elevation.

Output data include discharge, velocity and area for each overbank and channel section, slope, head loss and water surface elevation.

Cross Sections

Channel and overbank cross-sections were determined from large scale two-foot topographic maps near the plant site furnished by Northern States Power Company and from smaller scale 10-foot contour interval maps prepared by the USGS. Points in the cross-section were described at each major break in the side slope so that sub-areas computed by assumed trapezoidal sections would not differ from the true area by a significant amount.

Cross-sections were determined at average intervals of about one-fourth mile near the power station and about one and one-half miles in the downstream reaches of the river near Monticello.

Starting Elevations

The first cross-section on the Mississippi River in the study area is about five and three-quarter miles below the generating plant site and about one mile below Monticello, Minnesota. A stage-discharge relationship was determined for this cross-section using Manning's formula.

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

where
- Q = Discharge, cfs
- n = Manning's coefficient of roughness
- A = Area of the cross-section
- R = Hydraulic radius which is equal the Area divided by the wetted perimeter
- S = Average channel slope

The rating curve was developed by assuming various values for water surface elevation. The area, hydraulic radius and discharge Q were then determined for each value. The average channel slope, S, was obtained from topographic maps.

Manning's Roughness Coefficients

Values of Manning's "n" coefficient used in the study were determined from examination of detailed topographic maps of the plant site and of USGS 10-foot contour maps with a scale of 1:24,000. Average values of "n" determined were .032 for the main channel, .050 for the left overbank and .045 for the right overbank. A somewhat higher value of .065 was used for the right overbank in Monticello and a value of .060 was used for the island immediately upstream of the plant site. These "n" values were determined by assuming a basic "n" value and then making adjustments for irregularity, changes in shape, obstructions, vegetation, and meander.

Verification of Procedure

The maximum flood of record at the site occurred in April, 1965, with a discharge of approximately 51,000 cubic feet per second. For this flood, records of water surface elevation exist at several points along the river near the plant site. A trial backwater computation was made starting from a point of known water surface elevation slightly more than a mile downstream from the plant site. The trial computation yielded a water surface elevation at the plant site which agreed within 0.2 feet of the measured water surface elevation for the flood of record.

For the determination of the water surface elevation corresponding to the probable maximum flood, two different starting elevations were selected from the rating curve downstream of Monticello. Elevations were selected for stages somewhat higher, as well as somewhat lower, than that anticipated for the probable-maximum flood. Analysis was then made to determine backwater profiles for the river reach extending to the plant. The profiles converged to within 0.4 feet at the plant site, indicating that the river stage at Monticello plant would not be greatly effected by adjustment of the starting elevation. An average of their values was used for the probable maximum flood stage.

As a further verification, it was decided to determine what maximum stage would occur at the plant site if the values for Manning's roughness coefficient "n" were lowered for the overbank sections of the channel reach. Lowering "n" for both the left and right overbank by 0.005 yielded a probable maximum flood stage elevation of 938.9 or about 0.3 feet lower than the elevations obtained by using the higher "n" values. It is believed that any further decrease in the roughness coefficient would be unrealistic in view of the channel and overbank characteristics.

Stage Discharge Curve

Several sets of backwater computations were made using water surface elevations and their corresponding discharges as determined from the rating curve downstream from Monticello. Using the discharges and the water surface elevations determined, a stage discharge curve was then constructed for the plant site (Exhibit 8).

Chapter V

CONCLUSIONS

The probable maximum flood at the project site was determined to be 364,900 cubic feet per second and to have a corresponding peak stage of 939.2 feet MSL. The probable maximum flood hydrograph is shown on Exhibit 9. 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 elevation 930.0 for about 11 days.

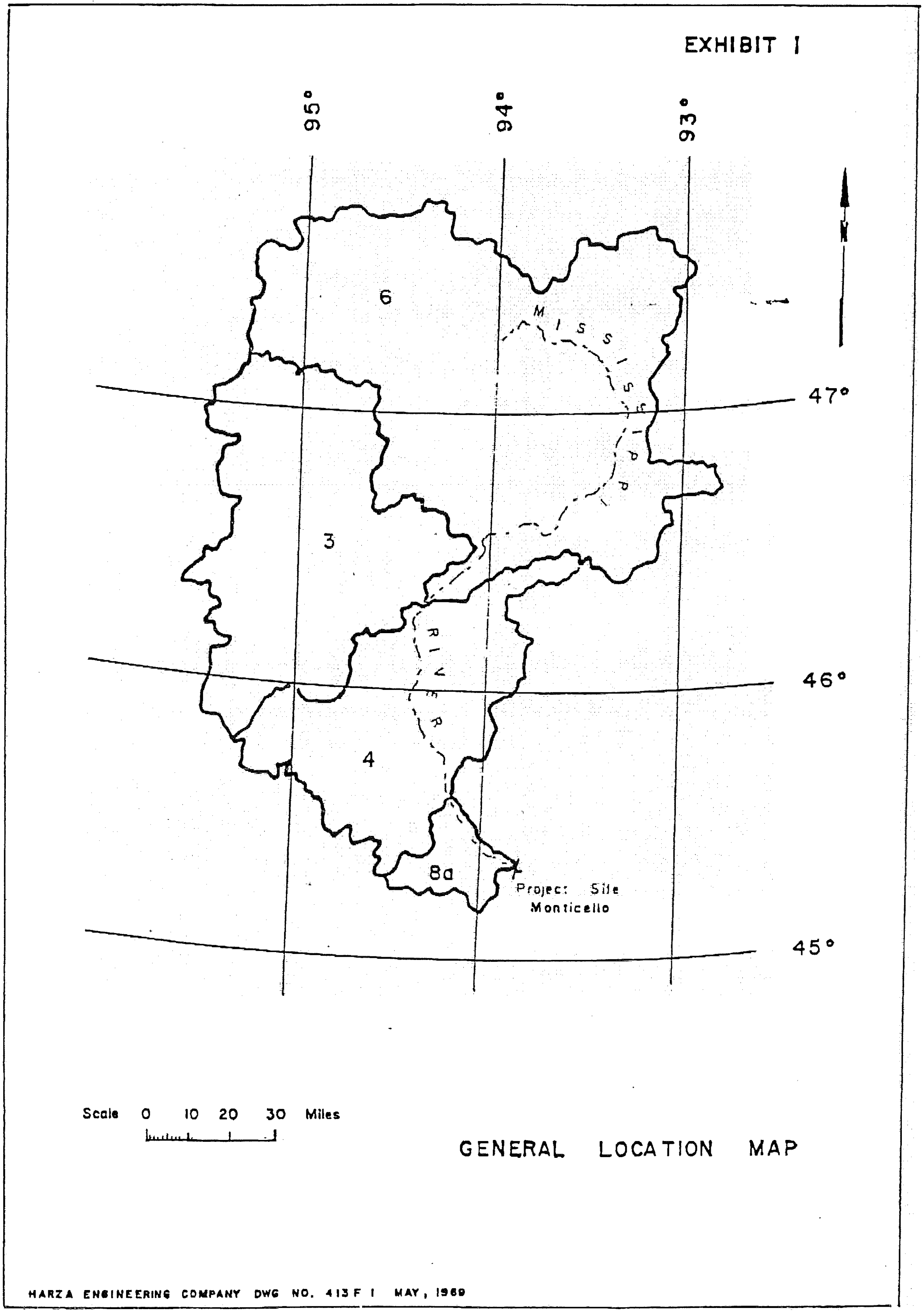


EXHIBIT I
95°
94°
93°
47°
46°
45°
6
3
4
8a
MISSISSIPPI
RIVER
Project Site
Monticello
Scale 0 10 20 30 Miles
GENERAL LOCATION MAP
HARZA ENGINEERING COMPANY DWG NO. 413 F I MAY, 1969

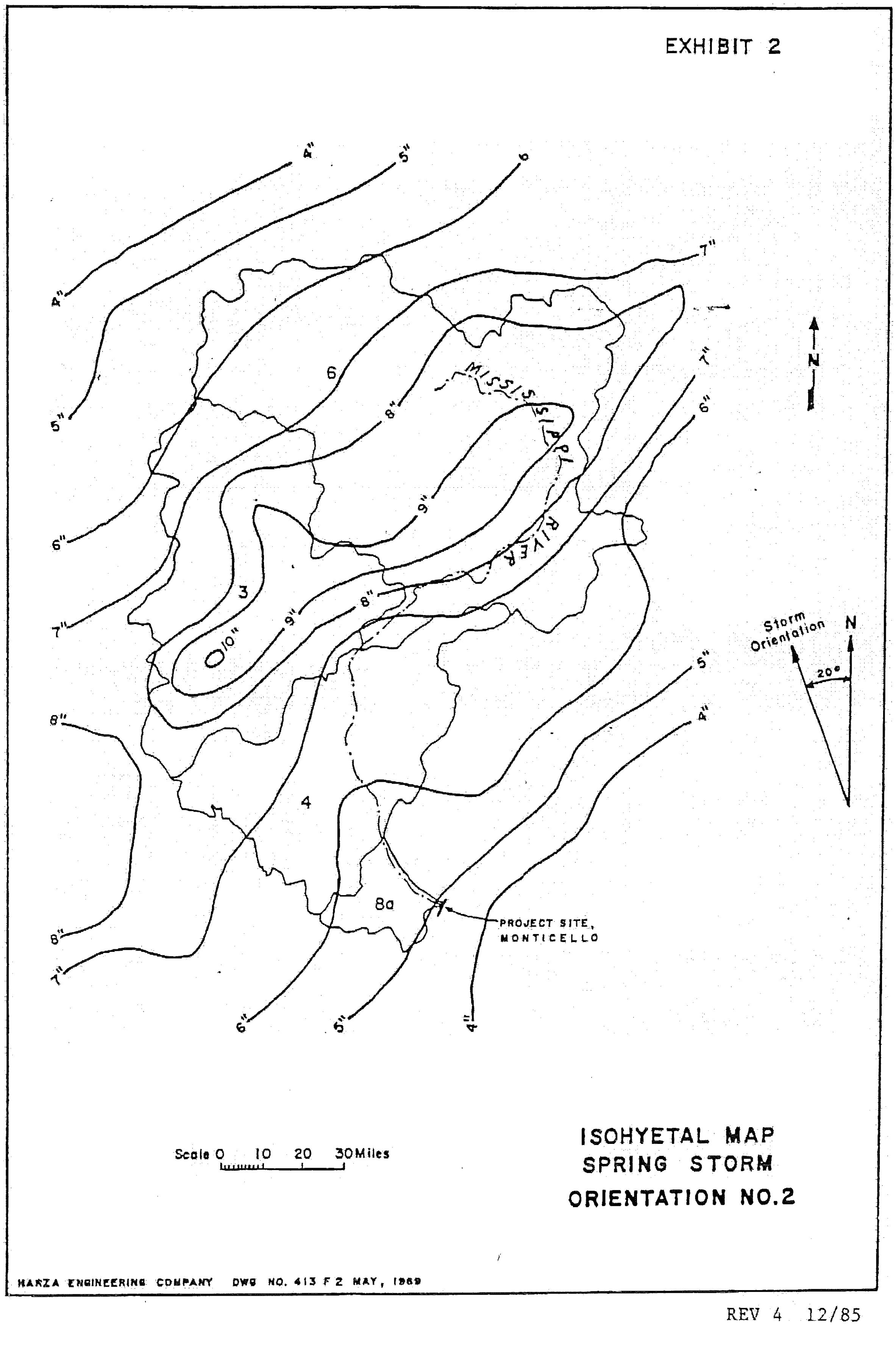
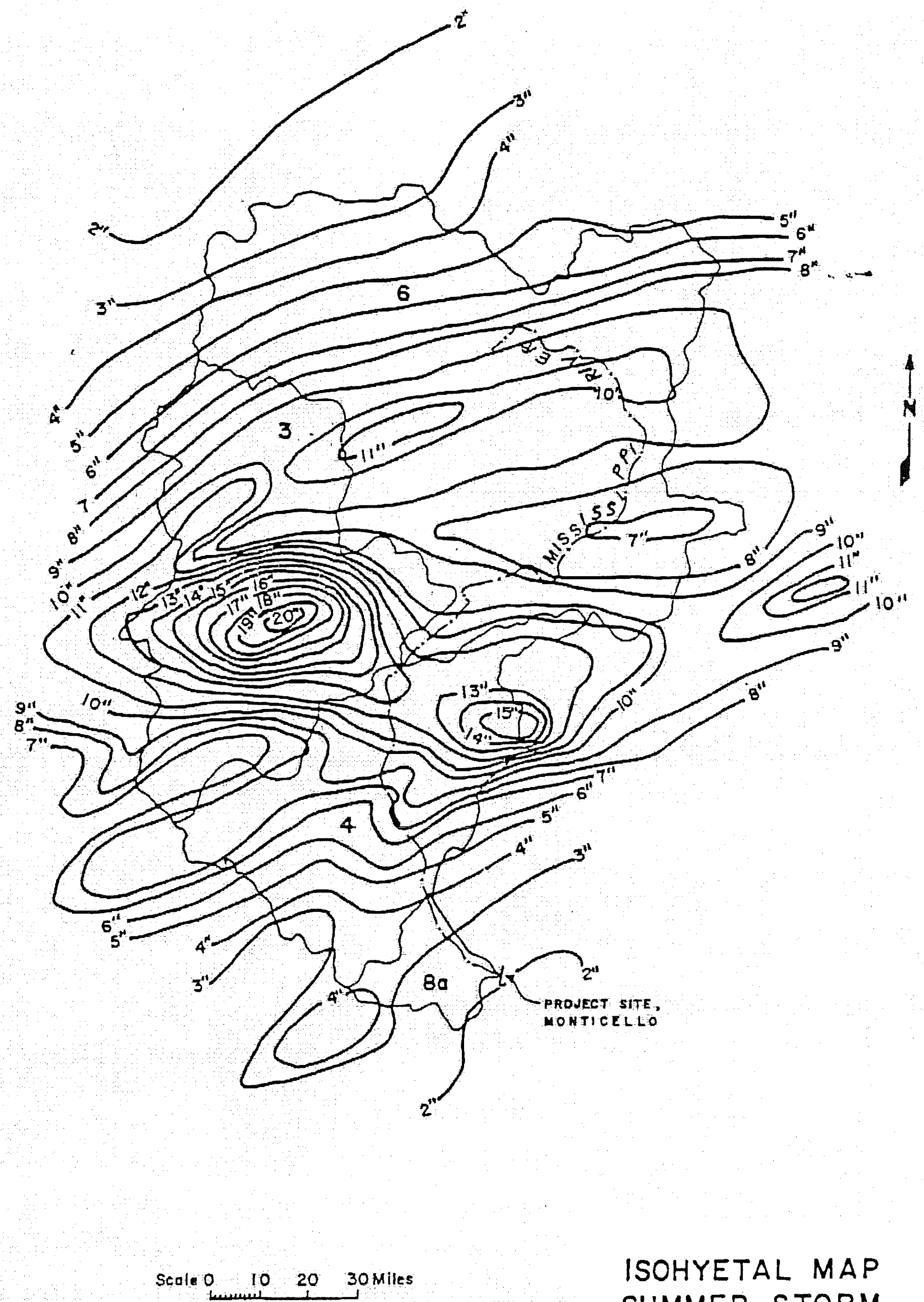


EXHIBIT 2
4"
5"
6"
7"
8"
9"
10"
6
3
4
8a
MISSISSIPPI RIVER
N
Storm Orientation
20°
PROJECT SITE, MONTICELLO
Scale 0 10 20 30 Miles
ISOHYETAL MAP
SPRING STORM
ORIENTATION NO.2
HARZA ENGINEERING COMPANY DWG NO. 413 F 2 MAY, 1969

EXHIBIT 3



ISOHYETAL MAP
SUMMER STORM
ORIENTATION NO.2

HARZA ENGINEERING COMPANY DWG NO. 413 F 3 MAY, 1969

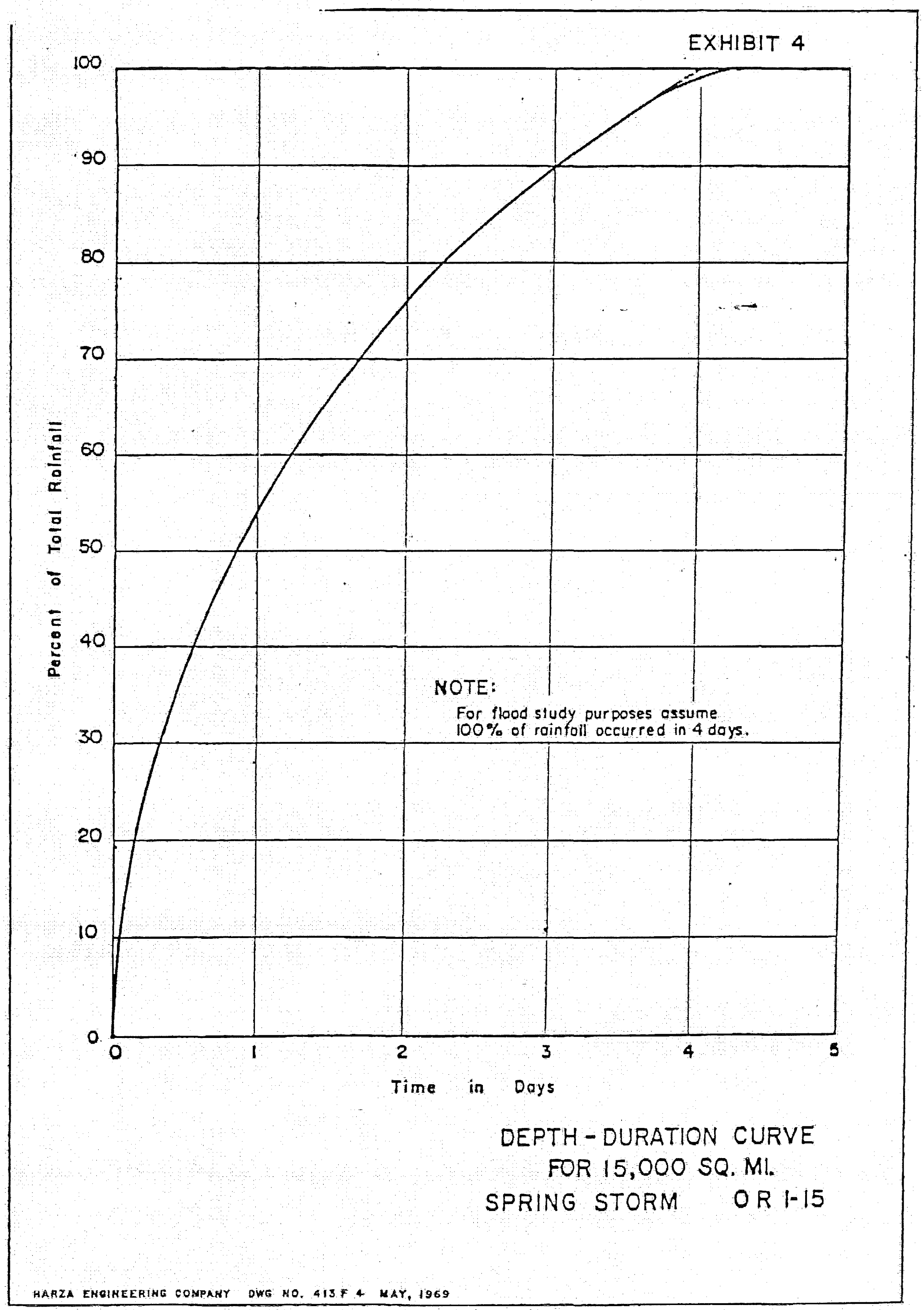
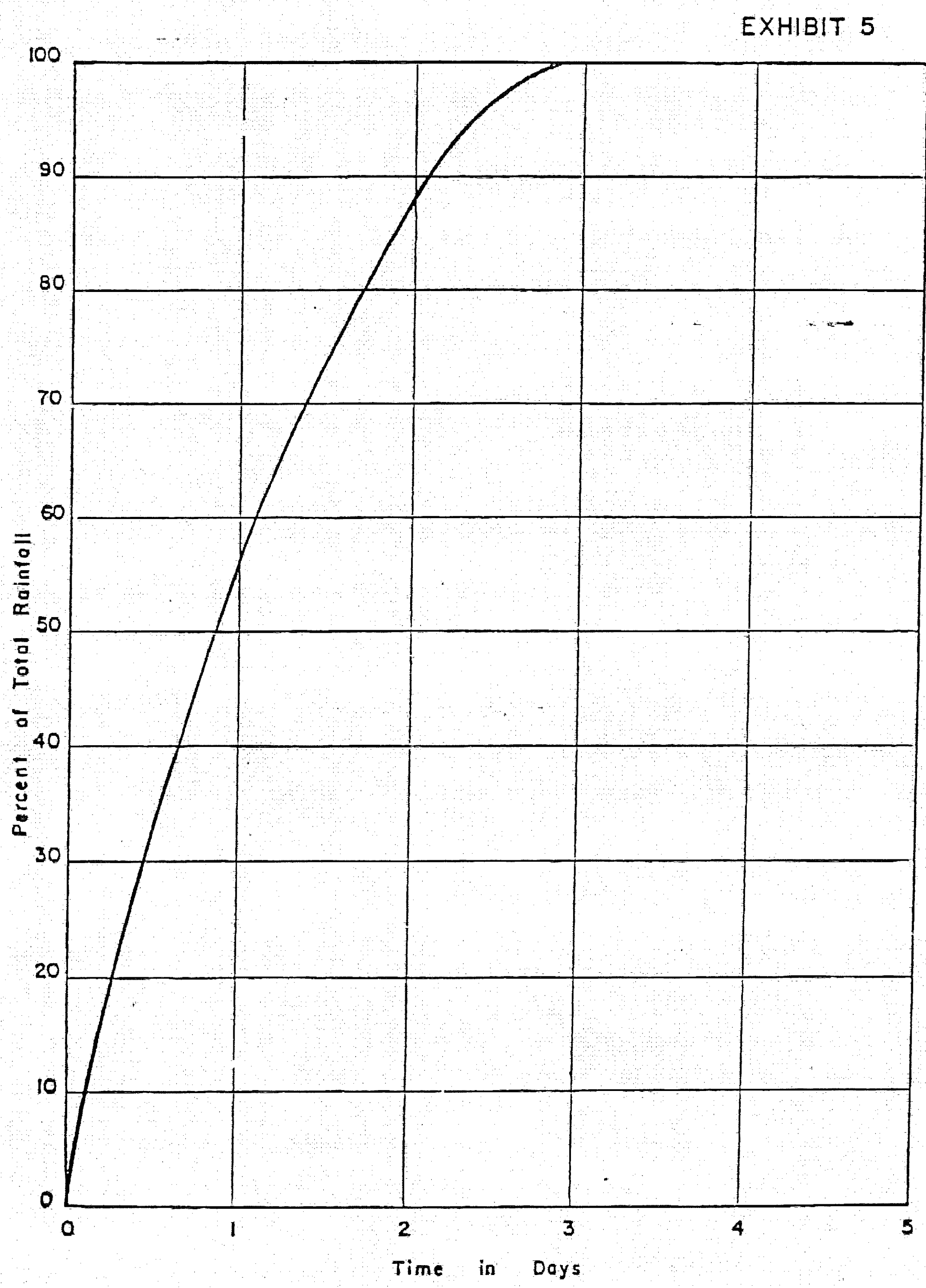


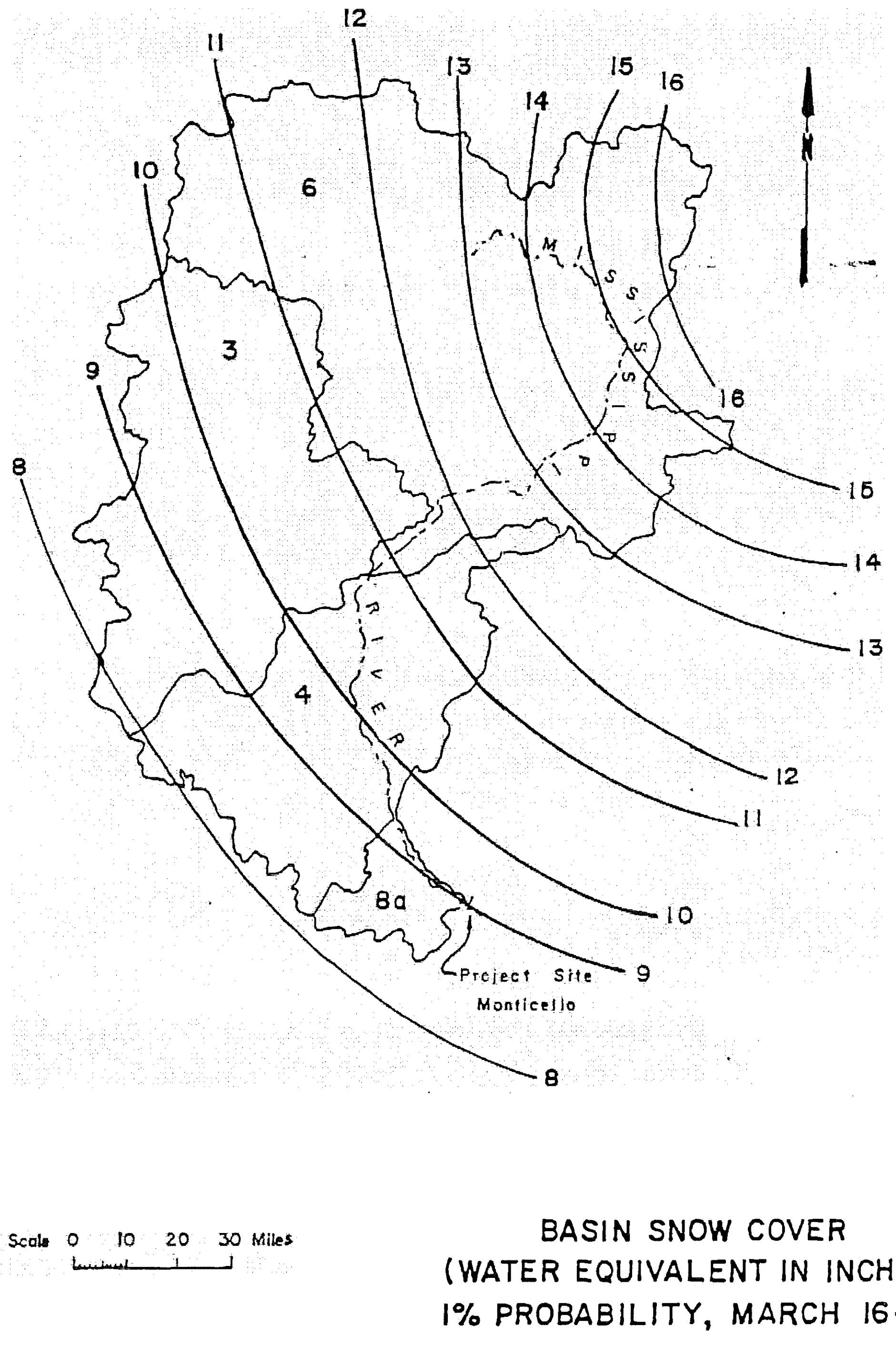
EXHIBIT 4
100
90
80
70
60
50
40
30
20
10
0
Percent of Total Rainfall
0
1
2
3
4
5
Time in Days
NOTE:
For flood study purposes assume
100% of rainfall occurred in 4 days.
DEPTH - DURATION CURVE
FOR 15,000 SQ. MI.
SPRING STORM OR I-15
HARZA ENGINEERING COMPANY DWG NO. 413 F 4 MAY, 1969



DEPTH - DURATION CURVE
FOR 15,000 SQ. MI.
SUMMER STORM UMV I-22

HARZA ENGINEERING COMPANY DWG NO. 413 F 5 MAY, 1969

EXHIBIT 6

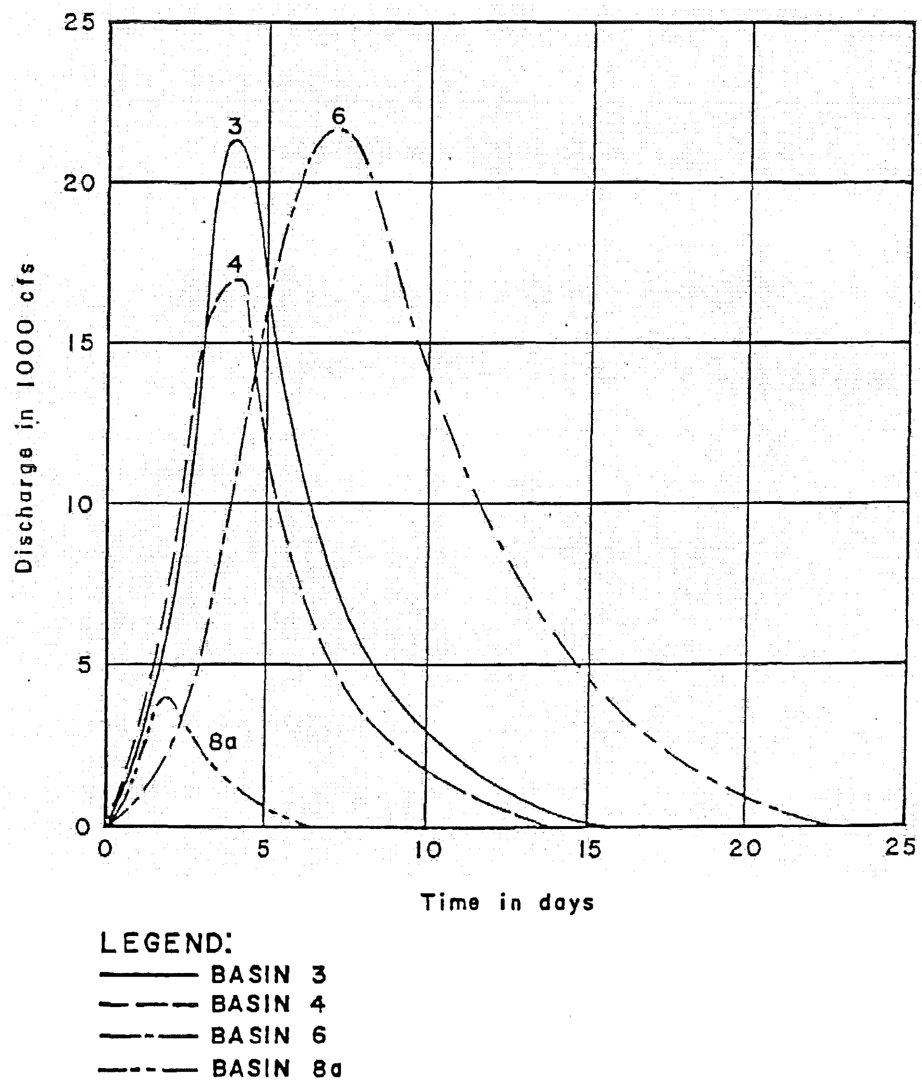


BASIN SNOW COVER
(WATER EQUIVALENT IN INCHES)
1% PROBABILITY, MARCH 16–31

HARZA ENGINEERING COMPANY DWG NO. 413 F 6 MAY, 1969

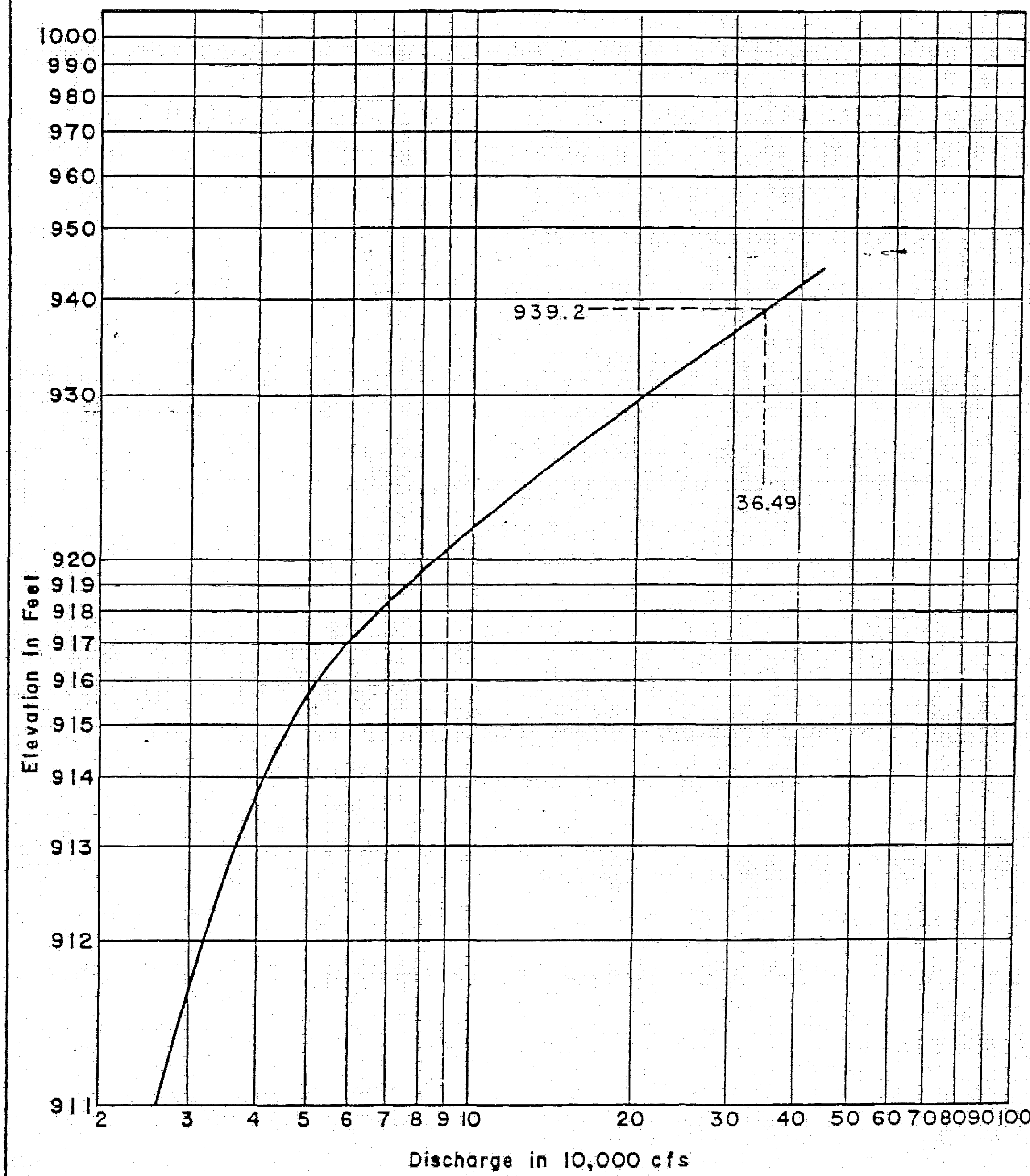
EXHIBIT 7

24-HOUR UNIT HYDROGRAPHS
BASINS 3, 4, 6 AND 8a



HARZA ENGINEERING COMPANY DWG. NO. 413 F 7 MAY, 1969

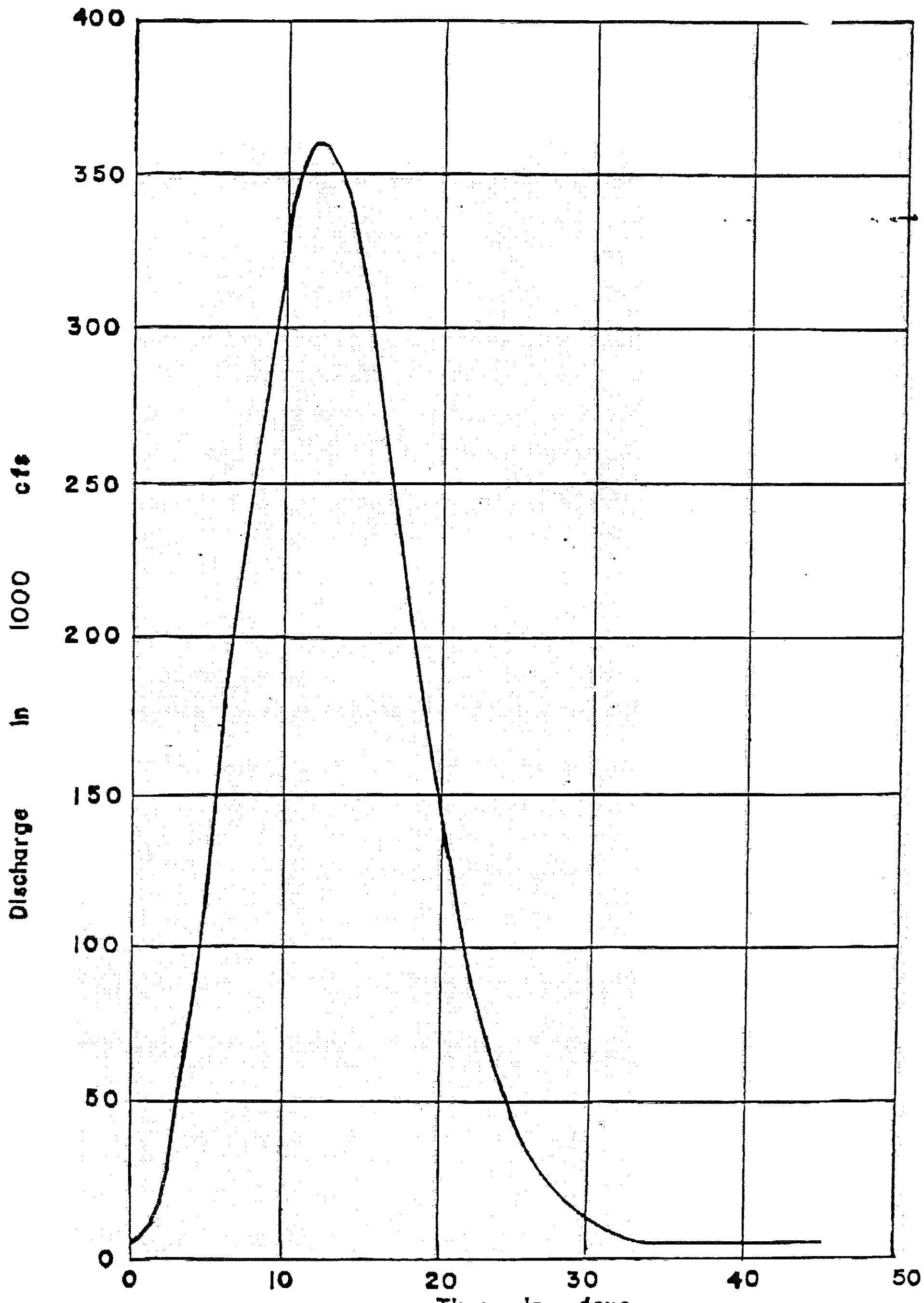
EXHIBIT 8



DISCHARGE RATING CURVE
MISSISSIPPI RIVER AT MONTICELLO, MINN.

HARZA ENGINEERING COMPANY DWG NO. 413 F 8 MAY, 1969

EXHIBIT 9



PROBABLE MAXIMUM FLOOD HYDROGRAPH
MISSISSIPPI RIVER AT MONTICELLO, MINN.

HARZA ENGINEERING COMPANY DWG NO 415F 9 MAY, 1969