PRELIMINARY EVALUATION OF
CHANNEL CHANGES DESIGNED TO
RESTORE FISH HABITAT



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Department of Civil Engineering & Engineering Mechanics Montana State University Bozeman

# PRELIMINARY EVALUATION OF CHANNEL CHANGES DESIGNED TO RESTORE FISH HABITAT



Prepared for the

STATE OF MONTANA

DEPARTMENT OF HIGHWAYS
PLANNING AND RESEARCH BUREAU

and

DEPARTMENT OF FISH AND GAME
ENVIRONMENT BUREAU

in cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Montana Department of Highways, Department of Fish and Game or the Federal Highway Administration

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October 31, 1972

ABSTRACT

An evaluation of the fish habitat in two meanders constructed in the Clark Fork River west of Drummond, Montana, shows the hydraulic, topographic and fish population characteristics of these artificial meanders to be similar to those found in comparable natural sections of the river. A design procedure based on observations of meanders in stream being altered is recommended.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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## 1. INTRODUCTION

Preliminary plans for the construction of 15 miles of Interstate Highway I-90 west of Drummond called for channel changes which would shorten the Clark Fork River by approximately 1800 ft. Based on the preliminary plans and the authority of the Stream Preservation Law enacted by the Montana Legislature in 1965, the Montana Fish and Game Commission recommended that provisions be made for preserving the total length of the river in this 15-mile section of highway. The Montana Highway and the Fish and Game Commissions mutually agreed that a workable solution would be to construct two artificial meanders with combined lengths sufficient to recover the 1800 ft of stream length. The location of the project and its channel change sections are shown in Fig. 1.[1/] The two meanders, shown in Figs. 2 and 3 and constructed at the locations indicated in Fig. 1, have approximate meander lengths of 2600 ft. each and replace existing channel lengths of 1500 ft each. The upstream meander (C2) is referred to as the Hazel Marsh Meander; the downstream (C1), the Weaver Meander.

A summary of the channel changes in this section of highway given in Table 1 includes original and new stream lengths, change in lengths and mean values of old and new slopes (based on difference in channel bed elevations at each end divided by stream length). The excavation quantities required for constructing the meanders are also given in Table 1.

The construction of the two meanders was completed in the fall of 1969. The runoff in the spring of 1970 was the first high discharge passing through these sections. Acknowledging the possibility of constructing similar meanders for preserving the length of trout streams adjacent to future highway projects, the Montana Highway Commission and the Federal Highway Administration requested an evaluation of the artificial meanders. A study was initiated on December 1, 1970 to evaluate channel changes designed to restore fish habitat. The

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| No. | Location* Sta. to Sta. | | Channel length Original ft | New ft | Change ft | Elevation difference ft | Average channel slope Original % | New % |
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| 7 | 648+00 | 674+62 | 2920 | 2662 | -258 | 5.32 | 0.18 | 0.20 |
| 8 | 712+75 | 730+50 | 2060 | 1775 | -285 | 3.37 | 0.16 | 0.19 |
| | | Subtotal of changes in length: | | | -1736 | | | |
| | | Meander channels constructed | | | | | | |
| C1[a] | 355+00 | 370+00 | 1550 | 2615 | +1065 | 3.62 | 0.23 | 0.14 |
| C2[b] | 731+00 | 745+00 | 1460 | 2600 | +1140 | 4.80 | 0.33 | 0.18 |
| | | Subtotal of change in length: | | | +2205 | | | |
| | | Net change in total length: | | | + 469 | | | |

a. Weaver Meander: 59,400 cu yd excavation; 7910 cu yd class B rip-rap

b. Hazel Marsh Meander: 58,235 cu yd excavation; 9503 cu yd class B rip-rap

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evaluation is based on (1) the hydraulic characteristics of the constructed meander channels and (2) the acceptability of the constructed meander channels as life-supporting habitat by species of fish found in the Clark Fork River near Drummond. Studies of the hydraulic characteristics were conducted by the Department of Civil Engineering and Engineering Mechanics of Montana State University; the fish population studies by the Fisheries Division of Montana Fish and Game Department in cooperation with the Bozeman Unit of the U. S. Bureau of Sport Fisheries and Wildlife.

## 2. BASIS OF EVALUATION

The preliminary evaluation was made by comparing the hydraulic characteristics and fish populations in existing natural meanders with those in the constructed meanders.

The hydraulic character of river for fish habitat is determined by the following factors: water surface slope, bed profile, velocity, thalweg (line connecting the deepest points of the channel), and pool-riffle periodicity. The ratio of the thalweg to the down valley distance is used as an index to the susceptibility of a stream to provide fish habitat and is greater than one for all streams. The greater this ratio, the more pools per 1000 ft of stream length. The pool-riffle periodicity is given as the ratio of the distance between riffles (shallow, fast-water sections) to the average stream width.

Criteria for defining a meander are given by Leopold and Langbein (1966) and Leopold, Wolman and Miller (1964). The former report indicates meanders are characterized by a ratio of meander length to average radius of curvature in the bend of 4.7. The latter consider a stream segment to be considered meandering if its sinuosity (ratio of channel length to down valley distance) is greater than 1.5.

The studies of stream alterations on fish habitat and population reported by Elser (1968), Johnson (1964), Swedberg (1965), and Whitney and Bailey (1959) give quantitative data on the reduction of fish population caused by highway construction but do not present sufficient hydraulic data to determine design criteria. Lewis (1969) indicates that cover (brush, overhanging vegetation, undercut banks, and dead submerged portions of bank vegetation) and velocity are the two most significant physical factors affecting variation in trout populations in streams. Although optimum pool velocities were not indicated, the velocities in the study range from 0.30 to 1.67 fps. Elser (1968) also gives data on channel measurements from Little Prickly Pear Creek in altered and unaltered sections indicating pool-riffle perodicities ranging from 4 to 9 and ratios of the thalweg to down valley distance ranging from 1.18 to 1.66 for unaltered sections. Leopold and Langbein (1966) indicate the spacing of successive riffles is ordinarily from 5 to 7 times the width.

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The water surface slope, bed profile, average velocity, cross-sectional area, samples of bed material and fish population data from natural meander sections are compared with similar data taken in the constructed meanders. The thalweg indicies, velocities, and pool-riffle frequencies found will also be compared with those indicated in the literature cited above.

## 3. RIVER CHARACTERISTICS

### 3.1 Description of area

The Clark Fork River is formed by the confluence of Willow Creek and Silver Bow Creek approximately 5 miles east of Anaconda. It flows northerly for nearly 35 miles to Garrison then northwesterly for 25 miles through Drummond where it turns and flows more westerly through the Garnet-Bearmouth area. Flint Creek is the only perennial tributary with a significant flow entering the Clark Fork in the portion studied; it flows into the Clark Fork at Drummond, between the natural meanders upstream and the Hazel Marsh Meander. Numerous intermittent tributaries feed the Clark Fork from both sides of the valley.

Between its origin and Garrison the Clark Fork flows through a broad lowland bordered by low terraces which slope gently upward to the mountains on either side. At Garrison the river turns sharply to the northwest and flows through a series of deep gorges interspersed with rolling uplands and well-drained slopes. The present flood plain west of Drummond is made up of alluvial deposits of sand and gravel.

The section of the Clark Fork River studied has an average gradient of 5 to 10 ft per mile and is limited in its lateral meandering by the slope of the sides of the valley. These features classify it as a mountainous stream. Valley streams are characterized by gradients less than 2 to 3 ft per mile flowing in broad valleys allowing great latitude in the meandering.

The vegetation in the Clark Fork River Valley west of Drummond consists of native bunch grasses, pine, fir, spruces, aspen, willow and alder. The aspen, willow, and alder are predominant along the river banks.

### 3.2 River discharge records

Discharge records for the upper reaches of the Clark Fork River are very meager. The only discharges of record consist of daily readings for the months of April, May and June for 1968, 1969, 1970, and 1971 plus the discharge measurements taken as part of the data for this study. The former were taken for the U. S. Weather Bureau; the latter were taken monthly by a local observer and also on days when hydraulic and topographic field data

Table 2. Clark Fork River Discharge at Drummond

| | Oct '70 | Nov '70 | Dec '70 | Jan '71 | Feb '71 | Mar '71 | Apr '71 | May '71 | June '71 | July '71 | Aug '71 | Sept '71 | Oct '71 | Nov '71 | Dec '71 | Jan '72 | Feb '72 | Mar '72 | Apr '72 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | 3260 | | 725 | 990 | 2050 | | | | | | | | | | |
| 2 | | | | | | | 625 | 920 | 1960 | | | | | | | | | | |
| 3 | | | 625 | | 1200 | | 637 | 1080 | 1688 | | | | | | | | | | |
| 4 | | 700 | | | | 550 | 622 | 1195 | 1625 | | | | | | | | | | |
| 5 | | | | | | | 687 | 1412 | 1765 | | | | | | | | | | |
| 6 | | | | | | | 725 | 1660 | 1550 | | | | 610 | | | | | | |
| 7 | | | | | | | 740 | 1585 | 1550 | | | | | | | | | | |
| 8 | | | | 1500* | | | 700 | 1525 | 1490 | 420 | | | | | | | | | |
| 9 | | | | | | | 725 | 1670 | 1505 | | | | | | 420* | | | | |
| 10 | | | | | | | 675 | 1810 | 1625 | | | | | | | | | | |
| 11 | | | | | | | 600 | 1810 | 1650 | | | | | | | | | | |
| 12 | | | | | | | 670 | 1810 | 1625 | | | | 556 | | | 379 | | | |
| 13 | | | | | | | 662 | 1862 | 1450 | | | | 570 | | | | | | |
| 14 | | | | | | | 637 | 1962 | 1410 | | | | | 708 | 500 | | | 1188 | |
| 15 | | | | | | | 687 | 1688 | 1455 | | 200 | 300 | 575 | | | | 571 | 1160 | |
| 16 | | | | | 787 | 550 | 775 | 1410 | 1460 | | | | | | | | | 1165 | |
| 17 | | | | 1250 | | | 700 | 1565 | | 315 | | | | 688 | | | | 1410 | 989 |
| 18 | | | | | | | 800 | 1400 | | 280 | | | | | | | | 1590 | |
| 19 | | | | | | | 780 | 1387 | | | | | | | | | | 1440 | |
| 20 | | | | | | | 737 | 1365 | | | | | | | 600* | | | | |
| 21 | | | | | | | 800 | 1120 | 1210 | | | | | | | | | 1250 | |
| 22 | | | | | | | 850 | 1025 | | | | | | | | | | 1245 | |
| 23 | | | | | | 550 | 900 | 900 | | | 192 | | 625 | | | | | 1195 | |
| 24 | | | | | 625 | | 910 | 1030 | | 225 | 190 | | | | | | | 1350 | |
| 25 | 812 | | | | | | 1070 | 930 | | | 190 | | 645 | | | | | 1200 | |
| 26 | | | | | | | 937 | 800 | 1150 | 212 | 190 | | | | | | | 1100 | |
| 27 | | | | 725 | | | 855 | 780 | 1075 | 220 | 190 | | | | | | | 1062 | |
| 28 | | | | | | | 940 | 900 | | 237 | 190 | | | | | | | 1100 | |
| 29 | | | 625 | | | | 1065 | 1237 | | 245 | | | | | | | | | |
| 30 | | | | | | | 1000 | 1665 | | | | | | | | | | 1115 | |
| 31 | | | | | | | | 1895 | | | | | | | | | | 1012 | |

*Backwater due to ice

were taken. The discharge data taken during the study period are given in Table 2.

The discharge of the Clark Fork in the proximity of study section is measured by a USGS wire-weight stage gage located at Drummond on the south side of the bridge on U. S. Highway 10A and is downstream from the mouth of Flint Creek. The maximum flow of record is 4450 cfs on June 2, 1969. The minimum discharge recorded during 1971 was approximately 125 cfs.

The discharge record for Flint Creek consists of nine monthly observations above Willow Creek (not same creek previously mentioned) from October, 1971, through June, 1972, and three at the mouth of Flint Creek at Drummond; these are given in Table 3.

Table 3. Flint Creek Discharge

| | Flint Creek Discharge, cfs | |
|---|---|---|
| Date | At Willow Creek | At Drummond |
| 10/13/71 | 137 | -- |
| 11/14/71 | 127 | -- |
| 12/14/71 | 114 | -- |
| 1/12/72 | 93 | -- |
| 2/15/72 | 90 | -- |
| 3/14/72 | 188 | -- |
| 4/13/72 | 172 | 218 |
| 5/15/72 | 432 | 419 |
| 6/13/72 | 377 | 317 |

The Willow Creek gaging station for Flint Creek is approximately five miles above the junction of Flint Creek with the Clark Fork River and was established in October, 1971 by the USGS. The Drummond gaging station for Flint Creek was installed in April, 1972.

### 3.3 Constructed meanders

The plans for the Hazel Marsh and Weaver Meanders are shown in Figs. 4 and 5 respectively. The typical channel cross-section in the curved portions of both meanders is shown at the top of Fig. 4 and in Fig. 6a with the deep portion of the channel oriented to the outside of the curve. The field notes for staking the construction indicate the cross-sections in the zone of transition (where the deep portion of the channel crossed from one side to the other) was as shown in Fig. 6b. The outside of the curves were armored with type "B" rip-rap whose average piece was in excess of 0.5 cu yd with some pieces as large as 3 to 4 cu yd. The armored areas are shown in Figs. 4 and 5.

The planimetric configurations of the constructed meanders were established by locating old meander channels of the river in the areas selected from aerial photographs. Gravel deposits and the patterns of vegetation noted in the photographs and by field reconnaissance provided sufficient evidence to relocate the old meander channels.

The hydraulic design criteria used for these meander channels was not established in this study. Attempts to determine any formal design procedure included a search of the field notes and the files in the Hydraulic Section of the Montana Highway Department. From discussions with the engineers in charge of laying out the meanders it was learned that the cross-sections in the constructed channels were designed in the field with the following provisions:

a. high-water stream width approximately equal to that in the natural channels,

b. maximum depth approximately equal to that in the natural channels,

c. deep flow area concentrated along outer bank of curve,

d. steep bank at outside of curve with gradual slope toward inside, and

e. constant slope along the centerline of channel.

The first four provisions were based on observations of sections of the natural channel. The calculations for the channel hydraulics were not established and design flow data were not available for this evaluation study.

As shown in Table 1, the Hazel Marsh Meander C2 is 2600 ft long with a fall of 9.5 ft per mile. The original length of this reach was 1460 ft and its fall was 17 ft per mile. The Weaver Meander C1 is 2615 ft long with a fall of 7.5 ft per mile. The original length of this reach was 1550 ft and its fall was 12 ft per mile.

### 3.4 Natural meanders

Four natural meanders initially were selected for study from aerial photographs (scale 1:4800) of the Clark Fork River taken by the Montana Highway Department on October 30, 1970. Tracings of the two constructed meanders were superimposed on tracings of natural meanders to determine which natural meanders were most geometrically similar to the constructed ones. Two of the natural meanders selected were located downstream and two upstream from the constructed meanders (see Fig. 1). The natural meanders are shown in Figs. 7, 8, 9, 10. The length and slope for each are given in Table 4. The length listed is the total length of the control section and extends beyond the individual meander curves.

Table 4. Length, slope of natural meanders

| No. | Name | Length, ft | Slope, ft/mi |
|---|---|---|---|
| N1 | D/S#1 | 2200 | 9 |
| N2 | D/S#2 | 2050 | 10.5 |
| N3 | Nelson | 1600 | 7 |
| N4 | Enman | 1550 | 7 |

## 4. EVALUATION METHODS

The methods used for the preliminary evaluation of the constructed meanders required field observations and measurements for obtaining data on the hydraulics and topographic characteristics and the fish population estimates in both the natural and constructed meanders.

The hydraulic, topographic and fish population data obtained for each meander are indicated in Table 5 along with their project reference names, aerial photograph numbers, land ownership and legal land descriptions. The designations I and II on water surface profiles and channel cross-sections indicate that these data were obtained at two different times as discussed in subsequent sections.

### 4.1 Hydraulics and topography

The principal hydraulic data observed were river discharge, water surface profiles, and transverse velocity distributions. Isolated samples of bed material, turbidity, and suspended sediment were obtained for comparison purposes. The principal topographic data were channel cross-sections. Transverse velocity distribution data were taken simultaneously with the channel cross-sections. The river discharge measured by the stage recorder at Drummond was recorded each day any observations were made. Attempts were made to measure bed load transport rates at selected points in the river by employing portable sediment traps designed in the laboratory. As these devices proved unreliable and unmanageable, it was mutually agreed by the principal investigator and the Montana Highway Research Engineer to forego the observations of sediment transport rates.

The methods used for obtaining the above-listed data are discussed more fully in the following paragraphs. The results of the hydraulic and topographic studies are presented graphically in Figs. 12 through 23 inclusive found in Appendix A and discussed in Section 5.

#### 4.1.1 Discharge measurements

The discharges occurring during the field measurements were obtained from the readings of the stage gage at Drummond and the USGS stage-discharge

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TABLE OF CONTENTS

LIST OF TABLES

# LIST OF FIGURES

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The Clark Fork River is formed by the confluence of Willow Creek and Silver Bow Creek approximately 5 miles east of Anaconda. It flows northerly for nearly 35 miles to Garrison then northwesterly for 25 miles through Drummond where it turns and flows more westerly through the Garnet-Bearmouth area. Flint Creek is the only perennial tributary with a significant flow entering the Clark Fork in the portion studied; it flows into the Clark Fork at Drummond, between the natural meanders upstream and the Hazel Marsh Meander. Numerous intermittent tributaries feed the Clark Fork from both sides of the valley.

Between its origin and Garrison the Clark Fork flows through a broad lowland bordered by low terraces which slope gently upward to the mountains on either side. At Garrison the river turns sharply to the northwest and flows through a series of deep gorges interspersed with rolling uplands and well-drained slopes. The present flood plain west of Drummond is made up of alluvial deposits of sand and gravel.

The section of the Clark Fork River studied has an average gradient of 5 to 10 ft per mile and is limited in its lateral meandering by the slope of the sides of the valley. These features classify it as a mountainous stream. Valley streams are characterized by gradients less than 2 to 3 ft per mile flowing in broad valleys allowing great latitude in the meandering.

The vegetation in the Clark Fork River Valley west of Drummond consists of native bunch grasses, pine, fir, spruces, aspen, willow and alder. The aspen, willow, and alder are predominant along the river banks.

### 3.2 River discharge records

Discharge records for the upper reaches of the Clark Fork River are very meager. The only discharges of record consist of daily readings for the months of April, May and June for 1968, 1969, 1970, and 1971 plus the discharge measurements taken as part of the data for this study. The former were taken for the U. S. Weather Bureau; the latter were taken monthly by a local observer and also on days when hvdraulic and topographic field data

Table 2. Clark Fork River Discharge at Drummond

| | Oct '70 | Nov '70 | Dec '70 | Jan '71 | Feb '71 | Mar '71 | Apr '71 | May '71 | June '71 | July '71 | Aug '71 | Sept '71 | Oct '71 | Nov '71 | Dec '71 | Jan '72 | Feb '72 | Mar '72 | Apr '72 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | 3260 | | 725 | 990 | 2050 | | | | | | | | | | |
| 2 | | | | | | | 625 | 920 | 1960 | | | | | | | | | | |
| 3 | | | 625 | | 1200 | | 637 | 1080 | 1688 | | | | | | | | | | |
| 4 | | 700 | | | | 550 | 622 | 1195 | 1625 | | | | | | | | | | |
| 5 | | | | | | | 687 | 1412 | 1765 | | | | | | | | | | |
| 6 | | | | | | | 725 | 1660 | 1550 | | | | 610 | | | | | | |
| 7 | | | | | | | 740 | 1585 | 1550 | | | | | | | | | | |
| 8 | | | | 1500* | | | 700 | 1525 | 1490 | 420 | | | | | | | | | |
| 9 | | | | | | | 725 | 1670 | 1505 | | | | | | 420* | | | | |
| 10 | | | | | | | 675 | 1810 | 1625 | | | | | | | | | | |
| 11 | | | | | | | 600 | 1810 | 1650 | | | | | | | | | | |
| 12 | | | | | | | 670 | 1810 | 1625 | | | | 556 | | | 379 | | | |
| 13 | | | | | | | 662 | 1862 | 1450 | | | | 570 | | | | | | |
| 14 | | | | | | | 637 | 1962 | 1410 | | | | | 708 | 500 | | | 1188 | |
| 15 | | | | | | | 687 | 1688 | 1455 | | 200 | 300 | 575 | | | | 571 | 1160 | |
| 16 | | | | | 787 | 550 | 775 | 1410 | 1460 | | | | | | | | | 1165 | |
| 17 | | | | 1250 | | | 700 | 1565 | | 315 | | | | 688 | | | | 1410 | 989 |
| 18 | | | | | | | 800 | 1400 | | 280 | | | | | | | | 1590 | |
| 19 | | | | | | | 780 | 1387 | | | | | | | | | | 1440 | |
| 20 | | | | | | | 737 | 1365 | | | | | | | 600* | | | | |
| 21 | | | | | | | 800 | 1120 | 1210 | | | | | | | | | 1250 | |
| 22 | | | | | | | 850 | 1025 | | | | | | | | | | 1245 | |
| 23 | | | | | | 550 | 900 | 900 | | | 192 | | 625 | | | | | 1195 | |
| 24 | | | | | 625 | | 910 | 1030 | | 225 | 190 | | | | | | | 1350 | |
| 25 | 812 | | | | | | 1070 | 930 | | | 190 | | 645 | | | | | 1200 | |
| 26 | | | | | | | 937 | 800 | 1150 | 212 | 190 | | | | | | | 1100 | |
| 27 | | | | 725 | | | 855 | 780 | 1075 | 220 | 190 | | | | | | | 1062 | |
| 28 | | | | | | | 940 | 900 | | 237 | 190 | | | | | | | 1100 | |
| 29 | | | 625 | | | | 1065 | 1237 | | 245 | | | | | | | | | |
| 30 | | | | | | | 1000 | 1665 | | | | | | | | | | 1115 | |
| 31 | | | | | | | | 1895 | | | | | | | | | | 1012 | |

*Backwater due to ice

were taken. The discharge data taken during the study period are given in Table 2.

The discharge of the Clark Fork in the proximity of study section is measured by a USGS wire-weight stage gage located at Drummond on the south side of the bridge on U. S. Highway 10A and is downstream from the mouth of Flint Creek. The maximum flow of record is 4450 cfs on June 2, 1969. The minimum discharge recorded during 1971 was approximately 125 cfs.

The discharge record for Flint Creek consists of nine monthly observations above Willow Creek (not same creek previously mentioned) from October, 1971, through June, 1972, and three at the mouth of Flint Creek at Drummond; these are given in Table 3.

Table 3. Flint Creek Discharge

| | Flint Creek Discharge, cfs | |
|---|---|---|
| Date | At Willow Creek | At Drummond |
| 10/13/71 | 137 | -- |
| 11/14/71 | 127 | -- |
| 12/14/71 | 114 | -- |
| 1/12/72 | 93 | -- |
| 2/15/72 | 90 | -- |
| 3/14/72 | 188 | -- |
| 4/13/72 | 172 | 218 |
| 5/15/72 | 432 | 419 |
| 6/13/72 | 377 | 317 |

The Willow Creek gaging station for Flint Creek is approximately five miles above the junction of Flint Creek with the Clark Fork River and was established in October, 1971 by the USGS. The Drummond gaging station for Flint Creek was installed in April, 1972.

### 3.3 Constructed meanders

The plans for the Hazel Marsh and Weaver Meanders are shown in Figs. 4 and 5 respectively. The typical channel cross-section in the curved portions of both meanders is shown at the top of Fig. 4 and in Fig. 6a with the deep portion of the channel oriented to the outside of the curve. The field notes for staking the construction indicate the cross-sections in the zone of transition (where the deep portion of the channel crossed from one side to the other) was as shown in Fig. 6b. The outside of the curves were armored with type "B" rip-rap whose average piece was in excess of 0.5 cu yd with some pieces as large as 3 to 4 cu yd. The armored areas are shown in Figs. 4 and 5.

The planimetric configurations of the constructed meanders were established by locating old meander channels of the river in the areas selected from aerial photographs. Gravel deposits and the patterns of vegetation noted in the photographs and by field reconnaissance provided sufficient evidence to relocate the old meander channels.

The hydraulic design criteria used for these meander channels was not established in this study. Attempts to determine any formal design procedure included a search of the field notes and the files in the Hydraulic Section of the Montana Highway Department. From discussions with the engineers in charge of laying out the meanders it was learned that the cross-sections in the constructed channels were designed in the field with the following provisions:

a. high-water stream width approximately equal to that in the natural channels,

b. maximum depth approximately equal to that in the natural channels,

c. deep flow area concentrated along outer bank of curve,

d. steep bank at outside of curve with gradual slope toward inside, and

e. constant slope along the centerline of channel.

The first four provisions were based on observations of sections of the natural channel. The calculations for the channel hydraulics were not established and design flow data were not available for this evaluation study.

As shown in Table 1, the Hazel Marsh Meander C2 is 2600 ft long with a fall of 9.5 ft per mile. The original length of this reach was 1460 ft and its fall was 17 ft per mile. The Weaver Meander C1 is 2615 ft long with a fall of 7.5 ft per mile. The original length of this reach was 1550 ft and its fall was 12 ft per mile.

### 3.4 Natural meanders

Four natural meanders initially were selected for study from aerial photographs (scale 1:4800) of the Clark Fork River taken by the Montana Highway Department on October 30, 1970. Tracings of the two constructed meanders were superimposed on tracings of natural meanders to determine which natural meanders were most geometrically similar to the constructed ones. Two of the natural meanders selected were located downstream and two upstream from the constructed meanders (see Fig. 1). The natural meanders are shown in Figs. 7, 8, 9, 10. The length and slope for each are given in Table 4. The length listed is the total length of the control section and extends beyond the individual meander curves.

Table 4. Length, slope of natural meanders

| No. | Name | Length, ft | Slope, ft/mi |
|---|---|---|---|
| N1 | D/S#1 | 2200 | 9 |
| N2 | D/S#2 | 2050 | 10.5 |
| N3 | Nelson | 1600 | 7 |
| N4 | Enman | 1550 | 7 |

# 4. EVALUATION METHODS

The methods used for the preliminary evaluation of the constructed meanders required field observations and measurements for obtaining data on the hydraulics and topographic characteristics and the fish population estimates in both the natural and constructed meanders.

The hydraulic, topographic and fish population data obtained for each meander are indicated in Table 5 along with their project reference names, aerial photograph numbers, land ownership and legal land descriptions. The designations I and II on water surface profiles and channel cross-sections indicate that these data were obtained at two different times as discussed in subsequent sections.

## 4.1 Hydraulics and topography

The principal hydraulic data observed were river discharge, water surface profiles, and transverse velocity distributions. Isolated samples of bed material, turbidity, and suspended sediment were obtained for comparison purposes. The principal topographic data were channel cross-sections. Transverse velocity distribution data were taken simultaneously with the channel cross-sections. The river discharge measured by the stage recorder at Drummond was recorded each day any observations were made. Attempts were made to measure bed load transport rates at selected points in the river by employing portable sediment traps designed in the laboratory. As these devices proved unreliable and unmanageable, it was mutually agreed by the principal investigator and the Montana Highway Research Engineer to forego the observations of sediment transport rates.

The methods used for obtaining the above-listed data are discussed more fully in the following paragraphs. The results of the hydraulic and topographic studies are presented graphically in Figs. 12 through 23 inclusive found in Appendix A and discussed in Section 5.

### 4.1.1 Discharge measurements

The discharges occurring during the field measurements were obtained from the readings of the stage gage at Drummond and the USGS stage-discharge

Table 5. Schedule of data observed on meander channels

| Name | Type | Location | Owner | Aerial photo no. | Water surface profiles I | Water surface profiles II | Channel cross-sections I | Channel cross-sections II | Bed material samples | Turbidity samples | Fish population |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Enman, N4 | N* | NW1/4 S9 T10N,R12W | Malcom Enman | 204-226 | X | | | X | X | | X |
| Nelson, N3 | N | NE1/4 S8 T10N,R12W | Dingwall Corp. | 204-225 | X | X | X | | X | X | X |
| Hazel Marsh,C2 | C | NE1/4 S17 T11N,R13W | Elvin Baker | 204-185 | X | X | X | X | X | X | X |
| Weaver, C1 | C | SE1/4 S17 T11N,R14W | Maurice Weaver | 204-153 | X | X | X | | X | X | |
| Downstream, N2 No. 2 | N | NE1/4 S19 T11N,R14W | Maurice Weaver | 204-149 | X | | | | | | |
| Downstream, N1 No. 1 | N | NW1/4 S19 T11N,R14W | State of Montana | 204-148 | X | X | X | | | | |

*N - Natural channel
C - Constructed channel

rating curve shown in Fig. 11. The discharges for meanders N1, N2, C1 and C2 were assumed to be equal to those at the gaging station. The discharges for meanders N3 and N4 (Nelson and Enman, respectively) were found by subtracting the flows estimated for Flint Creek using Table 2 from the discharge at the gaging station on the Clark Fork at Drummond.

The short period of discharge records for both the Clark Fork River and Flint Creek, the infrequent observations of data, and the fact that the existing data show that no observations of all three gaging stations were taken on the same day prior to April, 1972, make any estimate of the flow contributed by Flint Creek during the study period purely an estimate.

The flow of Flint Creek is estimated to contribute from 18 to 31 percent of the discharge in the Clark Fork below Drummond. The discharge observed for the meanders below Drummond (C1, C2, N1, N2) and estimated for those upstream (N3, N4) from the gaging station are indicated in Figs. 12 through 17 and discussed in Section 5.

#### 4.1.2 Water surface profiles

The first set of water surface profiles (labelled I in Table 5) were taken on all six meanders in late June and early July, 1971, as soon as practicable after the high water period, to determine if the natural meanders selected were similar to the constructed ones in (1) overall slope and (2) general pool-riffle frequency.

Points marking the flow lines of the meander channels were established by a stadia traverse run on both sides of river. A level circuit was run to determine the water surface elevations adjacent to these flow line points for plotting the water surface profiles. After reviewing the first set of water surface profiles further field work was carried out on the two constructed (C1 and C2), and one upstream (the Nelson, N3) and one downstream (the Downstream No. 1, N1) natural meanders.

The second set of water surface profiles (II, Table 5) were taken on the two constructed meanders and the Nelson and Downstream No. 1 natural meanders in late August, 1971, during the low water period of the river.

Water surface profiles were also obtained from cross-section data taken on the Enman and Hazel Marsh meanders in March, 1972.

The planimetric views of the meander studied and their water surface profiles are shown in Figs. 12, 13, 14, 15, 16, and 17 and discussed in Section 5.1.

4.1.3 Channel cross-sections

The first set of channel cross-sections (I, Table 5) were taken on the two constructed (C1, C2) and the Nelson (N3) and Downstream No. 1 (N1) natural meanders in late August, 1971, at the locations shown in Figs. 12, 14, 17 and 18 to determine if the cross-sections at selected points in the constructed channels were similar to those at the same relative locations in the natural meanders. The distance between these transects varied from 250 to 500 ft apart measured along the center of the flow line. Velocity distribution data were recorded at five or more points on each cross-section.

Cross-section data were obtained by the generally accepted methods using a level, a rod and a tape (or a transit for stadia measurements). Velocity distribution data were obtained by using a No. 622-F Gurley current meter to record flow velocities at three or more points on each vertical of five or more points on the transects.

A review of the channel cross-section along with the data available from the initial fish population samples indicated the cross-sections were too far apart along the length of the stream to give meaningful bed profile data. It was mutually agreed among the Montana Highway Department Research Engineer, the Fish and Game Fish Habitat Leader and the principal investigator to obtain more intensive data on one of the constructed and one of the natural meanders. The Hazel March (C2) and Enman (N4) Meanders were selected as the constructed and natural channel sections, respectively, for intensive study based on discussions among Dr. Richard Graham of the Bureau of Sport Fisheries and Wildlife, Mr. Ron Marcoux of the Fisheries Division of the Montana Fish and Game Department and the principal investigator.

The second set of channel cross-sections (II, Table 5) were taken in late March, 1972, at the locations approximately 100 ft apart on the Enman and Hazel Marsh Meanders. The Enman Meander section used in the March survey was approximately 1000 ft longer than originally used for the first set of water surface profiles to give a larger sampling area for the fish population data.

The results of the hydraulic and topographic surveys are shown in Appendix A in Figs. 12 through 23, inclusive.

4.1.4 Bed material samples

Samples of bed material were obtained at selected points shown in Figs. 14, 16, and 17 from the two constructed meanders and one natural meander (Nelson) in October, 1971, at same relative locations in the meanders and stream-flow patterns. These were taken to determine if the gradation of the sand and gravel in the constructed meanders is similar to that found in the same relative positions in natural meanders. These initial samples, obtained in periods of low water, were taken on the banks and bars adjacent to the flow sections. A shovel and plastic-lined bags were used to collect the individual 15-lb samples.

Additional samples were taken during the more intensive studies of the Enman (N4) and Hazel Marsh (C1) Meanders in April at the points shown in Figs. 19 and 20. A specially constructed sampler made from a 3-in-dia steel pipe 6 ft long was used to obtain bed samples out in the stream.

4.1.5 Water turbidity and suspended sediment samples

Water samples for comparing the turbidity levels of the stream flow in the natural meanders with those in the constructed meanders were taken at one or two points on each of three transects in the two constructed and one natural (Nelson) meanders shown in Figs. 14, 16 and 17 in late October, 1971. Water from two 1000-ml pothyethylene bottles filled with depth-integrated samples at each point were analyzed using a Hach Model 2100 turbidimeter within fifteen minutes from time of sampling in accordance with the nephelometric technique described in Par. 163A, Standard Methods (1971).

Suspended sediment samples were taken during the same observation period at points on the same transects used for turbidity samples. Generally three depth-integrated samples were taken in 1000-ml polyethylene bottles at each sampling point. The quantities of suspended sediment were determined by filtration and evaporation techniques adapted from Section 224, Standard Methods.

### 4.2 Fish population survey

Fish populations were sampled from a boat with the aid of a variable voltage D-C electrofishing shocker. A mark and recapture method of Peterson (described by Ricker, 1958) utilizing two or more marking survey runs in each designated meander followed in approximately one week by one or more recapture runs was the basis for all estimates. Fish captured during marking runs were measured, weighed, marked with distinctive fin clips and released near the point of capture. Trout estimates were for yearlings and older fish during the summer and fall sampling periods and for fish two years old and older during the spring sampling. The separation into age groups was made using the length frequency distribution. Sampling for trout in the younger age groups was very inefficient. Population estimates were limited to whitefish longer than 7 inches.

Initial sampling was done on the upper natural meanders (N3, N4) and the constructed meanders (C1, C2) in late August and early September, 1971. In addition, a survey run was made on 14,000 feet of the unaltered river above the constructed meanders in a reach including the Nelson (N3) and Enman (N4) Meanders to obtain an estimate of the average population density.

Too few fish were captured in the 1971 survey runs in all study sections except the Hazel Marsh meander to make valid population estimates. It was mutually agreed to confine and intensify additional sampling to the Hazel Marsh Meander (C2) and the Enman Meander (N4) with an increased length. These sections were sampled in March and August, 1972.

Pronounced riffle areas were used to delineate the boundaries of sampling sections so that fish movement would be minimized. This resulted in fish sampling sections that were somewhat longer than those used to obtain hydraulic and topographic data.

## 5. PRESENTATION AND DISCUSSION OF RESULTS

The results of the hydraulic, topographic and fish population data obtained for a preliminary evaluation of the constructed meanders are presented and discussed in the following. Results appearing in tabular form are located in this section; results summarized graphically are found in Figs. 12 through 23 in Appendix A.

### 5.1 Hydraulic and topography

The hydraulic and topographic field data have been reduced to a series of drawings shown in Figs. 12 through 23 giving the planimetric view, water surface profiles, flow cross-sections, topography and velocity distributions of the study sections.

Figures 12 through 17 show the planimetric configuration of the stream, the profiles of the water surfaces and channel profiles, and typical channel cross-sections. The planimetric views contain stationing marks 200 ft on center and indicate the location where channel cross-section data were taken. The profile views show the water surface profiles obtained from level circuits and channel profiles of the thalweg obtained from cross-section data. Points along the stream where channel cross-section were taken are indicated on the profile view. The channel cross-sections presented are shown as viewed looking downstream when located at the channel section. Information obtained from scaled-up drawings similar to Figs. 12 through 17 for comparing the planimetric properties of the sections including stream length, average width, down valley distance, average radius of curvature, ratio of meander length to average curve radius, and sinuosity are summarized in part (a) of Table 6. The average radii of curvature were determined graphically by constructing bisectors to chord lengths connecting adjacent points along the stream centerline. The radii to different points along the stream centerlines were scaled from the approximate locus of the intersections of the chord bisectors. The down valley distance is the chord distance across the principal curve of the meander between the principal inflection points. Values used were scaled from the planimetric views.

Table 6. Meander characteristics

a. Planimetric characteristics

| Meander (1) | Length of primary curve, $L_c$ ft (2) | Average stream width, W ft (3) | Average curve radius, R ft (4) | Down valley distance, D ft (5) | Meander ratio $L_c/R$ (6) | Sinuosity $L_c/D$ (7) | Radius-width ratio R/W (8) |
|---|---|---|---|---|---|---|---|
| N2 | 1400 | 116 | -- | 822 | -- | 1.7 | -- |
| N1 | 1740 | 118 | 440 | 920 | 3.9 | 1.7 | 3.7 |
| N3 | 1450 | 98 | 395 | 822 | 3.7 | 1.8 | 4.0 |
| N4 | 1090 | 89 | 270 | 550 | 4.0 | 2.0 | 3.0 |
| C1 | 1760 | 100 | 425 | 940 | 4.1 | 1.9 | 4.2 |
| C2 | 1400 | 105 | 335 | 750 | 4.2 | 1.9 | 3.2 |

b. Hydraulic characteristics

| Meander | Date (9) | Discharge Q cfs (10) | Average slope of water surface S ft/mi (11) | Pool-riffle freq. (12) | Maximum average velocity, $V_{max}$ fps (13) | Minimum average velocity, $V_{min}$ fps (14) | Mean average velocity, $V_{mean}$ fps (15) |
|---|---|---|---|---|---|---|---|
| N1 | 6/26/71 | 1150 | 10.8 | 4.1 | -- | -- | -- |
| N2 | 6/21/71 | 1210 | 10.2 | 4.6- | 4.9 | 2.8 | 3.7 |
| | 8/23/71 | 192 | 9.2 | 5.0 | 1.6 | 0.7 | 1.2 |
| N3 | 7/17/71 | 315[a] | 6.8 | 9.0 | 3.3 | 1.5 | 2.3 |
| | 8/27/71 | 190[a] | 5.7 | | 2.8 | 1.2 | 1.9 |
| N4 | 7/8/71 | 420[b] | 7.4 | 3.4- | 6.4 | 2.3 | 3.9 |
| | 3/24/72 | 1000[c] | 7.1 | 6.0 | 4.8 | 2.9 | 3.8 |
| C1 | 6/27/71 | 1075 | 7.1 | -- | 4.2 | 2.6 | 3.7 |
| | 8/24/71 | 190 | 5.6 | | 1.7 | 1.0 | 1.3 |
| C2 | 7/18/71 | 280 | 6.6 | 5.7- | -- | -- | -- |
| | 8/26/71 | 190 | 6.2 | 6.5 | 1.7 | 1.1 | 1.4 |
| | 3/22/72 | 1225 | 7.8 | | 4.9 | 2.5 | 3.7 |

a. Discharge at Drummond uncorrected for Flint Creek inflow as records unavailable

b. Discharge reading not recorded; this is extrapolated from trend of readings before and after date

c. Discharge corrected for inflow at Flint Creek

The hydraulic characteristics of the meanders including discharge, average slope of water surface, pool-riffle frequency, maximum average velocity, minimum average velocity, and mean average velocity are summarized in part (b) of Table 6. The profiles were plotted to a scale greater than shown in Figs. 12 through 17 for analysis. The pool-riffle frequency was determined by dividing the distances from the beginning of one pool to the beginning of the next by the average stream width throughout that reach. The pools were judged to occur in regions of the stream having a flat profile.

The average velocity values shown in columns 13, 14, 15, of Table 6 were obtained by dividing the discharges by the flow areas of the cross-sections given in Figs. 12 through 17; the water surface was placed on the respective sections according to its elevation on the date given in column 9. The discharges indicated for the Nelson meander (N3) are the same as those occurring downstream from Drummond as the records of the Flint Creek flow were not begun until October, 1971.

The velocity ranges shown are based only on values obtained at seven cross-sections in each meander except for those given for N4 on 3/24/72 and for C2 on 3/22/72. The velocity values for the March, 1972 discharges are based on 26 cross-sections in each meander section.

### 5.1.1 Quantitative characteristics

The quantitative data summarized in Table 6 show the following:

a. With the exception of N1, the planimetric parameters (meander ratio, Lc/R; sinuosity, Lc/D; radius-width ratio, R/W) indicate all the meanders selected for tentative study have similar geometric characteristics. The compound curve feature of N1 created two distinct radii of curvature. These did not allow a single average radius of curvature to typify this curve. Based on the radius-to-width ratio, meanders N3 and C1 should be compared as one set and meanders N4 and C2 as another.

b. The slopes of the water surfaces indicate that the meanders N1 and N2 are significantly steeper for all ranges of flow than are those of N3, N4, C1 and C2. For flows greater than 1000 cfs, N4, C1, and C2 have slopes ranging from 7.1 to 7.8 ft per mile; for flows less than 350 cfs, the slopes of N3, C1 and C2 range from 5.6 to 6.8 ft per mile.

c. The range of average velocities for N2, N4, C1 and C2 indicates the channels have approximately the same degree of non-uniformity for higher flows. Non-uniformity reflects the changes in stream cross-sections along the flowline of the river. The variation between the maximum average velocity and the minimum average velocity for the constructed sections C1 and C2 are nearly the same as indicated for the natural sections.

d. The pool-riffle frequencies indicated from the water surface profiles and calculated for Table 6 correspond to the ranges observed by Elser (1968). A definite pool-riffle formation could not be detected in the water surface profile of the Weaver Meander (C1). This may be attributed to the fact that the artificial meanders were constructed on a constant grade throughout their reaches.

5.1.2 Qualitative characteristics

The qualitative data summarized in Figs. 12 through 17 show the following:

a. The cross-sections show the flow area of the stream approaching the meander is well-distributed over the width of the channel. As the flow enters the curved portion of the channel, the flow area deepens, narrows and shifts to the outside of the curve. It was noted for 4 of the 5 sections where discharge and cross-section data were obtained that the minimum average velocities occurred in the deep, narrow sections although the maximum local point velocities also occurred in these regions.

b. The effect of the small islands on the water surface profile of the Downstream Meander No. 2 (N2) precluded any further investigations of this reach. This was not unexpected; the water surface profiles were taken to document this type of stream configuration.

The lateral bar formations in the Downstream Meander No. 1 (N1) appeared during the low water period in August, 1971. Although bars similar to those were not expected to be formed yet in the constructed meander sections, cross-section data were taken for future reference on this or similar projects.

c. In general, the shape of the flow cross-sections in the constructed meanders (C1, C2) shown in Figs. 16 and 17 are similar to those found at the comparable stream locations in the natural meander sections (N3, N4) shown in Figs. 14 and 15.

d. The design of the constructed channels in the principal section of the meander curves (sections 2, 3, 4 and 5 in Fig. 16 and sections 2, 3, 4 and 5 in Fig. 17) appears to be a stable configuration for those particular channels. The design of the channels in the upstream and downstream reaches of the meanders where the current and main flow crosses from one side of the stream to the other did not conform to the design channel configuration. This is noted in sections 1, 6 and 7 of Fig. 16 and to a lesser degree in sections 1, 6 and 7 in Fig. 17. The cross-over sections occur over longer lengths than provided in the design and at locations 50 to 100 ft downstream from the inflection point of the compound channel curve.

e. The thalweg profiles are highly irregular and that of the constructed meander (C2, Fig. 17) does not bear a strong resemblance to the thalweg of the natural meander (N4, Fig. 15) yet. The thalweg of the constructed meanders may tend toward those of natural channels with time. The dashed line representing the thalweg profiles in Figs. 12, 14, 16, 17 were plotted from the data of the cross-sections spaced 250 to 500 ft. This proved to be insufficient to represent the bed profile accurately as shown by the thalweg data points plotted as circles in Fig. 17. The latter data and the thalweg profile shown in Fig. 15 were taken from the intensive study of the Hazel Marsh Meander (C2) and the Enman Meander (N4). A close examination of the thalweg data of Fig. 17 indicates that some scour has taken place between August 26, 1971, and March 22, 1972.

#### 5.1.3 Results of intensive studies

More detailed field studies were conducted on one natural meander and one constructed meander to obtain more complete hydraulic, topographic and fish population data. Based on the quantitative and qualitative results of the preceding sections and the considerations of accessibility for the fish sampling data, the more intensive studies were conducted on the Enman Meander (N4) and the Hazel Marsh Meander (C2). Channel cross-sections and velocity distribution measurements were taken at intervals of approximately 100 ft of stream length. The discharges were 1225 cfs in C2 and 995 cfs in N4.

The typical channel cross-sections and stream profile data are shown in Fig. 15 and 17 for the Enman and the Hazel Marsh Meanders, respectively.

Topographic maps of the channel beds based on data from the intensive studies are shown in Fig. 19 and 20 for C2 and N4, respectively. The topography of the Hazel Marsh Meander (C2) as constructed is shown in Fig. 18.

Maps with lines of constant velocity are shown in Figs. 21 and 22. The transverse velocity distributions at selected cross-sections of C1 and N4 are shown in Fig. 23.

5.1.3.1 Channel topography

(A) A comparison of the channel topography of C2 observed in March 1972 (Fig. 19) with constructed contours (Fig. 18) shows:

a. A riffle area is forming on the inside of the curve in the region of the upstream crossover between stations 18+00 and 20+00.

b. Localized scour is creating deep holes in two areas (between stations 15+00 and 17+00 and between 7+00 and 10+00) along the outside of the primary meander curve.

c. The deposition of material downstream from station 3+00 is filling in the central section of the channel and restructuring the pool along the outside of the curve in the vicinity of stations 2+00 and 5+00.

(B) A comparison of the channel topography of C2 (Fig. 19) with that of N4 (Fig. 20) shows the bed of the constructed meander is tending toward the configuration of the natural meander. The following points illustrate this tendency:

a. The pool forming between stations 20+00 and 24+00 on the upstream end of the constructed meander (C2, Fig. 19) corresponds to the pool found between sections 24 and 26 of the natural meander (N4, Fig. 20).

b. The riffle forming between stations 18+00 and 20+00 of C2 corresponds to the broad riffle located between sections 21 and 24 of N4.

c. The pool forming between stations 15+00 and 17+00 of C2 corresponds to the pool located between sections 20 and 21 of N4.

d. The pool forming between stations 7+00 and 10+00 of C2 is similar to that between sections 16 and 18 of N4.

e. The restructured topography between station 2+00 and 5+00 of C2 is similar to that between sections 11 and 14 of N4.

5.1.3.2 Channel hydraulics

(A) A comparison of the velocity distribution patterns observed in the constructed meander C2 (Fig. 21) with those in the natural meander N4 (Fig. 22) shows:

a. Two areas of velocity in excess of 5 ft per sec (fps) between stations 20+00 and 24+00 in the inflow section of C2 correspond to the single area with a velocity greater than 5 fps between sections 24 and 26 of N4.

b. The second zone of velocity in excess of 5 fps in C2 is located further downstream and around the curve from the comparable high-velocity zone in N4. The difference in the relative locations is caused by the difference in channel topography of this portion of the respective meanders: the bed profile of the constructed meander C2 (Fig. 17b) has less slope between station 16+00 and 18+00 than the slope of the natural meander N4 (Fig. 15b) between sections 20 and 23. Also the curvature of the channel for C2 in this reach is greater than that for N4.

c. The two small zones of velocity greater than 5 fps between stations 7+00 and 9+00 of C2 correspond to those at section 16 and between sections 12 and 14 of N4.

d. The region of velocity in excess of 4 fps extends from station 5+00 to station 21+00 throughout the primary curve of the constructed meander C2. Two separate regions of velocity in excess of 4 fps exist in the primary curve of the natural meander N4. This indicates a somewhat more pronounced pool-riffle tendency in the natural meander.

(B) The transverse velocity distributions at seven cross-sections situated at similar locations on the constructed (C2) and natural (N4) meanders are shown in Fig. 23. The velocities used were obtained at six tenths of the depth (0.6D) at each of the points indicated on the cross-sections. The locations of the cross-section in the meanders are shown in Figs. 15 and 17. The data were taken March 22-23, 1972 when the discharges were 1225 cfs and 995 cfs in C2 and N4, respectively. Noting that the Hazel Marsh Meander (C2) curves to the right and the Enman Meander (N4) to the left, Fig. 23 shows the transverse velocity distribution patterns for cross-sections at comparable stream locations in the two sections to be similar:

a. The point of maximum velocity is shifted toward the bank on the inside of the meanders in the inflow sections (C2, sec. 1,2; N4, sec. 22,24).

b. The point of maximum velocity is shifted toward the outside of the meanders in the central sections of the principal curve (C2, sec. 4,5,6; N4, sec. 16,17.2,18,20).

c. The point of maximum velocity is again shifted toward the inside of the meander in the outflow sections (C2, sec. 7; N4, sec. 14).

(C) The depth-velocity characteristics of the constructed (C2) and natural (N4) meander sections are summarized in Table 7 for the data obtained March 22-23, 1972. Data for C2 is found in Table 7a; for N4, in Table 7b. The flow areas (cols. 2 and 9) were obtained by plotting the cross-sections and planimetering the areas. The average depths of flow (cols. 4 and 11) are the flow areas divided by the surface widths. The similarities between the ratios of maximum depth to average depth and maximum velocity to average velocity for comparable sections in the respective meanders may be determined from Table 7. An indication of the similarities of the meanders based on the maximum, minimum and averages of these ratios for the respective meanders is shown in the following chart:

| | Hazel Marsh(C2) | Enman(N4) |
|---|---|---|
| Max. $d_m/d$ | 1.97 | 1.90 |
| Min. $d_m/d$ | 1.01 | 1.09 |
| Ave. $d_m/d$ | 1.53 | 1.55 |
| | | |
| Max. $V_m/V$ | 1.59 | 1.57 |
| Min. $V_m/V$ | 1.11 | 1.01 |
| Ave. $V_m/V$ | 1.35 | 1.33 |

Table 7. Depth-velocity characteristics of meander sections

| Station (1) | Flow area, $ft^2$ A (2) | Surface width, ft B (3) | Ave. depth, ft d (4) | Max. depth, ft $d_m$ (5) | Ave. velocity, fps V (6) | Max. velocity, fps $V_m$ (7) |
|---|---|---|---|---|---|---|
| 7a. Hazel Marsh Meander (C2) | | | | | | |
| 1+00 | 255 | 118 | 2.1 | 3.0 | 4.8 | 6.0 |
| 2+00 | 316 | 122 | 2.6 | 3.0 | 3.9 | 4.9 |
| 3+00 | 405 | 108 | 3.8 | 6.0 | 3.0 | 4.3 |
| 4+00 | 346 | 109 | 3.2 | 5.5 | 3.6 | 3.3 |
| 5+00 | 360 | 110 | 3.3 | 4.0 | 3.4 | 5.0 |
| 6+00 | 312 | 106 | 3.9 | 5.0 | 3.8 | 4.5 |
| 7+00 | 335 | 101 | 3.2 | 6.0 | 3.7 | 5.0 |
| 8+00 | 337 | 111 | 3.0 | 5.0 | 3.6 | 4.7 |
| 9+00 | 285 | 107 | 3.8 | 5.0 | 4.3 | 5.0 |
| 10+00 | 286 | 99 | 2.9 | 5.0 | 4.3 | 4.6 |
| 11+00 | 315 | 105 | 3.0 | 5.0 | 3.9 | 4.9 |
| 12+00 | 330 | 112 | 2.9 | 6.0 | 3.7 | 5.0 |
| 13+00 | 343 | 110 | 3.0 | 5.0 | 3.6 | 5.0 |
| 14+00 | 251 | 112 | 2.2 | 5.0 | 4.9 | 6.1 |
| 15+00 | 271 | 95 | 2.8 | 5.0 | 4.5 | 5.5 |
| 16+00 | 368 | 80 | 4.6 | 6.0 | 3.3 | 4.7 |
| 17+00 | 346 | 91 | 3.8 | 5.0 | 3.7 | 4.7 |
| 18+00 | 438 | 104 | 4.2 | 5.0 | 2.8 | 4.3 |
| 19+00 | 381 | 112 | 3.4 | 5.0 | 3.2 | 4.3 |
| 20+00 | 346 | 106 | 3.3 | 3.0 | 3.5 | 5.6 |
| 21+00 | 345 | 91 | 3.8 | 7.0 | 3.5 | 5.4 |
| 22+00 | 262 | 91 | 3.0 | 5.0 | 4.5 | NG |
| 23+00 | 306 | 101 | 3.0 | 5.0 | 4.0 | 5.6 |
| 24+00 | 345 | 109 | 3.2 | 4.0 | 3.6 | 5.6 |
| 25+00 | 332 | 119 | 2.8 | 5.0 | 3.7 | 4.5 |
| 25+96 | 492 | 140 | 2.5 | 6.0 | 2.5 | 3.9 |

NG - Error in observation of maximum velocity

(Table 7 - Cont'd)

| Section (8) | Flow area, $ft^2$ A (9) | Surface width, ft B (10) | Ave. depth, ft d (11) | Max. depth, ft $d_m$ (12) | Ave. velocity, fps V (13) | Max. velocity, fps $V_m$ (14) |
|---|---|---|---|---|---|---|
| 7b. Enman Meander (N4) | | | | | | |
| 6 | 293 | 97 | 3.0 | 3.0 | 3.4 | 5.1 |
| 7 | 210 | 99 | 2.1 | 3.0 | 4.7 | 6.9 |
| 8 | 240 | 70 | 3.0 | 4.0 | 4.2 | 6.1 |
| 9 | 209 | 129 | 1.6 | 3.0 | 4.8 | 5.7 |
| 10 | 219 | 123 | 1.8 | 2.0 | 4.6 | 5.3 |
| 11 | 258 | 90 | 2.8 | 4.0 | 3.9 | 3.9 |
| 12 | 235 | 92 | 2.6 | 4.0 | 4.2 | 5.8 |
| 13 | 236 | 80 | 3.0 | 5.0 | 4.2 | 5.7 |
| 14 | 252 | 128 | 2.0 | 2.0 | 4.0 | 5.8 |
| 15 | 261 | 126 | 2.1 | 4.0 | 3.8 | 4.5 |
| 16 | 230 | 92 | 2.4 | 4.0 | 4.3 | 5.2 |
| 17 | 276 | 79 | 3.5 | 6.0 | 3.6 | 4.0 |
| 17.1 | 353 | 96 | 3.6 | 6.0 | 2.9 | 3.9 |
| 17.2 | 243 | 77 | 3.3 | 5.0 | 4.1 | 4.7 |
| 18 | 345 | 99 | 3.5 | 6.0 | 2.9 | 4.6 |
| 19 | 243 | 88 | 2.8 | 5.0 | 4.1 | 5.1 |
| 20 | 214 | 92 | 2.3 | 3.0 | 4.7 | 4.3 |
| 21 | 307 | 92 | 3.3 | 5.0 | 3.1 | 4.3 |
| 22 | 310 | 136 | 2.3 | 3.0 | 3.2 | 5.8 |
| 23 | 310 | 164 | 1.9 | 3.0 | 2.3 | 6.1 |
| 24 | 218 | 86 | 2.4 | 4.0 | 4.6 | 5.3 |
| 25 | 206 | 78 | 2.6 | 4.0 | 4.8 | 5.4 |
| 26 | 181 | 87 | 2.1 | 4.0 | 5.5 | NG |

5.2 Fish population estimates

The data for sampling the fish population in the meanders studied are presented in Tables 8 and 9. The number of fish captured in the preliminary survey runs of 1971 are shown in Table 8. The estimates of the fish population in the Hazel Marsh (C2) and Enman (N4) Meanders given in Table 9 were calculated using the Chapman modification of the Petersen estimator (equation 3.5, Ricker, 1958).

The most common fish collected in order of decreasing abundance were mountain whitefish, brown trout and largescale sucker. Others collected in much smaller numbers included longnose sucker, northern squawfish and rainbow trout. Although suckers (combined species) were collected about as frequently as brown trout, the recapture rates were so low that population estimates were not possible.

The only population estimates that could be made for the summer, 1971 sampling were for brown trout and whitefish in the Hazel Marsh Meander (C2) and brown trout in the control survey. Estimated number and weight per 1,000 feet of stream for brown trout in the control survey were 40 (± 16) and 37 (± 15) pounds, respectively. The 1971 summary of fish sampling (Table 8) shows low recapture rates in the Nelson (N3), Enman (N4) and Weaver (C1) meanders. These low or non-existant recapture rates do not permit valid population projections to be made. The data also show:

a. more fish of all species were captured in the Hazel Marsh Meander (C2) than in the Weaver Meander (C1), and

b. more fish per 1000 feet of stream were captured in the Hazel Marsh meander (C2) than in the Nelson Meander (N3), the Enman Meander (N4) or the 14,000 ft control survey section.

These results may only reflect a greater efficiency in the sampling rather than a greater fish population per 1000 ft in the Hazel Marsh Meander.

The population estimates for both brown trout and whitefish based on the intensified studies in the Hazel Marsh (C2) and Enman (N4) Meanders given in Table 9 are of limited accuracy as is shown by the large confidence intervals. Considering the variations between sampling periods and the large overlap of confidence intervals there was no significant difference in numbers and pounds of fish per 1000 ft of stream length between the constructed (C2) and natural (N4) meanders. Also the population estimates of brown trout for the

Table 8. Fish captured during summer, 1971

| | Numbers Captured | | | |
|---|---|---|---|---|
| | Brown Trout | Whitefish | Suckers | Squawfish |
| Nelson - N3 (1,650 ft) | | | | |
| Marking Runs (2) | 15 | 16 | 2 | 0 |
| Recapture Run (1) | 2 (0)* | 26 (0) | 11 (1) | 0 |
| Enman - N4 (1,550 ft) | | | | |
| Marking Runs (2) | 14 | 27 | 22 | 0 |
| Recapture Run (1) | 18 (2) | 27 (0) | 7 (0) | 1 (0) |
| Weaver - C1 (2,615 ft) | | | | |
| Marking Run (1) | 2 | 32 | 8 | 1 |
| Recapture Run (1) | 0 (0) | 13 (0) | 7 (0) | 0 (0) |
| Hazel Marsh - C2 (2,600 ft) | | | | |
| Marking Runs (2) | 50 | 86 | 65 | 3 |
| Recapture Run (1) | 24 (11) | 95 (8) | 26 (2) | 3 (0) |
| Control Survey (14,000 ft) | | | | |
| Marking Runs (2) | 146 | 177 | 118 | 2 |
| Recapture Run (1) | 68 (17) | 257 (4) | 53 (6) | 1 (0) |

*Numbers in parentheses = recaptures

Table 9. Fish population estimates for the Enman (N4) and Hazel Marsh (C2) meanders

| Species (Section) | Date | Length (inches) Range | Avg. | Population Estimates Number | Weight (lbs) | No./1000 ft | lbs/1000 ft |
|---|---|---|---|---|---|---|---|
| Brown Trout | | | | | | | |
| Enman - N4 | 3/72 | 4.0-22.5 | 13.1 | 156(±109)* | 132(± 93) | 47(± 33) | 40(± 28) |
| (3,300 ft) | 8/72 | 6.3-18.2 | 12.6 | 80(± 50) | 65(± 40) | 24(± 15) | 20(± 12) |
| Hazel Marsh - C2 | 8/71 | 6.4-18.5 | 13.7 | 106(± 42) | 115(± 46) | 37(± 14) | 40(± 16) |
| (2,900 ft) | 3/72 | 3.9-18.6 | 11.5 | 131(±106) | 124(± 36) | 45(± 36) | 43(± 34) |
| | 8/72 | 7.8-18.4 | 13.4 | 140(± 95) | 138(± 93) | 48(± 33) | 48(± 33) |
| Whitefish | | | | | | | |
| Enman - N4 | 3/72 | 5.5-17.7 | 11.3 | 1,840(±802) | 962(±419) | 558(±243) | 291(±127) |
| (3,300 ft) | 8/72 | 7.5-16.6 | 11.5 | 1,126(±626) | 662(±368) | 341(±190) | 201(±112) |
| Hazel Marsh - C2 | 8/71 | 7.9-18.0 | 11.5 | 899(±540) | 529(±318) | 310(±186) | 182(±110) |
| (2,900 ft) | 3/72 | 8.9-16.8 | 13.1 | 755(±590) | 451(±353) | 260(±203) | 156(±122) |
| | 8/72 | 8.2-17.3 | 11.9 | 1,560(±824) | 1,069(±565) | 538(±284) | 369(± 98) |

*Numbers in parentheses = 95% confidence intervals two study meanders (C2,N4) were not significantly different from that found in the control survey of 14,000 ft of stream. The average lengths of brown trout and whitefish in the constructed meander were not significantly different from those in the control meander.

Attempts to sample the fish population in the Weaver Meander (C2) were also made in March and August, 1972. The number of fish captured on both dates was too low to allow any population estimates to be made. The population in this meander may be relatively high and comparable to that in the Hazel Marsh Meander but the combination of deep and fast water along the outside of the curve made it difficult to control the boat containing the shocker. The lack of control did not permit adequate probing for fish in the deep, fast water areas and made the capture of fish difficult.

5.3 Bed materials

The results of the sieve analyses of 14 samples of bed materials obtained from selected locations in the meanders studied are presented in Table 10. The sieve sizes given are for U. S. Standard sieves; $d_{50}$ is the median grain size (50 percent larger and 50 percent smaller). The general size distribution is shown by the fractions of cobbles, coarse aggregates, coarse sand, fine sand and silt in each sample.

The results summarized in Table 10, indicating the size of bed materials range from +2 inches down to 200 mesh, do not present an accurate distribution as a higher percent of larger cobbles are found in areas of both the constructed and natural meanders. The devices and techniques employed for obtaining samples restricted the gradation to be similar to the material shown in Fig. 24a found on the point bar forming at station 15+00 in the Hazel Marsh Meander (C2). Fig. 24b shows a representative sample of the material found at the upstream end (station 17+00) of the same bar. Figs. 25a and 25b illustrate the natural gradation of material along the bar formed on the inside bank of a meander channel. Fig. 25a shows the larger cobbles deposited at the upstream end of the bar where Figs. 24a and 24b were photographed. Fig. 25b shows the fine sands deposited at the downstream end of the same bar. Similar size gradations are noted in the photographs of point bar formations in the Enman Meander (N4) in Figs. 26a and 26b. Fig. 26a is at section 18 and 26b at section 14 on N4.

The data for the four samples obtained at different points across the stream at section 23 of the Enman Meander (N4) indicate the variability of material througout a given cross-section.

The foregoing remarks indicate that isolated bed samples yield only limited information and should be supported by other field observations.

The data of Table 10 and field observations indicate the material in the two constructed meanders to be slightly coarser than that in the natural meanders. This may be attributed to the existence of local gravel deposits uncovered in the area of the constructed meanders. Also the duration of flow through these new channels has not been sufficient to deposit any appreciable amount of fine sand into the slow water areas of the meanders.

The data also indicate that there is very little silt in the total reach of the river studied.

### 5.4 Suspended sediment and turbidity

The results of the analyses for turbidity and suspended sediment of water samples from the two constructed (C1,C2) and one natural (N3) meanders are given in Table 11. The location of the cross-sections indicated in column 1 are referred to Figs. 14, 16 and 17. The R or L designations indicated distances from the right or left bank at the edge of the water when facing upstream. The suspended sediment shown is the average of two or three samples taken at each point on the cross-section and is given in parts per million (ppm). The measure of turbidity is given in Jackson turbidity units (JTU) as described in Par. 163 of the Standard Methods (1971). A JTU index of 5 or less is suitable for domestic water supplies without clarifying.

The results given in Table 11 show:

a. The amount of suspended sediment varies with location in the cross-section and location of the cross-section in the meander.

b. The amount of suspended sediment in the constructed meanders is nearly the same as that indicated in the natural meander at this time of the year.

c. The level of turbidity in the constructed meanders is the same as in the natural meander.

The suspended sediment and turbidity samples were taken during a period of relatively low water to have an indication of conditions more typical of

Table 10. Analysis of bed material

| Location | Median size $d_{50}$ mm (1) | Cobbles, +2 in. (2) | Coarse aggregate, 2"-#10 % (3) | Coarse sand, #10-#40 % (4) | Fine sand, #40-#200 % (5) | Silt -#200 % (6) |
|---|---|---|---|---|---|---|
| Nelson (N3) | | | | | | |
| Sec. 4, lt bk[a] | 0.8 | -- | 42 | 13 | 42 | 3 |
| Enman (N4) | | | | | | |
| Sec. 12, 15' lt bk | 0.5 | -- | 19 | 70 | 9 | 2 |
| Sec. 20, 30' lt bk | 0.5 | -- | 2 | 51 | 42 | 5 |
| Sec. 23, 30' rt bk | 1 | -- | 44 | 14 | 42 | -- |
| Sec. 23, WE rt bk | 0.4 | -- | 76 | 14 | 10 | -- |
| Sec. 23, 20' lt bk | 8 | -- | 5 | 32 | 63 | -- |
| [b]Sec. 23, 30' lt bk | 1 | -- | 32 | 35 | 33 | -- |
| Weaver (C1) | | | | | | |
| 200' U/S from sec. 1 rt bk | 10 | -- | 79 | 18 | 3 | -- |
| 200' D/S from sec. 7 rt bk | 10 | -- | 74 | 22 | 4 | -- |
| Hazel Marsh (C2) | | | | | | |
| 6+00, lt bk | 15 | 4 | 71 | 15 | 10 | -- |
| 6+60, lt bk | 0.4 | -- | -- | 40 | 60 | -- |
| 10+50, lt bk | 20 | 25 | 55 | 8 | 12 | -- |
| 13+50, lt bk | 0.4 | -- | 2 | 48 | 38 | 10 |
| 24+50, rt bk | 20 | 14 | 63 | 17 | 6 | -- |

a - lt bk indicates left bank facing upstream; rt bk, right bank; 30' lt bk indicates 30' out into stream from water's edge at left bank

b - this sample was obtained approximately 40 ft upstream from section 30 and at the head of a riffle.

Table 11. Analysis of suspended sediment and turbidity

| Cross-section (1) | Point (2) | Distance ft (3) | Suspended sediment, ppm (4) | Turbidity units, JTU (5) | Temperature °F |
|---|---|---|---|---|---|
| Weaver (C1) | | | | | |
| 200' U/S from sec. 1 | 1 | 36 lt bk | 15 | 3.9 | |
| | 2 | 76 | 18 | 3.2 | 45 |
| | 3 | 106 | 40 | | |
| Sec. 5 | 1 | 38 lt bk | 30 | -- | |
| | 2 | 46 | 40 | 3.4 | 45 |
| | 3 | 60 | 54 | -- | |
| 200' D/S from sec. 7 | 1 | 36 lt bk | 18 | -- | |
| | 2 | 52 | 36 | 3.1 | 45 |
| | 3 | 77 | 16 | -- | |
| Hazel Marsh (C2) | | | | | |
| 24+50 | 1 | 20 lt bk | 29 | 4.3 | |
| | 2 | 60 | 29 | 4.2 | 39 |
| | 3 | 80 | 19 | | |
| 11+50 | 1 | 20 lt bk | 21 | -- | |
| | 2 | 45 lt bk | 21 | 4.1 | 40 |
| 6+00 | 1 | 35 lt bk | 22 | -- | |
| | 2 | 50 | 35 | 4.4 | 45 |
| | 3 | 85 | 14 | 4.8 | |
| Nelson (N3) | | | | | |
| Sec. 4 | 1 | 35 rt bk | 33 | -- | |
| | 2 | 60 | 20 | 3.8 | 43 |
| | 3 | 80 | 31 | 3.9 | |

River discharge at Drummond, 645 cfs

the fishing season and spawning periods. The period of maximum amounts of suspended sediment and turbidity occurs annually during the spring runoff but is of a temporary nature. High levels of suspended sediments in low water periods are more indicative of conditions adverse to fish than those occurring in the runoff periods.

The results of these analyses indicate the construction of the meanders has not uncovered or created any permanent sources of suspended sediment or turbidity-producing material.

5.5 Other conditions observed

A major consideration in the design of fish habitat concerns the cover available along the banks of streams and the resting areas to be found in long runs of swift water. In natural meanders the vegetative growth along the stream often provides both. Examples of this are given in Figs. 27a and 27b showing fast water sections along the bank in the Enman Meander (N4).

Fig. 27a shows the flow (toward the bottom of the picture) sweeping around the point bar with the swift water section crossing to the outside of the bend. The root structure and occasional fallen tree trunks protruding into the fast flow create small local zones of relatively slow water along the bank where the trout may rest and find cover. The foliage also provides shade for cover in the summer.

Fig. 27b (with flow toward the bottom again) shows a condition similar to that of Fig. 27a with the riffle at the cross-over in the upper right corner of the picture more pronounced. The important feature of Fig. 27a is that although the main channel is essentially a tangent from the lower left to the upper right of the picture, the flow has come around the curve on the right side of the stream and continues to curve around back to the left side of the stream. The vegetation on the left side then provides the cover and resting spots in the swift water. This view is looking upstream from section 6 in the Enman Meander (N4). Trout were generally captured on the outside of bends where zones of relatively deep and fast water were interrupted by root structures or protruding vegetation.

A larger resting pool in a swift water zone is provided by the backwater area downstream from the rock jetty in Fig. 28. The observer is facing upstream; the jetty is shown at section 21 of the Enman Meander (Fig. 20). Althought the tip of the jetty does not extend out into the zone of maximum velocity (Fig. 22), it does create a scour hole downstream from it. Residents of the area related that two other similar jetties were constructed downstream; one between section 18 and 19 and the other between 18 and 17.5(1). As no evidence of either of these could be located, it was conjectured that the tips of the jetties extended into the swift water (which is nearer bank in this region) and were eroded. Apparently the rock fragments used in the construction of these jetties was not large enough to withstand the high velocities accompanying the spring runoff flows.

The swift water zones in the constructed meanders occur along the rip-rapped banks as shown in the photographs of the Hazel Marsh Meander (C2) in Figs. 29a and 29b. Looking upstream from station 19+00 Fig. 29a shows the high velocity flow separating from the rip-rap section on the left and starting the cross-over. It is to be noted that a well-defined riffle has not yet formed in this cross-over region. Fig. 29b shows the same cross-over as viewed looking downstream from station 22+00.

The large individual pieces of rip-rap along the edge of the high velocity zone create local backwater and slow water pools along the bank. Trout were often captured around or behind these large boulders, particularly during the high water of the March 1972 sampling period. Two good examples of this are the two boulders noted midway on the left side of Fig. 29a and just above the midpoint on the right side of Fig. 29b. The flow conditions in the vicinity of these two rocks are shown in Figs. 30a and 30b. The quiescent area between the two rocks (Fig. 30a) affords a deep pool as a rest area. The white water zone just off the tip of one of these pieces of rip-rap (Fig. 30b) provides a certain amount of cover for the rest area behind the rock.

The relatively steep banks and the random placement of the large individual pieces in the rip-rap sections provide bank stability and create a diversity of habitat for trout and other aquatic life. Uniform placement of smaller rock on flatter backslopes (2:1) will provide bank stability and a more efficient hydraulic section but will not provide as suitable habitat for trout and whitefish.

If the individual rip-rap pieces were much smaller than those placed in the constructed sections, the high velocities of the spring runoff would wash them out over a relatively short period of years. According to the residents in the vicinity, the outer bank of the Enman Meander (N4) was rip-rapped with hand-lain rock between sections 18 and 21 (Fig. 20). The maximum size of the individual pieces was approximately 18 x 18 x 10 inches; most were smaller. The residents claim this rip-rap was installed 5 or 6 years prior to this study (1972). A few scattered pieces and one section 20 ft long were the only remnants found. Apparently the combination of scour at the toe of the bank and the high velocity along the face of the bank during the high runoff periods have taken this rip-rap out. This indicates the necessity of placing heavy class "B" rip-rap along the exposed outer bank of the curved sections in meander channels. The excavation for and placement of rip-rap below the grade of the stream bed and extending out from the toe (Fig. 6) is necessary to prevent the scour from undercutting the bank rip-rap.

One deficiency in the meander channels is noted in Figs. 29a and 29b. The rip-rap extends to bank height and the establishment of natural vegetation along the normal river flow line is not possible.

It was noted that filamentous algae had become established on the bed and rip-rap in the Hazel Marsh Meander and appeared to be as abundant as in the control sections. Algae is important in food-chain relationships and may provide some cover for small fish.

## 6. CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

This evaluation of the two meander channels constructed to regain the length of stream lost in eight channel changes in the Clark Fork River due to the construction of Interstate Highway I-90 west of Drummond, Montana shows that:

a. the meander channels constructed do provide hydraulic, topographic and fish habitat characteristics similar to those found in natural meanders,

b. fish of the same size, species and quantities found in similar natural meanders of the river were also found in the constructed meander channels three years after construction,

c. the method and criteria used in the design of the meander channel was adequate to provide habitat for the trout and whitefish native to this section of the river, and

d. the mark-and-recapture method of estimating fish population provided adequate data for comparing the population in a constructed meander with that in a natural meander of the river although the confidence limits on the estimates of the absolute number of fish in the sections sampled were not as low as can be obtained by this method.

### 6.2 Discussion

The above-listed conclusions must be interpreted subject to the following conditions:

a. The results and conclusions are biased toward the comparison of the conditions in the Hazel Marsh Meander (C2) with those in the Enman Meander (N4) as these were judged to have the greatest similarity and were studied more intensively than the other meanders.

b. The results and conclusions are good for mountainous trout streams with the type of bed material, gradient, planimetric configuration and rip-rap material encountered in this study. The variability of these parameters and others with the individual streams and with different locations in the same stream make it inadvisable to extrapolate these results to other cases.

c. The depth and velocity of flow during the fish population sampling and the overall size of the river were greater than normally encountered for the electrofishing to be effective. The techniques and analysis for streams of this size have not been developed to as high a degree of accuracy as for the smaller trout streams. For this reason the fish data are good for comparing the populations of the two meanders but are not as reliable for the absolute population estimates as have been obtained using the mark-and-recapture method on smaller streams.

The backwater effect created by the construction of the meander channels could not be evaluated. The average gradient of the stream bed between the end points of the Hazel Marsh Meander (C2) was reduced from 17.5 to 9.5 ft per mile; that for the Weaver Meander (C1) from 12.1 to 7.4 ft per mile. The effects of gradient changes of this magnitude require the knowledge of the hydraulic, topographic, planimetric and fish habitat conditions upstream and downstream from the constructed meander prior to any alteration of the channel. In addition to recovering the stream length, decreasing the gradient, and increasing the sinuosity and pool frequency in the constructed meander, similar effects may occur in short reaches of the river upstream.

## 6.3 Recommendations

As a result of this evaluation study a number of recommendations can be made on the procedure for designing meander channels with fish habitat considerations and for conducting future studies to augment the proposed design procedure.

### 6.3.1 Design procedure

The number of parameters involved in designing a meander channel with suitable habitat for supporting trout varies from stream to stream and between locations on the same stream to such an extent that a strict codified design procedure cannot be formulated at this time. The field work, quantitative data and other observations associated with this evaluation of two meander channels constructed to restore fish habitat provide a basis for recommending the following design guidelines:

a. A study of the geomorphology of the stream will show the type of stream being dealt with and what its natural tendencies are toward meandering. This may be aided by photogrammetry and field observations.

b. A study of the hydraulic, topographic, and planimetric conditions of the stream in the area of a proposed channel change will establish the design criteria for integrating the constructed section into the natural environment. The data obtained should include high and low discharge rates, channel gradient, typical cross-sections in meander curves, average stream width and general planimetric configuration of meanders.

c. The design of a typical uniform cross-section based on the hydraulic characteristics of the natural stream and held constant throughout the curve of the meander channel will simplify the construction. This cross-section should be of designed to allow the scour and deposition of bed materials to occur with a minimum movement of material (i.e., deep toward the outside of the curve with a gradual slope back toward the inner bank).

d. The design of the bed gradient as a series of relatively flat slopes interspersed with occasional steep (riffle) sections will accelerate the scour and deposition processes in attaining a natural state. A steep gradient skewed across the stream in the riffle areas should be located downstream from the inflection points of the main curve at the inflow and outflow sections of the meanders. These riffles will provide the cross-over sections for the current.

e. The random placement of rip-rap containing a high percentage of pieces with volumes greater than one cubic yard each will provide bank stability and create a diversity of habitat for aquatic life. Rip-rap should be placed as steep as practicable within the slope stability limitations of the bank. The toe of the rip-rap should extend out into the stream and to a depth below the design bed grade to prevent scour holes from undercutting the rip-rap. The depth of the scour holes and their proximity to the bank may be based on data obtained from conditions in natural meanders of the same river having similar geometry, bed material and gradients.

f. The design of the rip-rap section with fine bed material placed slightly above the design high water level will allow vegetation to be established. Eventually the vegetation will provide shade and cover for the fish habitat and a more aesthetic natural-appearing streambank.

g. The aquisition of right-of-way for meander channels with allowance for a walkway on the top of the bank on at least one side of the stream will provide fisherman access to the stream. Without this provision the restoration of fish habitat through constructed meanders loses its purpose.

6.3.2 Future studies

The number of parameters enterring the design of meander channels with suitable habitat for trout does not permit an effective study of this problem to be conducted in a given laboratory type experimental investigation much less by analytical analysis and mathematical modelling alone. The approach suggested for future research is that of the case study. This requires the complete documentation of the effects of channel changes on fish habitat for selected specific cases, including those previously constructed and those planned for future construction. The results from case studies will be used to modify and improve the guidelines and criteria listed in previous paragraphs.

Specific recommendations for future studies include:

a. A conference should be initiated with the personnel from the Planning and Research Section of the Montana Highway Department to ascertain the number and location of highway projects requiring channel changes in trout streams within the next 5 to 10 years.

b. A program should be established for studying the streams in those areas where channel changes may be required. These studies would include obtaining data on fish population, streamflow records, bed materials, flow line profiles, planimetric configurations and stream geomorphology. It is important to obtain data on baseline conditions prior to construction to afford a basis of comparison with conditions after alterations have been effected.

c. Selected channel change sections previously constructed should be chosen for study of fish population, hydraulic and topographic data. The hydraulic and topographic data from these sections would be compared with the construction plans to determine the changes which have occurred over the years. The fish population estimates would be compared with similar data from other sections of the same river to determine the effect of the channel change on the fish population after a period of several years.

d. The Hazel Marsh Meander and the Enman Meander should be monitored for fish population estimates and changes in bed topography at 3-year intervals to form a continuous record of changes in these test sections.

e. A comprehensive economic analysis should be carried out on a future channel change involving the construction of a meander to restore fish habitat to determine the cost-benefit ratio of such projects.

f. A study of the effects of the proximity of the constructed meander channel to the section of stream altered by the highway location should be conducted. Two meander channels totalling approximately 5200 ft of new channel were constructed to recover approximately 1750 ft of channel length lost in eight sections of stream altered for highway location. The eight sections are located over a 7-mile length of highway. The stream lengths lost in the individual alternations range from a maximum of 485 ft to a minimum of 80 ft. The gradient changes (average $\Delta S = +0.02\%$) in the individual altered sections are much less than the gradient changes (average $\Delta S = -0.12\%$) between the end points of the constructed meanders (ref. Table 1). The Hazel Marsh Meander (C2) is located immediately upstream from one altered section; the Weaver Meander (C1) is 2250 ft upstream and 4200 ft downstream (highway stationing) from the nearest sections altered by the highway location. Other than recovering the length of stream lost the effects of the two constructed meanders on the reaches of the river immediately upstream and downstream were not determined. It may be better from the consideration of the stream hydraulics and from the economics to recover the stream length in short sections close to the alterations caused by highway locations rather than regaining the length in one or two long meanders some distance away.

## LITERATURE CITED


Elser, A. A.
1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Amer. Fish. Soc. 97(4): 389-397.

Johnson, R. L.
1964. Southwest Montana fishery study -- stream channel alteration survey -- Shields River. D. J. Completion Report, Project F-9-R-12. Mont. Fish and Game Dep., 4 pp.

Leopold, L. B. and Langbein, W. B.
1966. River meanders. Sci. Amer. 214(6):60-70.

__________, Wolman, M. G., and Miller, J. P.
1964. Fluvial processes in geomorphology. W. H. Freemand & Co., San Francisco. 522 pp.

Lewis, S. L.
1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Amer. Fish. Soc. 98(1):14-19.

Ricker, W. E.
1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Bd. Canada, Bull. 119. 300 pp.

Swedberg, S. E.
1965. Central Montana fisheries study -- evaluation of fish habitat destruction in Prickly Pear Creek due to construction of Interstate Highway I-15. D. J. Completion Report, Project F-5-R-13. Mont. Fish and Game Dep., 14 pp.

Whitney, A. N. and Bailey, J. E.
1959. Detrimental effects of highway construction on a Montana stream. Trans. Amer. Fish. Soc. 88(1):72-73.

APPENDIX

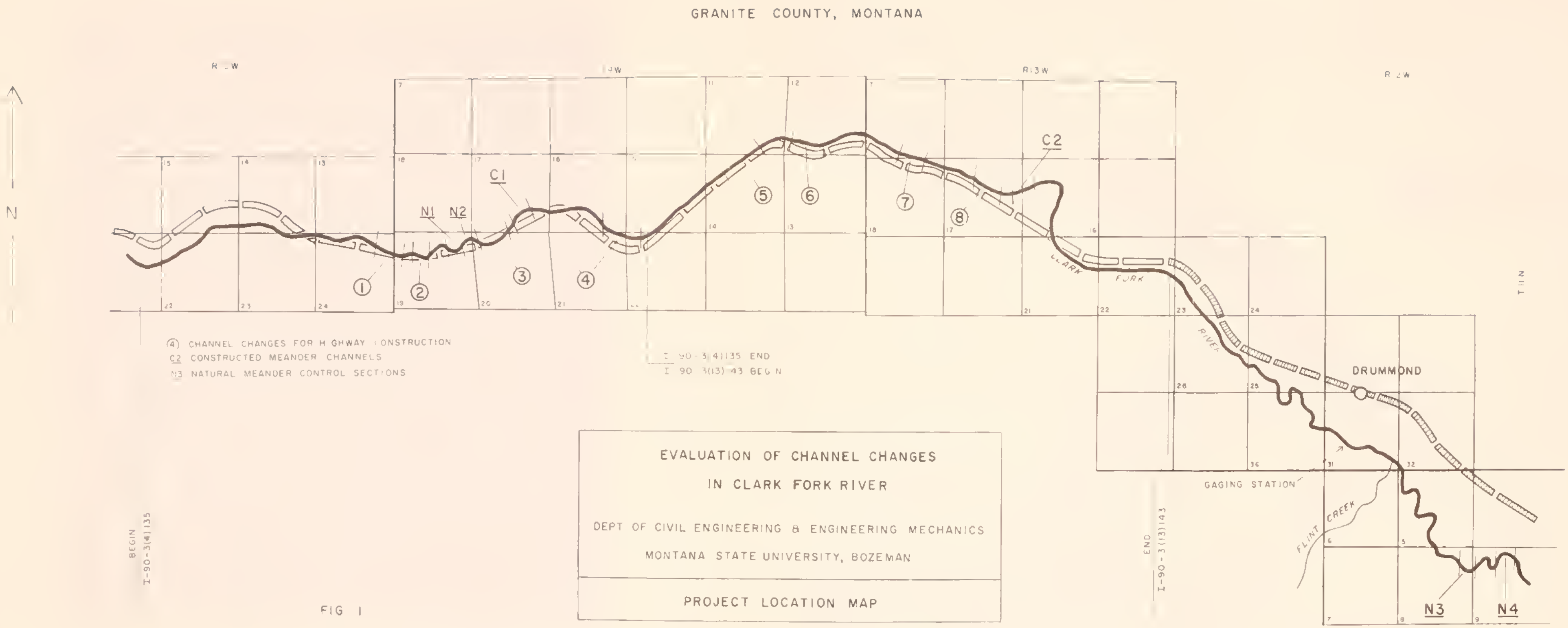

GRANITE COUNTY, MONTANA
R13W
N
C1
C2
N1
N2
N3
N4
CLARK FORK RIVER
DRUMMOND
GAGING STATION
FLINT CREEK
(4) CHANNEL CHANGES FOR HIGHWAY CONSTRUCTION
C2 CONSTRUCTED MEANDER CHANNELS
N3 NATURAL MEANDER CONTROL SECTIONS
BEGIN I-90-3(4)135
I 90-3(4)135 END
I 90 3(13)143 BEGIN
END I-90-3(13)143
EVALUATION OF CHANNEL CHANGES
IN CLARK FORK RIVER
DEPT OF CIVIL ENGINEERING & ENGINEERING MECHANICS
MONTANA STATE UNIVERSITY, BOZEMAN
PROJECT LOCATION MAP

FIG 1

Fig. 2. WEAVER MEANDER

Fig. 3. HAZEL MARSH MEANDER

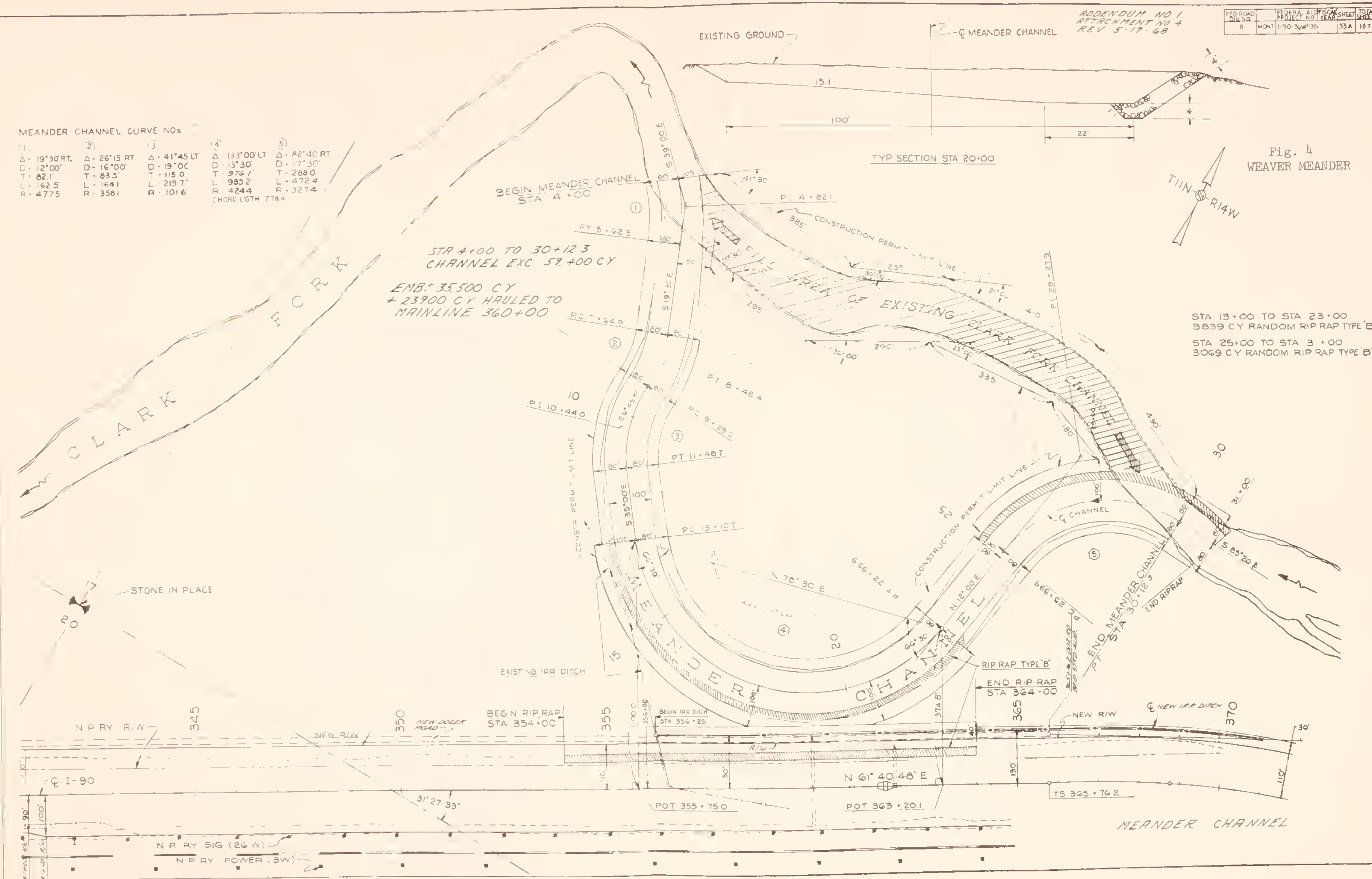



Fig. 4
WEAVER MEANDER

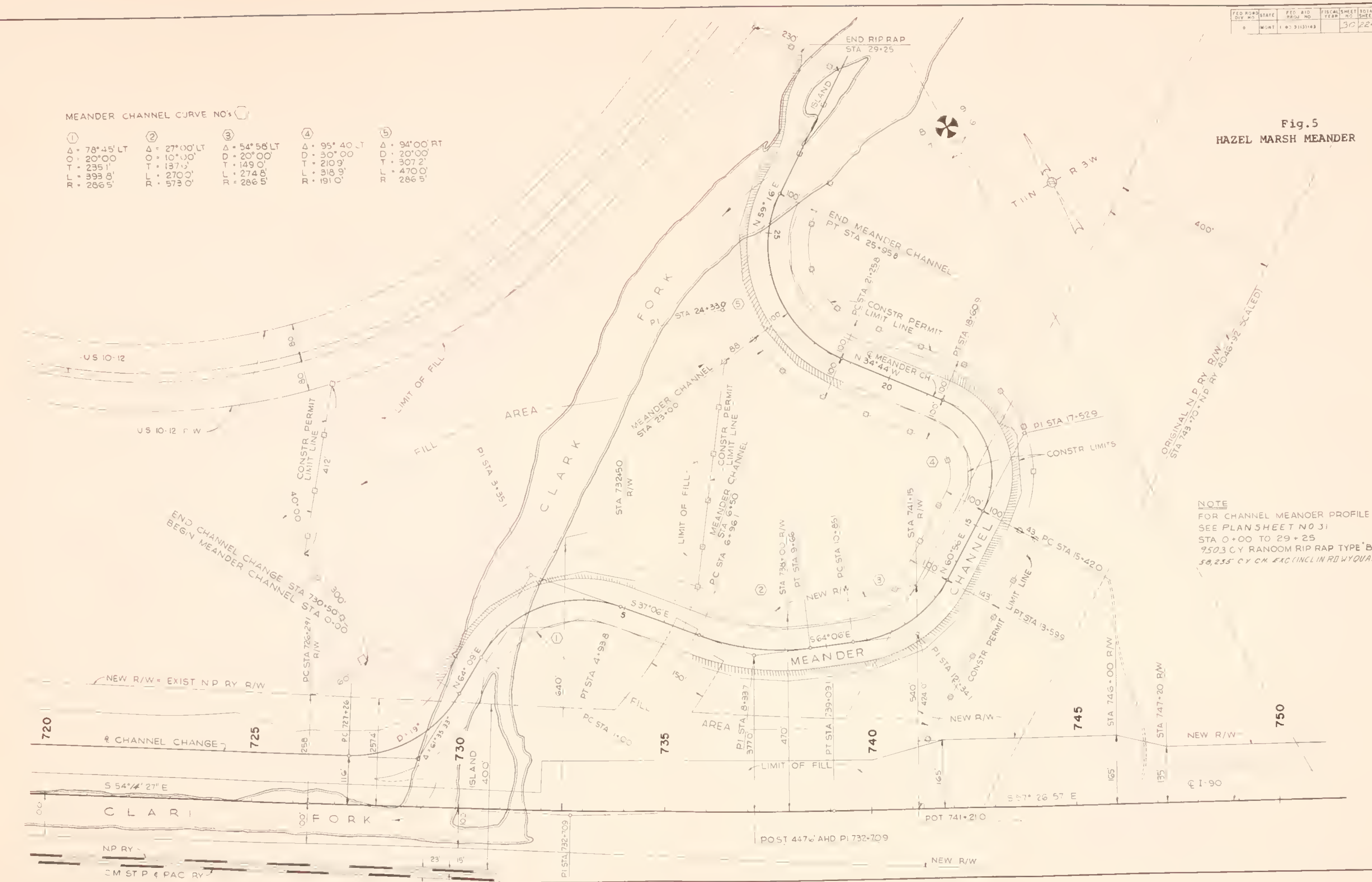
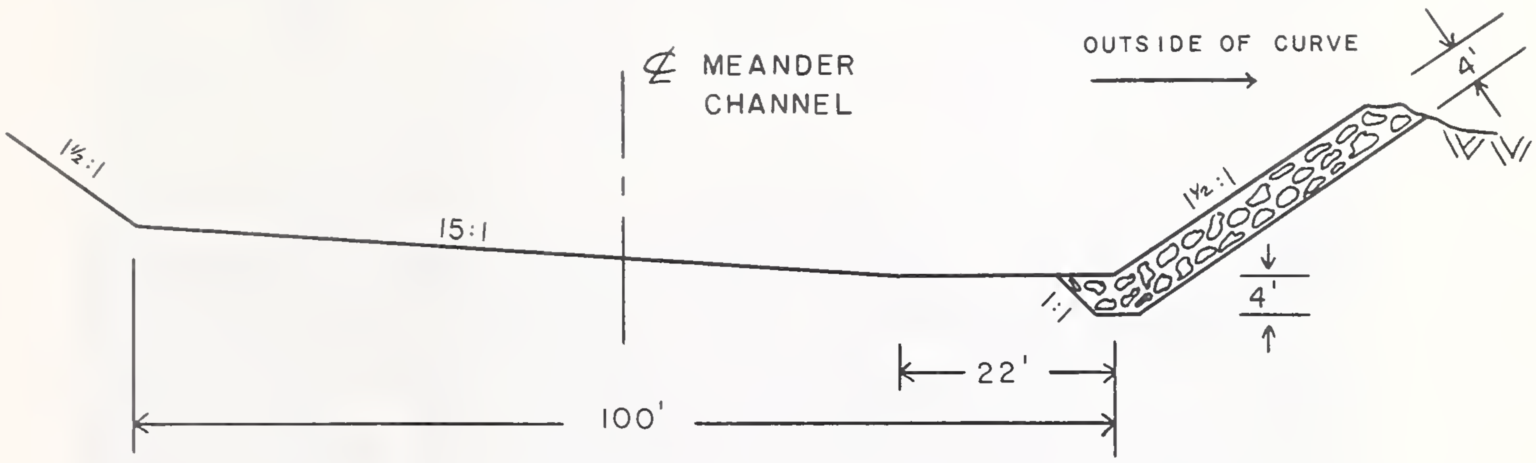
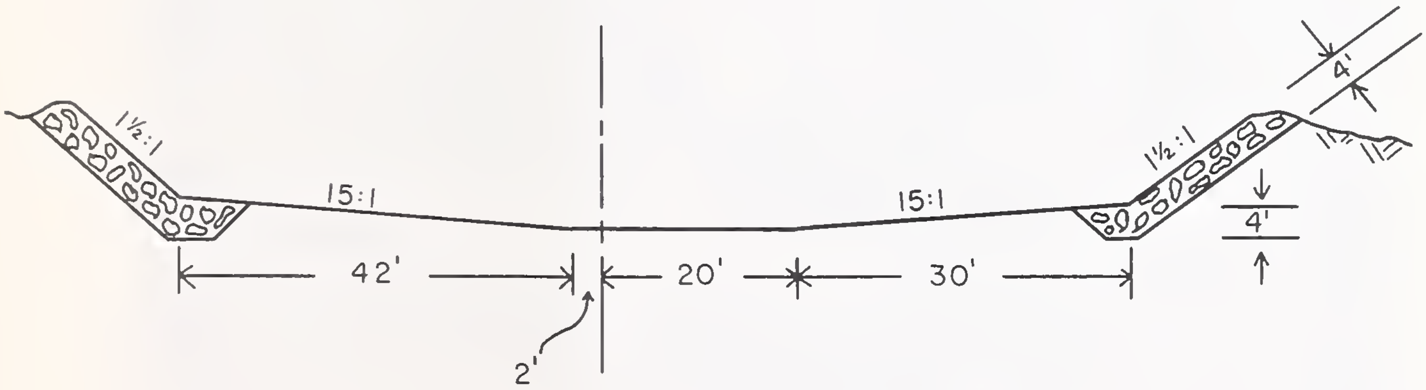



Fig.5
HAZEL MARSH MEANDER




(a) TYPICAL SECTION OF CHANNEL IN CURVE OF MEANDER




(b) TRANSITION SECTION FOR CROSS-OVER (STA. 20+50, HAZEL MARSH MEANDER)

CONSTRUCTED CHANNEL SECTIONS

FIG. 6

Fig. 7. DOWNSTREAM MEANDER NO. 1

Fig. 8. DOWNSTREAM MEANDER NO. 2

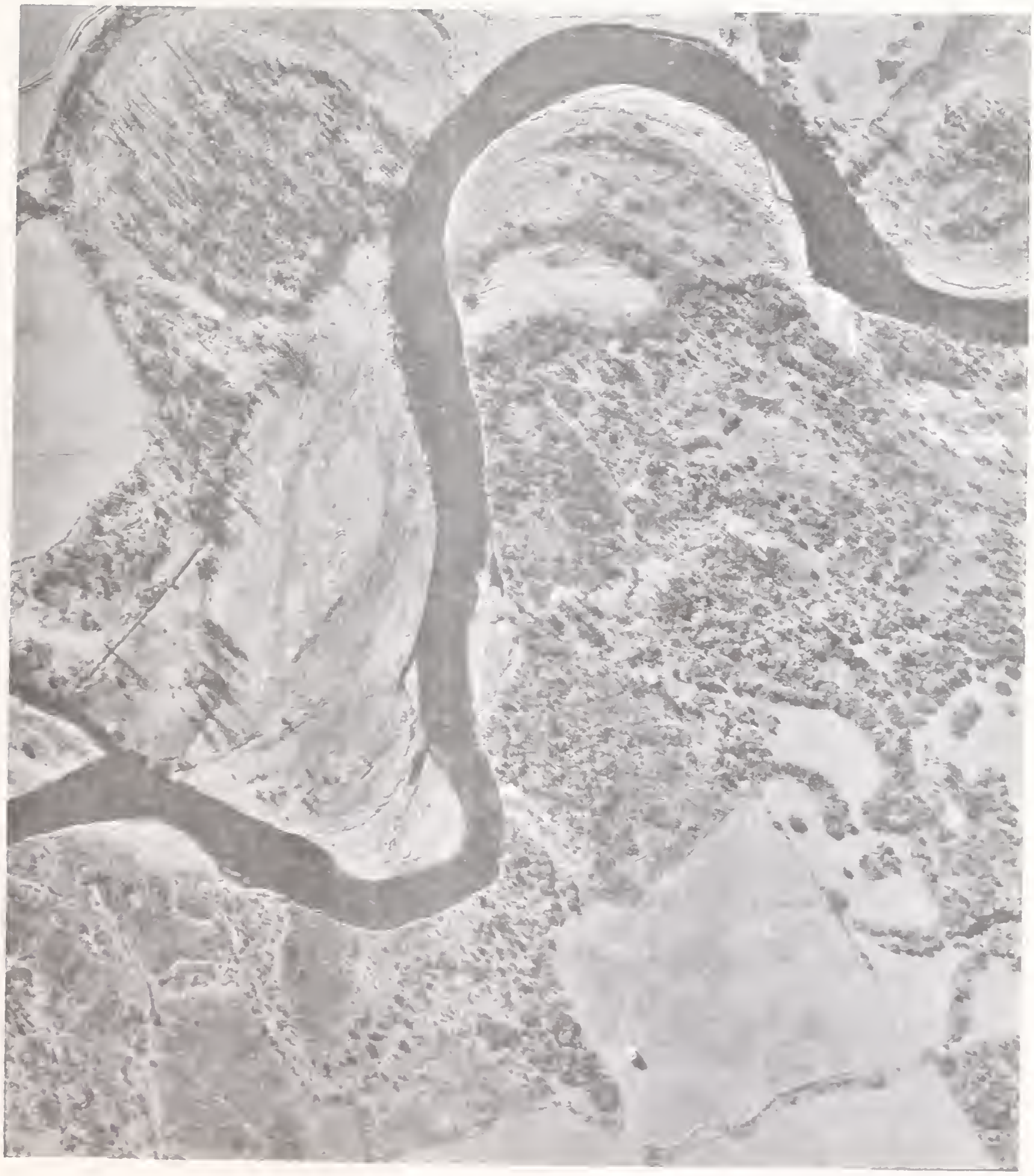
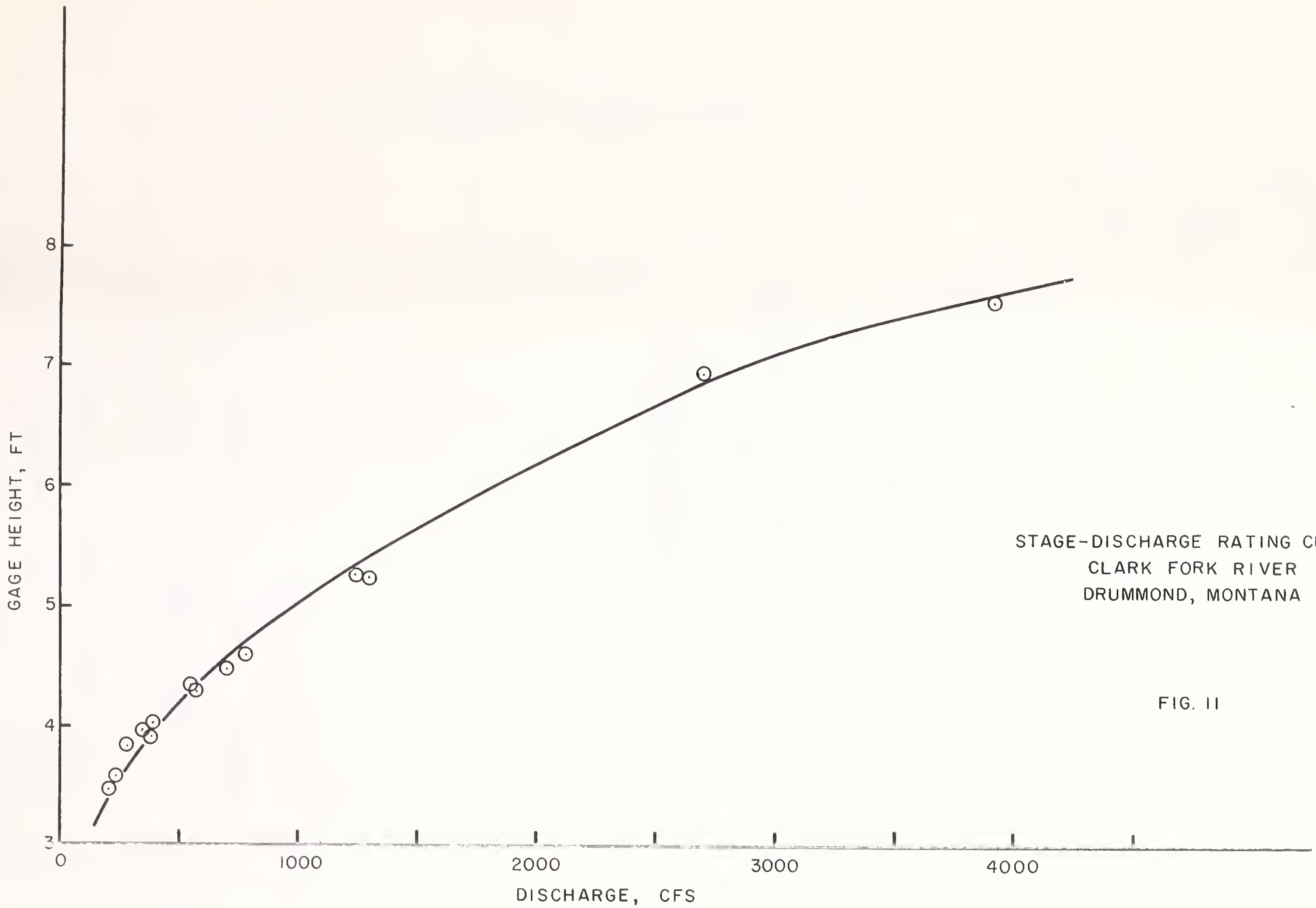


Fig. 9. NELSON MEANDER

Fig. 10. ENMAN MEANDER




STAGE-DISCHARGE RATING CURVE
CLARK FORK RIVER
DRUMMOND, MONTANA

FIG. 11

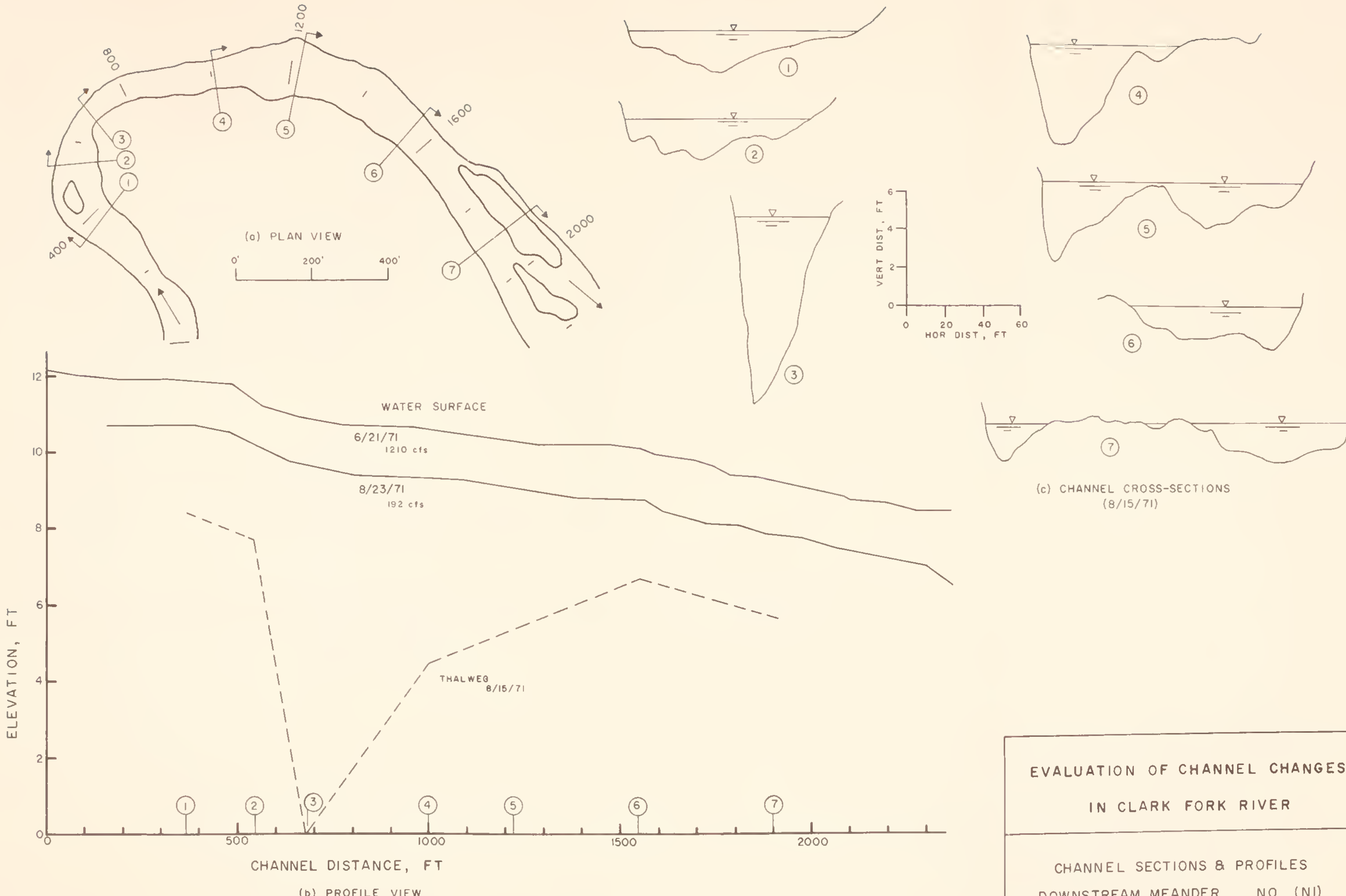
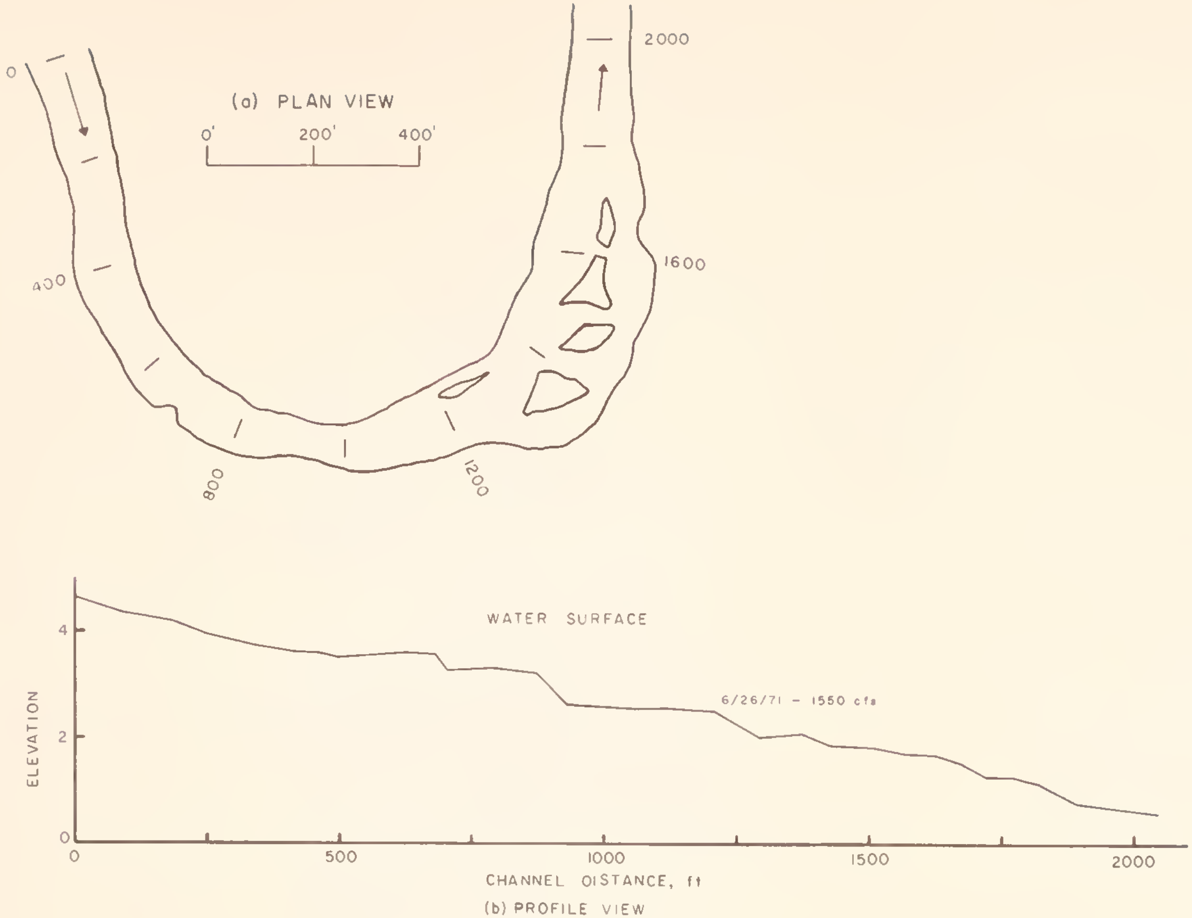



FIG. 12

EVALUATION OF CHANNEL CHANGES IN CLARK FORK RIVER

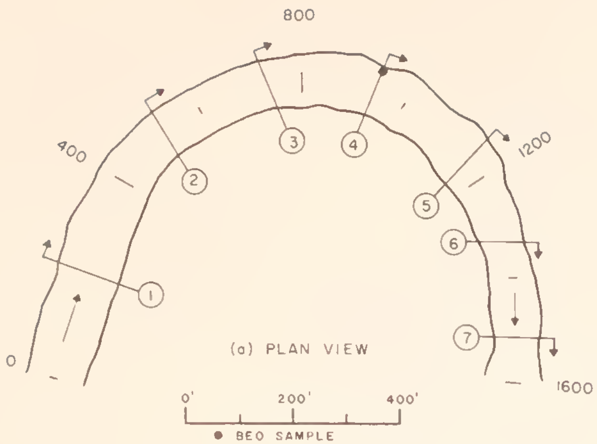
CHANNEL SECTIONS & PROFILES
DOWNSTREAM MEANDER NO (N1)



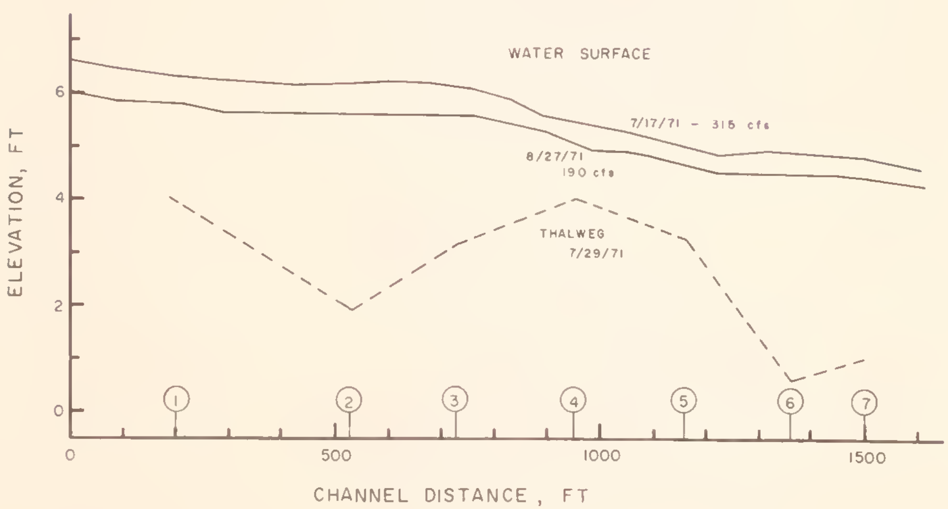

EVALUATION OF CHANNEL CHANGES IN CLARK FORK RIVER

CHANNEL SECTIONS & PROFILES DOWNSTREAM MEANDER NO. 2 (N2)

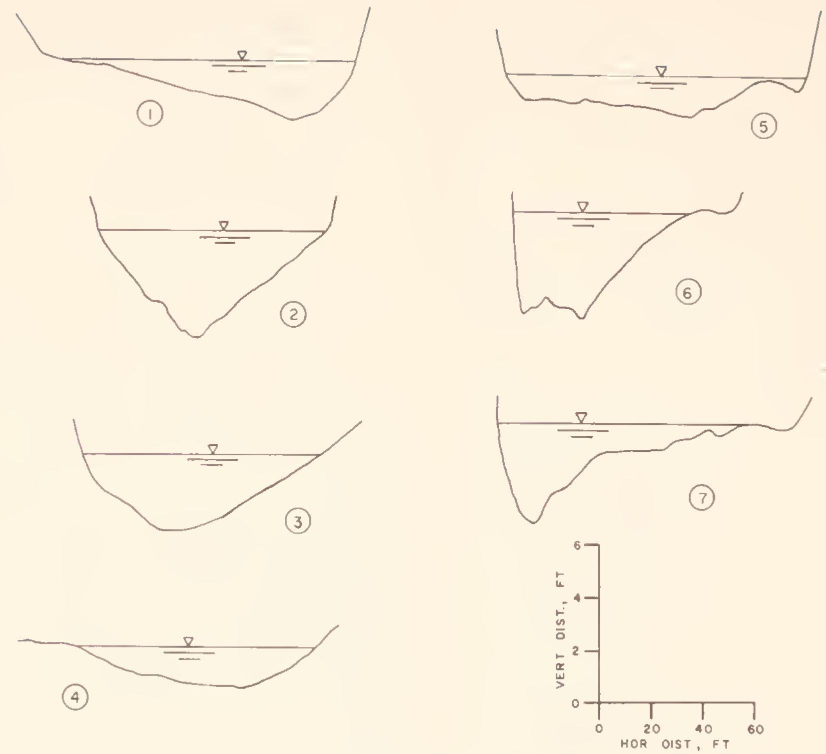
FIG. 13




(a) PLAN VIEW




(b) PROFILE VIEW

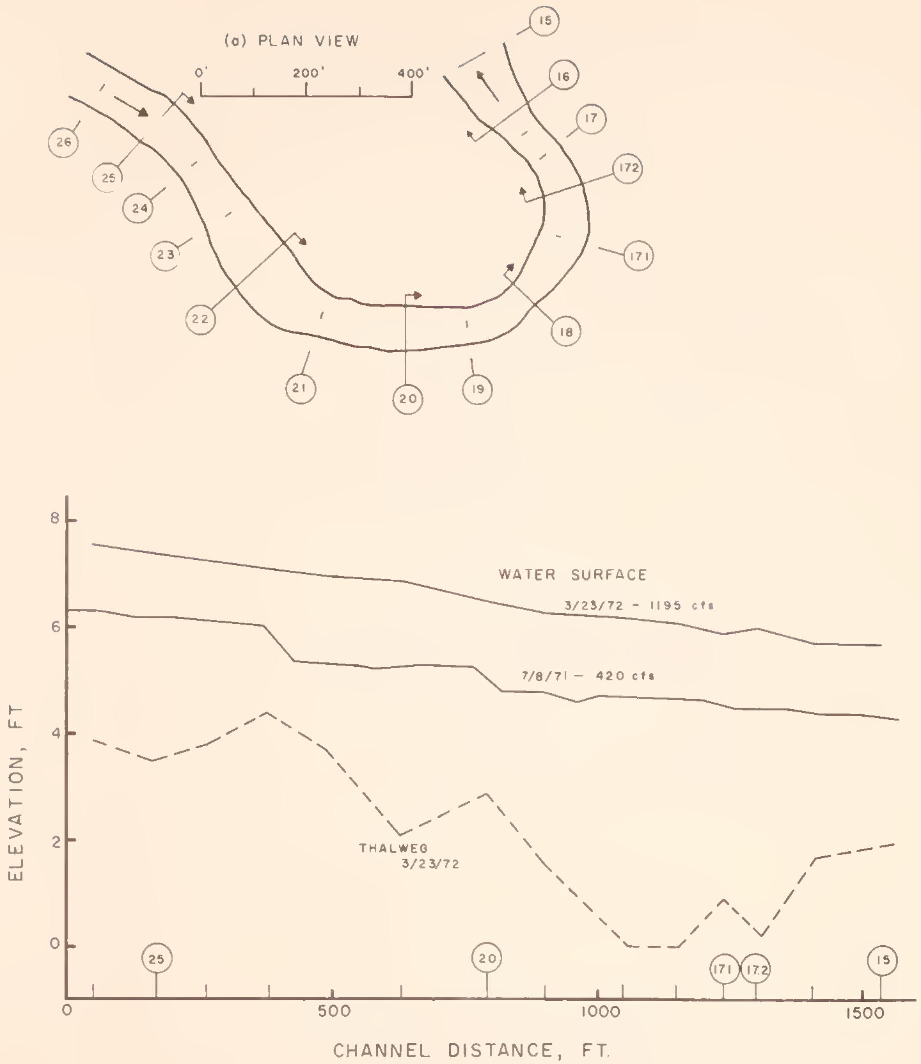



(c) CHANNEL CROSS SECTIONS
(7/29/71)

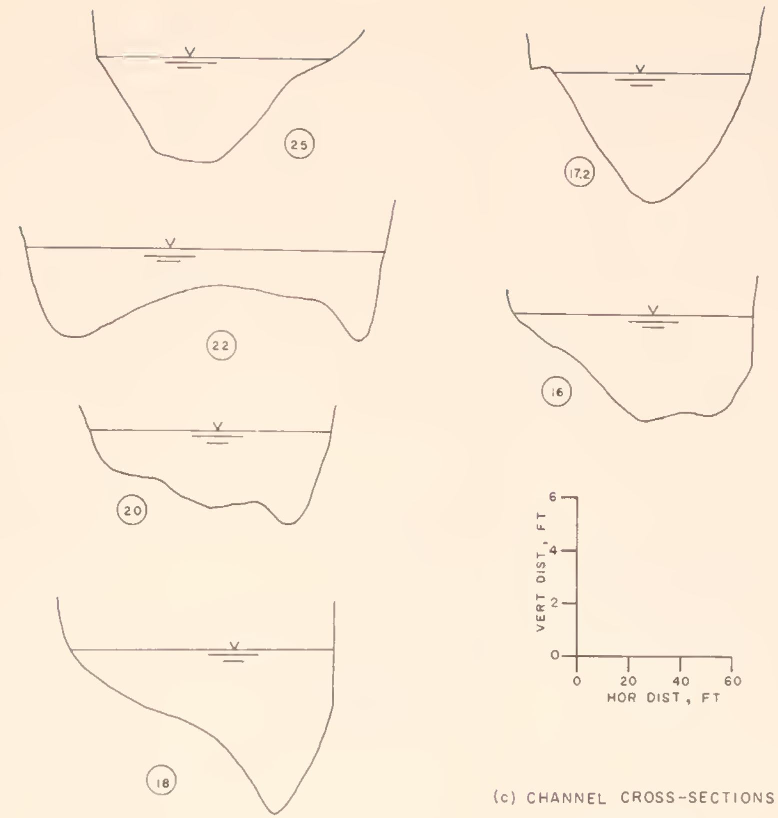
FIG. 14

EVALUATION OF CHANNEL CHANGES
IN CLARK FORK RIVER

CHANNEL SECTIONS & PROFILES
NELSON MEANDER (N3)




(b) PROFILE VIEW




(c) CHANNEL CROSS-SECTIONS
(3/23/72)

FIG. 15

EVALUATION OF CHANNEL CHANGES
IN CLARK FORK RIVER

CHANNEL SECTIONS & PROFILES
ENMAN MEANDER (N4)

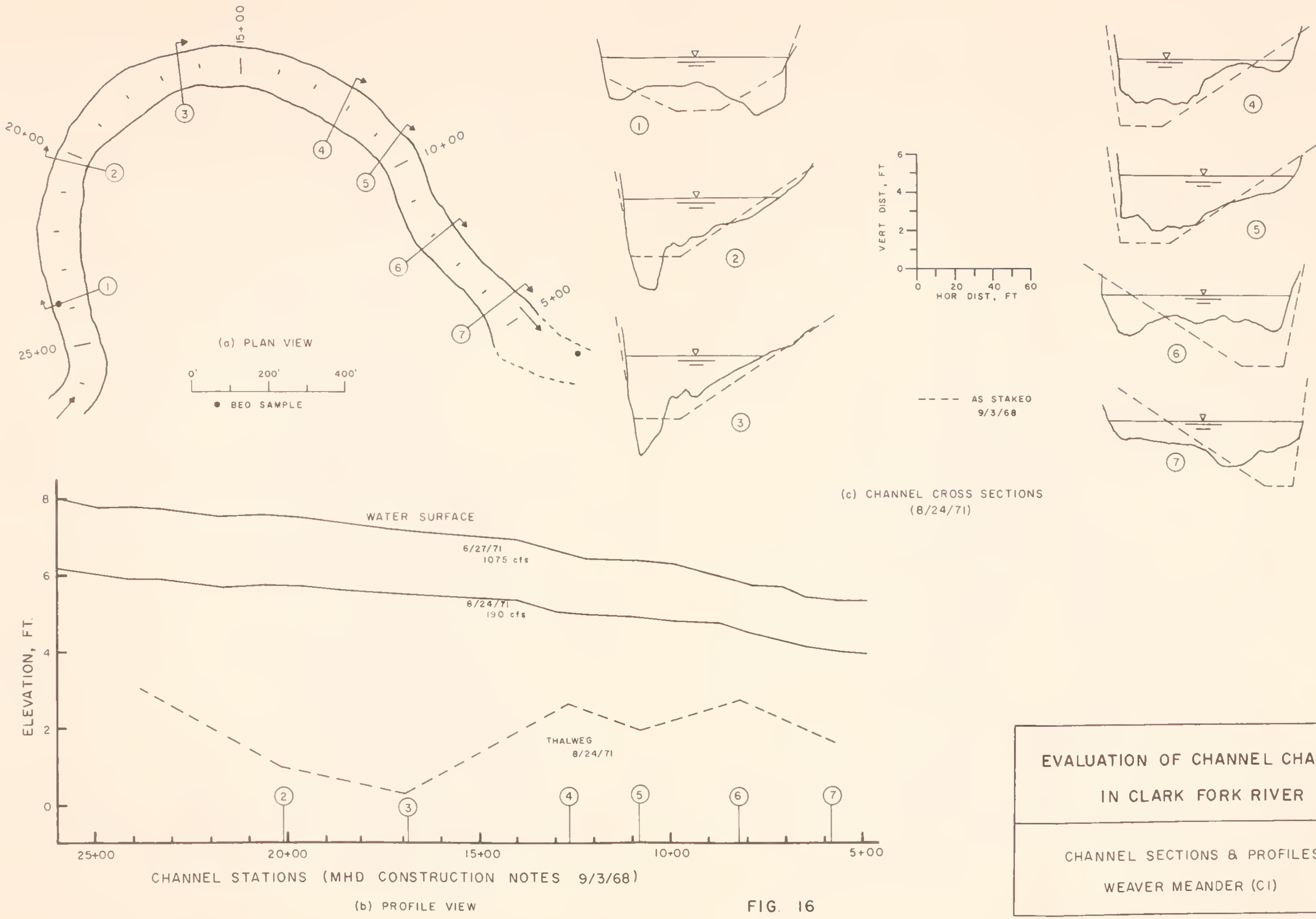



FIG. 16

EVALUATION OF CHANNEL CHANGES IN CLARK FORK RIVER

CHANNEL SECTIONS & PROFILES

WEAVER MEANDER (C1)

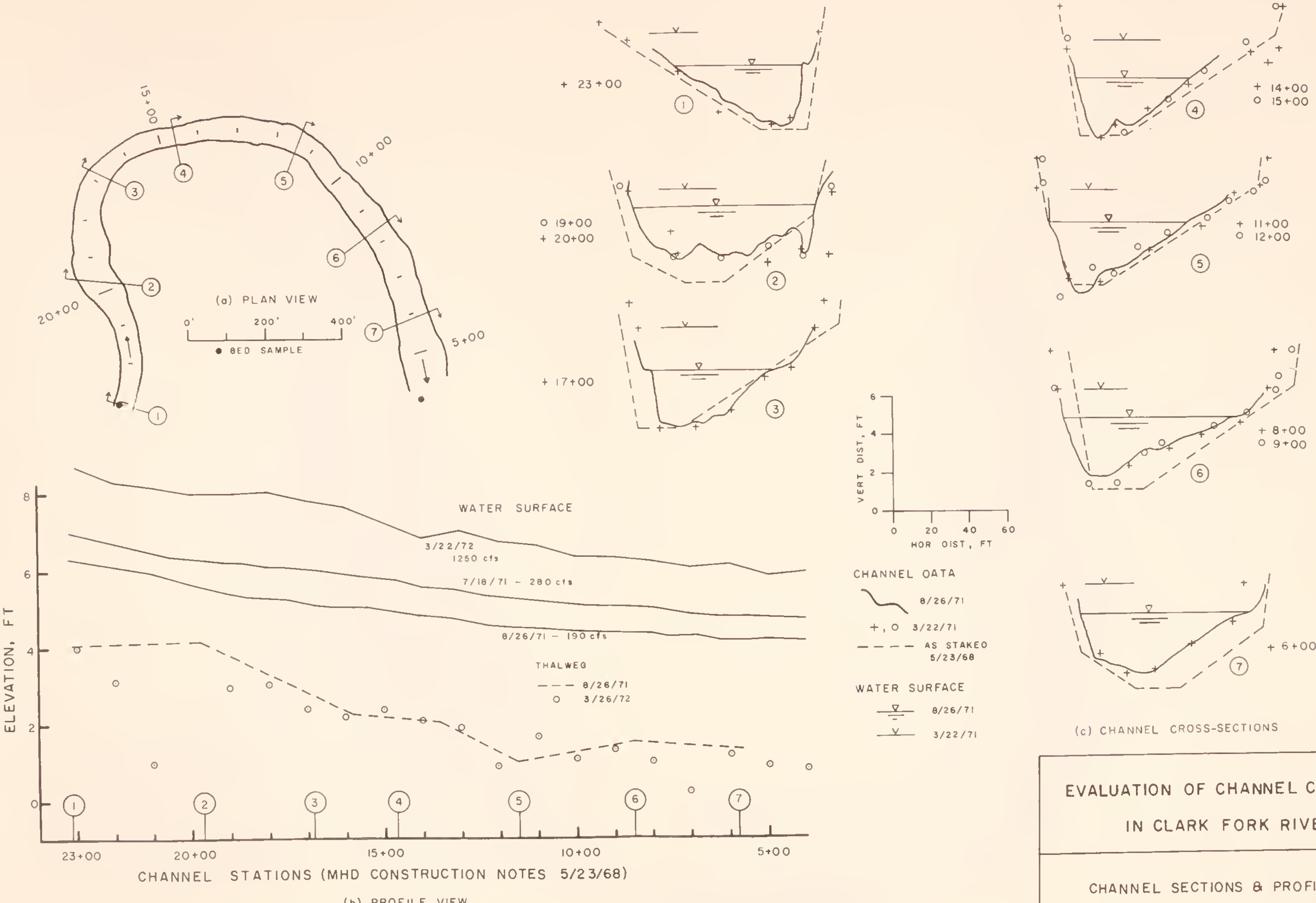
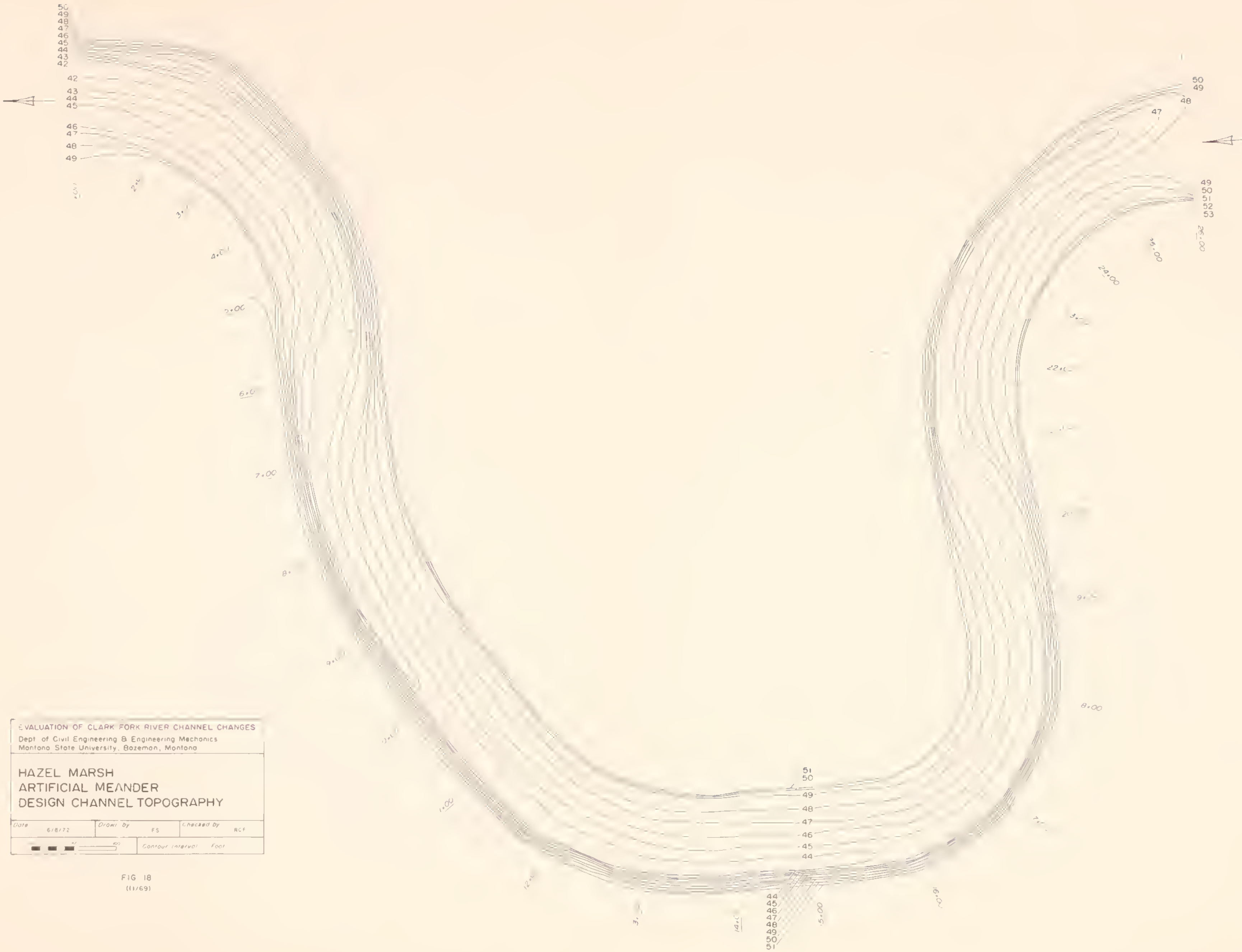



FIG. 17

EVALUATION OF CHANNEL CHANGES IN CLARK FORK RIVER

CHANNEL SECTIONS & PROFILES
HAZEL MARSH MEANDER (C2)




EVALUATION OF CLARK FORK RIVER CHANNEL CHANGES
Dept. of Civil Engineering & Engineering Mechanics
Montana State University, Bozeman, Montana

HAZEL MARSH
ARTIFICIAL MEANDER
DESIGN CHANNEL TOPOGRAPHY

| Date 6/8/72 | Drawn by FS | Checked by RCF |
|---|---|---|

Contour Interval 1 Foot

FIG 18
(11/69)

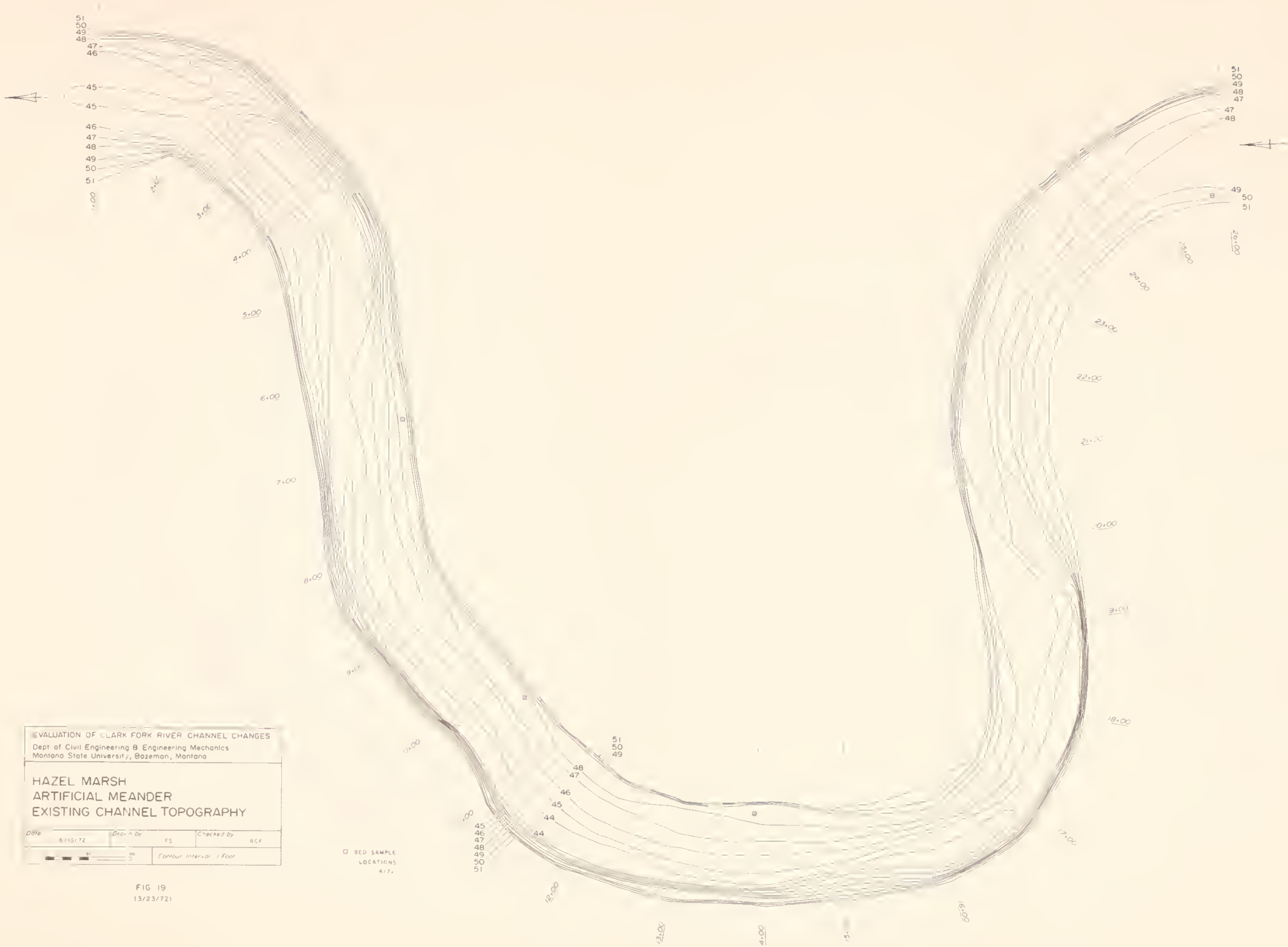
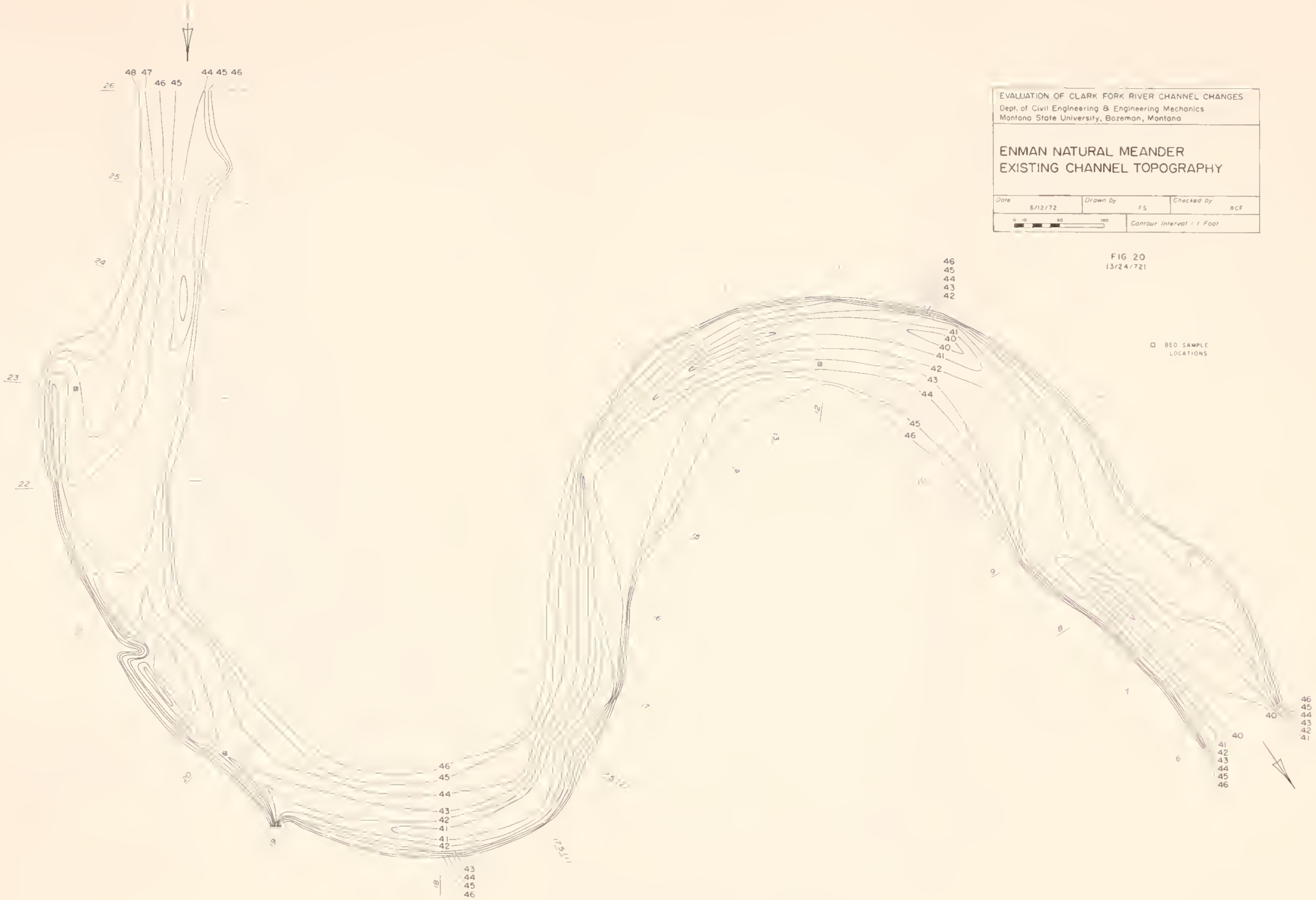

EVALUATION OF CLARK FORK RIVER CHANNEL CHANGES
Dept of Civil Engineering & Engineering Mechanics
Montana State University, Bozeman, Montana
HAZEL MARSH
ARTIFICIAL MEANDER
EXISTING CHANNEL TOPOGRAPHY
Date 6/10/72
Drawn by FS
Checked by RCF
Contour Interval 1 Foot
□ BED SAMPLE LOCATIONS
51
50
49
48
47
46
45
45
46
47
48
49
50
51
4+00
5+00
6+00
7+00
8+00
12+00
13+00
14+00
16+00
17+00
18+00
22+00
23+00
24+00
25+00
26+00
44
44

FIG 19
(3/23/72)




EVALUATION OF CLARK FORK RIVER CHANNEL CHANGES
Dept. of Civil Engineering & Engineering Mechanics
Montana State University, Bozeman, Montana

ENMAN NATURAL MEANDER
EXISTING CHANNEL TOPOGRAPHY

| Date 6/12/72 | Drawn by FS | Checked by RCF |
|---|---|---|

Contour Interval = 1 Foot

FIG 20
(3/24/72)


0
1
2
3
4
5
1+00
2
3+00
4+00
5+00
6+00
7+00
8+00
9+00
10+00
11+00
12+00
13+00
14+00
15+00
16+00
17+00
18+00
19+00
20+00
21+00
22+00
23+00
24+00
25+00
26+00
Q = 1225 cfs
EVALUATION OF CLARK FORK RIVER CHANNEL CHANGES
Dept. of Civil Engineering & Engineering Mechanics
Montana State University, Bozeman, Montana
HAZEL MARSH
ARTIFICIAL MEANDER
VELOCITY CONTOURS
Date 6/14/72
Drawn by FS
Checked by RCF
Contour Interval 1 FPS

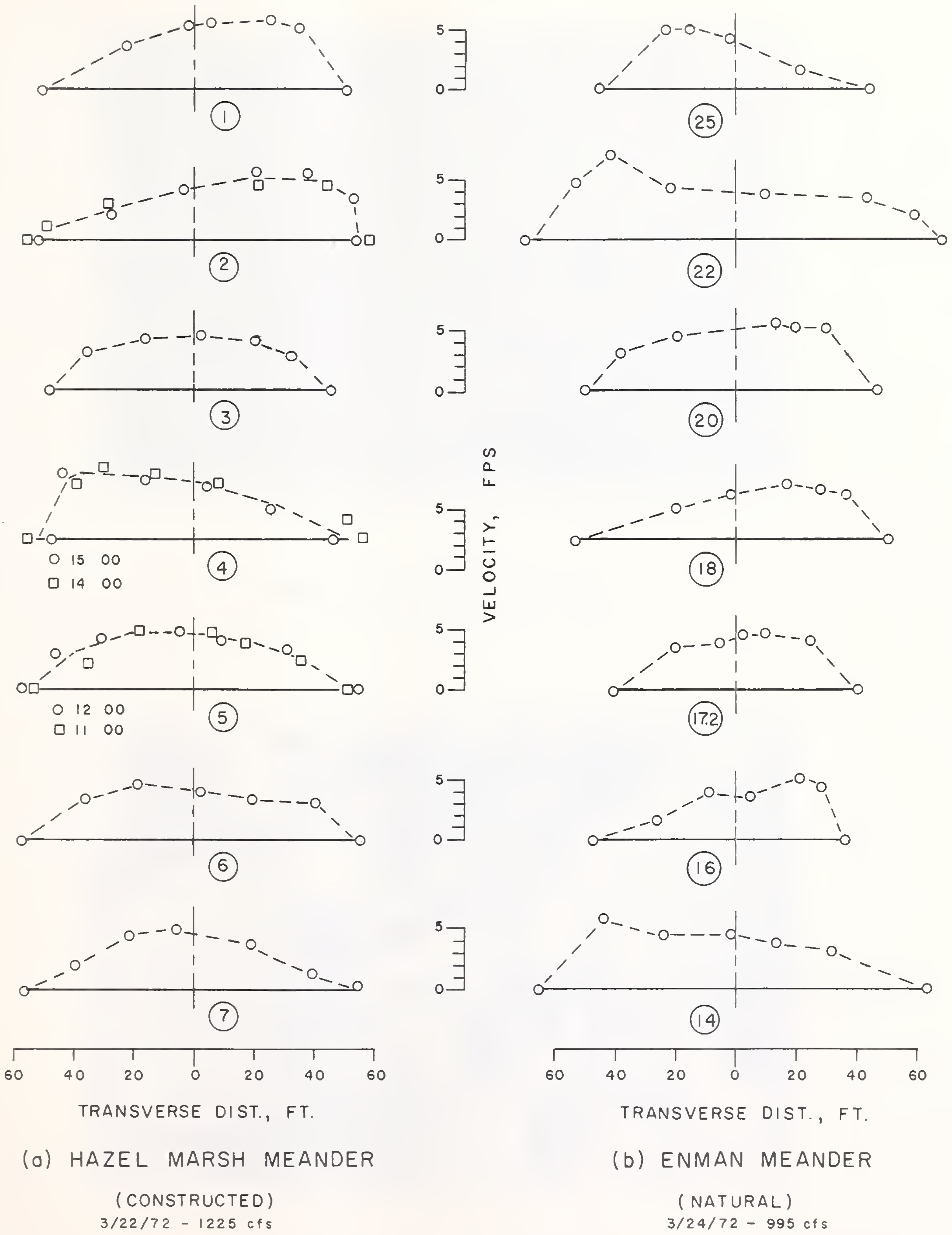
FIG 21
(3/23/72)


EVALUATION OF CLARK FORK RIVER CHANNEL CHANGES
Dept. of Civil Engineering & Engineering Mechanics
Montana State University, Bozeman, Montana

ENMAN NATURAL MEANDER
VELOCITY CONTOURS

| Date 6/15/72 | Drawn by FS | Checked by RCF |
| --- | --- | --- |
| 0 10 60 100 | Contour Interval = 1 FPS | |

FIG 22
(3/24/72)




TRANSVERSE VELOCITY DISTRIBUTION
FIG. 23

a. Material at mid-length of bar

b. Material at upstream end of bar

Fig. 24. SIZE DISTRIBUTION OF BED MATERIALS

a. Material at upstream end of bar

b. Material at downstream end of bar

Fig. 25. POINT BAR DEPOSITS, HAZEL MARSH MEANDER

a. Material at upstream end of bar

b. Material at downstream end of bar

Fig. 26. POINT BAR DEPOSITS, ENMAN MEANDER

a. Upstream from Section 10

b. Upstream from Section 6

Fig. 27. STREAM FLOW CROSS-OVERS, ENMAN MEANDER

Fig. 28. ROCK JETTY, ENMAN MEANDER

a. Upstream from Sta. 19+00

b. Downstream from Sta. 22+00

Fgi. 29. STREAM FLOW CROSS-OVERS, HAZEL MARSH MEANDER

a. Pool in rip-rap section

b. Flow around single rock

Fig. 30. FLOW NEXT TO RIP-RAP, HAZEL MARSH MEANDER