Roughness Characteristics of Natural Channels

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Color photographs and descriptive data for 50 stream channels for which roughness coefficients have been determined

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Presentation of information—Continued

Symbols

A Area of channel cross section
C Flow-resistance factor
d Diameter of bed material
h Water-surface elevation
h_v Velocity head
h_f Energy loss due to boundary friction
Δh_v Upstream velocity head minus the downstream velocity head
k A coefficient
K Cross section conveyance
L Length of reach
n Coefficient of roughness
Q Discharge
R Hydraulic radius
S Energy gradient
V Average velocity

ROUGHNESS CHARACTERISTICS OF NATURAL CHANNELS

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Abstract

Color photographs and descriptive data are presented for 50 stream channels for which roughness coefficients have been determined.

All hydraulic computations involving flow in open channels require an evaluation of the roughness characteristics of the channel. In the absence of a satisfactory quantitative procedure this evaluation remains chiefly an art. The ability to evaluate roughness coefficients must be developed through experience. One means of gaining this experience is by examining and becoming acquainted with the appearance of some typical channels whose roughness coefficients are known.

The photographs and data contained in this report represent a wide range of channel conditions. Familiarity with the appearance, geometry, and roughness characteristics of these channels will improve the engineer's ability to select roughness coefficients for other channels.

INTRODUCTION

The principal objective of this report is to present descriptive data and photographs for 50 different stream channels for which roughness coefficients have been determined. This information, which has been accumulated by the U.S. Geological Survey during the past 15 years, was previously available only in a photographic slide library in three-dimensional color. Numerous requests for copies of the slides from organizations and private individuals led to the justification for the present report.

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All hydraulic computations involving flow in open channels require an evaluation of the roughness characteristics of the channel. At the present state of knowledge, the selection of roughness coefficients for natural channels remains chiefly an art. There are no resistance diagrams or quantitative relationships available similar to those used for steady flow in uniform pipes or for the frictional resistance of ships. Consequently the ability to evaluate roughness coefficients for natural channels representing a wide range of conditions must be developed through experience.

The experience necessary for the proper selection of roughness coefficients can be obtained in several ways, namely (1) to understand the factors that affect the value of the roughness coefficient, and thus acquire a basic knowledge of the problem, (2) to consult a table of typical roughness coefficients for channels of various types (Woodward and Posey, 1941), and (3) to examine and become acquainted with the appearance of some typical channels whose roughness coefficients are known.

Photographs of channels of known resistance are thus useful in estimating the roughness characteristics of similar channels. The photographs and data presented in this report cover a wide range in conditions. Familiarity with the geometry, appearance, and roughness characteristics of these channels will improve the engineer's ability to select roughness coefficients for other channels.

To the untrained beginner, the selection of a roughness coefficient can be no more than a guess, and different individuals obtain different results. Furthermore, it is sometimes difficult to convince either the layman or the scientist that consistently reliable roughness coefficients can be selected by trained engineers on the basis of sound judgment and experience. Fortunately, even though the selection of the coefficients is classified as an art, the accuracy of many selections can be evaluated in exact engineering or statistical terms.

The ability to evaluate the roughness characteristics of channels is important in the hydraulic work of the U.S. Geological Survey. This ability, for example, is involved in the

methods (Benson and Dalrymple, 1966; Dalrymple and Benson, 1966; Bodhaine, 1966; Matthai, 1966; Hulsing, 1966) which are used in defining the peak discharge of most major floods. For this reason the Survey maintains a program which both trains young engineers in the evaluation of channel roughness and tests the accuracy of roughness coefficients by veteran engineers. The results of these tests as reported by Bailey and Ray (1966) indicate that trained engineers can select roughness coefficients with an accuracy of plus or minus 15 percent under most conditions. These facts prove that present methods are sound but that there is much room for improvement. A quantitative procedure for determining the roughness characteristics of channels has been the goal of research in the Survey and in other organizations for many years, but as yet little practical success has been achieved.

ACKNOWLEDGMENTS

SCOPE OF REPORT

Information on the geometry and roughness characteristics of 50 different stream channels is presented in the report. All of the stream channels are considered to be stable. Sand-channel streams were not included in the report because roughness coefficients for streams of this type have been defined in terms of size of bed material and other variables (Simons and Richardson, 1962).

The 50 sites include a wide range of hydraulic conditions from the boulder-strewn mountain stream of the western conterminous United States to the heavily vegetated flat-sloped stream of the southern conterminous United States.

The techniques used in field investigations at each site are first discussed in the report. The procedures used in computing the value of the roughness coefficient are then described. The remainder of the report consists of the presentation of a set of data and photographs for each of the 50 sites.

FIELD INVESTIGATION

Sites were selected for study after a major flood had occurred in a given region. Each site met the following criteria:

1. The peak discharge of the flood was measured by the current-meter method, or determined from a well-defined stage-discharge relation;
2. Good high-water marks were available to define the water-surface profile at the time of the peak;
3. A fairly uniform reach of channel was available near the gage;
4. The flood discharge was within the channel banks—that is, extensive flow in flood plains did not exist.

A transit-stadia survey of each reach was completed shortly after the flood. The necessary information was obtained in this survey to plot accurately to a common datum (1) the water-surface profile as represented by high-water marks, (2) a plan view of the reach, (3) cross sections at intervals along the reach. Surveying techniques used in this investigation are described in detail by Benson and Dalrymple (1966).

Photographs of the reach were taken during the time of the survey. The photographs shown in this report thus represent conditions in the reach immediately after the flood.

A size description of the bed material at most of the sites was determined by sampling methods (Wolman, 1954). These samples were in general taken several years after the flood for which the roughness coefficient was determined. The samples may or may not be representative of the bed material at the time of the peak. Frequency distributions of bed-material size were determined by sieve analysis where the medium size of the material was less than 50 mm and, where the material was too large to sieve, by measuring the intermediate axis of particles selected at random from the bed surface.

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COMPUTATION OF REACH PROPERTIES AND ROUGHNESS COEFFICIENTS

Formulas

Most open-channel flow formulas can be expressed in the following general terms,

$$Q = C A R^x S^y \tag{1}$$

where Q is the discharge, in cubic feet per second; C is a factor of flow resistance; A is the cross-sectional area of the channel, in square feet; R is the hydraulic radius, in feet; and S is the energy gradient. The Manning equation, one of the well-known variations of equation 1, was used as the basis for computing the reach properties and roughness coefficients given in this report. The Manning equation is

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2} \tag{2}$$

where n is a roughness coefficient and other variables in the equation are as defined above.

The Manning equation was developed for conditions of uniform flow in which the water-surface profile and energy gradient are parallel to the streambed, and the area, hydraulic radius, and depth remain constant throughout the reach. For lack of a better solution, it is assumed that the equation is also valid for nonuniform reaches, invariably found in natural channels, if the energy gradient is modified to reflect only the losses due to boundary friction. The energy equation for a reach of nonuniform channel between sections 1 and 2 in figure 1 is (see p. 9)

$$(h+h_v)_1 = (h+h_v)_2 + (h_f)_{1.2} + k(\Delta h_v)_{1.2} \tag{3}$$

where

h = elevation of the water surface at the respective sections above a common datum;

h_v = velocity head at the respective section = $\alpha V^2/2g$;

h_f = energy loss due to boundary friction in the reach;

$\Delta h_v =$ upstream velocity head minus the downstream velocity head;

$k(\Delta h_v) =$ energy loss due to acceleration of velocity or deceleration of velocity in a contracting or expanding reach; and

$k =$ a coefficient taken to be zero for contracting reaches and 0.5 for expanding reaches.

In computing the values of n listed in this report the value of α, the velocity head coefficient, was always considered to be 1.00.

The friction slope S to be used in the Manning equation is thus defined as

$$S = \frac{h_f}{L} = \frac{\Delta h + \Delta h_v - k(\Delta h_v)}{L} \tag{4}$$

where Δh is the difference in water-surface elevation at the two sections and L is the length of the reach.

In using the Manning equation the quantity $(1.486/n)AR^{2/3}$, called conveyance and designated K, is computed for each cross section. The mean conveyance in the reach between any two sections is computed as the geometric mean of the conveyance of the two sections. The discharge equation in terms of conveyance is

$$Q = \sqrt{K_1 K_2\, S} \tag{5}$$

where S is the friction slope as previously defined.

In this investigation the average value of the Manning n was computed for each reach from the known discharge, the water-surface profile, and the hydraulic properties of the reach as defined by 2–17 cross sections. The following equation, which is based on the same concepts and definitions as equations 2–5, was used in these computations. The equation is applicable to a multisection reach of M cross sections which are designated 1, 2, 3, ... $M-1$, M.

$$n = \frac{1.486}{Q} \sqrt{\frac{(h+hv)_1 - (h+hv)_M - [(k\,\Delta hv)_{1.2} + (k\,\Delta hv)_{2.3} + \ldots + (k\,\Delta hv)_{(M-1).M}]}{\dfrac{L_{1.2}}{Z_1 Z_2} + \dfrac{L_{2.3}}{Z_2 Z_3} + \ldots + \dfrac{L_{(M-1).M}}{Z_{(M-1)} Z_M}}} \tag{6}$$

where $Z = AR^{2/3}$ and other quantities are as previously defined.

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Computation Procedure

A planimetric map of each reach was developed by plotting from the notes of the field survey. The location of all high-water marks and cross sections was shown on the map. The distances between cross sections were determined from the map.

The profile of the water surface through the reach was developed separately along each bank by plotting the elevation and stationing of high-water marks. The water-surface elevation at each cross section was determined as the average of the water-surface elevation on each bank as taken from the water-surface profiles.

Cross sections were plotted from the field notes, and data on stationing, distance, ground elevations, depths, and top widths were tabulated. The area and wetted perimeter for each panel between given ground elevations were computed. The area, wetted perimeter, and hydraulic radius for each cross section were determined, and values of $AR^{2/3}$ were computed.

The average value of n for each reach was then determined by substituting the proper quantities in equation 6.

The computation procedure is virtually the same as for computation of discharge by the slope-area method. This procedure is described in detail by Dalrymple and Benson (1966).

APPLICATION OF ROUGHNESS COEFFICIENTS

The values of n presented in the report are intended for use in the Manning equation

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \qquad \text{(English units)}$$

or
$$V = \frac{R^{2/3} S^{1/2}}{n} \qquad \text{(metric units)}$$

The value of n may be converted to values of the Chezy C by the relation

$$C = \frac{1.486 \, R^{1/6}}{n} \qquad \text{(English units)}$$

and the value of C may then be used in the Chezy equation

$$V = C\sqrt{RS}$$

All these equations are limited to turbulent flow in fully rough channels. Flow in natural channels normally meets this criterion.

PRESENTATION OF INFORMATION

A four-page set consisting of channel data, plan sketches (not to scale) and cross sections, and photographs, is presented for each reach in the following section of the report. Each set of data is identified by the permanent gaging-station number and name used by the U.S. Geological Survey in publication of streamflow-records.

The data tabulation shows the location of the gage and a reference cross section, the drainage area of the stream, the date of the flood, the peak gage height at the gage and at section 1 during the flood, the peak discharge measured by current-meter method, the computed roughness coefficient for the reach, a general description of the channel, the median bed-material size, d_{50}, and the reference size for which 84 percent of the bed material is finer, d_{84}. The area, top width, mean depth (area/top width), hydraulic radius, and mean velocity corresponding to the water-surface elevation at the time of the peak are listed for each cross section. The distance or length between cross sections and the fall in water surface between cross sections are also shown. Information for two or more peak discharges is available at some sites. These data are listed according to the magnitude of discharge. Data corresponding to the largest discharge appear first.

At several sites a small percentage of the flow occurred in the shallow flood plain adjacent to the main channel. For each of these sites the data and computations reflect the flow of the main channel.

Data for the site, Rolling Fork at Boston, Ky., are unique in that roughness coefficients were computed for both the overflow plain and the main channel.

Two color photographs taken immediately after the flood are shown for each reach. The position of the camera and the

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number of the picture are shown on the plan sketch by a pointer, which shows the direction in which the camera was pointed. The water level at the time of the peak is indicated in some of the photographs by a horizontal rod or tape.

The initial station for cross sections is at the left bank. Plots are arranged so that the left bank appears on the reader's left. The water levels shown on the cross sections correspond to the water-surface profile at the time of the peak as defined by high-water marks.

Sites are arranged according to the value of the computed roughness coefficient, in ascending order.
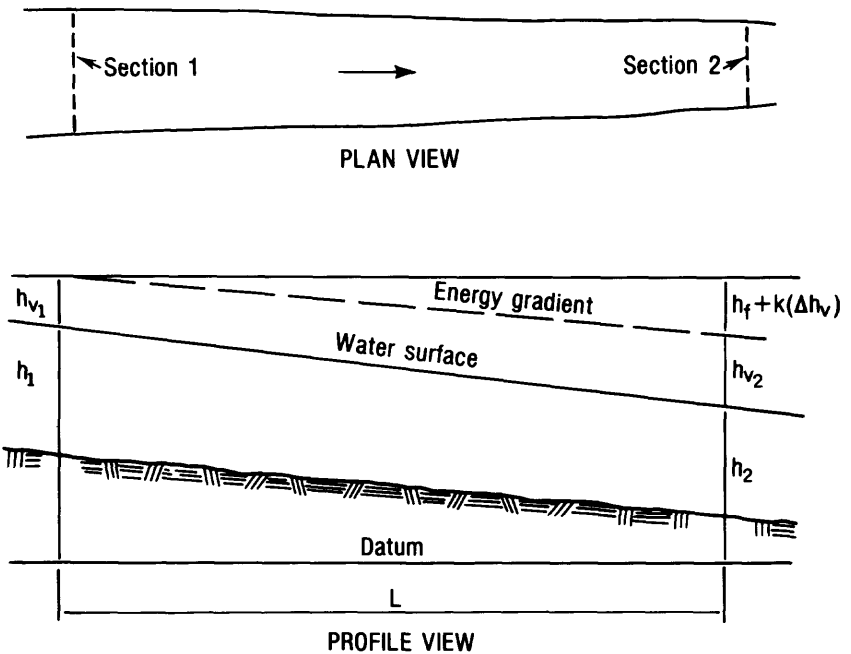

Figure 1. — Definition sketch of a slope-area reach.

12–4645. Columbia River at Vernita, Wash.

Gage location.—In sec. 11, T. 13 N., R. 24 E., at the Richmond ferry site, 0.5 mile north of Vernita station. Gage presently operated 50 miles upstream for station called Columbia River at Trinidad, Wash. Section 1 is 5,000 ft upstream from cableway at Vernita gage.

Drainage area.—89,700 sq mi, approximately.

Date of flood.—May 22, 1949.

Gage height.—48.33 ft at Trinidad gage; 29.5 ft (different datum) at section 1.

Peak discharge.—406,000 cfs.

Computed roughness coefficient.—Manning $n = 0.024$.

Description of channel.—Bed consists of slime-covered cobbles and gravel. The straight and steep left bank is composed of cemented cobbles and gravel. The gently sloping right bank consists of cobbles set in gravel and is free of vegetation.

Reach properties

Section	Area (sq ft)	Top width (ft)	Mean depth (ft)	Hydraulic radius (ft)	Mean velocity (ft per sec)	Length (ft) between sections	Fall (ft) between sections
1	47,100	1,800	26.2	26.16	8.65	. . . .	. . . .
2	49,000	1,650	29.7	29.56	8.28	2,500	0.48
3	49,600	1,760	28.2	28.10	8.17	2,500	.49

Notes.—

PLAN SKETCH
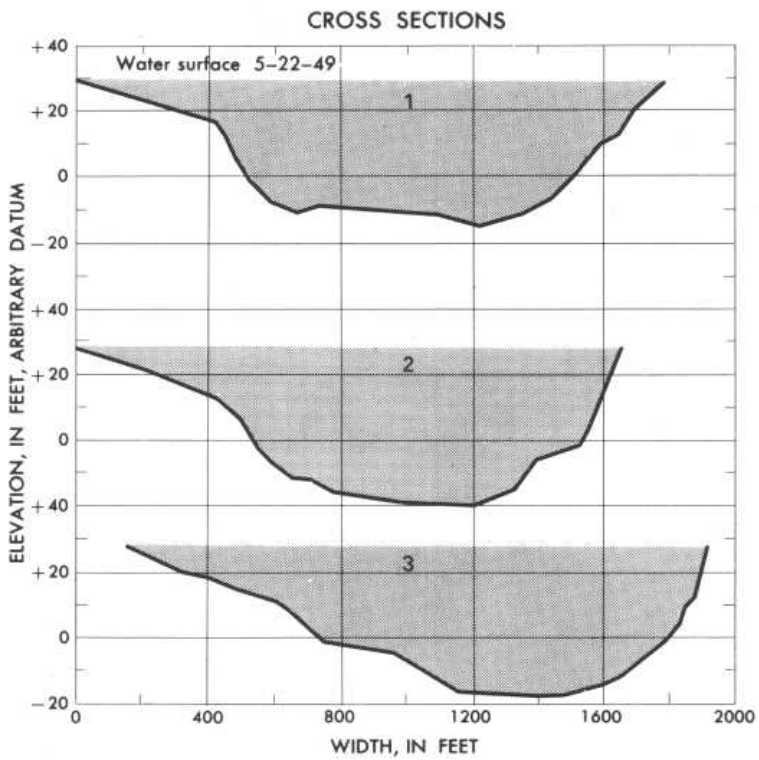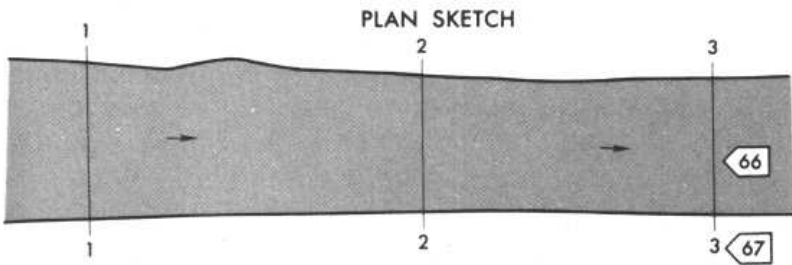
CROSS SECTIONS
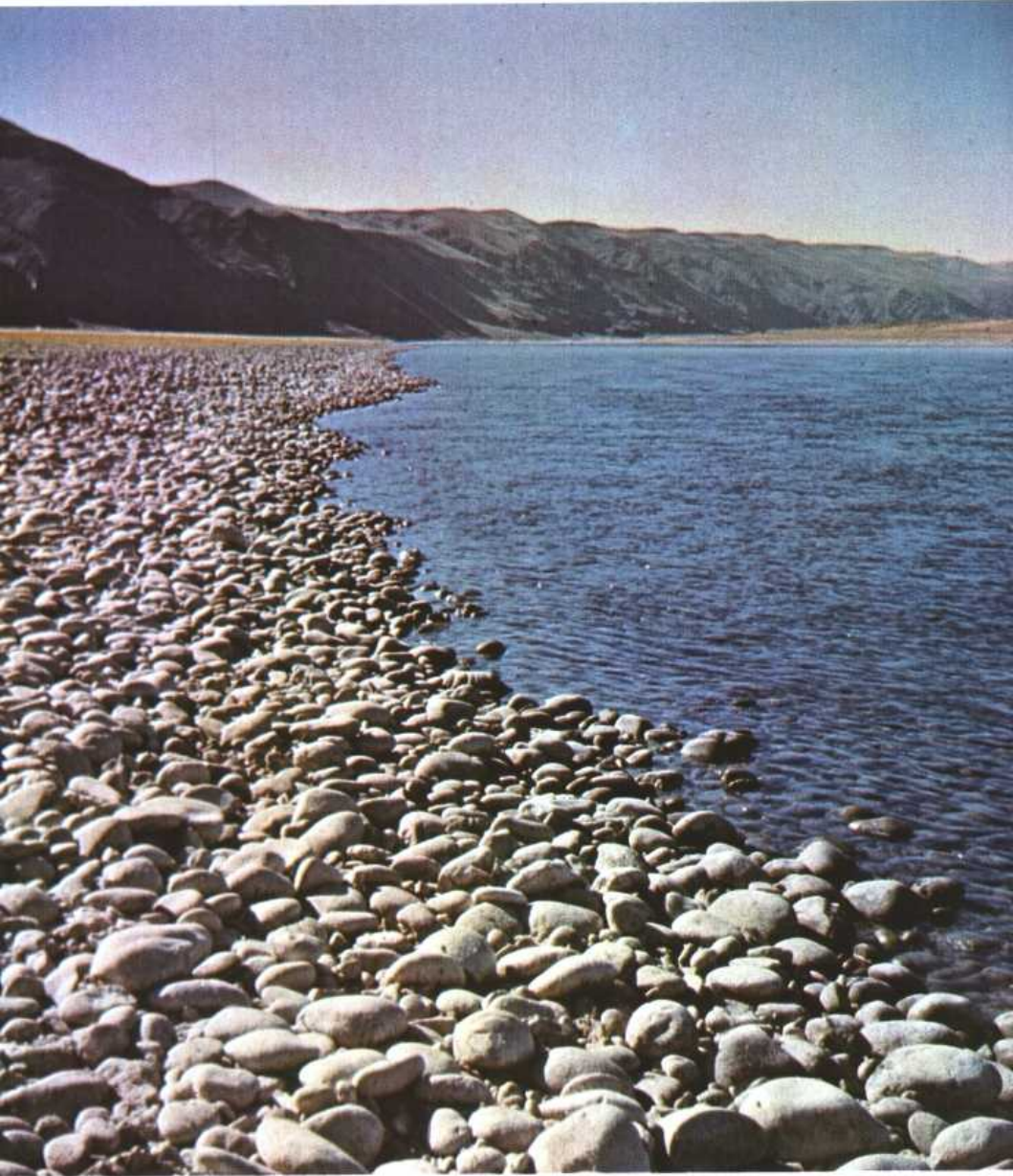

Plan sketch and cross sections, Columbia River at
Vernita, Wash.

No. 67 upstream from top of bank at section 3,
Columbia River at Vernita, Wash.

No. 66 upstream along right bank from section 3,
Columbia River at Vernita, Wash.

3–1215. Indian Fork below Atwood Dam, near New Cumberland, Ohio

Gage location.—Lat 40°31′30″, long 81°17′20″, in SE¼ sec. 28, T. 15 N., R. 7 W., on left bank 500 ft downstream from Atwood Dam, 0.5 mile upstream from mouth, and 1.5 miles southeast of New Cumberland, Tuscarawas County. Section 1 is about 300 ft downstream from gage.

Drainage area.—70.3 sq mi.

Date of flood.—May 11, 1948.

Gage height.—10.27 ft at gage; 9.99 ft at section 1.

Peak discharge.—768 cfs.

Computed roughness coefficient.—Manning $n = 0.026$.

Description of channel.—Bed and banks are composed of clay. Banks are clear except for short grass and exposed tree roots in some places.
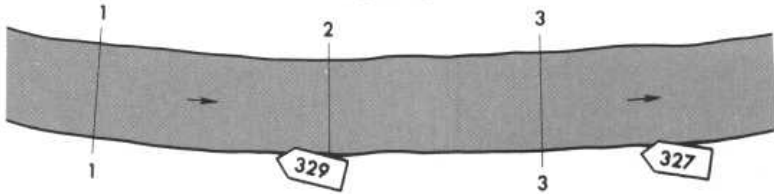
Reach properties

Section	Area (sq ft)	Top width (ft)	Mean depth (ft)	Hydraulic radius (ft)	Mean velocity (ft per sec)	Length (ft) between sections	Fall (ft) between sections
1	280	52	5.4	4.87	2.74	. . . .	. . . .
2	273	51	5.4	4.82	2.82	257	0.08
3	279	52	5.4	4.97	2.76	202	.05

Notes.—

$n = 0.026$

PLAN SKETCH

CROSS SECTIONS

Water surface 5/11/48

ELEVATION, IN FEET, GAGE DATUM

WIDTH, IN FEET
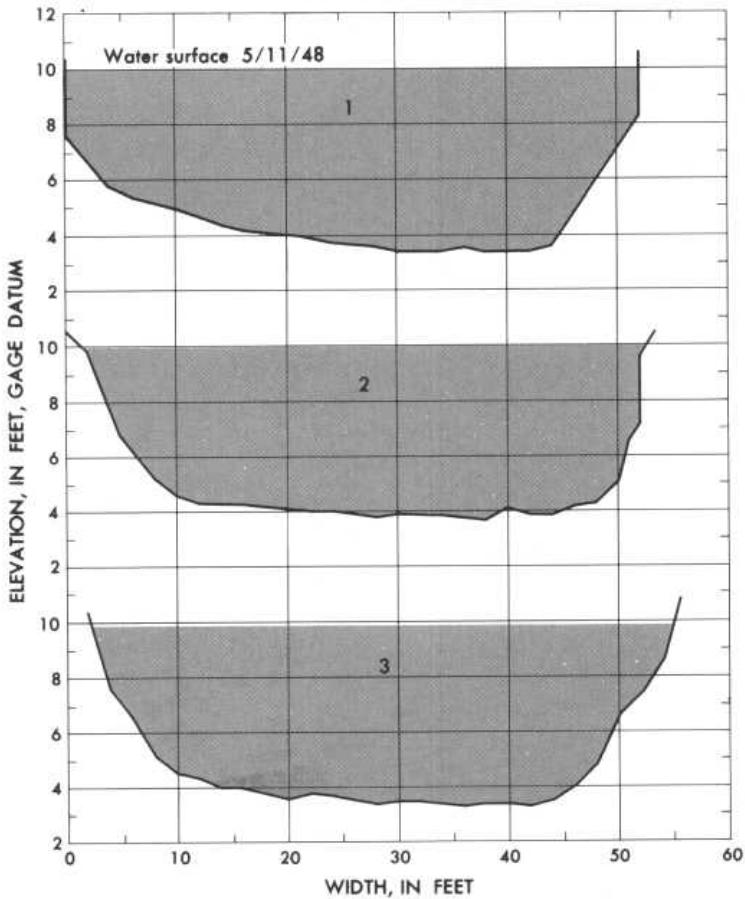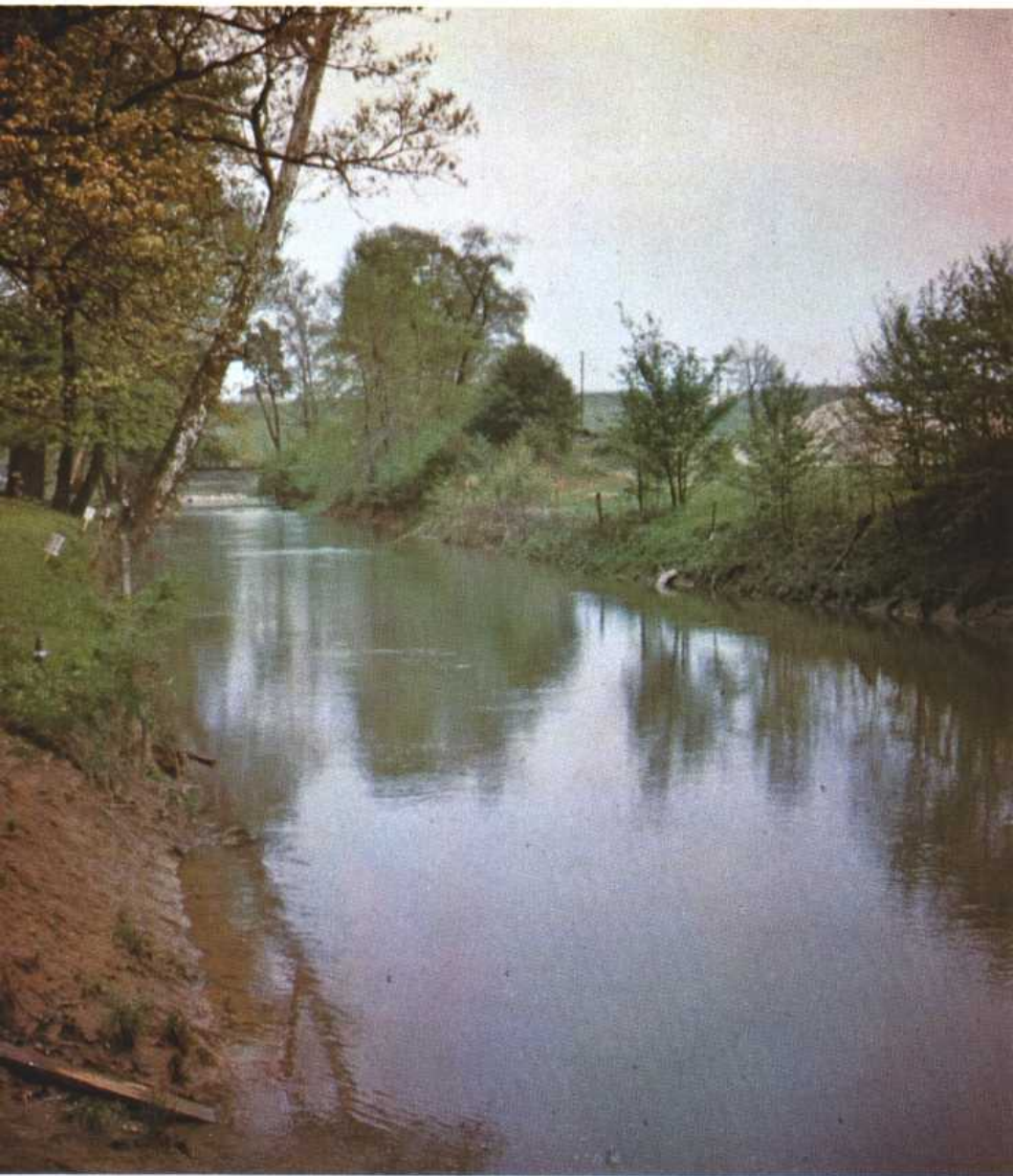
Plan sketch and cross sections, Indian Fork below
Atwood Dam, near New Cumberland, Ohio.

No. 327 upstream from right bank below section 3,
Indian Fork below Atwood Dam, near New Cumberland, Ohio.

No. 329 upstream from right bank at section 2,
Indian Fork below Atwood Dam, near New Cumberland, Ohio.

8–1235.   Champlin Creek near Colorado City, Tex.

Gage location.—Lat 32°19', long 100°49', on right bank 600 ft downstream from South Fork, 5 miles southeast of Colorado City, Mitchell County, and 5.5 miles upstream from mouth. Section 2 is 350 ft downstream from gage.

Drainage area.—158 sq mi.

Date of flood.—May 17, 1949.

Gage height.—5.05 ft at gage; 4.24 ft at section 2.

Peak discharge.—2,390 cfs.

*Computed roughness coefficient.*—Manning *n* = 0.027.

Description of channel.—Bed consists of gravel deposits over smooth to rough rock.   Banks are covered with grass and have a few outcrops.

Reach properties

Section	Area (sq ft)	Top width (ft)	Mean depth (ft)	Hydraulic radius (ft)	Mean velocity (ft per sec)	Length (ft) between sections	Fall (ft) between sections
2............	412	85	4.8	4.71	5.80	....	....
3............	344	79	4.4	4.20	6.96	176	0.43
4............	307	70	4.4	4.24	7.78	148	.71

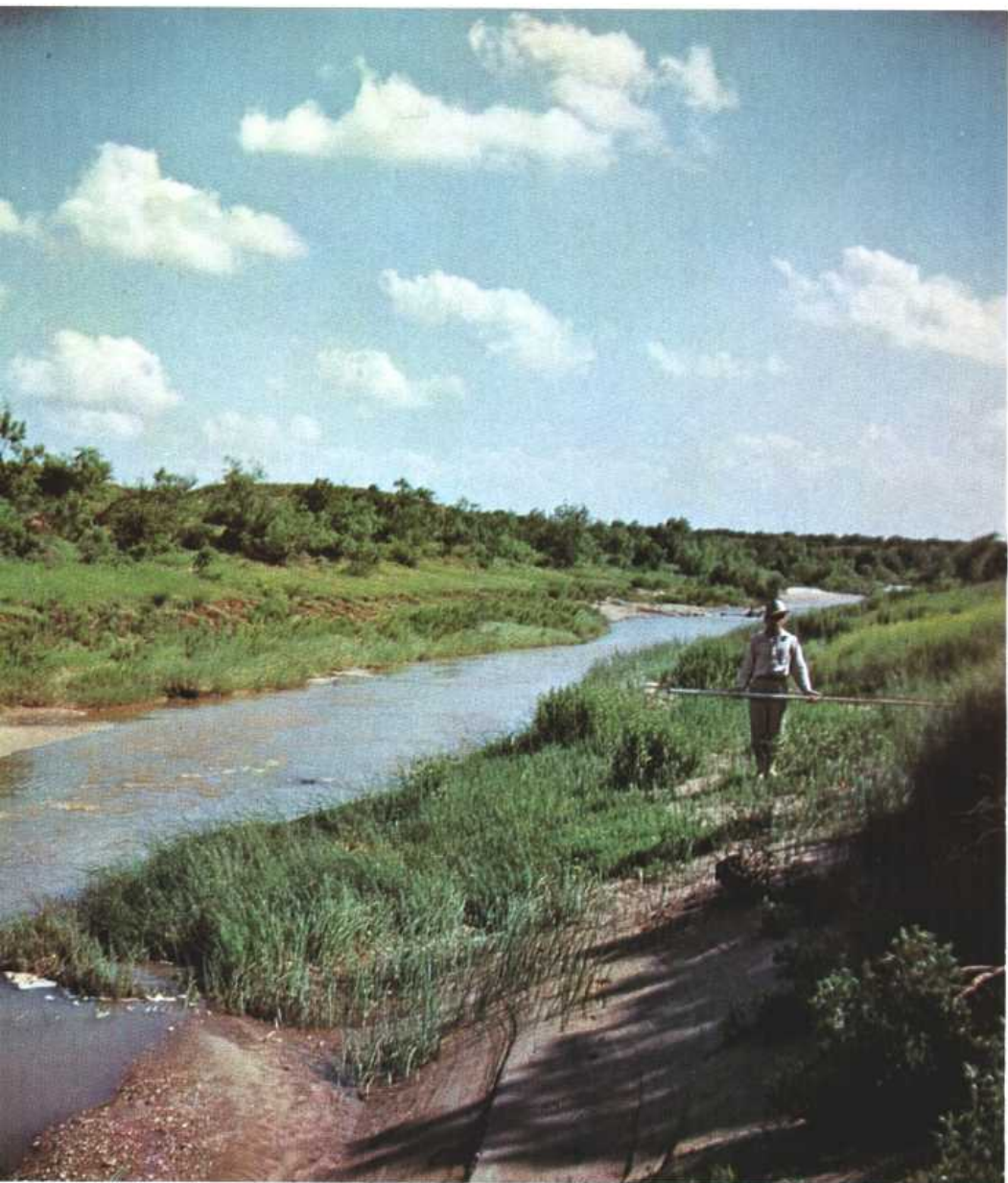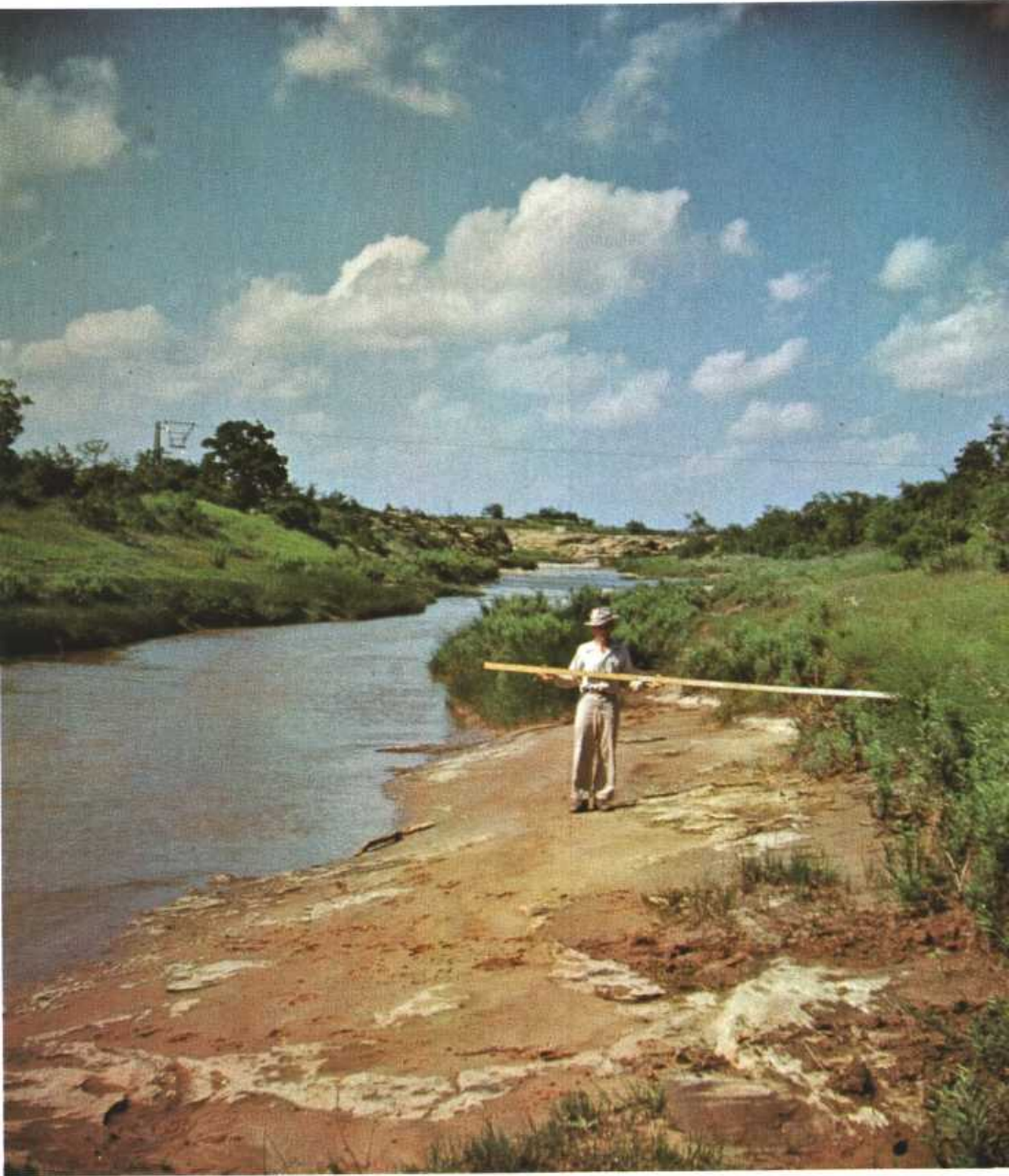Notes.—
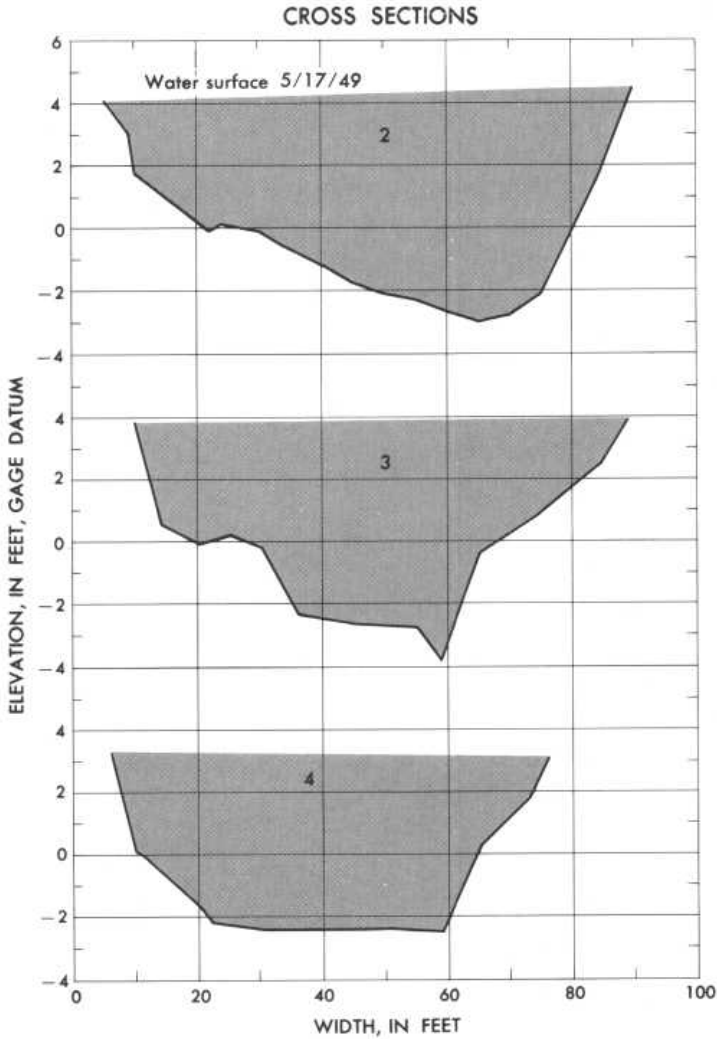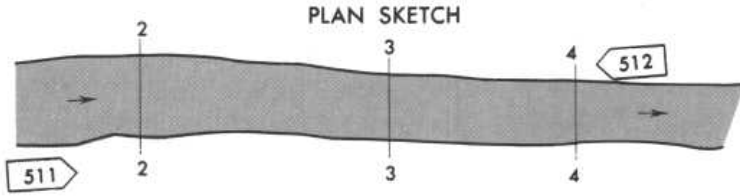
Plan sketch and cross sections, Champlin Creek near
Colorado City, Tex.

n = 0.027

No. 511 downstream along right bank from above section 2,
Champlin Creek near Colorado City, Tex.

No. 512 upstream along left bank from below section 4,
Champlin Creek near Colorado City, Tex.

n = 0.028

12–3545.   Clark Fork at St. Regis, Mont.

Gage location.—Lat 47°18'05", long 115°05'15", in center of SW ¼ sec. 19, T. 18 N., R. 27 W., on left bank at St. Regis, 0.5 mile downstream from St. Regis River.   Section 1 is 660 ft upstream from gage.

Drainage area.—10,709 sq mi.

Date of flood.—May 24, 1948.

Gage height.—19.96 ft at gage; 20.42 ft at section 1.

Peak discharge.—68,900 cfs.

Computed roughness coefficient.—Manning $n = 0.028$.

Description of channel.—Bed consists of well-rounded boulders; $d_{50} = 135$ mm, $d_{84} = 205$ mm.   Banks are composed of gravel and boulders, and have tree and brush cover.

Reach properties

Section	Area (sq ft)	Top width (ft)	Mean depth (ft)	Hydraulic radius (ft)	Mean velocity (ft per sec)	Length (ft) between sections	Fall (ft) between sections
1...........	6,860	404	16.98	16.70	10.04	....	....
2...........	6,976	429	16.26	16.04	9.88	755	0.555
3...........	7,194	454	15.85	15.64	9.58	438	.32

Notes.—
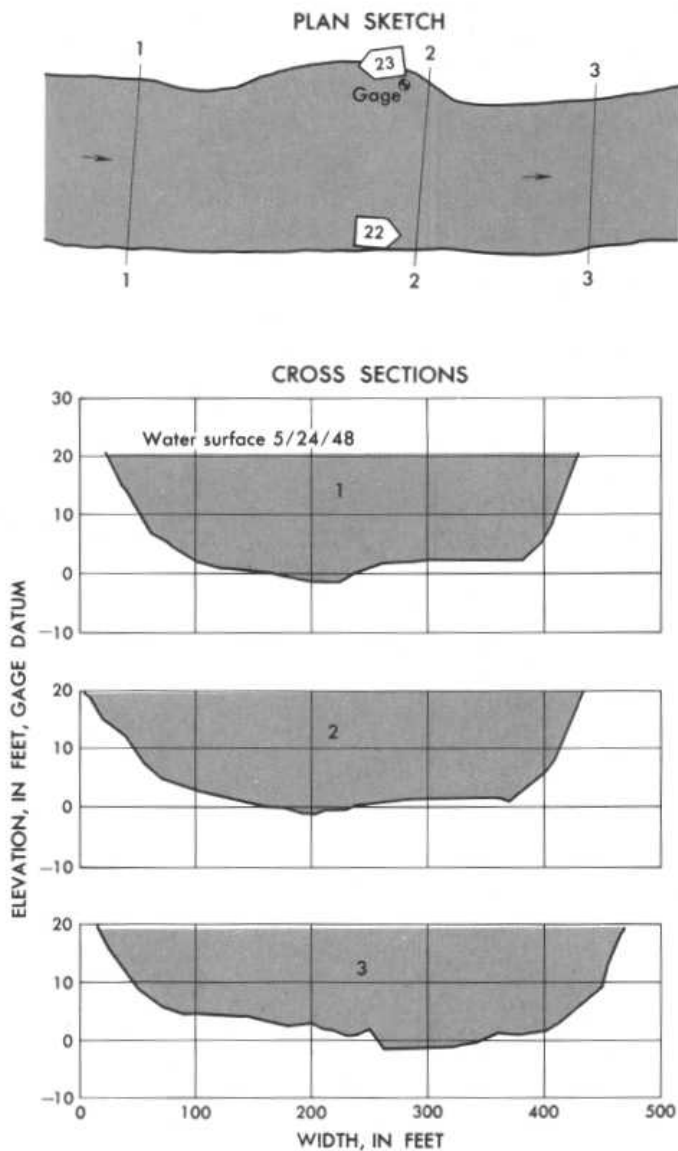
Plan sketch and cross sections, Clark Fork at St. Regis, Mont.

No. 22 downstream along right bank from section 2,
Clark Fork at St. Regis, Mont.

No. 23 upstream along left bank from section 2,
Clark Fork at St. Regis, Mont.

12–3405.   Clark Fork above Missoula, Mont.

Gage location.—Lat 46°52'40", long 113°55'40", in NW¼NW¼ sec. 19, T. 13 N, R. 18 W., on right bank 3 miles downstream from Blackfoot River and 3 miles east of Missoula. Section 1 is 405 ft upstream from gage.

Drainage area.—5,999 sq mi.

Date of flood.—May 23, 1948.

Gage height.—13.07 ft at gage; 14.54 ft at section 1.

Peak discharge.—31,500 cfs.

*Computed roughness coefficient.*—Manning $n = 0.030$.

Description of channel.—Bed is composed of sand, gravel, and boulders; $d_{50} = 175$ mm, $d_{84} = 325$ mm.   Thick undergrowth is along right bank and along the left bank in the lower part of the reach.
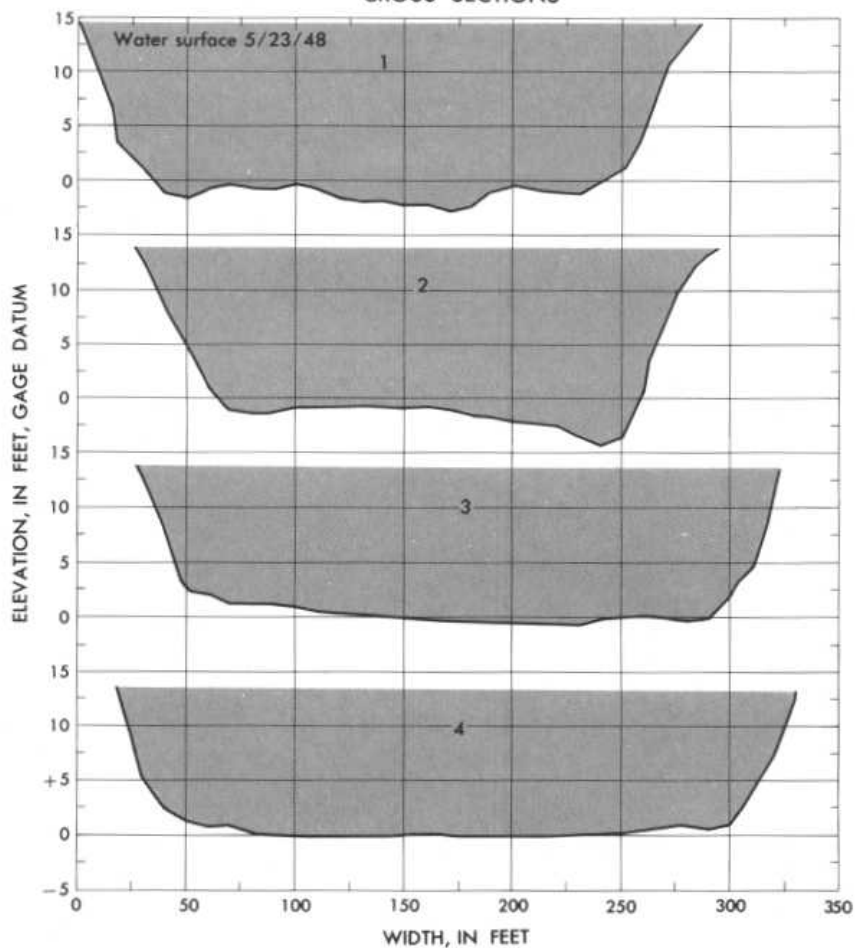
Reach properties

Section	Area (sq ft)	Top width (ft)	Mean depth (ft)	Hydraulic radius (ft)	Mean velocity (ft per sec)	Length (ft) between sections	Fall (ft) between sections
1............	3,866	285	13.56	13.24	8.15	....	....
2............	3,461	267	12.96	12.64	9.10	305	0.63
3............	3,634	294	12.36	12.10	8.67	243	.25
4............	3,798	312	12.17	11.95	8.29	297	.18

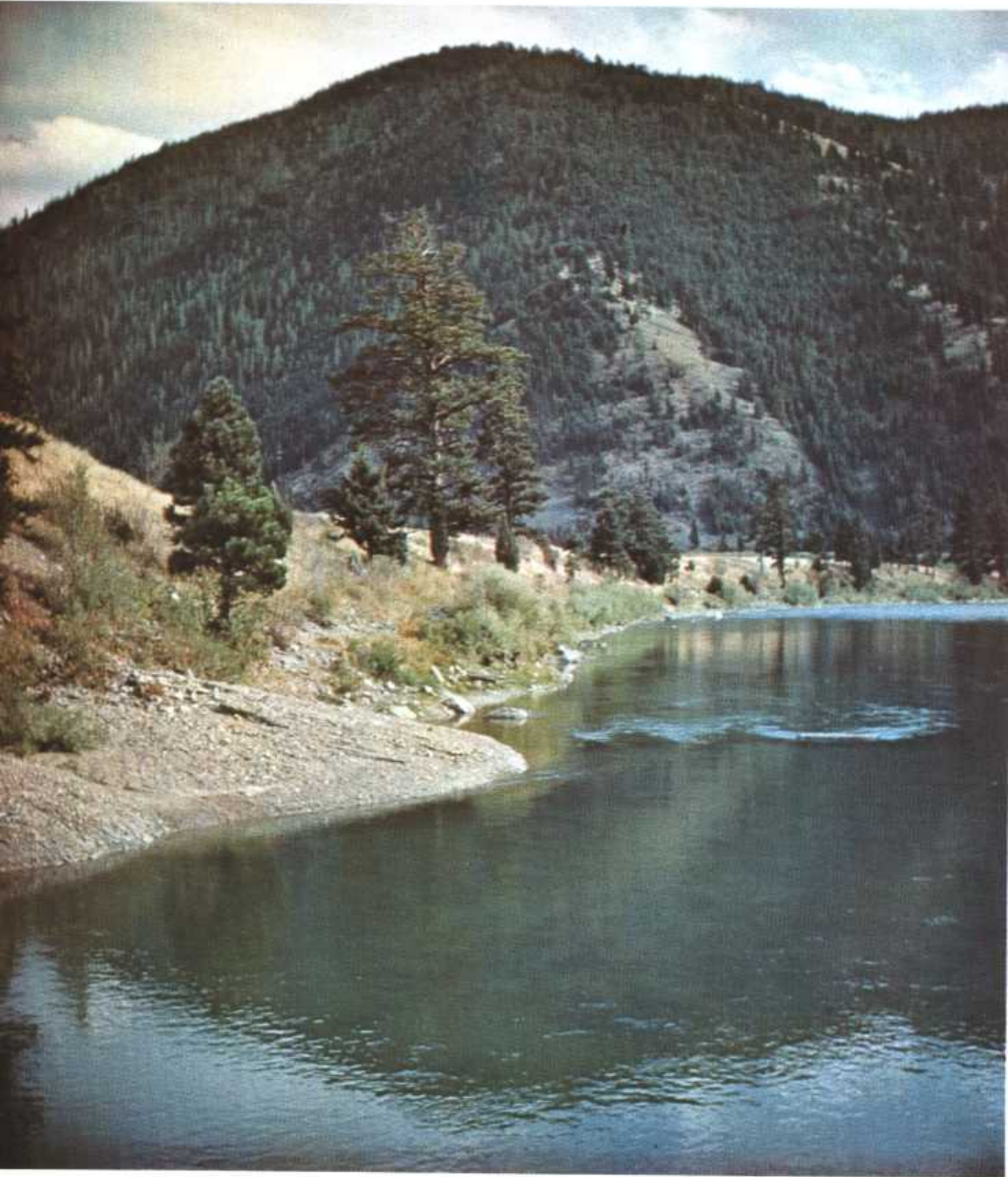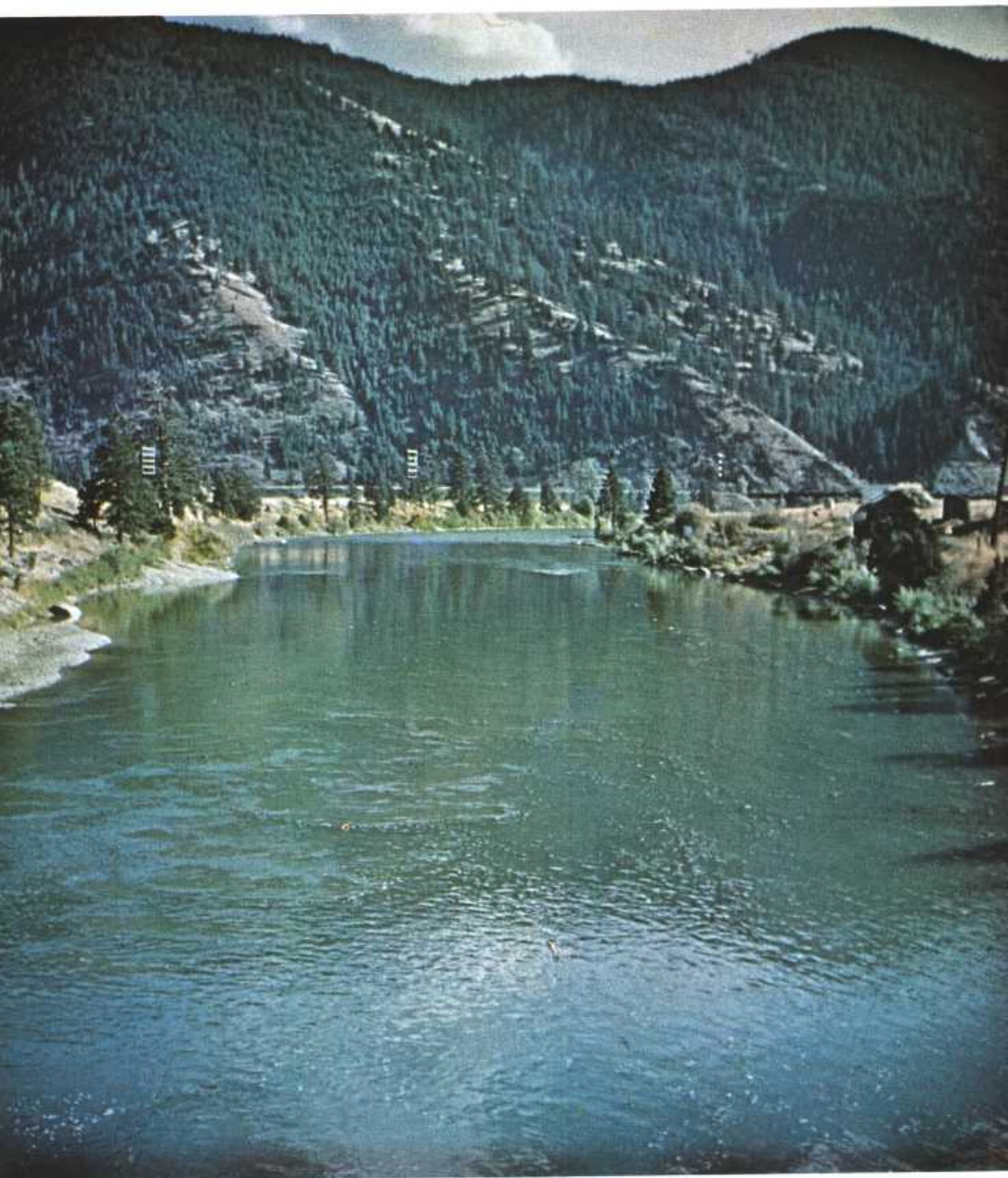Notes.—
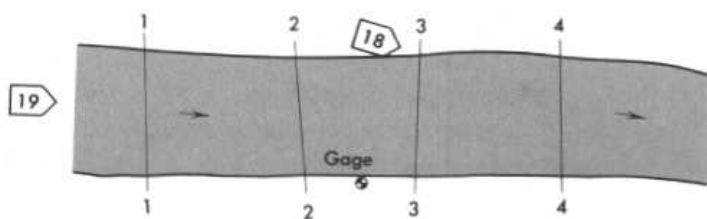
Plan sketch and cross sections, Clark Fork above
Missoula, Mont.

$n = 0.030$

No. 18 downstream along left bank from above section 3,
Clark Fork above Missoula, Mont.

No. 19 downstream through reach from bridge 400 ft above
section 1, Clark Fork above Missoula, Mont.