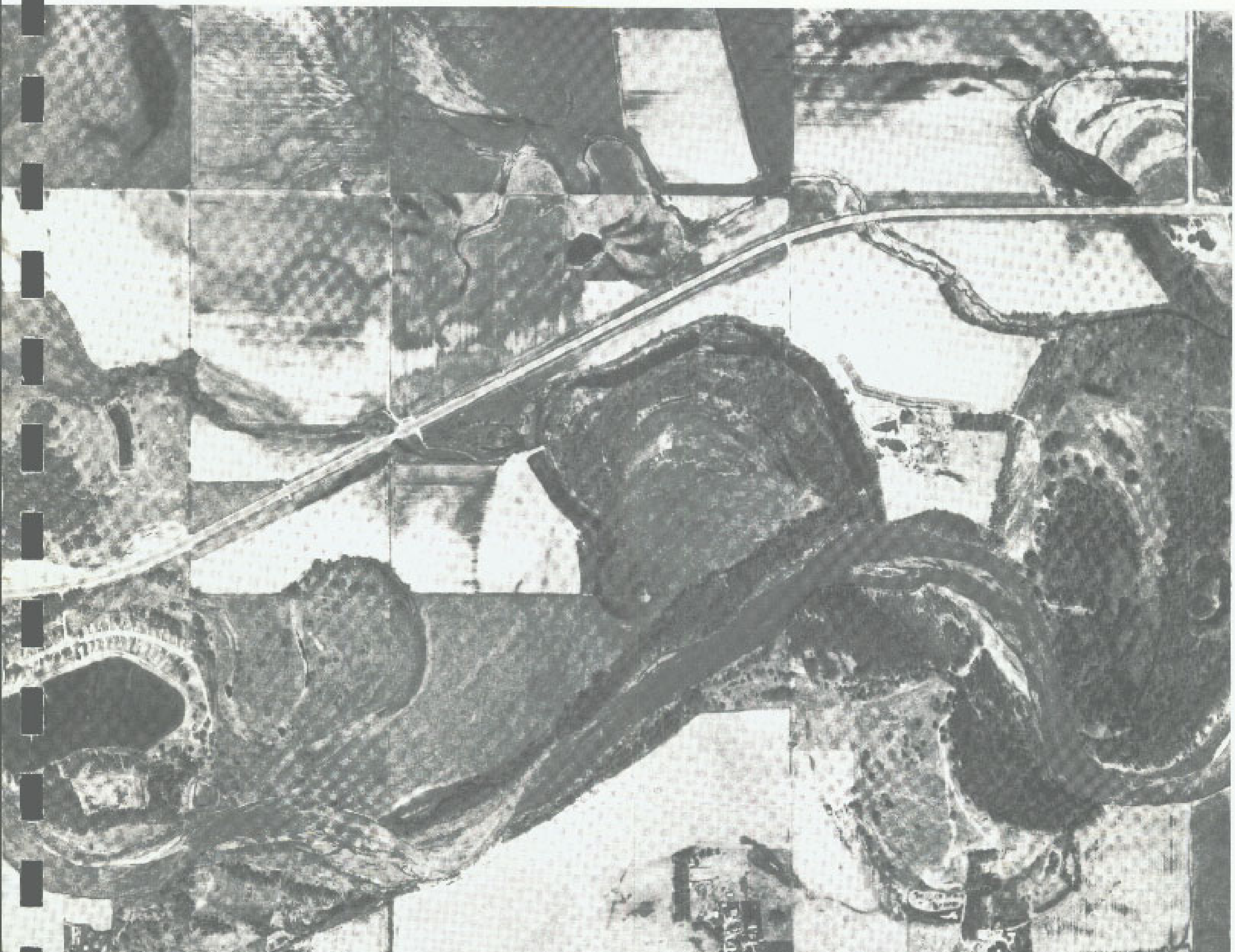
FLOOD PLAIN STUDY
ELKHORN RIVER



VOLUME 3:
MADISON COUNTY, NEBRASKA
Prepared by the
NEBRASKA NATURAL RESOURCES COMMISSION

June 1988

FLOOD PLAIN STUDY
ELKHORN RIVER

VOLUME 3
MADISON COUNTY
NEBRASKA

PREPARED BY
NEBRASKA NATURAL RESOURCES COMMISSION

301 Centennial Mall South
P.O. Box 94876
Lincoln, Nebraska 68509

Dayle E. Williamson
Director of Natural Resources

Albert E. Mathews, P.E.
Head, Flood Plain Management Section

Brian P. Dunnigan, P.E.
Project Engineer

Compiled by
Photogrammetry Section NRC

Terry L. Cartwright
Graphics-Layout Design

June 1988

TABLE OF CONTENTS

ACKNOWLEDGMENTS

1. **FLOOD DAMAGE AND CONTROL AND HYDROLOGY AND HYDRAULICS.** Missouri River Basin Commission, Platte River Basin, Nebraska, Level B Study, Technical Papers, September 1975.

2. **FLOOD HAZARD BOUNDARY MAP.** Village of Battle Creek, Nebraska. U.S. Department of Housing and Urban Development, Federal Insurance Administration, Janaury 1976.

3. **FLOOD HAZARD BOUNDARY MAP.** Madison County, Nebraska. U.S. Department of Housing and Urban Development, Federal Insurance Administration, January 1978

4. **FLOOD HAZARD BOUNDARY MAP.**Village of Meadow Grove, Nebraska. U.S. Department of Housing and Urban Development, Federal Insurance Administration, February 1976.

5. **FLOOD HAZARD BOUNDARY MAP.**City of Tilden, Nebraska. U.S. Department of Housing and Urban Development, Federal Insurance Administration, July 1975.

6. **FLOOD INSURANCE STUDY.**City of Norfolk, Nebraska. Federal Emergency Management Agency, Federal Insurance Administration, September 1980.

7. **FLOOD PLAIN MANAGEMENT: AN APPORACH FOR OHIO.** Battelle-Columbus Laboratories, Ohio State University, Dobson-Linablom Associates, Inc., August 1971.

8. **GUIDE FOR SELECTING ROUGHNESS COEFFICIENT "N" VALUES FOR CHANNELS.** Guy B. Fasken, U.S. Department of Agriculture, Soil Conservation Service, December 1963.

9. **GUIDELINES FOR DETERMINING FLOOD FLOW FREQUENCY: BULLETIN #17B.** U.S. Department of the Interior, Geological Survey, Office of Water Date Coordination, Revised September 1981 with Editorial Corrections March 1982.

10. **HEC-2 WATER SURFACE PROFILES: USERS MANUAL.** U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California, September 1982.

11. **LOWER ELKHORN NATURAL RESOURCES DISTRICT GROUNDWATER MANAGEMENT PLAN.** Olsson Associates Consulting Engineers-Architects, December 1985.

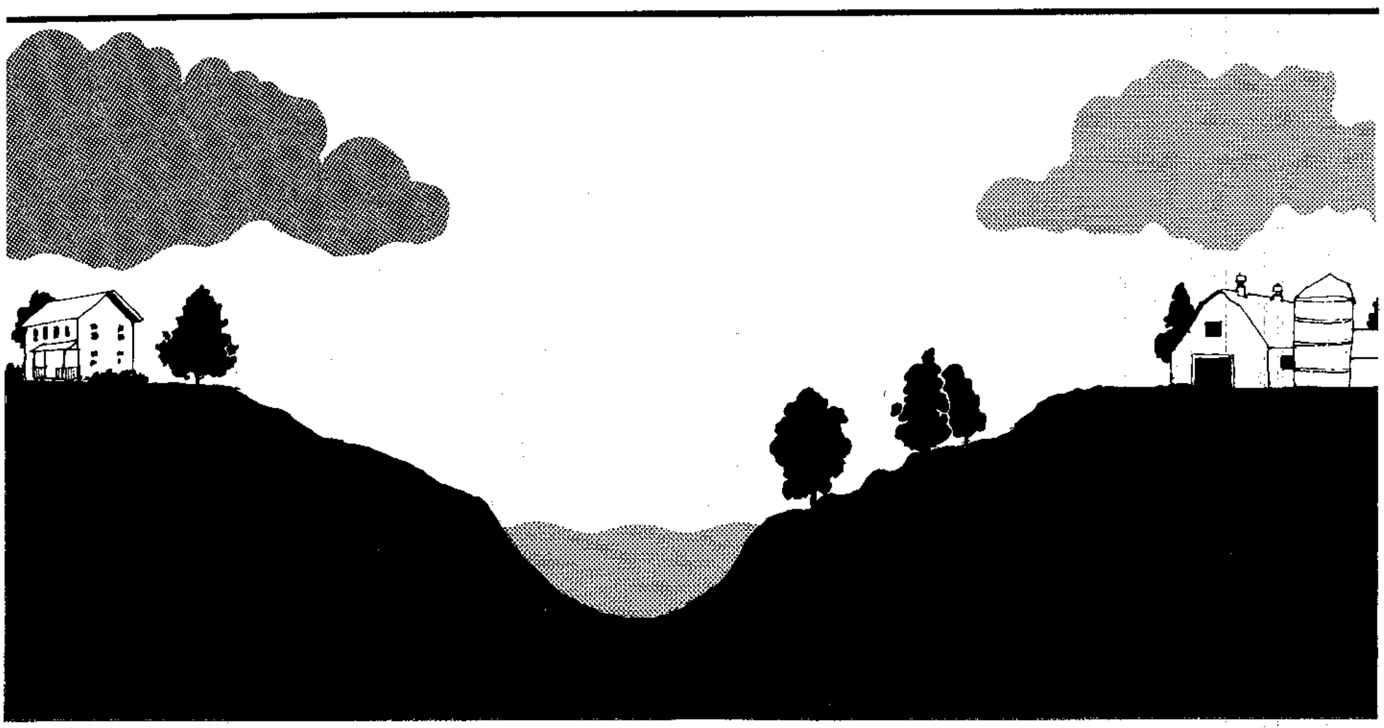
12. **WATER SUPPLIES AND THE LAND - THE ELKHORN RIVER BASIN OF NEBRASKA.** Ray Bentall and Others, Conservation and Survey Division, University of Nebraska-Lincoln, April 1976.

INTRODUCTION

A major component of a river or stream is the adjoining land area which, in the event of a flood, helps to carry or store excess flow. This area is a **flood plain**. As man develops and builds structures in flood plains, flood hazards are created. ~~Flood hazards~~ can be of such severe magnitude that action must be taken to control the development of flood plains.

The **1983 Nebraska Flood Plain Management Act** directs the Nebraska Natural Resources Commission (NNRC) to prepare maps adequate to develop or support reasonable flood plain regulation by local governments. This report presents the results of the flood plain study done on the **Elkhorn River** from the **Stanton-Madison county line upstream to the Madison-Antelope county line.**

The contents of the report include engineering data, maps, and profiles indicating the approximate extent of flooding which could be expected in the event of a future 100-year flood under existing conditions. The information, as presented, is intended to be used as an aid in the identification of local flood problems to promote proper land use in areas which are subject to flooding. It should be emphasized that the flood hazards presented here are evaluated as of the date of this report and are subject to change with additional developments in the flood plain. Special plans and recommendations for the solution of flood problems are not included in this report as these are properly the responsibility of local government. Use of flood plain regulations, zoning or subdivision regulations, floodproofing and construction of flood protection works or a combination of these approaches may be implemented by planners to guide those who intend to use the flood plain.



THE STREAM AND ITS VALLEY

The **Elkhorn River** is the fourth largest tributary of the Platte River and drains an area of about 4,480,000 acres (7,000 square miles) in northeastern Nebraska. The Elkhorn River rises in Rock County and flows generally east-southeast to Cuming County where it veers to a generally south-southeast direction which it follows to its confluence with the Platte River in Sarpy County. Surface topography in the Elkhorn River basin ranges from approximately 2,700 feet to approximately 1,100 feet above Mean Sea Level.

The entire Elkhorn River Basin is agricultural in character. The upper reaches of the basin are sparsely populated and have few incorporated communities. The lower reaches of the basin are more densely populated and have a relatively large number of incorporated communities. The population of the entire basin is approximately 117,000 persons, according to 1980 census figures.

The climate of the Elkhorn River Basin is transitional between the humid east and the semi-arid western plains. The lower reaches of the basin lie mostly in a moist-subhumid climate while the upper reaches lie mostly in a dry-subhumid climate. The basin is generally well suited for raising livestock and growing of feed and grain crops. The spring

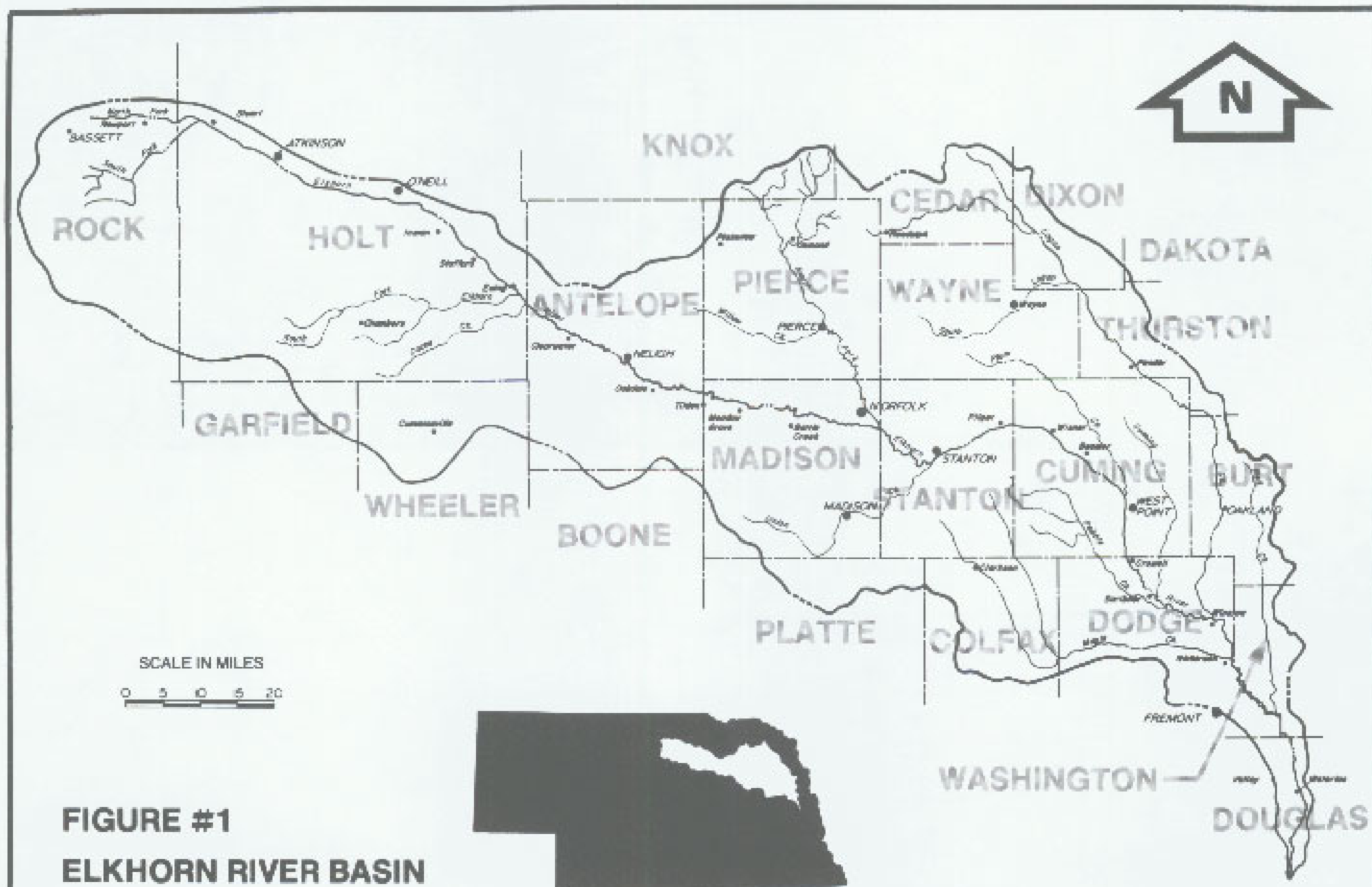


FIGURE #1
ELKHORN RIVER BASIN

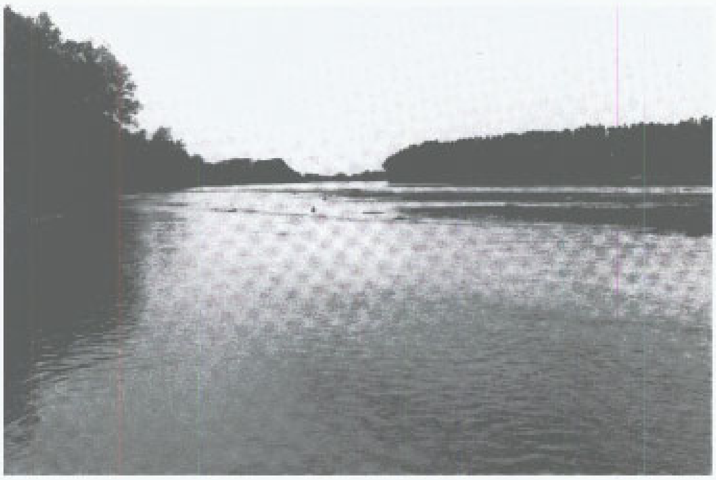
months are cool, normally with considerable rain. Summers are hot and relatively dry. Autumn is generally pleasant with occasional rains, and winters are cold with significant precipitation in the form of snow.

Average annual precipitation ranges from approximately 29 inches in lower reaches of the basin to approximately 21 inches in the upper reaches. Normally, 65 to 67 percent of the annual precipitation occurs during the growing season between May and September. The average number of frost free days is approximately 160 with the average annual temperature being about 50 degrees Fahrenheit.

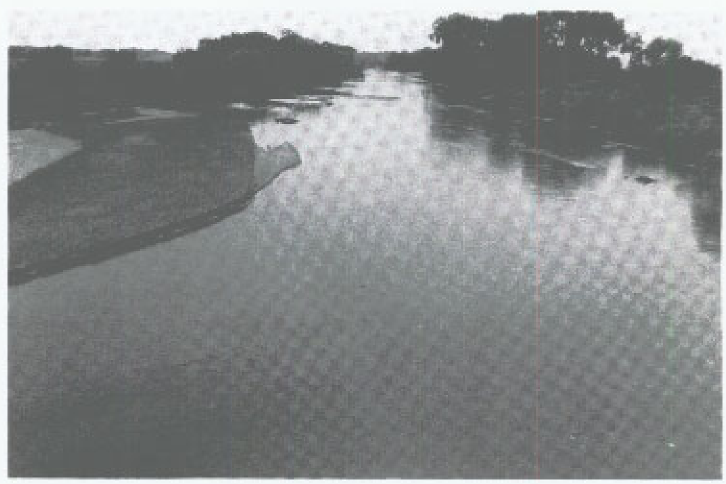
Flood records dating back to 1881 indicate that damaging floods occur within the Elkhorn River drainage area nearly every year. The extent of late winter and early spring flooding is often aggravated by ice jams.

About 354,000 acres of land in the Elkhorn River Basin are subject to inundation by a flood event expected to occur once in a hundred years. This represents about 8 percent of the land area.

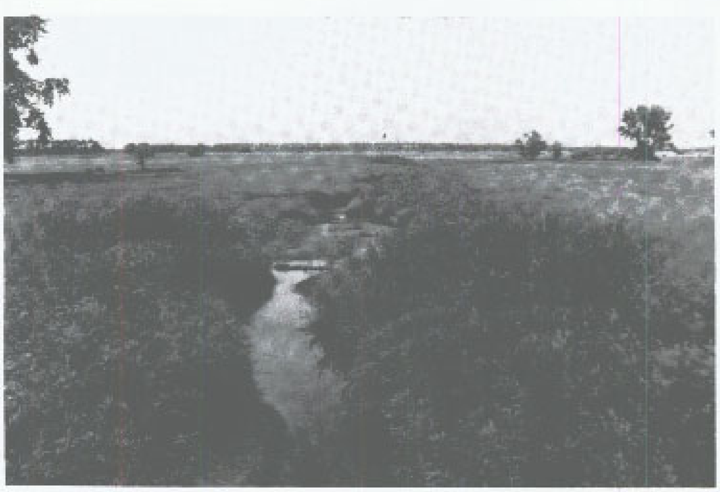
Changes in the River



Elkhorn River in Sarpy County



Elkhorn River in Madison County



Elkhorn River in Rock County

STUDIES COMPLETED

The Federal Emergency Management Agency (FEMA) completed a detailed Flood Insurance Study for the City of Norfolk on September 16, 1980. The FEMA study covers the incorporated area and area of extraterritorial jurisdiction (two-mile limit) of the city. All of the results given in this report for cross sections A through U are from the FEMA study. A new 100-year flood plain delineation for the Elkhorn River based on the profile presented in the FEMA study was prepared by the NNRC and is shown on plates 2 through 5. The floodway for this area can be found on the FEMA Floodway Maps for the City of Norfolk.

FEMA has also prepared flood maps for Battle Creek, Meadow Grove, Tilden, and Madison County.

HYDROLOGICAL REQUIREMENTS

Hydrologic analyses were carried out to establish the 100-year flood discharge. The Log Pearson III method of flood frequency analysis as outlined in the publication "Guidelines for Determining Flood Flow Frequency: Bulletin #17B", was used. The annual peak discharges obtained from the United States Geological Survey (USGS) gaging station on the Elkhorn River near Norfolk from 1940 through 1983 were used in the computations. A 100-year discharge of 30,000 cfs was calculated and adopted for use in this study and is shown in **Table 1**.

The Nebraska Department of Roads used a 100-year design discharge of 30,000 cfs on two new county bridge designs on the Elkhorn River in Madison County.

HYDRAULIC REQUIREMENTS

Valley cross sections were surveyed at representative locations throughout the study area. The location of these cross sections are shown on the Flood Area maps, and are also indicated on the Flood Elevation Profile in **Appendix C**. Cross sections are numbered consecutively moving upstream from the Stanton-Madison county line. Cross sections that include a decimal point were additional cross sections usually taken at bridges to improve accuracy in those areas.

Realistic adjustments were made to the valley cross section for use in the computer program to eliminate areas which would be ineffective in carrying floodwater. Such areas included gravel pits, small lakes and ponds, and small tributaries or ditches running nearly parallel to the cross sections.

Measurements at bridges were taken to establish the area and shape of the bridge opening, size and location of piers, and the elevation of the low steel.

TABLE 1

100-YEAR FLOOD DISCHARGES
LISTED BY REACH OF THE ELKHORN RIVER

REACH XSEC to XSEC	Q_{100} (cubic feet per second)
Start of Study - U	41,900*
104 - 140.3	30,000

* This information is from the FEMA Flood Insurance Study for the City of Norfolk.

This information is used to hydraulically model the bridge structure.

Values of Manning's roughness coefficient were selected for each cross section based on channel and overbank conditions along that cross section. These "n" values were varied horizontally along each cross section to reflect the variations in shape and size of cross sections, obstructions, vegetation, and the meandering of the channel.

HYDRAULIC ANALYSIS

The computer program entitled, "HEC-2 Water Surface Profiles", obtained from the Hydrologic Engineering Center of the Corps of Engineers in Davis, California, was used to determine the water surface profile of the 100-year flood. **Appendix B** contains a short description of the HEC-2 computer program.

Energy losses caused by structures such as bridges and culverts were modeled using either the "normal bridge" routine or the "special bridge" routine. Bridge data used for the modeling is given in **Table 2**.

After a natural water surface profile was determined for the 100-year flood, the cross sections were modified to permit an encroachment on the 100-year flood plain which would cause a maximum rise of one foot in the water surface elevation, thus establishing the boundaries of the floodway. This modification was accomplished by using an option in the HEC-2 program which establishes flood plain encroachments. This option computes encroachments so that the conveyance within the encroached section at a water surface elevation one foot higher than the natural water surface elevation is equal to the original conveyance. The encroachments were determined so that an equal loss of conveyance *(at the higher elevation)* occurred on each overbank, if possible. If half the conveyance loss could not be obtained on one overbank the difference was made up, if possible, on the other overbank except that encroachments were not allowed to fall within the main channel.

During floods, debris collecting on bridges and culverts could reduce the conveyance of the flood plain resulting in greater water depth *(backwater effect)* upstream of the structures. Since the occurrance and amount of debris are indeterminate factors, only the physical characteristics of the structures were considered in computing the water surface profiles. Similarly, maps of the flooded areas show only the backwater effects of the bridges and culverts and do not reflect any increase in water surface elevation which might be caused by debris collecting against the structures or by deposition of silt in the stream channel under structures.

Water velocities during floods depend largely on the size and shape of the cross sections, condition of the stream and valley, and the bed slopes *(all of which could vary at different locations on a stream).* During a 100-year flood in the study area, flood water velocities ranged from approximately 0.5 feet per second to approximately 9.9 feet per second. Water flowing at the higher velocities are capable of causing erosion to streambanks and fill around

TABLE 2

BRIDGES ACROSS THE ELKHORN RIVER IN MADISON COUNTY, NEBRASKA

Bridges are assigned the number of the nearest downstream cross section. Elevations are in feet above Mean Sea Level.

		ELEVATIONS			
Bridge Number	Identification	Stream Bed	Low Steel	Bridge Floor	100-year Flood Elev. Upstream
* G	1st Street	1502.2	1516.1	1521.4	1513.2
* L	U.S. Highway 81	1506.9	1520.3	1525.8	1518.2
* O	Railraod	1512.5	1524.6	1529.2	1523.0
106.2	County Road	1523.6	1537.2	1542.8	1534.7
108.1	Railroad	1526.3	1540.8	1543.6	1537.5
112.2	County Road	1546.5	1555.0	561.5	1556.7
116.2	U.S. Highway 275	1562.6	1574.5	1579.5	1572.8
119.2	County Road	1568.9	1579.9	1585.4	1577.1
130.2	County Road	1610.3	1624.1	1629.0	1621.6
136.2	County Road	1626.4	1639.4	1640.9	1637.1
140.2	County Road	1647.4	1657.4	1661.5	1656.6

* This information is from the FEMA Flood Insurance Study for the City of Norfolk.

bridge abutments as well as transporting large objects. In developed areas, such as town or farmsteads, higher water velocities would tend to increase as floodwaters are forced to flow around buildings and other obstacles which inhibit flow. Point velocities in thses areas may be much higher than the average velocities which are shown.

SUMMARY OF RESULTS

Table 3 contains the 100-year flood water surface elevation, floodway elevations, depth of floodwaters in the channel, and average floodwater velocities in the channel and overbank areas at each cross section location. Also included in this table is the total width of the floodway at each cross section. All elevation in this report are based on bench marks using the United States Geological Survey (USGS) monuments through the study reach and are referred to mean sea level. A complete description of the USGS and the NNRC surveyed bench marks used in this study can be obtained from the local Soil Conservation Service (SCS) office, the local Natural Resources District (NRD) office, or from the Natural Resources Commission.

All areas contained in the flood plain are shown on the Flood Area maps in **Appendix C**. An index map showing the general relationship of these areas is found on Plate 1. The aerial photographs which were used for the background of these maps were taken at an altitude of 15,000 feet by Western Air Maps, Inc. of Lenexa, Kansas, in May of 1985. Channel cross sections used in developing the computer model were originally surveyed in the fall of 1981 and were updated in January and February of 1987. Site specific surveys were made at locations around Norfolk which had changed since the original survey was completed. Appropriate corrections in the delineations were made to reflect these changes.

On the aerial photographs in **Appendix C**, the area within the 100-year flood plain is outlined in red. Therefore, the area inside this red line would be inundated in the event of a 100-year flood. The area shaded in yellow represents the floodway. This area is reserved in order to discharge the 100-year flood without cumulatively increasing the water surface elevation by more than one foot *(see Figure 2)*.

Actual flood limits may vary from those shown on the Flooded Area Plates due to map limitations, difficulty in interpretation between cross sections, and changes in surface characteristics since study completion. In any case, the floodwater elevation *(as taken from the Flood Elevation Profile Plates in Appendix C)* should be the determining factor when deciding whether or not a specific property is susceptible to flood damage.

Water flowing at high velocities is capable of causing erosion to streambanks and fill around bridge abutments as well as transporting large objects.

In developed areas, higher water velocities would tend to increase as flood waters are forced to flow around building and other obstacles which inhibit flow.

TABLE 3

SUMMARY OF RESULTS: ELKHORN RIVER FLOOD PLAIN STUDY MADISON COUNTY

Cross Section Number	Cross Section Location (River Miles From Stanton-Madison Co. Line)	100-Yr. Flood Water Surface Elevation (M.S.L.)	Depth of Flood Waters In Channel (ft.)	100-Year Flood Average Velocity (ft./sec.)*			Floodway Elevation (M.S.L.)	Total Floodway Width (ft.)
				Left Overbank	In Channel	Right Overbank		
A	0.36	1502.3					1502.9	3824
B	0.70	1504.3					1505.0	2500
C	1.04	1506.4					1506.9	1803
D	1.16	1508.0					1508.4	2000
E	1.45	1509.9					1510.2	1994
F	1.84	1511.8					1511.9	2500
G	2.14	1513.2					1513.8	2915
H	2.22	1513.6					1514.3	2900
I	2.40	1513.9					1514.7	2362
J	2.53	1515.3					1516.1	2619
K	2.78	1516.6	This information is from the FEMA Flood Insurance Study for the City of Norfolk				1517.2	2900
L	3.16	1518.2					1519.2	1800
M	3.23	1520.0					1520.4	1360
N	3.70	1521.3					1522.3	2220
O	4.16	1523.0					1523.9	2080
P	4.13	1526.2					1526.3	1607
Q	4.50	1526.7					1526.7	817
R	4.78	1527.3					1527.5	1162
S	5.14	1528.7					1529.4	2010
T	5.46	1530.4					1531.0	1600
U	5.94	1531.9					1532.5	1456
105	6.02	1532.1	9.7	1.1	4.9	**	1533.1	1800
106	6.38	1533.8	10.5	1.2	8.0	1.5	1534.7	366
106.1	6.47	1534.6	11.0	**	8.7	**	1535.6	366
106.2	6.48	1534.7	11.1	**	8.7	**	1535.7	366
106.3	6.56	1536.3	11.9	1.0	5.8	1.5	1536.8	988
107	6.81	1537.8	11.5	1.0	6.3	3.0	1538.5	694
108	6.81	1537.4	11.1	**	8.3	**	1538.4	694
108.1	6.81	1537.5	11.2	**	8.1	**	1538.5	694
108.2	6.82	1538.2	11.9	1.1	5.7	2.8	1538.7	694
109	7.62	1541.8	11.9	1.5	4.6	1.6	1542.7	1600
110	8.34	1544.2	11.3	1.0	5.3	1.4	1545.1	2150
110.5	9.07	1547.1	10.3	0.6	4.2	1.3	1548.1	2780
111	9.72	1550.0	9.4	1.1	6.6	2.0	1550.9	1450
112	10.68	1556.0	10.0	1.4	5.5	1.2	1556.9	2880
112.1	10.78	1556.4	9.9	1.5	5.7	1.2	1557.3	3126
112.2	10.78	1556.7	10.2	1.3	5.2	1.2	1557.5	3126
112.3	10.87	1557.0	10.0	1.4	5.5	1.2	1557.8	3370
113	11.72	1560.2	8.8	1.5	4.3	1.2	1561.1	2880
114	12.69	1564.2	7.4	1.6	6.5	2.0	1565.2	3040
115	13.50	1569.1	9.1	1.7	5.4	1.5	1569.4	2300
116	13.97	1570.9	9.2	2.1	6.1	1.7	1571.3	2350
116.1	14.06	1571.3	8.8	2.6	8.0	**	1571.8	2055
116.2	14.07	1572.8	10.2	2.0	5.5	**	1573.7	2055
117	14.10	1573.1	10.1	1.6	4.6	1.3	1574.0	2200
118	14.50	1573.9	9.1	1.0	2.8	1.3	1574.7	4350
119	15.32	1575.6	6.8	1.9	5.1	2.0	1576.0	4100
119.1	15.35	1575.8	6.9	1.8	4.8	1.9	1576.2	4100
119.2	15.36	1577.1	8.2	1.2	3.0	1.3	1577.4	4100
119.3	15.39	1577.2	8.2	1.3	3.0	1.3	1577.5	4100
120	16.18	1580.0	6.2	1.6	6.8	2.2	1581.0	3650
121	17.11	1585.8	9.4	1.0	4.6	1.5	1586.8	2740
122	17.60	1587.2	9.5	0.6	3.6	1.0	1588.2	3131
122.5	18.18	1589.2	6.9	**	4.6	1.7	1590.0	2631
123	18.76	1592.6	8.7	2.9	7.9	1.7	1593.5	3150
124	19.66	1598.0	8.5	**	4.4	1.8	1598.0	2946
125	20.32	1601.1	9.6	1.6	8.0	1.7	1601.7	1777
125.5	20.94	1605.7	10.2	1.6	6.4	1.0	1606.7	3200
126	21.83	1608.9	10.6	1.5	5.2	1.3	1609.9	2630
127	22.40	1610.3	9.8	1.2	2.9	1.2	1611.3	2660

***No flow in this overbank area.*

Continued

TABLE 3

Continued

Cross Section Number	Cross Section Location (River Miles From Stanton-Madison Co. Line)	100-Yr. Flood Water Surface Elevation (M.S.L.)	Depth of Flood Waters In Channel (ft.)	100-Year Flood Average Velocity (ft./sec.)* Left Overbank	In Channel	Right Overbank	Floodway Elevation (M.S.L.)	Total Floodway Width (ft.)
128	22.85	1611.1	9.1	1.4	8.7	2.0	1612.1	2250
129	23.78	1617.6	10.3	1.0	5.3	1.5	1618.1	2701
130	24.33	1619.8	9.8	1.7	4.8	1.9	1620.7	2141
130.1	24.39	1620.0	9.7	**	5.7	2.2	1621.0	2321
130.2	24.40	1621.6	11.3	**	3.8	1.7	1622.0	2321
130.3	24.44	1621.7	11.2	1.0	3.2	1.4	1622.1	2441
131	25.05	1622.7	7.7	1.0	3.0	1.5	1623.4	2700
132	25.39	1623.9	6.9	3.1	7.1	2.1	1624.6	2080
133	26.04	1629.3	11.1	1.6	7.0	1.2	1629.7	2770
134	26.54	1631.3	10.4	1.3	3.8	1.1	1632.0	2917
135	26.98	1632.8	9.6	2.4	7.3	1.9	1633.7	2310
136	27.57	1636.8	10.8	1.3	6.3	2.9	1637.0	486
136.1	27.63	1636.8	10.4	**	9.9	**	1637.2	312
136.2	27.63	1637.1	10.7	**	9.6	**	1637.3	312
136.3	27.68	1638.7	12.0	1.1	5.8	2.2	1638.7	680
137	28.43	1642.0	11.7	0.5	6.0	1.5	1642.8	1099
138	30.52	1648.2	7.2	1.0	3.6	1.4	1649.0	3791
139	31.23	1651.2	7.2	2.1	8.9	3.6	1651.9	1870
140	31.87	1655.7	8.4	1.3	4.4	1.2	1656.7	2210
140.1	31.92	1655.9	8.5	1.3	4.3	1.2	1656.9	2200
140.2	31.93	1656.6	9.2	1.1	3.6	1.0	1657.3	2200
140.3	31.97	1656.7	9.2	1.1	3.6	1.0	1657.4	2250

*** No flow in this overbank area.*

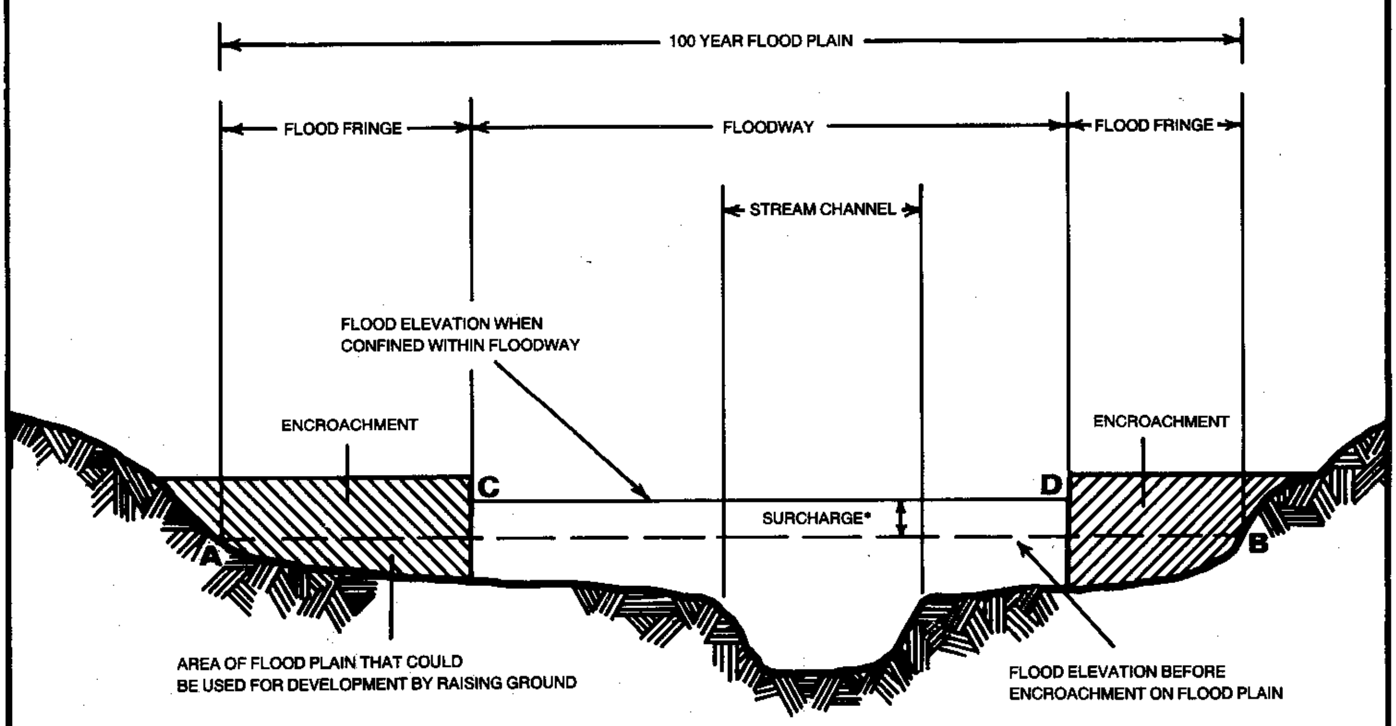


FIGURE #2

FLOODWAY SCHEMATIC

LINE A-B IS THE FLOOD ELEVATION **BEFORE** ENCROACHMENT
LINE C-D IS THE FLOOD ELEVATION **AFTER** ENCROACHMENT

*SURCHARGE NOT TO EXCEED 1.0 FOOT

APPENDIX A

DEFINITIONS

1. **ANNUAL PEAK DISCHARGE** - The highest flow rate recorded at a given stream location during a specified year.

2. **BENCH MARK** - A permanent marker or monument of known elevation and horizontal location.

3. **CONVEYANCE** - A measure of the carrying capacity of a stream reach.

4. **CRITICAL DEPTH** - The stream flow depth when the Froude number equals unity. Also the stream depth when specific energy is at a minimum.

5. **CROSS SECTION** - "XSEC". Survey ground points along a defined line that show the trend of the flood plain.

6. **DISCHARGE** - The volume rate of stream flow usually expressed in cubic feet per second.

7. **ENCROACHMENT** - Any natural or mad-made obstructions in the flood plain which adversely affects the natural passage of flood waters.

8. **FLOOD** - An overflow of water onto normally dry land. Floods have two essential characteristics: the inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river, stream, ocean, lake, or other body of standing water.

9. **FLOOD FREQUENCY** - The average frequency statistically determined, for which it is expected that a specific flood level or discharge may be equalled or exceeded.

10. **FLOOD FRINGE** - That portion of the 100-year flood plain which is outside the floodway in which total encroachment may occur *(see Figure 2)*.

11. **FLOOD STAGE** - The elevation at which overflow of the natural banks of a river, stream, or watercourse begins in the reach or area in which the elevation is measured.

12. **FLOODWAY** - The channel of a river or stream and the adjacent land areas that are necessary to be reserved in order to discharge the 100-year flood without cumulatively increasing the water surface elevation more than one foot *(see Figure 2)*. The area included within the floodway on the Elkhorn River is shown as a shaded yellow area on the Flooded Area maps in Appendix C.

13. **GAGING STATION** - A particular site on a stream, river, canal, lake, or reservoir where systematic observations of gage height or discharge are collected.

14. **HYDRAULICS** - That branch of engineering dealing primarily with the flow of water and the application of fluid mechanics.

15. **HYDROLOGY** - The scientific study of the various processes involved in the hydrologic cycle.

16. **LEFT OVERBANK** - The bank which lies to the left side of the stream as one looks downstream.

17. **100-YEAR FLOOD OR BASE FLOOD** - The flood having a one percent chance of being equalled of exceeded in magnitude in any given year. Contrary to popular belief, it is not a flood occurring once every 100 years. The 100-year flood magnitude is based on statistical analysis of stream flow records available for a particular stream and analysis of rainfall and runoff characteristics in a particular region or watershed.

18. **100-YEAR FLOOD PLAIN** - The area adjoining a river, stream, or watercourse covered by water in the event of a 100-year flood. The boundaries of the 100-year flood plain for the Elkhorn River in Madison County are shown as red lines on the Flooded Area maps in Appendix C. The elevations of the 100-year flood in this area are shown on the Flood Elevation Profile in Appendix C.

19. **PHOTOGRAMMETRY** - The science of making reliable measurements from aerial photographs.

20. **REACH** - A longitudinal segment of a river or stream.

21. **RIGHT OVERBANK** - The bank which lies to the right side of the stream as one looks downstream.

22. **ROUGHNESS COEFFICIENT** (Mannings) - Denoted by "n" is a measure of surface roughness.

23. **STAGE** - The elevation of floodwaters above some reference datum, that datum usually being the established elevation of a stream gage.

24. **SUBCRITICAL FLOW** - Flow in an open channel with a mean velocity less than the velocity which occurs at critical depth.

25. **SUPERCRITICAL FLOW** - Flow in an open channel with a mean velocity equal to or greater than the velocity which occurs at critical depth.

26. **TOPOGRAPHIC MAP** - Maps which show planimetric detail plus terrain relief.

27. **WATER SURFACE PROFILE** - A graph showing the relationship of water surface elevation to location, the latter generally expressed as a distance upstream from some reference point.

APPENDIX B

GENERAL OUTLINE OF HEC-2 PROGRAM
as used by the Nebraska Natural Resources Commission
Flood Plain Management Section

A. General

The HEC-2 Water Surface Profiles Computer Program was developed by the Corps of Engineers Hydrologic Engineering Center in Davis, California, in 1972. The program has been continuously updated by the use of error corrections and modifications.

The program computes and plots the water surface profile for river channels of any cross section for either subcritical or supercritical flow conditions. The effects of various hydraulic structures such as bridges, culverts, weirs, embankments, and dams may be considered in the computations. The principal use of the program is for determining profiles for various frequency floods for both natural and modified conditions. The latter may include channel improvements, levees and floodways. Input may be in either English or Metric units.

The Nebraska Natural Resources Commission (NNRC) uses HEC-2 to compute required elevations and other data for the 1% annual frequency flood (the "100-year flood"). This information is then used to delineate flood plains in the state and to enforce L.B. 35, the state statute regulating flood plain use.

HEC-2 is also used to delineate a floodway for enforcement purposes. This floodway is computed by using Method 4 in the HEC-2 Program *(specifying a one-foot rise in flood elevation)* and by a trial and error method. This trial and error method involves manually specifying station locations of encroachments on each cross section and checking the resulting flood elevation against the natural non-encroached flood elevation for a one foot rise in flood elevation.

The Nebraska Natural Resources Commission has a version of HEC-2 ~~which is run on the IBM Personal Computer XT microcomputer.~~

B. Basic Theory

The computational procedure applies Bernoulli's Theorem for the total energy at each cross section and Manning's formula for the friction head loss between cross sections. In the program, average friction slope for a reach between two cross sections is determined in terms of the average of the conveyances at the two ends of the reach. Other losses are computed using one of several methods. The critical water surface elevation corresponding to the minimum specific energy is computed using an iterative process.

C. Subcritical or Supercritical Flow

The computation begins at a control section *(location of known water surface elevation)* in the river channel and proceeds upstream for subcritical flow or downstream for supercritical flow. The direction of flow is specified by the user. In cases where flow passes from subcritical to supercritical or vice-versa, during computations, it is necessary to compute the entire profile twice assuming alternately subcritical and supercritical flow. From the above results the most likely water surface profile can be determined.

D. Starting Elevation

The water surface elevation for the beginning cross section may be specified in one of three ways: (1) as critical depth, (2) as a known elevation, (3) by the slope area method. By setting the variable STRT on card J1 equal to -1, critical depth will be computed and used as the starting water surface elevation. With variable STRT left blank the starting water surface elevation is specified by variable WSEL on card J1. When using the slope area method, STRT is set equal to the estimated slope of the energy grade line *(must be a positive value)* and WSEL is used as the initial estimate of the water surface elevation. The flows computed for the fixed slope and estimated depth are compared with the starting flow and the initial depth is adjusted until the computed flow is within 1% of the starting flow. The last assumption of initial water surface elevation thus determined is then used as the starting water surface elevation for water surface profile computations.

E. Discharge

The river discharge may be specified and altered in several ways. The variable Q on card J1 specifies the starting discharge for single profile runs. When it is desired to change the discharge for a single profile run, the variable QNEW on card X2 can be used to permanently change the discharge at any cross section.

An alternate procedure utlilizes the QT cards. QT cards may be used to specify starting discharges and to permanently change discharges at any cross section in a data set.

F. Manning's "n"

Since Manning's coefficient of roughness "n" depends on such factors as type and amount of vegetation, channel configuration and stage, several options are available to vary "n". When three "n" values are sufficient to describe the channel and overbank roughness, the first three fields of card NC *("n" value change)* are used. Any of the "n" values may be permanently changed at any cross section by using another NC card. Often three values are not enough to adequately describe the lateral roughness variation in the overbanks in which case card NH *("n" value - horizontal)* is used. These "n" values will be used for all subsequent cross sections unless changed by another NH card or NC card.

Data indicating the variation of Manning's "n" with river stage may be used in the program. Manning's "n" and the corresponding stage elevation *(beginning with the lowest elevation)* are entered on card NV *("n" value - vertical)*.

Manning's "n" can be determined from known high water marks along the river reach if the discharge, relative ratios of the "n" values for the channel and overbanks, and the water surface elevation at each cross section are known.

G. Multiple Stream Profiles

The water surface profile computations may be computed up both forks of a river or throughout a whole river basin for single or multiple profiles in a single computer run.

H. Critical Depth Computation

Critical depth will not be computed for all cross sections in this program unless that option is requested on the J2 card, since this takes about half the computation time. However, the program will check each cross section to see if the depth is close to critical. If the depth is near critical, it will calculate critical depth using subroutine DC by determining the point of minimum specific energy using a discharge weighted velocity head. Critical depth will always be computed for a supercritical profile and it will be determined for low flow for the cross section upstream of a special bridge.

I. River Cross Sections

Cross sections are required at representative locations throughout the river reach. These are locations where changes occur in slope, cross sectional area, or channel roughness; locations where levees begin or end; and at bridges. In general, for rivers of flat slope and fairly uniform section *(drop of three or four feet per mile)* cross sections are taken at least every mile. For steeper slopes and very irregular cross sections, four or five cross sections per mile may be necessary. Where an abrupt change occurs in the profile, several cross sections are used to describe the change regardless of the distance. Every effort is made to obtain cross sections that accurately represent the river geometry.

Each point in each cross section is given a station number corresponding to the horizontal distance from the first point on the left. The station number and corresponding elevation of each point are input as variables on card GR. Up to 100 points may be used. Cross sections may be oriented looking either upstream or downstream since the programs considers the left side to be the lowest station number and the right side the highest. For consistency, the NNRC usually sets up cross section looking downstream. The left and right stations separating the channel from the overbank areas are specified as variables on card X1. End points of a cross section that are too low *(below the computed water surface elevation)* will automatically be extended vertically by the program and a message giving the vertical distance extended will be printed.

The previous cross section may be used as the current one *(for uniform channels)*, with or without a modification, or the current cross section may itself be modified by using the options available in the program.

Channel encroachments may be included in the analysis by using variables on card X3. ENCFP is used to specify a width between encroachment areas which is centered in the channel midway between the left and right bank stations. This width will be used for each cross section until another value of ENCFP is entered. Another method for specifying encroachments is to enter the station and elevation of the encroachment as variables STENCL and ELENCL on the left and STENCR and ELENCR on the right. If only the station is required, the elevation should be omitted and it will be assumed to be very high.

J. Interpolated Cross Sections

Sometimes it is necessary to insert cross sections between those specified on the GR cards because the change in velocity heads between cross sections is too great to accurately determine the hydraulic gradient. Variable HVINS on card J1 is used to specify when interpolated cross sections should be used. This variable specifies the maximum change in velocity head allowed between cross sections. If this value is exceeded, up to three interpolated cross sections will be generated between given cross sections. Interpolated cross sections should be omitted when computing several profiles on the same stream in order to use exactly the same cross sections.

K. Distance Between Cross Sections

The actual distance between cross sections used in the computation is specified on card X1 as variables XLOBL, XLOBR and XLCH for the left overbank, right overbank, and the channel respectively. These three values can be equal. There are conditions where they will differ, such as at river bends, or where the channel meanders considerably and the overbanks are straight. Where the distance between cross sections for channel and overbanks are different, a discharge-weighted reach length is determined based on the discharges in the main channel and left and right overbank segments of the reach. The discharge used for each segment is an arithmetic average of the discharge determined for that segment at cross sections at each end of the reach.

L. Transition Losses

Expansion or contraction of flow due to changes in the channel cross section is a common cause of energy losses within a reach. Whenever this occurs, the loss may be computed by specifying on card NC the expansion and contraction coefficients. The coefficients are multiplied by the absolute difference in velocity heads between the cross sections to give the energy loss caused by the transition. Where the change in river cross section is small, coefficients CEHV and CCHV are on the order of 0.3 and 0.1, respectively. When the change in cross sections is abrupt such as at bridges, CEHV and CCHV may be as high as 1.0 and 0.6. These values may be changed at any cross section by inserting a new NC card, however, these new values will be used until changed again by another NC card.

M. Bridge Losses

Energy losses caused by structures such as bridges and culverts are computed in two parts. First, the losses due to expansion and contraction of the cross section on the upstream and downstream sides of the structure are computed. Secondly, the loss through the structure itself is computed by either the normal bridge routine or the special bridge routine.

The normal bridge routine handles the cross section at the bridge just as it would any river cross section with the exception that the area of the bridge below the water surface is subtracted from the total area and the wetted perimeter is increased where the water surface elevation exceeds the low chord. Pier losses are accounted for by the increased wetted perimeter of the piers as described on card GR. The normal routine is particularly applicable for bridges without piers, bridges under high submergence, and for low flow through circular and arch culverts.

The special bridge routine computes losses through the structure for low flow, weir flow and pressure flow or for any combination of these. The type of flow is determined by a series of comparisons. First, the energy grade line elevations are computed assuming alternately low flow and pressure flow control. The higher energy grade line elevation determines the appropriate type of flow. If pressure flow appears to control and the energy grade line is above the minimum top of roadway elevation, then a combination of pressure flow and weir flow exists. If the energy gradient is below the minimum top of roadway, then pressure flow alone controls. If low flow appears to control, and the corresponding energy gradient elevation is above the minimum top of roadway elevation, then a combination of low flow under the bridge and weir flow over the roadway approach exists. If the energy elevation is below the minimum top of roadway, then low flow controls.

The special bridge routine can be used for any bridge, but should be used for bridges with piers where low flow controls, for pressure flow, and whenever flow passes through critical depth when going through a structure. The computer program will automatically shift from the special bridge routine to the normal bridge routine when there are no piers and low flow controls.

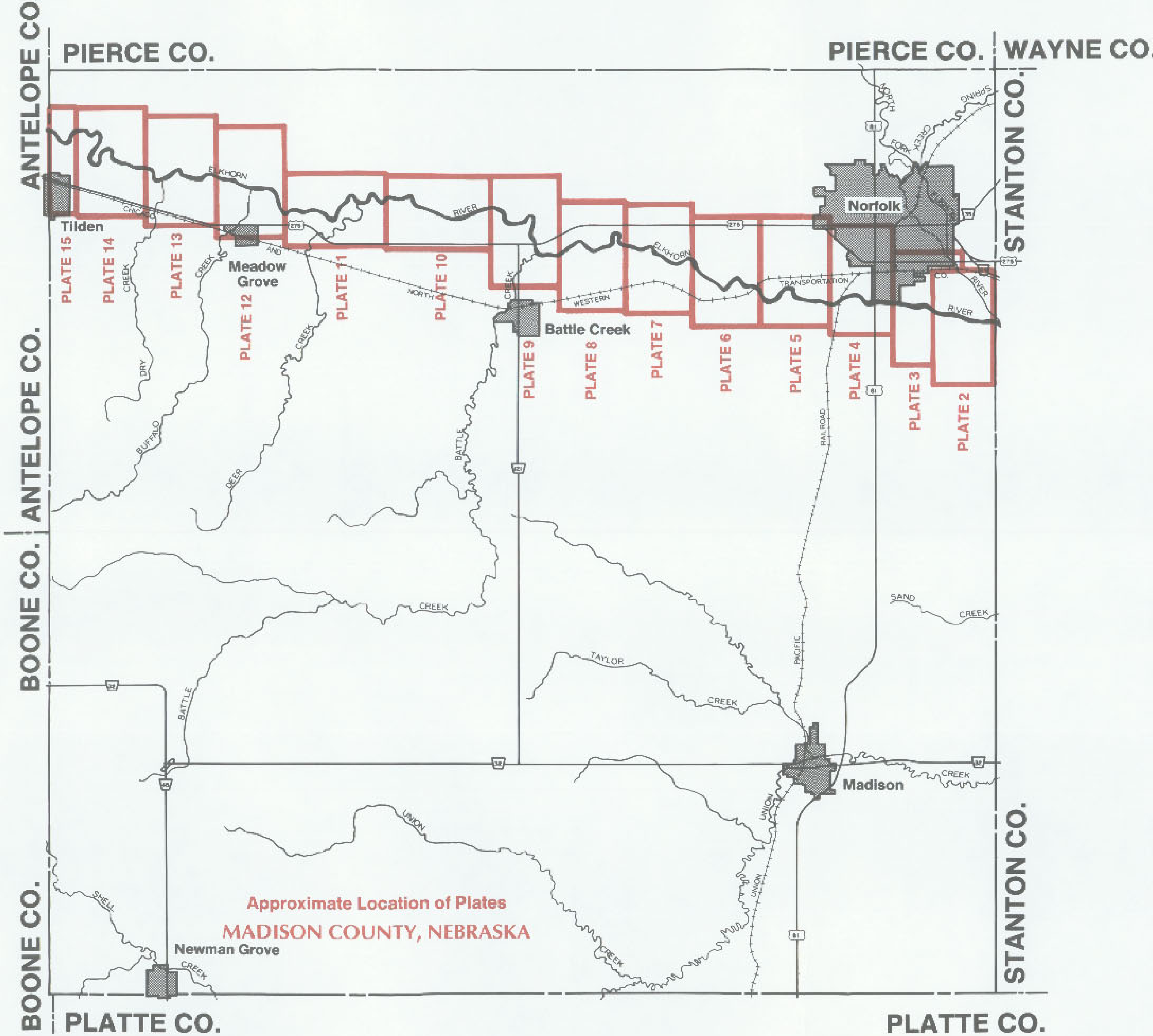
N. Output

The output from the HEC-2 Program includes the following:

1) A listing of all input data.
2) A summary of results at each cross section consisting of water surface elevation, slope of channel, velocities in the channel and in the overbank areas, etc.
3) A table of specific results at each cross section as requested by the user. This table is a convenience option and may be omitted by the user.
4) Cross section plots of any or all of the river cross sections to any scale may be requested by the users.
5) A profile plot which includes not only the water surface elevation, but the critical water surface elevation, energy grade line, channel bottom, left and right bank elevations, and the maximum elevation of the cross section may also be requested by the user.

APPENDIX C

FLOODED AREA MAPS AND FLOOD ELEVATION PROFILES



NEBRASKA
NATURAL RESOURCES COMMISSION
FLOOD PLAIN STUDY

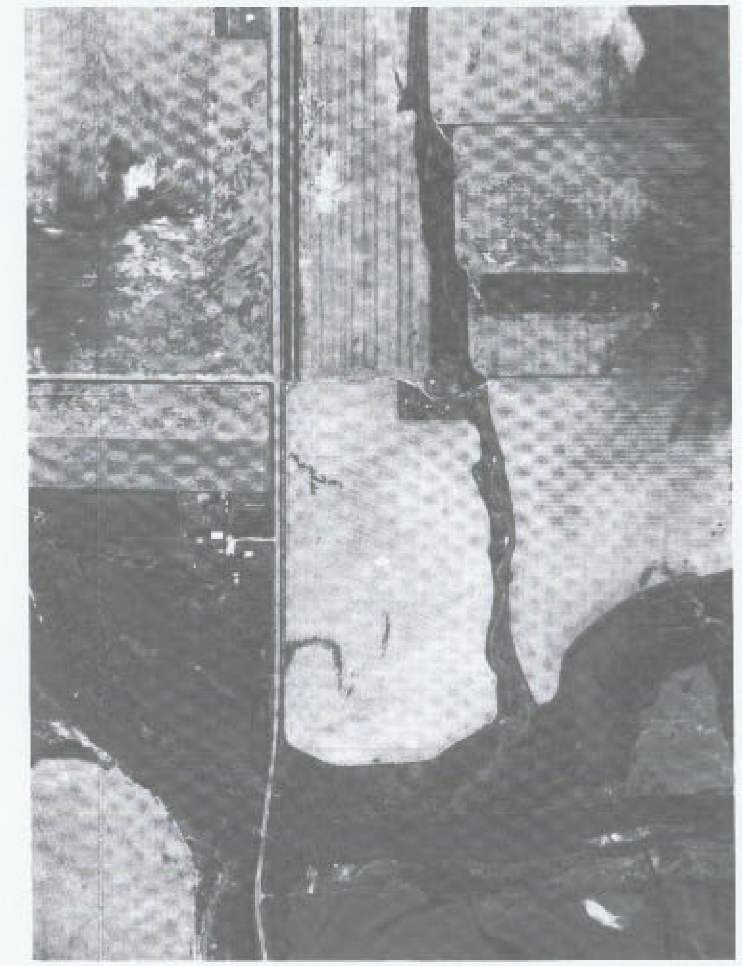


PLATE INDEX MAP

ELKHORN RIVER
MADISON CO.
PLATE 1

N

1 2 3 4 5
SCALE IN MILES

36 31 / 1 6 — SECTION CORNER AND SECTION NUMBERS

REFERENCE POINT AND CROSS SECTION LOCATIONS

100 YEAR FLOOD OUTLINE

FLOODWAY

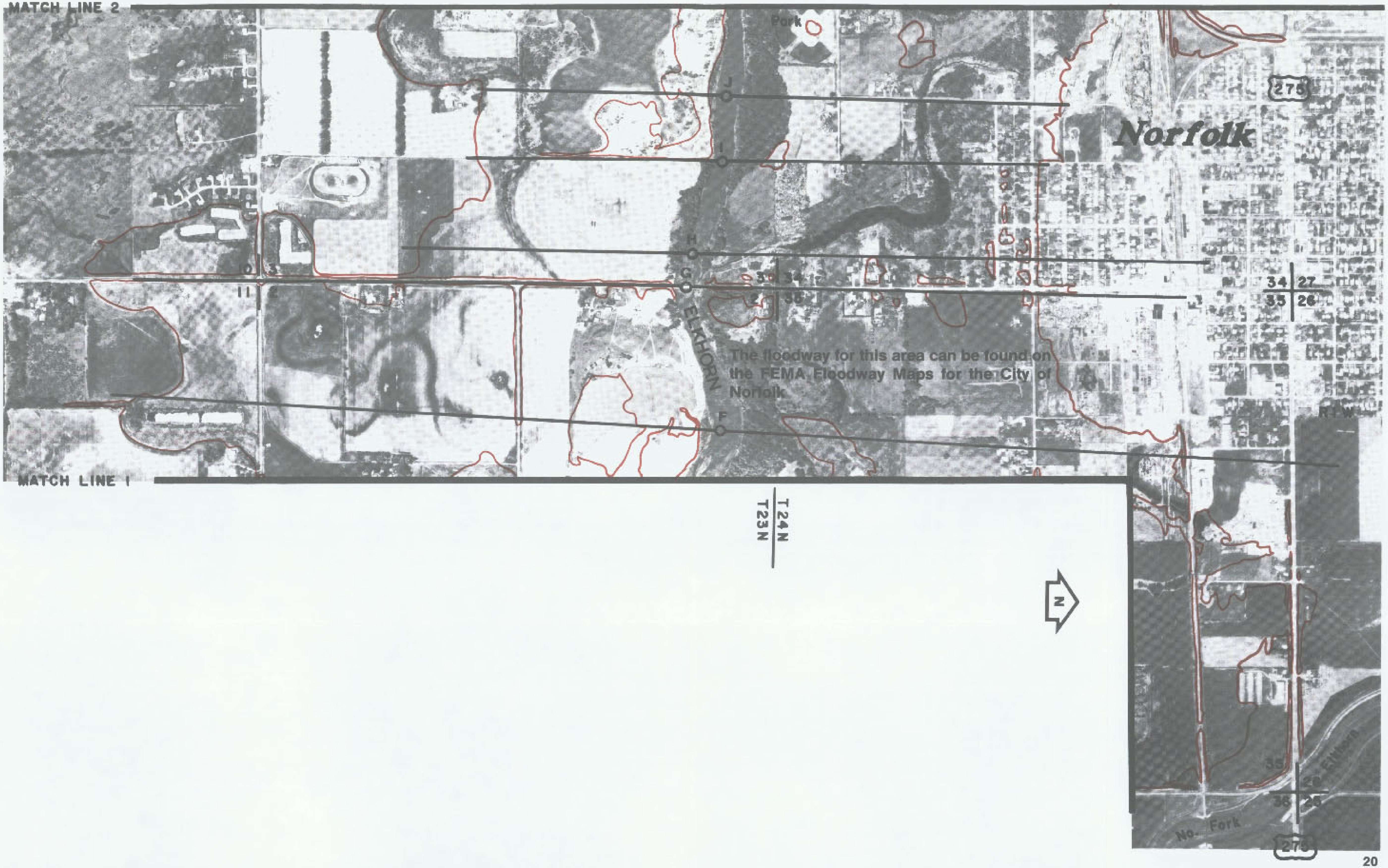
0 2 4 6 8 1000 SCALE IN FEET

NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 2



36 31 / 1 6	SECTION CORNER AND SECTION NUMBERS
(symbol)	REFERENCE POINT AND CROSS SECTION LOCATIONS
(red line)	100 YEAR FLOOD OUTLINE
(box)	FLOODWAY

0 2 4 6 8 1000 SCALE IN FEET

NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 3

SECTION CORNER AND SECTION NUMBERS | REFERENCE POINT AND CROSS SECTION LOCATIONS | 100 YEAR FLOOD OUTLINE | FLOODWAY

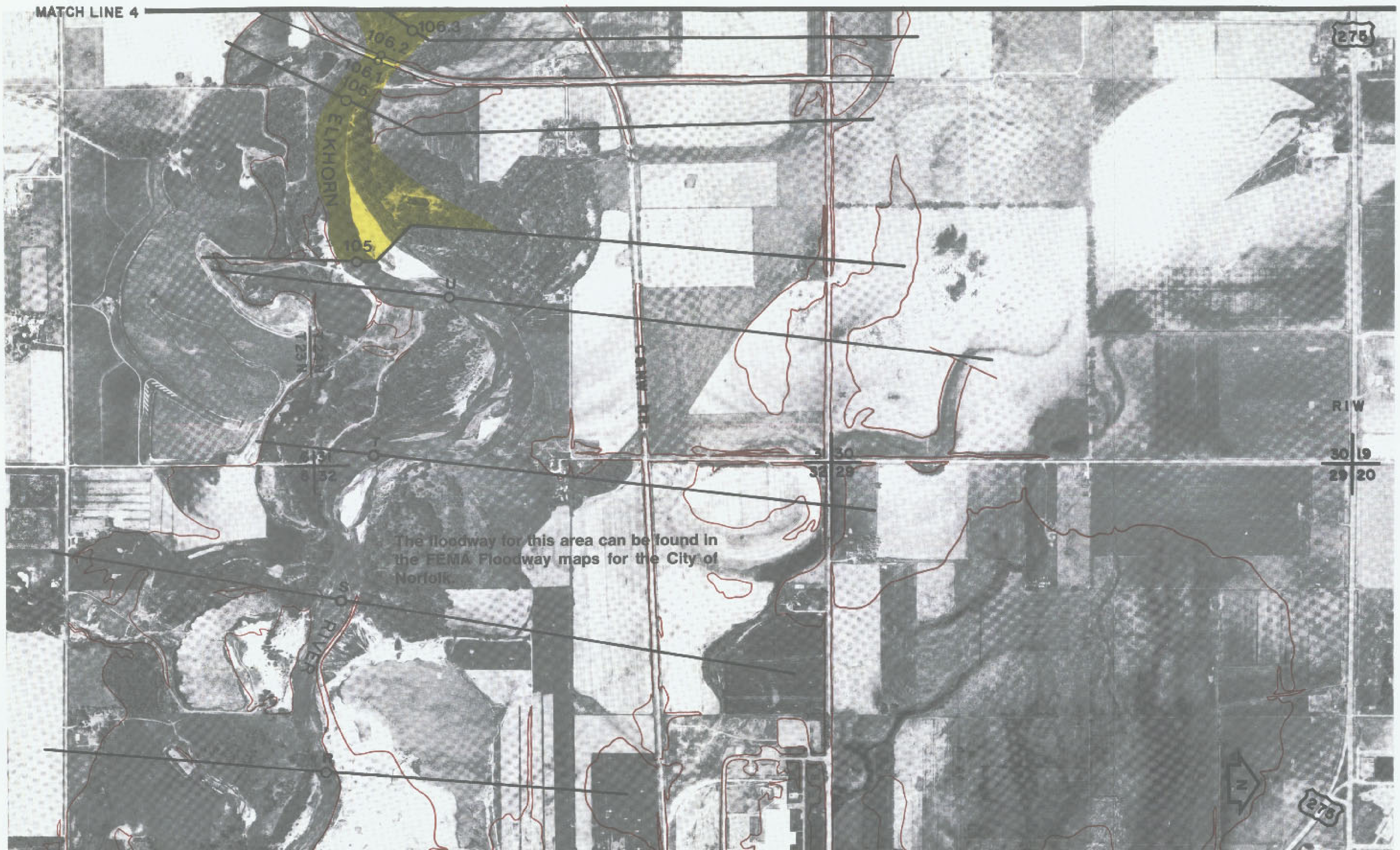
0 2 4 6 8 1000 SCALE IN FEET

NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 4



36 | 31 / 1 | 6 SECTION CORNER AND SECTION NUMBERS

REFERENCE POINT AND CROSS SECTION LOCATIONS

100 YEAR FLOOD OUTLINE

FLOODWAY

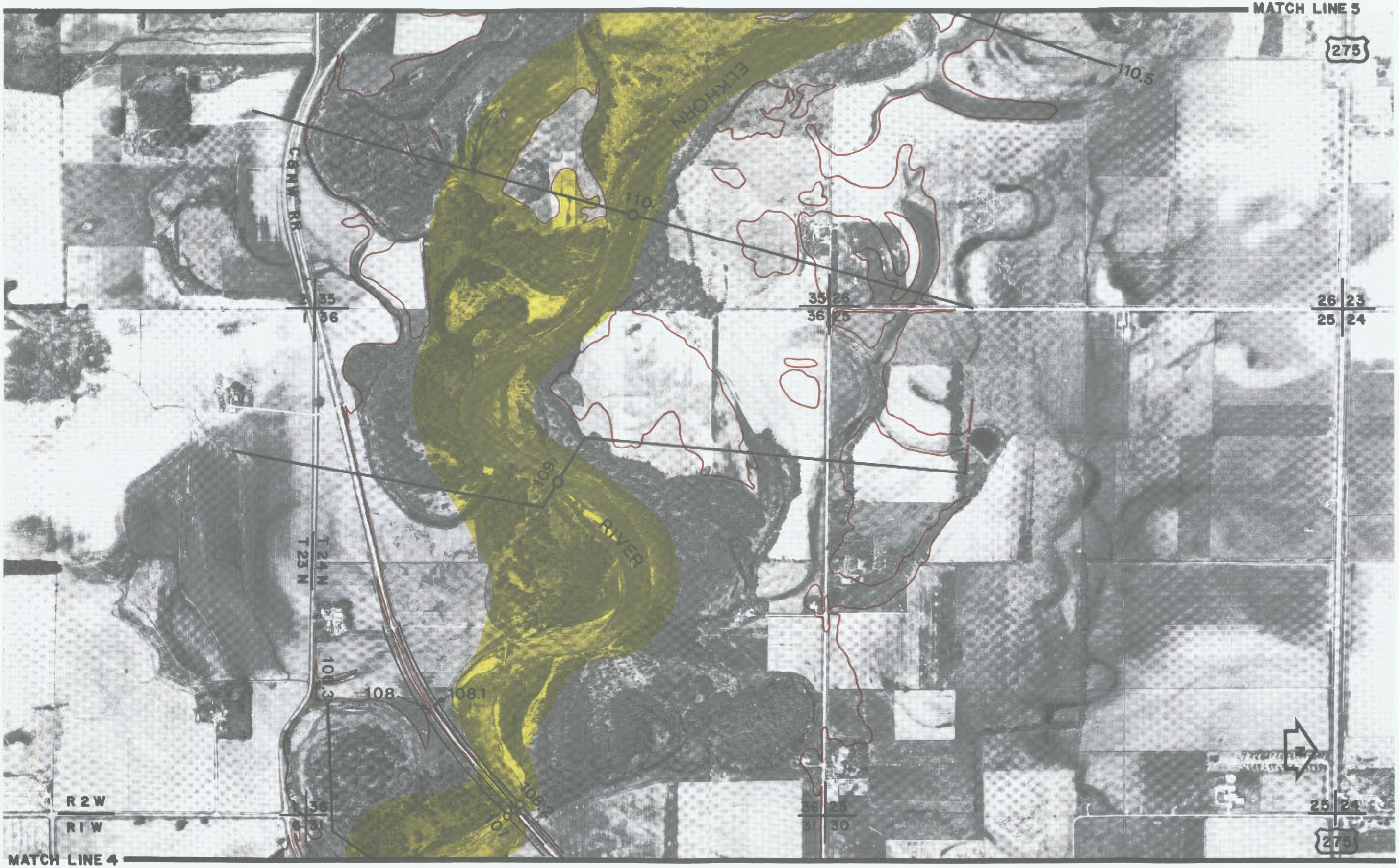
0 2 4 6 8 1000 SCALE IN FEET

NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 5



36 31 / 1 6	SECTION CORNER AND SECTION NUMBERS		REFERENCE POINT AND CROSS SECTION LOCATIONS		100 YEAR FLOOD OUTLINE		FLOODWAY

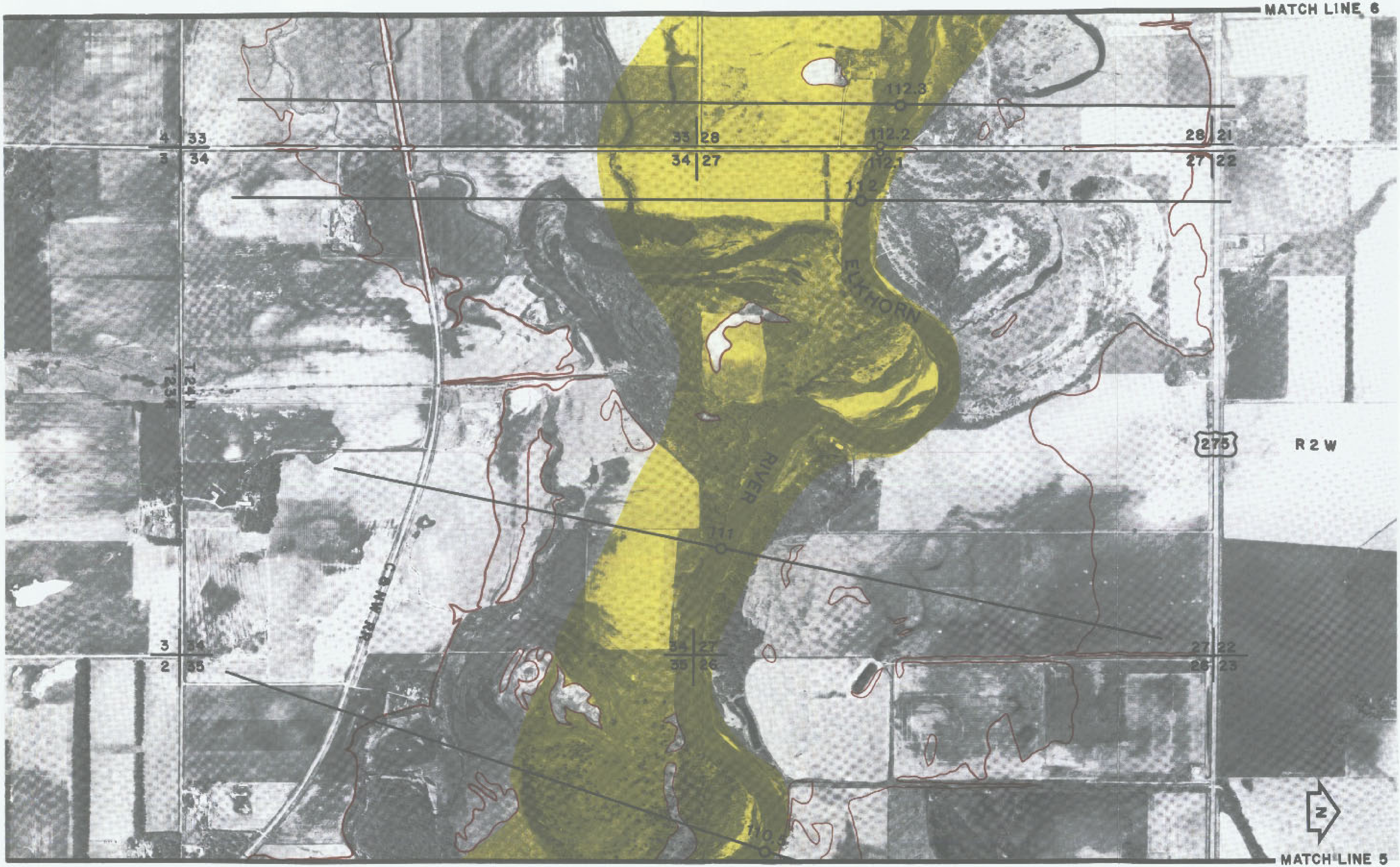
0 2 4 6 8 1000
SCALE IN FEET

NEBRASKA
NATURAL RESOURCES COMMISSION

ELKHORN RIVER
NEBRASKA

FLOODED AREAS

PLATE NO. 6



24

36 31 / 1 6 — SECTION CORNER AND SECTION NUMBERS	REFERENCE POINT AND CROSS SECTION LOCATIONS	100 YEAR FLOOD OUTLINE	FLOODWAY

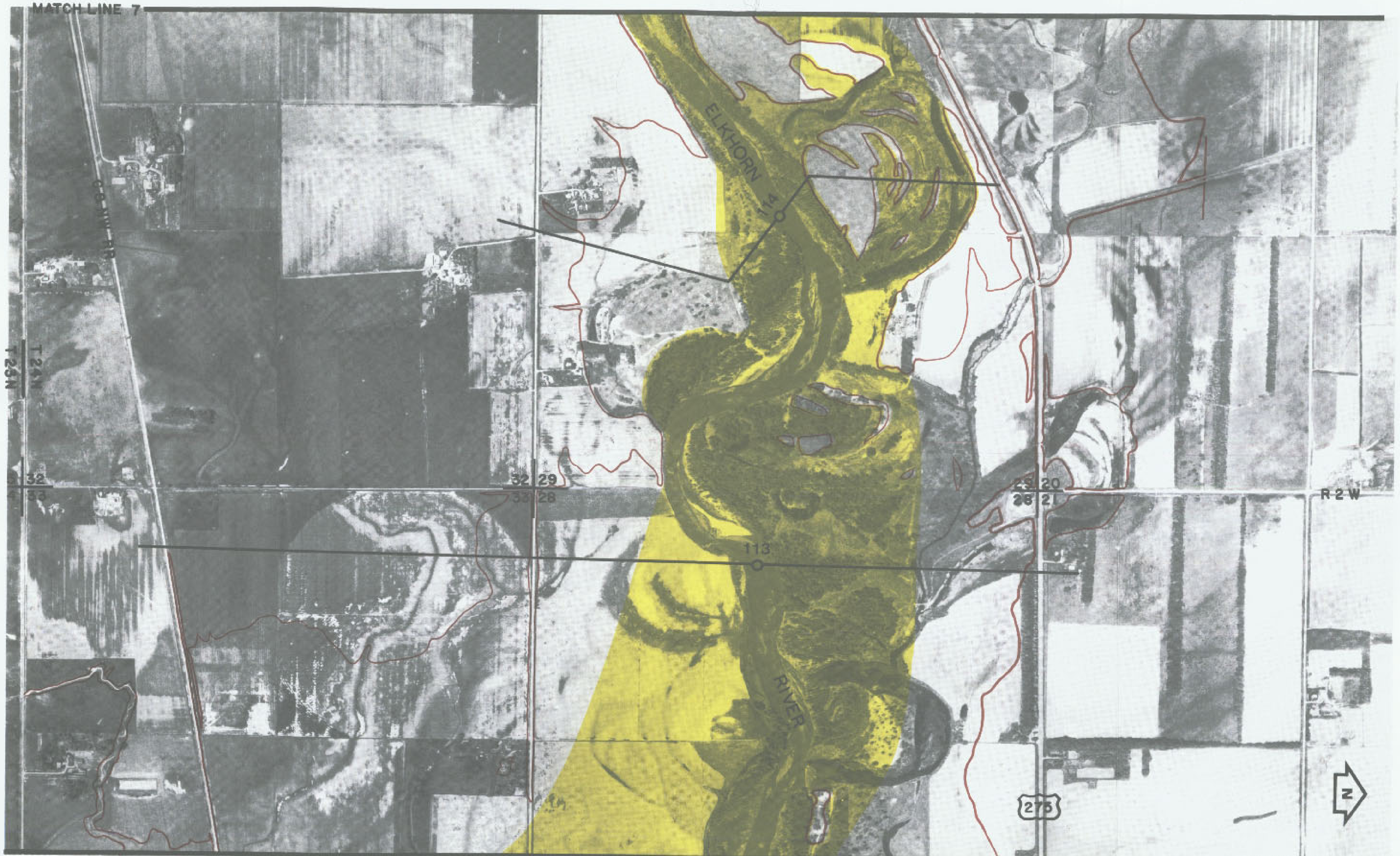
0 2 4 6 8 1000
SCALE IN FEET

NEBRASKA
NATURAL RESOURCES COMMISSION

ELKHORN RIVER
NEBRASKA

FLOODED AREAS

PLATE NO. 7



25

36 | 31 / 1 | 6 SECTION CORNER AND SECTION NUMBERS

REFERENCE POINT AND CROSS SECTION LOCATIONS

100 YEAR FLOOD OUTLINE

FLOODWAY

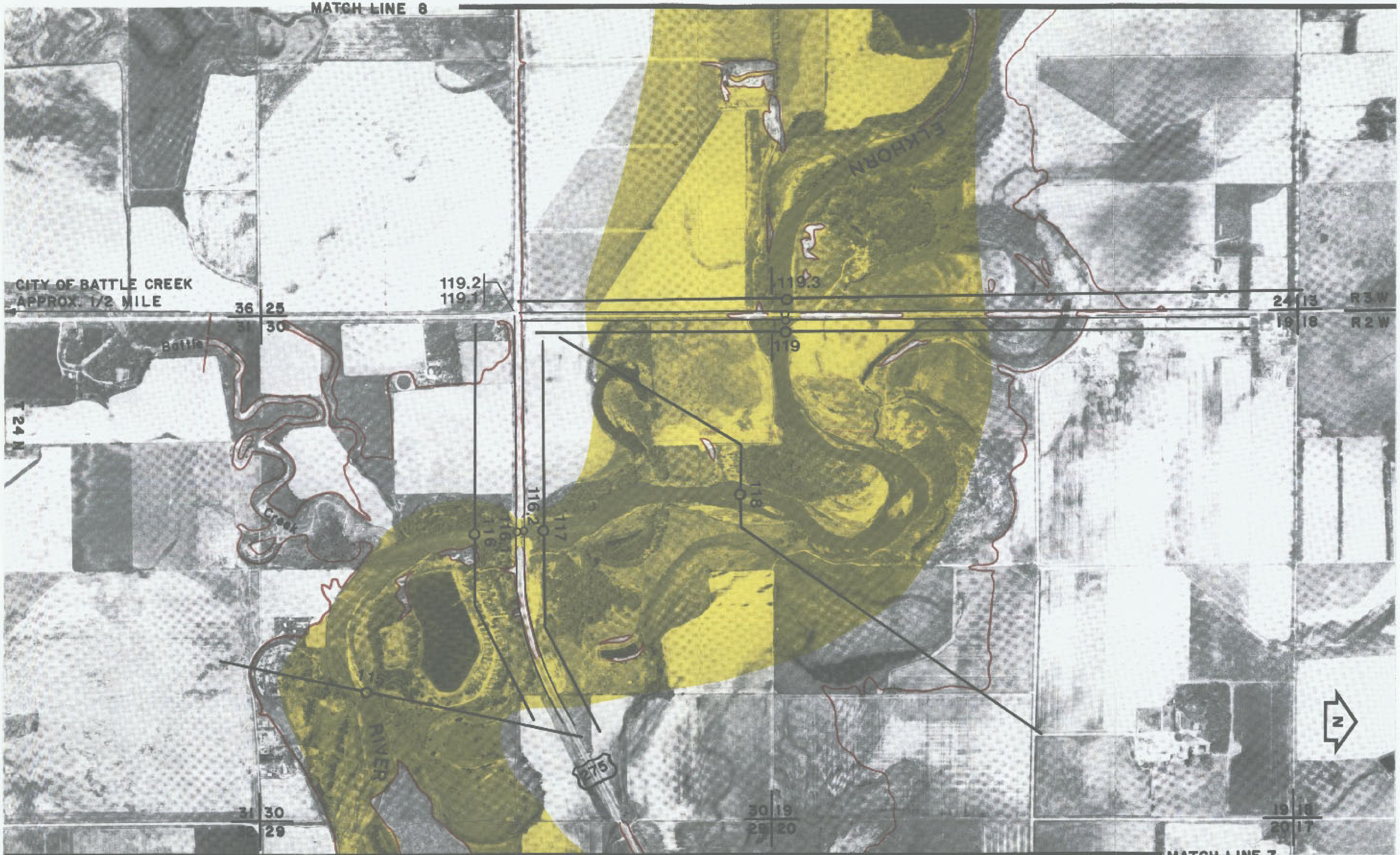
0 2 4 6 8 1000 SCALE IN FEET

NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 8



36 31 / 1 6 SECTION CORNER AND SECTION NUMBERS

REFERENCE POINT AND CROSS SECTION LOCATIONS

100 YEAR FLOOD OUTLINE

FLOODWAY

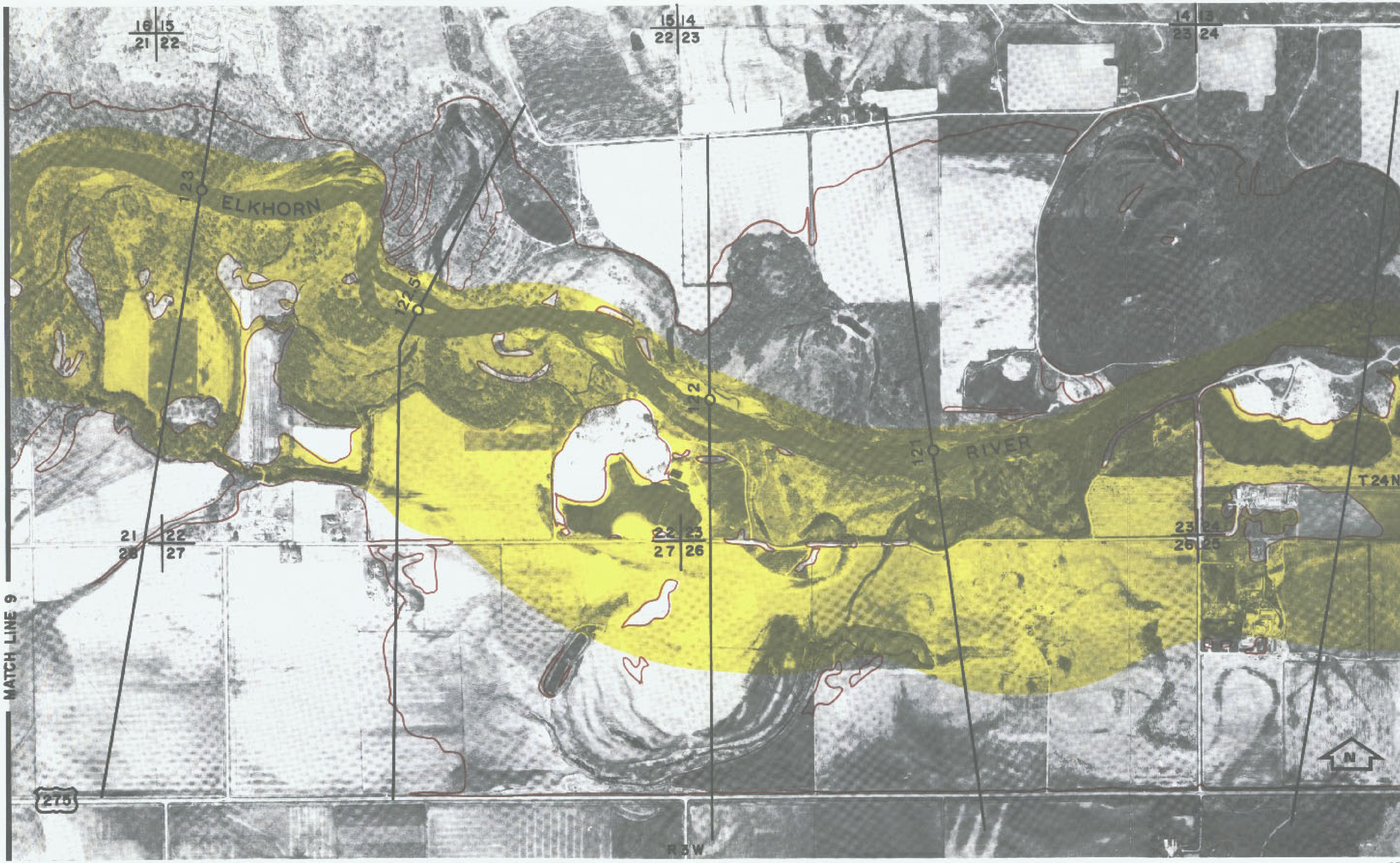
0 2 4 6 8 1000 SCALE IN FEET

NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 9



36 31 1 6 SECTION CORNER AND SECTION NUMBERS

REFERENCE POINT AND CROSS SECTION LOCATIONS

100 YEAR FLOOD OUTLINE

FLOODWAY

0 2 4 6 8 1000 SCALE IN FEET

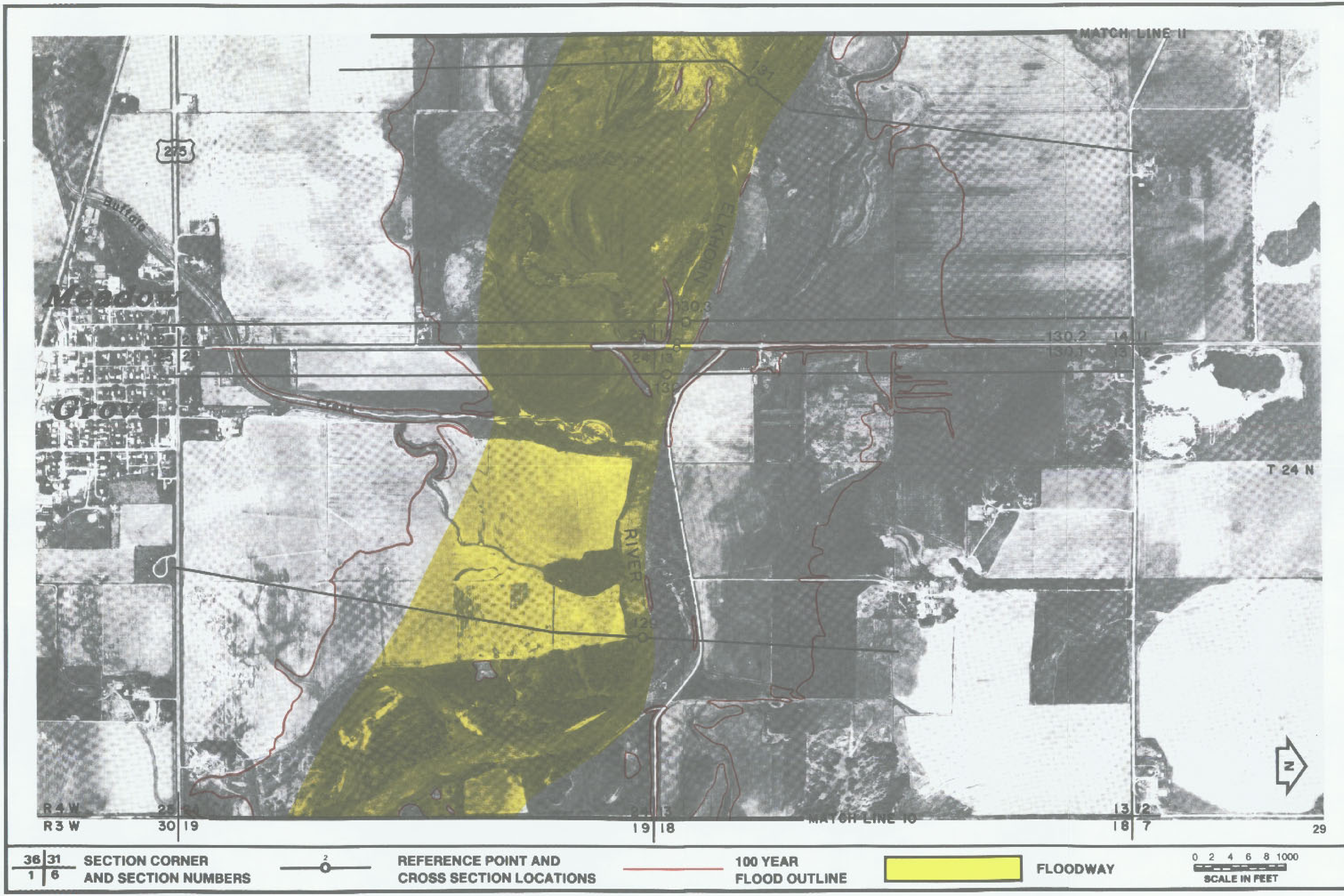
NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 10

PLATE NO. 11	FLOODED AREAS	ELKHORN RIVER NEBRASKA	NEBRASKA NATURAL RESOURCES COMMISSION

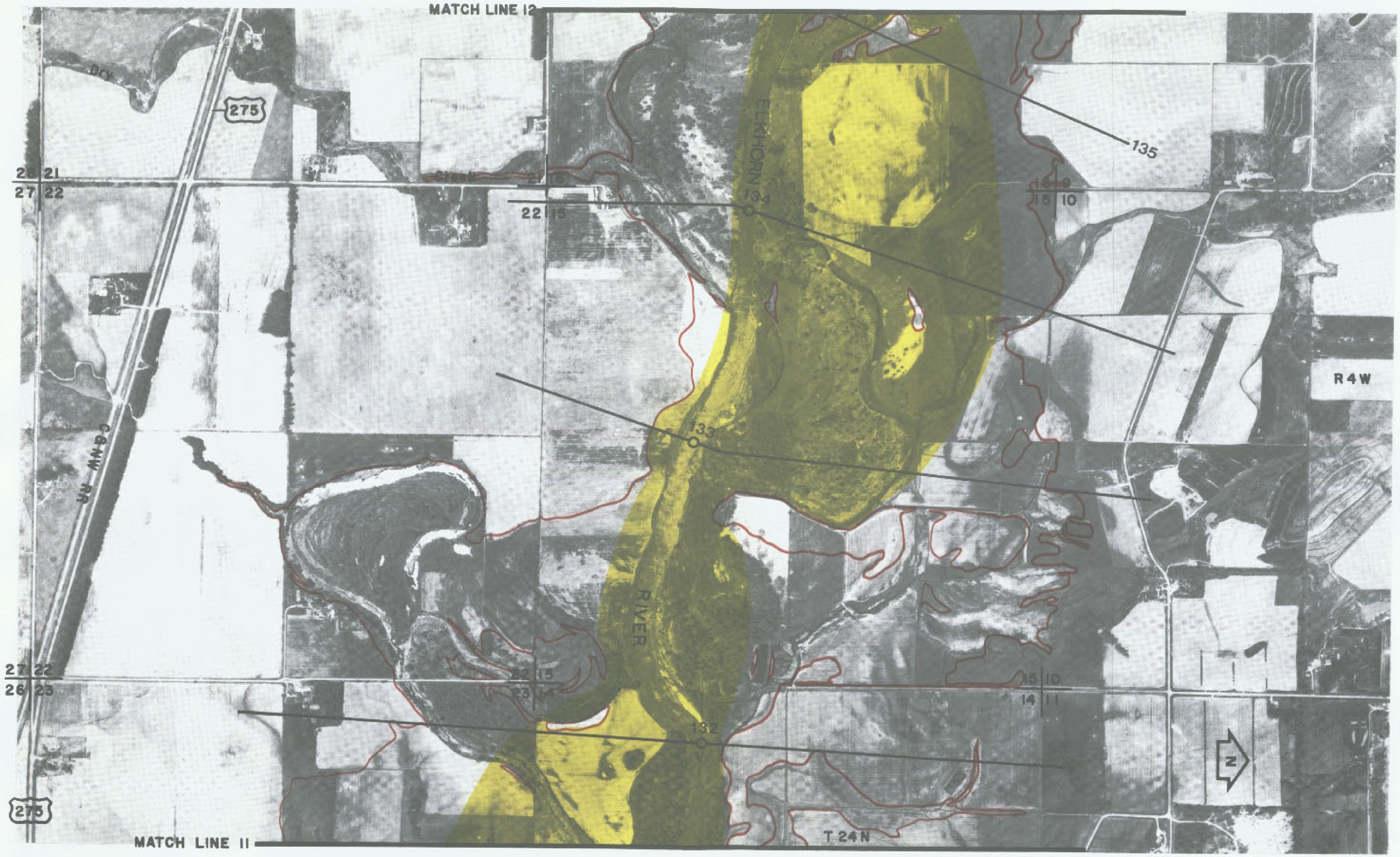


NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 12



36 31 / 1 6 SECTION CORNER AND SECTION NUMBERS

REFERENCE POINT AND CROSS SECTION LOCATIONS

100 YEAR FLOOD OUTLINE

FLOODWAY

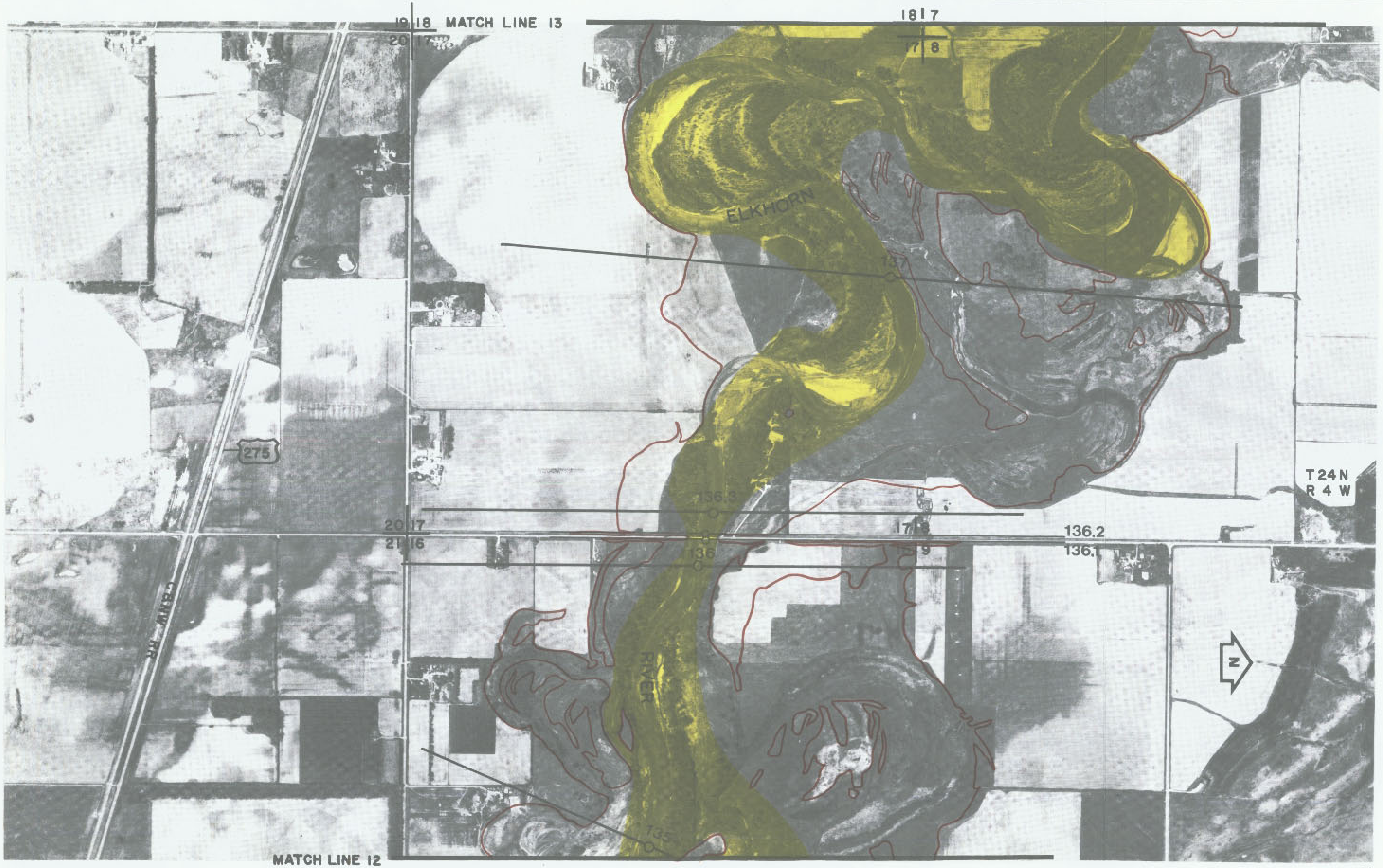
0 2 4 6 8 1000 SCALE IN FEET

NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 13



36 31 / 1 6 SECTION CORNER AND SECTION NUMBERS

REFERENCE POINT AND CROSS SECTION LOCATIONS

100 YEAR FLOOD OUTLINE

FLOODWAY

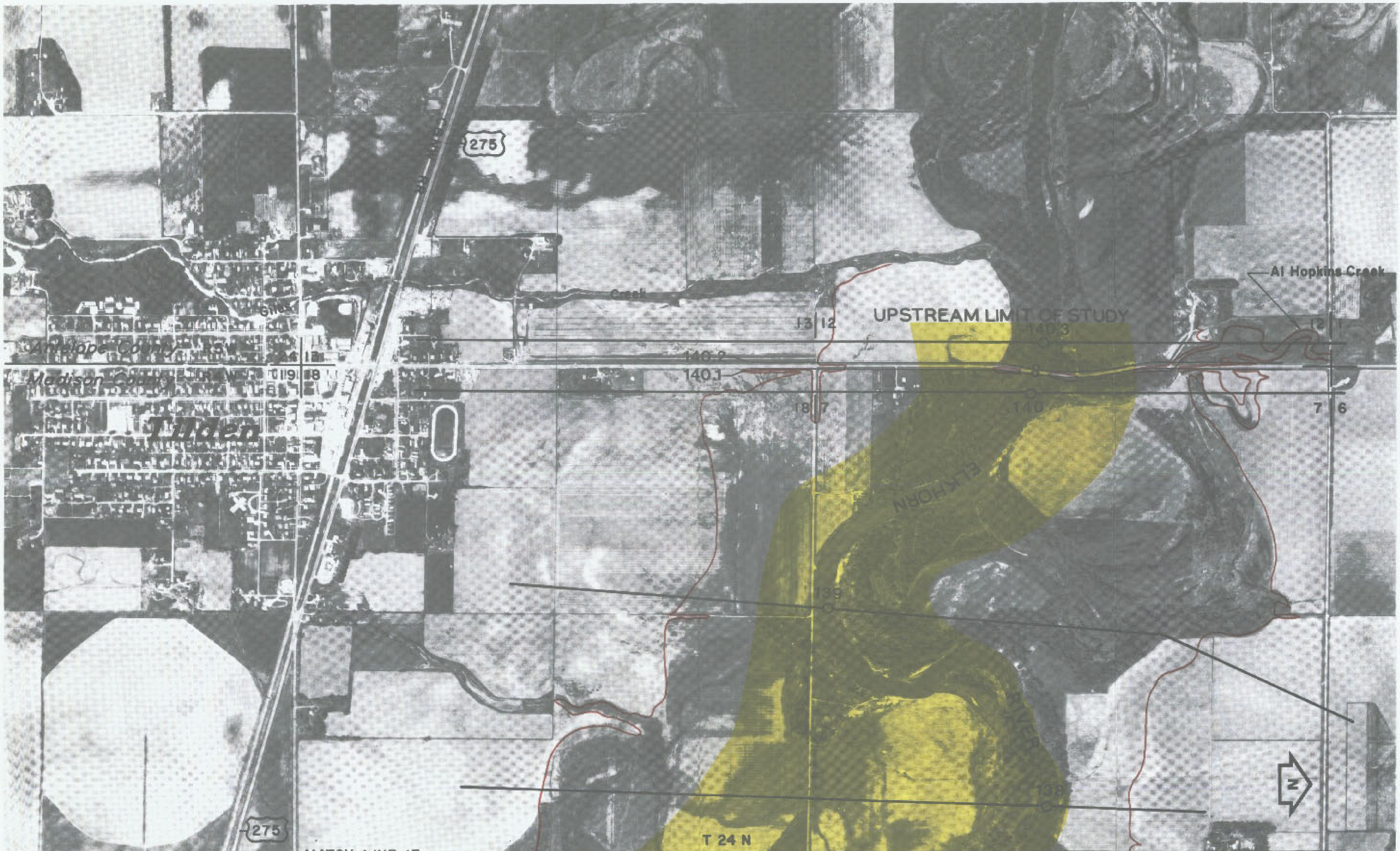
0 2 4 6 8 1000 SCALE IN FEET

NEBRASKA NATURAL RESOURCES COMMISSION

ELKHORN RIVER NEBRASKA

FLOODED AREAS

PLATE NO. 14



32

36 31 / 1 6	SECTION CORNER AND SECTION NUMBERS
─○─	REFERENCE POINT AND CROSS SECTION LOCATIONS
red line	100 YEAR FLOOD OUTLINE
yellow box	FLOODWAY

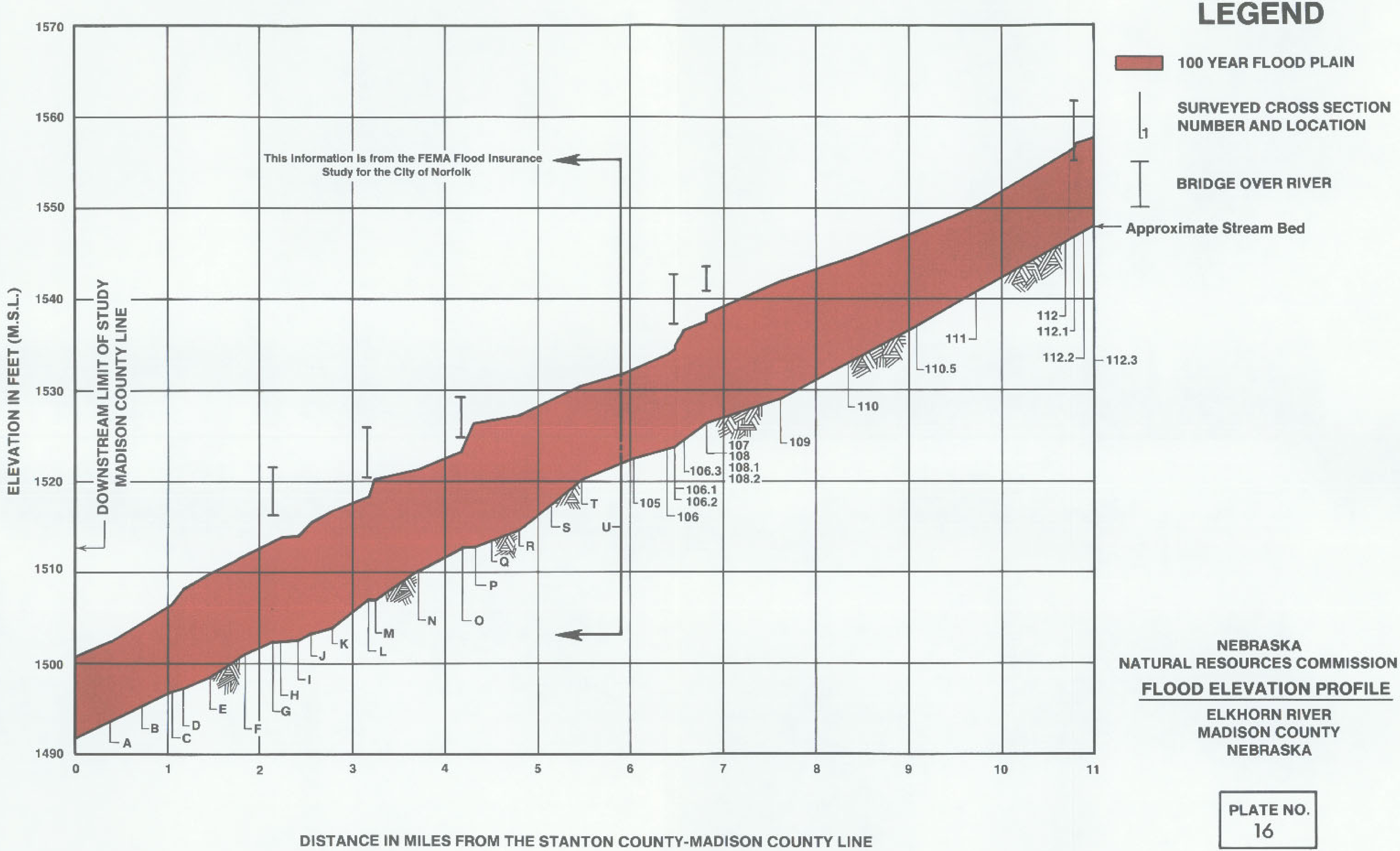
0 2 4 6 8 1000
SCALE IN FEET

NEBRASKA
NATURAL RESOURCES COMMISSION

ELKHORN RIVER
NEBRASKA

FLOODED AREAS

PLATE NO. 15



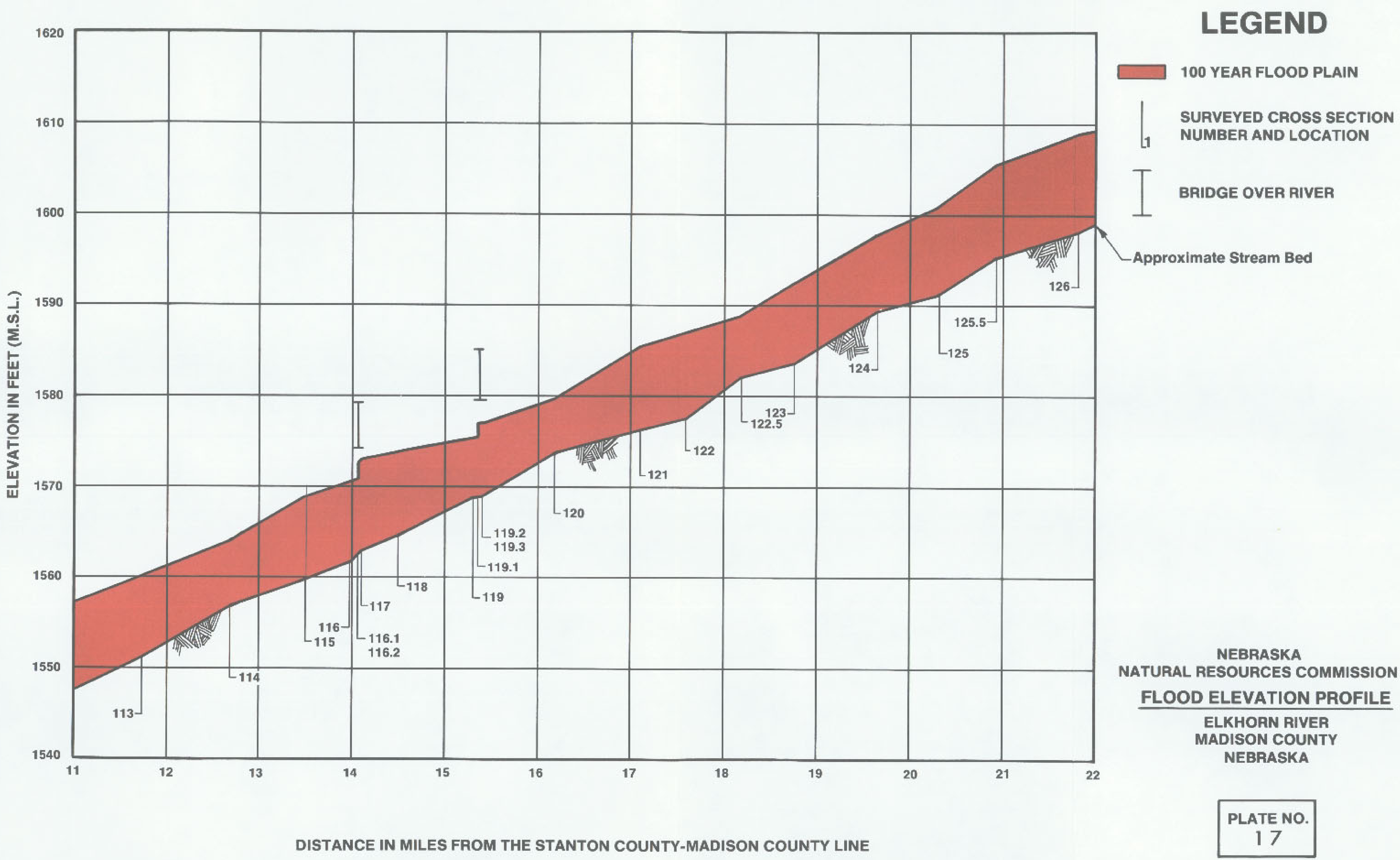
NEBRASKA
NATURAL RESOURCES COMMISSION

FLOOD ELEVATION PROFILE

ELKHORN RIVER
MADISON COUNTY
NEBRASKA

PLATE NO. 16

SHEET 1 OF 3



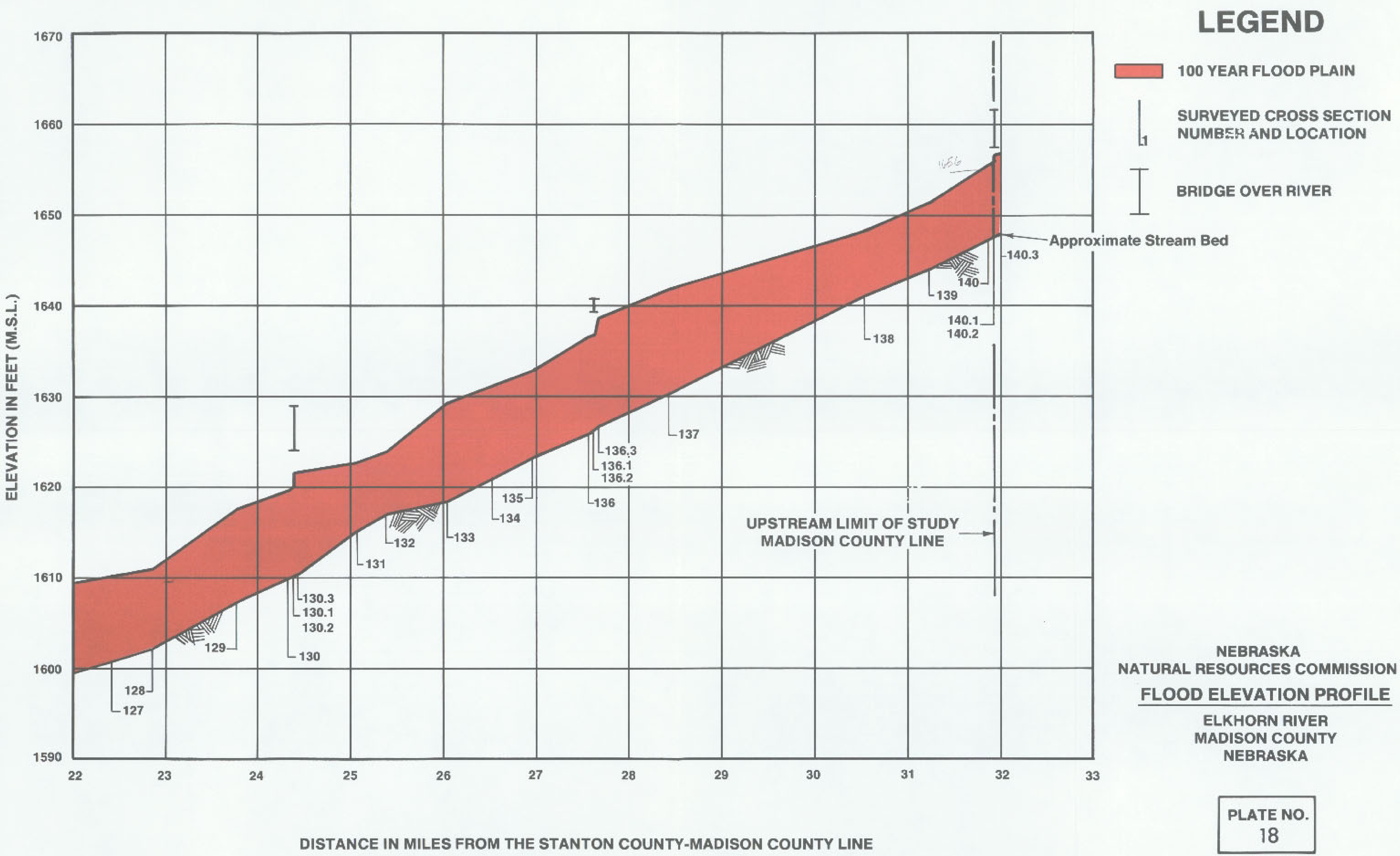
NEBRASKA
NATURAL RESOURCES COMMISSION

FLOOD ELEVATION PROFILE

ELKHORN RIVER
MADISON COUNTY
NEBRASKA

PLATE NO.
17

SHEET 2 OF 3



NEBRASKA
NATURAL RESOURCES COMMISSION

FLOOD ELEVATION PROFILE

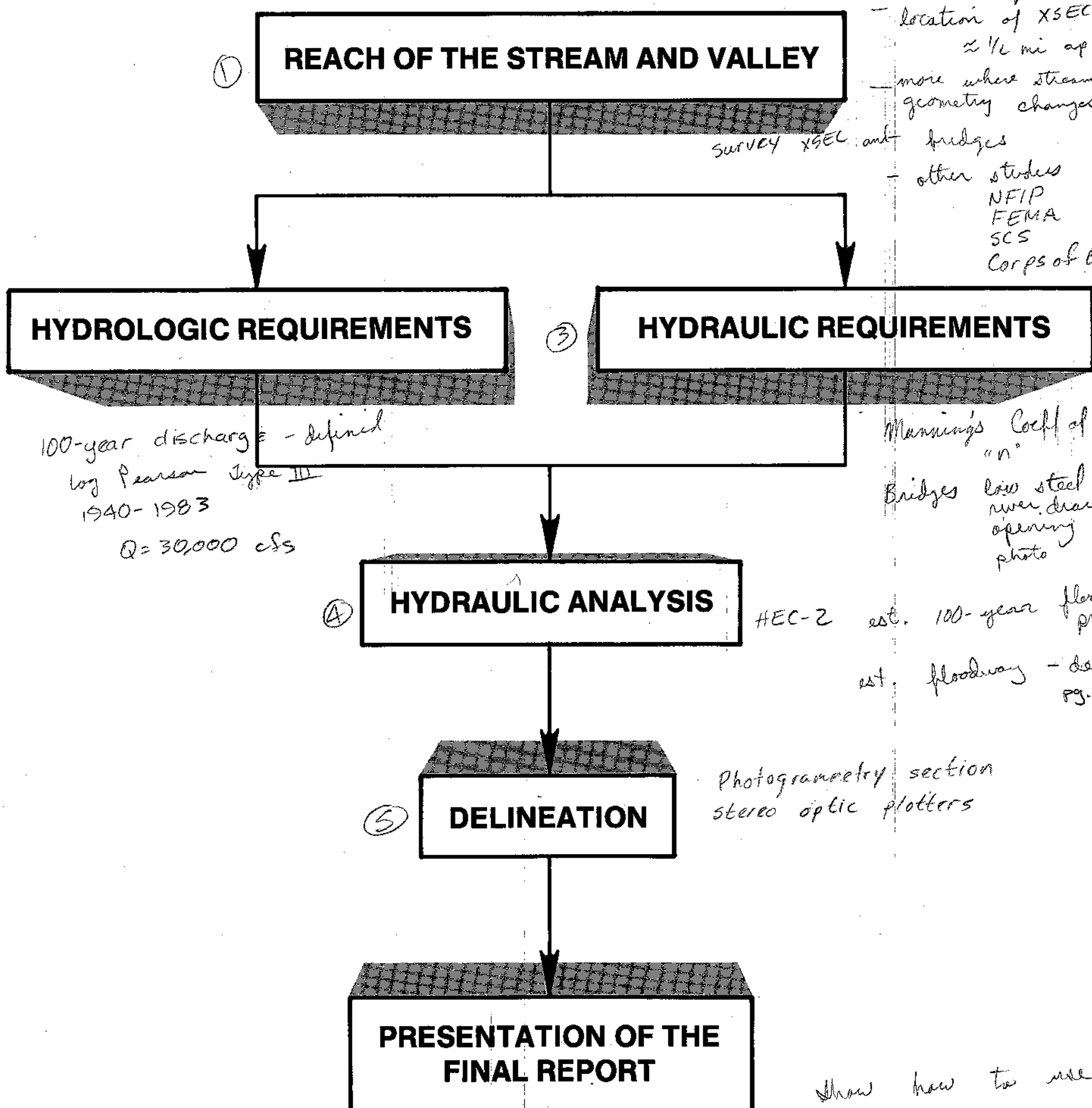
ELKHORN RIVER
MADISON COUNTY
NEBRASKA

PLATE NO.
18

SHEET 3 OF 3

This is a detailed engineering study based on
- field surveys
- aerial photography
- eng. computations
- other technical reports and studies

SCHEMATIC OF A FLOOD PLAIN STUDY



(1) Study of Area
- 7½ min. quad maps
- location of XSEC's ≈ ½ mi apart
- more where stream geometry changes
- survey XSEC and bridges
- other studies: NFIP, FEMA, SCS, Corps of Eng

(2) 100-year discharge - defined
log Pearson Type III
1940-1983
Q = 30,000 cfs

(3) Manning's Coeff of Roughness "n"
Bridges: low steel, river drain, opening, photo

(4) HEC-2 est. 100-year flood profile
est. floodway - def. pg. 9

(5) Photogrammetry section
stereo optic plotters

Show how to use the report