COMPUTER PROGRAM NCALC USER'S MANUAL--VERIFICATION OF MANNING'S ROUGHNESS COEFFICIENT IN CHANNELS

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4317

Lakewood, Colorado
1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

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METRIC CONVERSION FACTORS

Inch-pound units used in this report may be converted to SI (International System) units by using the following conversion factors:

Multiply	*By*	*To obtain*
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per foot (ft/ft)	0.3048	meter per meter
foot per second (ft/s)	0.3048	meter per second
foot per second square (ft/s^2)	0.3048	meter per second square
square foot	0.0929	square meter

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ABSTRACT

Computations involving flow in open channels commonly require an evaluation of the roughness characteristics of the channel. The U.S. Geological Survey engages in a continuing effort to improve the understanding of flow resistance, usually in terms of Manning's roughness coefficient, *n*, in channels in the United States. Procedures for computing values of Manning's roughness coefficient from known discharge, water-surface profiles, and channel cross-sectional properties are presented, and have been programmed for automatic computation. General theory, procedures for onsite investigations and surveys, a description of the use of the computer program, an example problem, and additional channel-roughness-verification research needs are presented.

INTRODUCTION

Hydraulic computations involving flow in open channels commonly require an evaluation of the roughness characteristics of the channel. The selection of roughness characteristics for channels is subjective, even though extensive guidelines are available (Cowan, 1956; Chow, 1959; Aldridge and Garrett, 1973). The U.S. Geological Survey has made an attempt to improve the quantification of flow-resistance coefficients, and to provide predictive equations to aid in the selection of these coefficients, most commonly Manning's roughness coefficient, *n*. Several studies have been conducted to verify roughness coefficients for selected stream channels covering a range of flow and hydraulic conditions in the United States; flow-resistance verification is a continuing effort of the U. S. Geological Survey. Barnes (1967) presented verified *n*-value data for near-bankfull discharges, with color photographs and descriptive data for 50 stream channels throughout the United States. Limerinos (1970) verified *n*-value data for 11 streams in California for various depths of flow and developed a predictive equation for Manning's *n* as a function of relative smoothness. Aldridge and Garrett (1973) presented verified and onsite selected *n*-value data and guidelines for selecting *n* values for 35 streams in Arizona, with emphasis on sand-bed streams. Jarrett (1984) presented verified *n*-value data for 21 primarily higher-gradient streams (slopes greater than 0.002 ft/ft) in Colorado for varying depths of flow, and presented a predictive equation for Manning's *n* as a function of friction or water-surface slope and hydraulic radius.

A computer program for computing values of Manning's roughness coefficient has been written. This computer program, NCALC, is used to compute the Manning coefficient n in an unsubdivided channel for a single event of measured or known relatively clear water. Input data are discharge, ground elevations and stationing to define individual cross sections, water-surface elevations at each cross section, and the distance downstream from a reference point to each cross section.

This report discusses the theory of the Manning equation, gives detailed instructions for collecting and preparing the data, general instructions for submitting the input data for computer analysis, an example n-verification problem, and additional n-verification research needs.

THEORY

The Manning equation is used as the basis for computing the reach properties and verified n values in this report. The roughness coefficient term, n, appears in the general Manning equation for open-channel flow:

$$V = \frac{1.486}{n} R^{2/3} S_f^{1/2} \; ; \qquad (1)$$

where

V = average cross-section velocity, in feet per second;

R = hydraulic radius, in feet;

S_f = energy gradient or friction slope; and

n = Manning's roughness coefficient.

The continuity equation may be written as:

$$Q = AV \; ; \qquad (2)$$

where

Q = discharge, in cubic feet per second; and
A = cross-sectional area, in square feet.

Substitution of equation 1 for V in equation 2 yields a variation of the Manning equation:

$$Q = \frac{1.486}{n} A R^{2/3} S_f^{1/2} \; , \qquad (3)$$

and the variables as previously defined. Equations 1 and 3 were developed for conditions of uniform flow in which the water-surface slope, friction slope, and energy gradient are parallel to the streambed, and the area, hydraulic radius, and depth remain relatively constant throughout the stream reach. The program has the capability to compute an n value for a single cross section. For lack of a better solution, the equation also is assumed to be valid for nonuniform reaches, invariably found in natural channels, if the energy gradient is modified to reflect only the losses due to boundary friction (Barnes, 1967). The Manning equation has been used extensively as an indirect method for computing discharges or depths of flow in natural channels.

In this application, the equation also is assumed to be valid for the nonuniform reaches usually found in natural channels and flood plains. The velocity distribution is assumed to be logarithmic (Chow, 1959). The Manning equation has provided reliable results when it has been used within the range of verified channel-roughness data.

Studies have shown that many factors influence flow resistance. Chow (1959) and Aldridge and Garrett (1973) expanded on a practical technique developed by Cowan (1956) to aid in evaluating total flow resistance in a channel reach. Total flow-resistance factors include cross-section irregularities, channel shape, obstructions, vegetation, channel meandering, suspended material, bed load, and channel and flood-plain conditions.

The energy equation for a stream-channel reach between two sections (1 and 2) as shown in figure 1 is:

$$(h + h_v)_1 = (h + h_v)_2 + (h_f)_{1.2} + k(\Delta h_v)_{1.2} \; ; \qquad (4)$$

where

h = the elevation above a common datum of the water surface at the respective section, in feet;

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

where

α = velocity-head coefficient equal to 1.0 for perfectly uniform flow distribution;

g = the acceleration due to gravity (32.2 ft/s^2);

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

Δh_v = the upstream-velocity head minus downstream-velocity head, in feet;

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

k = a coefficient generally assumed to be equal to 0 for contracting reaches, and equal to 0.5 for expanding reaches (Barnes, 1967).

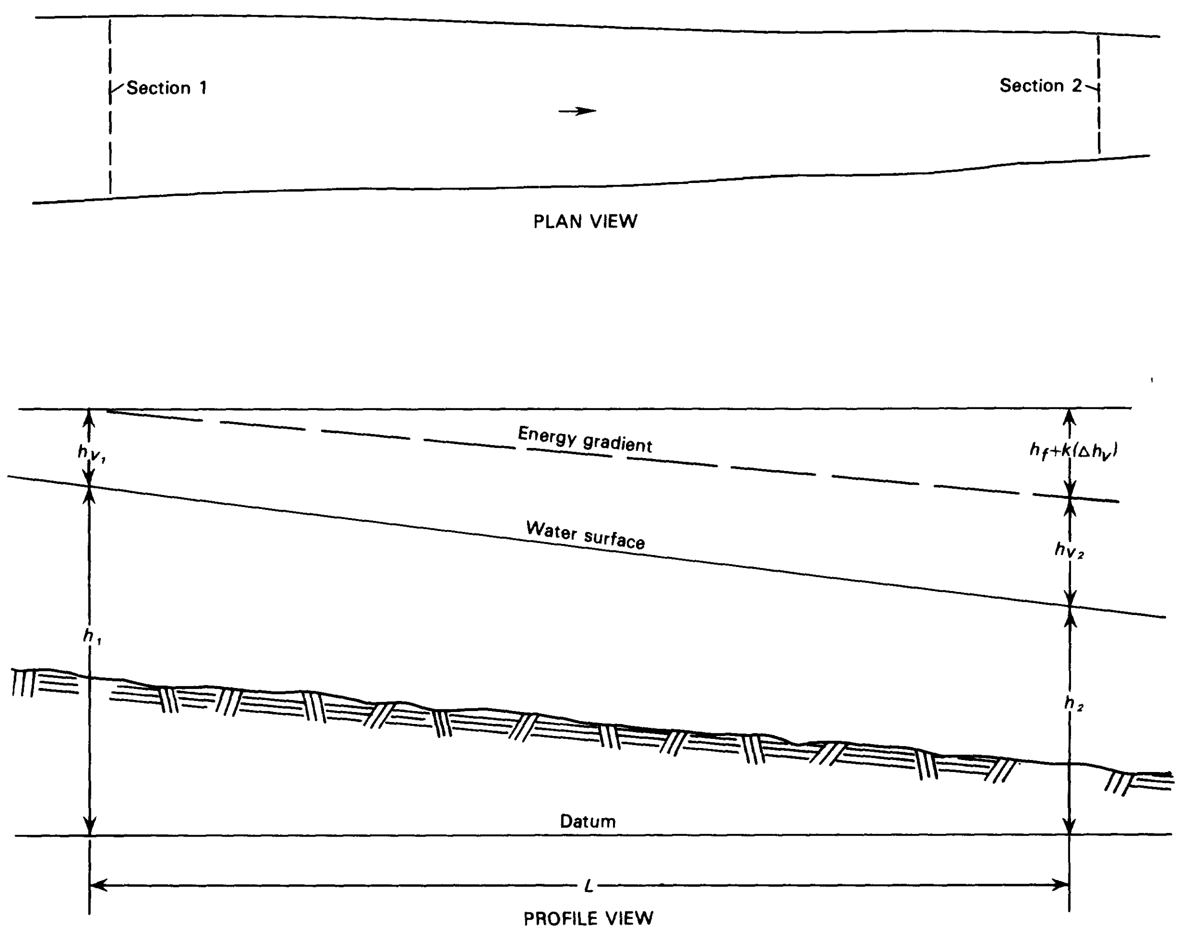

Figure 1.--Definition sketch of an *n*-verification reach.

In computing the values of n using this method, the value of alpha always is considered to be 1.0 in the main channel. Computed values of alpha have been shown to be as high as 2.0 in natural main channels (Jarrett, 1984). However, the n-verification computations (eq. 7, p. 6) for a multisection reach involves an evaluation of the difference between the alpha coefficients of upstream and downstream sections. Therefore, although the value of alpha may be greater than 1.0, the important factor, and, consequently, the factor that would affect the accuracy of the computed n value, is the relative difference between upstream and downstream alpha value. Measuring the alpha value of all cross sections at high flows would be nearly impossible. A primary requirement for selecting reaches used for n verification is that they are basically uniform throughout, or slightly contracting. Therefore, higher values of alpha should not introduce much error in computed n values. However, n verifications based on one cross section could introduce considerable error by assuming alpha equals 1.0 in a simple trapezoidal-shaped cross section.

The friction slope, S_f to be used in the Manning equation is defined as:

$$S_f = \frac{h_f}{L} = \frac{\Delta h + \Delta h_v - k(\Delta h_v)}{L} ; \qquad (5)$$

where

Δh = the difference in water-surface elevation at the two sections, in feet; and

L = the length of the reach (Dalrymple and Benson, 1967) in feet, and the remaining terms are as previously defined.

The quantity $(1.486/n)AR^{2/3}$ in the Manning equation (eq. 1) is called the conveyance, K, has units of cubic feet per second, and 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:

$$Q = \sqrt{K_1 K_2 S_f} ; \qquad (6)$$

where

S_f = the friction slope as previously defined.

Value of the Manning n is computed for each reach from the known discharge, the water-surface profile, and the hydraulic properties of the reach as defined by the cross sections. The following equation is applicable to a multisection reach of M cross sections, designated 1, 2, 3, ... M - 1,M:

$$n = \frac{1.486}{Q} \sqrt{\frac{(h + h_v)_1 - (h + h_v)_M - [(k\Delta h_v)_{1.2} + (k\Delta h_v)_{2.3} + \ldots + (k\Delta h_v)_{(M-1)\cdot M}]}{\frac{L_{1.2}}{Z_1 Z_2} + \frac{L_{2.3}}{Z_2 Z_3} + \ldots \frac{L_{(M-1)\cdot M}}{Z_{(M-1)} Z_M}}} \quad (7)$$

where

$Z = AR^{2/3}$ and other quantities are as previously defined (Barnes, 1967).

ONSITE INVESTIGATIONS

Data-collection procedures generally are the same as for computation of discharge by the slope-area method as in reports described by Dalrymple and Benson (1967), Benson and Dalrymple (1967), Barnes (1967), and Davidian (1984). Those reports are concerned primarily with the determination of discharge, using estimated values of n. For the procedures in this report, the discharge is known, and the equations are used to compute n values; otherwise, the procedures presented here are similar to those in the referenced reports.

Selection of Reach

Selection of a suitable reach is probably the most important element of an n-verification measurement. Water-surface elevations may be obtained by direct survey at the time of the flow event or a survey of high-water marks after the event. Discharge may be obtained by current meter measurement or from stream stage and a well-defined rating curve. Prior to the selection of a reach, the type of n-verification data to be collected must be determined. Studies by Barnes (1967), Limerinos (1970), Aldridge and Garrett (1973), and Jarrett (1984) generally included sites where reaches were relatively free from velocity-retarding influences, other than those associated with the size and size distribution of streambed particles. Some of the sites considered in Aldridge and Garrett (1973) were sand-bed material, that may have had additional form roughness associated with bed forms at a site--ripple, dune, plane bed, or antidune--where roughness varies with discharge or other hydraulic conditions. Some n-verification work has been done to incorporate the total flow resistance from several factors (Leutheusser and Chisholm, 1973).

The following criteria are suggested for selecting an n-verification reach:

1. Discharge is measured by the current-meter method, or determined from stream stage and a well-defined stage-discharge relation.

2. Good water-surface elevations or high-water marks must be available to define the water-surface profile. At a minimum, water-surface elevations or high-water marks should be obtained on each bank at each cross section. To minimize any effect of changing discharge, water-surface elevations need to be measured as close to the the same instant of time as possible. Alternately, enough water-surface elevation data need to be obtained so that adjustments to all cross section water-surface elevations can be made, to correspond to the water-surface elevation at the time of the discharge measurement. If the part 3 (the alternate method discussed later on page 11) computation is needed, then water-surface elevations should be measured on both banks, at points approximately half-way between cross sections, and at comparable distances upstream and downstream from the end sections.

3. The effect of surge on water-surface elevations, or on the high-water marks found on the banks, is an important consideration. Although some effect from surge frequently occurs, the water-surface elevations or high-water marks need to be used as found, and no adjustments are to be made for the effect of surge (Benson and Dalrymple, 1967). Any adjustments necessarily would be subjective and would lead to questionable results. This lack of application of adjustment is justified by the fact that roughness values, as determined from verification studies, are determined from water-surface elevations or from high-water marks on the banks, and any effect of surge is contained in the n values determined; if similar n values are applied for like conditions, using the same methods, then the effect of surge would be minimized.

4. The channel must be relatively stable, with no effects from backwater. The cross sections, obtained by survey, should represent conditions at the time of the measurement.

5. The method assumes that the cross-sectional area of the channel is fully effective, in that it is carrying water in accordance with the conveyance for various parts of the section. For this reason, it is desirable that the studied cross section be uniform for some distance upstream from the reach, so that discharge will be distributed in accordance with channel depths, roughness, and shape. Conditions, either upstream or downstream from a reach, that will cause an unbalanced distribution, need to be avoided. For example, for some distance downstream from a bridge that constricts the channel width, the effective flow will be more concentrated within the center of the channel; the sides of the channel will not carry water in proportion to the computed conveyance, and they may have negative (upstream) velocity. Natural channel constrictions or protrusions may produce the same effect. A sudden deepening of the channel also may represent a noneffective area. Such situations need to be avoided in n-verification reaches.

6. n-verification reaches in mountainous areas, where the channels are very rough and steep, may have free-fall over riffles or boulders. An n verification cannot be made through a reach when free-fall exists. Cross sections need to be located such that free-fall does not occur in any reach.

7. Channel bends often govern the length of a suitable reach. Influence of a channel bend on velocity distribution, slope, and water-surface elevations continues some distance downstream from the bend. If a straight reach away

from the influence of bends cannot be found, a long reach that includes one or more channel bends is used, with terminal sections in straight parts of the channel.

8. Geometry of the channel in the reach also is an important criterion. Marked changes in the shape of the channel along a reach should be avoided because of uncertainties regarding the value of the velocity-head coefficient. The channel needs to be as uniform as possible; but, in any event, the changes in channel conveyance need to be fairly uniform from section to section, to be consistent with the assumption that the mean conveyance is equal to the geometric mean of the conveyance at the end sections. It is desirable that flow be confined within a simple prismatic channel; however, compound channels can be used, if they are properly subdivided. Methods for *n* verification in compound channels are suggested in a later section, "*n* Verification in Compound Channels." Straight, uniform reaches are preferred, or the reach should be contracting, rather than expanding.

9. The reach must be long enough to develop a fall that is well beyond the range of error that might result from alternate interpretations of the high-water profile, or uncertainties that might result from the computation of velocity head. However, the length of a desirable reach often is governed by the geometry of the channel and the practical difficulties of surveying long reaches of river channel. One or more of the following survey criteria needs to be met, if possible, in selecting the length of an *n*-verification reach:

a. The length of the reach should be equal to or greater than 75 times the mean depth in the channel.

b. The fall in the reach should be equal to or greater than the velocity head.

c. The fall in the reach should be equal to or greater than 0.50 ft.

Onsite Survey

Ideally a transit-stadia survey of the reach would be made at the time of the discharge measurement, or as soon after as possible, to obtain water-surface elevations or high-water elevations. The information obtained in this survey is needed to plot accurately the following measurements to a common datum: (1) The water-surface profile, as represented by water-surface elevations or high-water marks; (2) a plan view of the reach, and (3) cross sections at intervals along the reach. Surveying techniques are described in detail by Benson and Dalrymple (1967). Photographs of the reach need to be taken, if possible, at high and low flows.

Cross sections represent samples of the geometry of the reach; thus, the accuracy of the measurement will, to some extent, depend on the number of sections taken. A minimum of three cross sections are needed, but more cross sections are preferred and generally result in more accurate results. Cross sections need to be located, as nearly as possible, at right angles to the flow direction. On large streams, the cross section may need to be broken at one or more points to maintain the section roughly perpendicular to the flow. Cross sections need to be identified as section 1, 2, 3, ..., M, in downstream order.

In *n*-verification measurements, the conveyance is assumed to vary uniformly between cross sections; therefore, cross sections need to be located at major breaks in the high-water profiles. Water-surface profiles usually are plotted to aid in the selection of cross-section location. If these profiles appear to represent a series of somewhat regular waves, the cross sections are located such that each end of the selected reaches are at comparable parts of the waves--all cross sections at the crest, or all cross sections at the trough.

Enough water-surface elevations or high-water marks need to be available near the ends of cross sections to define water-surface elevations. Additional high-water marks may be obtained at the cross-section endpoints.

In extremely rough channels, cross sections need to be located to represent average or typical conditions. Where large, scattered boulders are present, cross sections should not wholly avoid them nor include a disproportionate number of them.

Flow resistance in a stream channel is a function of several factors, particularly the size of the bed material. A median size and the frequency distribution of the bed material is needed, as determined by sampling methods suggested in Benson and Dalrymple (1967). Frequency distribution of the bed-material size subsequently can be determined and can be used in studies relating flow resistance to hydraulic- and bed-material characteristics.

COMPUTER PROGRAM

The computer program follows the basic computational procedures given in the "Theory" section, with an additional method for computing an overall *n* value for multisection reaches suggested by C.T. Jenkins (U.S. Geological Survey, oral commun., 1975). An option is available to include an alternate procedure to compute roughness coefficients for an individual cross section, based on its localized water-surface slope. This option is included in this program for comparison and evaluation with basic computational procedures.

The program has the capability to compute roughness coefficients for 98 subreaches, using 99 cross sections. Each cross section can be defined by 3 to 999 points. There is no provision in the program for subdividing cross sections.

One special feature is an editing subroutine. This subroutine examines input data for errors in tabulation, such as improper symbols, exceeded value limits, inconsistencies, omitted information, and out-of-sequence data. Any fatal error will stop the computation, and the output will include a brief description of the error source.

The computer results are output in four parts in tabular form. The first part is a listing of the input data and the computed cross-sectional properties of each cross section. The second part, based on the multisection equation (eq. 7), is a listing of the roughness coefficients for each successive subreach as well as the roughness coefficient for the entire reach.

The subreach coefficients provide an indication of the internal consistency of the total computation. A roughness coefficient for the entire reach also is computed by weighting the subreach coefficients computed above against their respective friction heads. The third part, which is optional, is the alternate method that lists the roughness coefficients computed for individual cross sections, using the respective value of local water-surface slope at each cross section. This local water-surface slope is calculated from water surface profiles externally from the program. The fourth part, an option discussed in the "Preparation of Data" section, lists the same items as the second part, except the user may preselect various combinations of cross sections, fewer in number than those of the total reach.

COMPUTER COMPUTATIONS

Part 1.--Computation of Reach Roughness Coefficient

The multisection equation (eq. 7) is applicable to a multisection reach of M cross sections that are designated 1, 2, 3, ... M-1, M. For each possible combination of cross sections in a reach, arrayed in a downstream direction, a roughness coefficient is computed for all sequential and nonsequential pairs of cross sections; for reaches with more than two cross sections, an overall roughness coefficient is computed, using all sections of the combination. Each possible combination of sections, the respective pairs of sections for which a roughness coefficient is computed, and the overall reach designated for each combination computed in a four-section reach, are shown in table 1.

Table 1.--*Combinations selected and roughness coefficients computed in a 4-section reach.*

[1,2,3,4--indicates section number; 1-2,2-3, etc.--indicates reach]

Combinations of sections selected	Pairs of sections in the combination for which a roughness coefficient is computed	Overall reach designation for which a roughness coefficient is computed[1]
1, 2, 3, 4	1-2, 2-3, 3-4	1-4
1, 3, 4	1-3, 3-4	1-4
1, 2, 4	1-2, 2-4	1-4
1, 2, 3	1-2, 2-3	1-3
2, 3, 4	2-3, 3-4	2-4
1, 2	1-2	
1, 3	1-3	
1, 4	1-4	
2, 3	2-3	
2, 4	2-4	
3, 4	3-4	

[1]Overall reach (when more than two cross sections are used) is designated by only the most upstream and downstream cross sections of the combination. The n value is computed, using only those cross sections included (shown in the center column).

Part 2.--Computation of Friction-Head Weighted Overall Roughness Coefficient

This computation uses the roughness coefficients computed for cross section pairs in Part 1, but then weights them with their respective friction heads, as in the following equation:

$$\text{weighted } n = \frac{(n_{1.2})(h_{f_{1.2}})+(n_{2.3})(h_{f_{2.3}})+\ldots+(n_{[M-1]\cdot M})(h_{f[M-1]\cdot M})}{h_{f_{1.2}} + h_{f_{2.3}} + \ldots + h_{f[M-1]\cdot M}} \quad . \qquad (8)$$

A weighted n is computed for each time an overall n, described in Part 1, is computed. The friction-head weighted method (Part 2) generally gives similar results as the Part 1 computations, except when a given subreach has a proportionately large computed friction head. The friction-head weighted n value is computed only to show the relative difference from the standard average reach n value (eq. 7) because of too large a friction-head in any subreach.

Part 3.--Computation of Individual Cross-Section Roughness Coefficient

This alternate method computes a roughness coefficient at each cross section from the formula:

$$n = \frac{1.486}{Q} A \; R^{2/3} \; S^{1/2} \; ; \qquad (9)$$

where S is a water-surface slope, computed from water-surface elevations obtained upstream and downstream from the cross section. This method, which ignores the effect of friction head, is incorporated into the program to compare its results with results obtained using the procedures in Parts 1 and 2. For the results of this method to be applicable, the reach should be relatively uniform. The above computation is made only for those reaches for which the user has specified a water-surface slope. If only part of the cross sections within a reach have values for water slope, the value of n from the above computation is shown as zero for those cross sections without a value for slope.

OFFICE COMPUTATIONS

Data reduction is similar to that used in the slope-area method (Dalrymple and Benson, 1967). The following instructions apply: (1) Plot the plan view using a designated scale; (2) determine reference distance at each cross section and lengths to compute the water-surface slope for the Part 3 computation; (3) plot the cross sections, showing the water-surface elevation from the left to the right bank; and (4) use the elevation of the midpoint of the water surface over each area for the input data for each cross section.

Preparation of Data

A form for preparation of the data is shown in figure 2. The form has a blocked-line format of seven card types for tabulating input data for the roughness-coefficient computations. All lines recorded need to be in numerical sequence, beginning with the sequence number (SEQUENCE) written on the STREAM HEADING CARD, number 1. Card 1 is required only for the initial (most upstream) cross section. The CROSS-SECTION PARAMETER, BASE DATA, and WATER-SURFACE ELEVATION CARDS (2, 3, and 5) are required for each cross section. There is no CARD 4 in the NCALC program to maintain a degree of continuity with the slope-area method computer program data entry (Lara and Davidian, U.S. Geological Survey, written commun., 1970). COMPUTATION CARD (6) is required, and OPTIONAL COMBINATIONS and OPTIONAL COMPUTATIONS CARDS (7 and 8) are optional and used only for the last cross section in a reach.

Stream Heading Card (1)

Columns 1-51.--STREAM IDENTIFICATION is any alphanumeric information identifying the stream and location.

Columns 54-61.--GAGING STATION NO. is the U.S. Geological Survey streamflow-gaging station number. If the measurement is for an ungaged site, this field may be left blank, or otherwise be used to record additional numeric, alphabetic, or alphanumeric information.

Columns 64-69.--DATE OF FLOW is the date of the measured discharge for which the *n* values are to be computed. The month, day, and last two digits of the year are listed in that order. Leading zeros are listed when values are less than ten.

Columns 71-72.--TOTAL NO. SECS. is the total number of cross sections in the reach; minimum is 1 (for Part 3 computations), and the maximum is 99.

Columns 74-78.--SEQUENCE is the sequence number beginning with any integer. Subsequent cards in this reach will have sequence numbers in ascending order in downstream direction. The sequence number of any card may be larger, by any number of 1 or more, than that of the preceding card. Negative sequence numbers may be used providing subsequent numbers are mathematically larger. Sequence numbers need to be right justified.

Column 80.--CARD is type 1.

Cross-Section Parameter Card (2)

The instructions for this card apply to each cross section in downstream order.

Columns 3-6.--SECTION is the cross-section identification, which may consist of any combination of alphanumeric characters.

Columns 8-10.--NO. OF STATIONS is the total number of ground elevations in the cross section; value must be right justified, maximum 999.

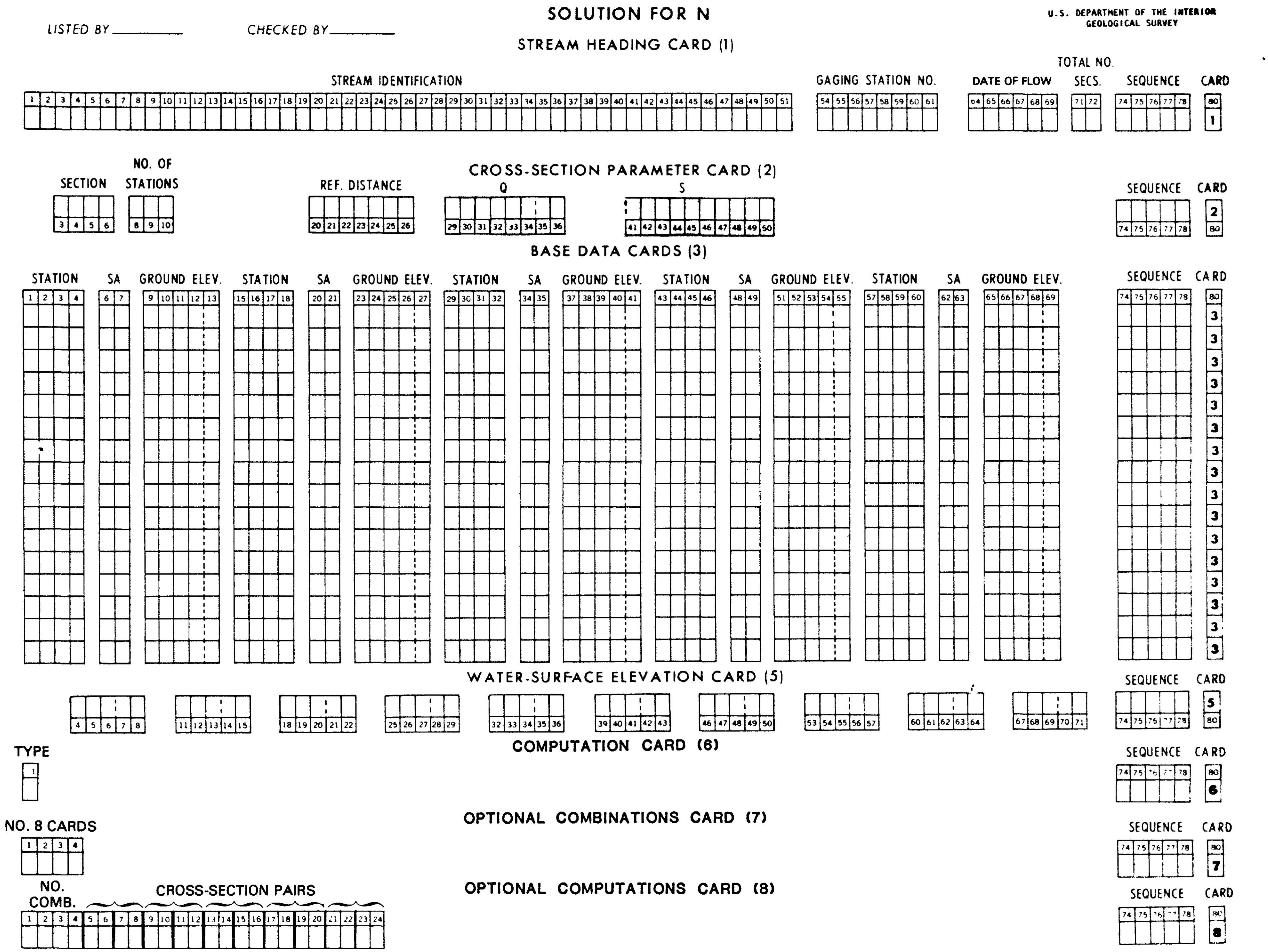

Figure 2.--Data form solution for *n*-verification computation.

Columns 20-26.--REF. DISTANCE is the distance, in whole feet, from a fixed reference point, measured downstream along the channel to this cross section. If this cross section is at the reference point, it is preferable to use zero, right justified. Negative distances may be used. Distances for subsequent cross sections must be mathematically larger in the downstream direction.

Columns 29-36.--*Q* is the discharge, in cubic feet per second, for which the *n* values are to be computed. *Q* is required for all cross sections. The dashed lines in the *Q* column represent an implied decimal position.

Columns 41-50.--*S* (optional) is the slope of the water surface, in feet per lineal foot of distance. The dashed line on the left side of the *S* columns represents the decimal position. The water-surface slope, if given, must be a positive value. If a value for water-surface slope is not specified for a particular cross section, an *n* value of zero is printed out for that cross section.

Columns 74-78.--SEQUENCE is the sequence number, right justified. (CARD 1 has the first sequence number of the series for the *n*-value computations.)

Column 80.--CARD is type 2.

Base Data Card (3)

Each base-data card 3 (one line)--provides space for 5 sets of cross-section coordinates. Each set comprises the distance (STATION) from an initial point on the section and the ground elevation (GROUND ELEV.) at that distance.

The form provides space for 16 card 3's, or 80 sets of station and ground points. If more than 80 sets are required, continue listing the sets on additional sheets. Give each card 3 used a sequence number and carry the sequence to the additional continuation sheet(s), if used. If more than one sheet is used, mark out the lines for cards 5, 6, 7, and 8 on all sheets except the one containing the last card 3 for the cross section. The card line 5 on that sheet is used. Card lines 1 and 2 need to be marked out on additional continuation sheets.

List the STATION, in whole feet, in ascending order, right justified. Negative STATION can be used, and is coded with a minus sign that appears in the column preceding the first digit of the number.

Columns labeled SA, subarea number, are reserved for possible future use.

Always list ground elevations to tenths of one foot. If elevation is known only to the nearest foot, add one zero for the tenth. Dashed lines in the GROUND ELEV. columns imply the decimal positions. Leading zeros may be left blank; zeros in the column for tenths always need to be entered. Ground elevations can be 0.0 ft, or even negative in value, with the minus sign coded in the column preceding the first digit of the number.

The last station of a cross section can fill any set of any card 3. The remainder of an incomplete line is left blank. Assign sequence numbers only to the card 3 lines that contain data.

The pattern described below is duplicated for each of the base-data card rows:

STATION (columns 1-4, 15-18, 29-32, 43-46, 57-60)

GROUND ELEV. (columns 9-13, 23-27, 37-41, 51-55, 65-69)

SEQUENCE (columns 74-78, sequence number, right justified)

CARD (column 80) is type 3.

Water-Surface Elevation Card (5)

The mean water-surface elevation for the cross section is listed in block 1 of the 10 blocks of columns provided (columns 4-8). The remaining 9 blocks are reserved for possible future use for subdivided cross sections. The dashed line implies the decimal position. Leading zeros may be left blank; zeros in the tenths and hundredths columns always need to be entered. Columns 74-78--SEQUENCE is the sequence number, right justified. Column 80--CARD is TYPE 5.

To prepare subsequent cross sections, continue preparation of individual coding forms, as necessary, for each cross section in the reach. Sequence numbers assigned to each line used on the coding form must increase in sequence but need not be consecutive; in any two successive lines (cards), the second line has to have a sequence number greater than the first.

Computation Card (6)

Enter the information required for card 6 on the coding form that contains the last set of the last cross section. Card 6 instructs the program to make the computations described in the section "Computer Computations Part 1", on the basis of every possible combination of cross sections or only for each sequential pair of cross sections. Computations described in Parts 2 and 3 of "Computer Computations" will be made as applicable.

In column one of card 6, specifying computation type of *T* indicates that computations are to be made on the basis of all possible combinations of cross sections. The letter *F* in column 1 indicates that computations are to be made with only sequential pairs of cross sections and with all sections. Columns 74-78--SEQUENCE is the sequence number, right justified. Column 80--CARD is type 6. Generally, TYPE T is used for most computations.

Optional-Combinations Card (7)

Optional-combinations card 7 and optional-computations card 8 allow the user to select various nonsequential cross sections for computations described in the sections "Computer Computations, Part 1 and Part 2" when card 6 TYPE is F. For columns 1-4--code the number of 8 cards that follow in NO. 8 CARDS, right justified. Columns 74-78--SEQUENCE is the sequence number, right justified. Column 80--CARD type is 7.

Optional-Computations Card (8)

The optional-computations card specifies the number of nonsequential pairs of cross sections for computation and the cross section numbers. Columns 1-4--NO. COMB. is the number of paired combinations, right justified. Leading zeros are left blank. Columns 5-6, 9-10, 13-14, 17-18, and 21-22 are coded, right justified, with the upstream cross-section number in the pair of cross sections, as applicable. Columns 7-8, 11-12, 15-16, 19-20, and 23-24 are coded, right justified, with the downstream cross-section number in the pair of cross sections, as applicable. Columns 74-78--SEQUENCE is the sequence number, right justified. Column 80--CARD is type 8.

For example, consider a 4 section reach, where 2 nonsequential paired computations are selected for cross sections 1-3 and 2-4. TYPE on card 6 is coded with the letter F in column 1; NO. 8 CARDS on card 7 is coded with a 1 in column 4; and, NO. COMB. on card 8 is coded with a 2 in column 4; column 6 and 10 are coded with cross-section numbers 1 and 2; columns 8 and 12 are coded with cross-section numbers 3 and 4. The remaining CROSS-SECTION PAIRS are uncoded. If more than 5 CROSS-SECTION PAIRS are used, additional OPTIONAL-COMPUTATIONS CARDS are used.

EXAMPLE OF AN *n* VERIFICATION

An example *n* verification is provided for streamflow-gaging station 09304200 White River above Coal Creek near Meeker, Colorado (Jarrett, 1984), for a measurement of 1,740 ft^3/s on June 20, 1980. The reach has three cross sections, and site selection meets the criteria outlined in the section "Onsite Investigations." The streamflow gage is located within the study reach. A photograph of the site is shown in figure 3.

Figure 3.--Downstream view on White River above Coal Creek near Meeker, Colorado. Photograph taken during low flow with rod held at level of *n*-verification measurement.

Note that the bridge completely spans the channel with no constriction for a flow of this magnitude. The bed and banks are composed of rounded gravel and cobble with an intermediate diameter bed-material size of 0.2 ft determined by the Wolman method (Wolman, 1954).

A plan sketch and cross sections are shown in figure 4. Water-surface profiles are shown in figure 5. Mean water-surface elevations for each cross section and local water-surface slope for each cross section (for the alternate method) were determined from the water-surface profiles. Completed input data forms are shown in figure 6. Input data and hydraulic properties are shown in figure 7. The properties shown are cross-sectional area, top width, wetted perimeter, hydraulic radius, mean water-surface elevation, average cross-sectional velocity, alpha, Froude number, and velocity head.

Verified *n* results are shown in figure 8. For this example, TYPE was coded T on card 6 to compute results for all combinations of cross sections. First, the verified values for each successive reach and combinations of subreaches, determined from equation 7, are shown; then the friction-head weighted *n* value for each computation is shown, using equation 8; finally, the *n* values, computed from the local water-surface slope for each cross section, using equation 9, are shown. For these computations, the subreach section numbers, change in velocity head, friction head, verified roughness coefficient, reach length, and weighted *n* values are presented. For the alternate method of computation, the cross section number, local water-surface slope (S), and computed *n*-value are shown.

The resulting *n* values must be examined and evaluated, based on properties of the reach, hydraulic properties, and consistency in individual *n* values. Generally, the longer and more uniform the reach and the better the definition of water-surface slope, the more reliable and consistent the results. Tranquil flow in lower-gradient streams generally provides more accurate and consistent results than does turbulent flow (with wave action that causes surge) in higher-gradient streams. <u>Generally, the accepted *n* value will be from the results for the total reach with all cross sections</u>; in this example, *n* equals 0.035 (the overall *n* and the weighted *n*). Consistency of separate subreaches is an indication of the reliability of the weighted *n* value for the entire reach. The White River site is relatively uniform and yields consistent results between subreaches, as well as between the three methods, except for the section 3 individual section *n*, which is about 20 percent low.

n VERIFICATION IN COMPOUND CHANNELS

The documented *n*-verification program is presently limited to a reach of channel with single subareas of relatively uniform prismatic shapes with minimal overbank flow. There may be cases where considerable flow is occurring in the flood plain resulting in compound flow. At the present time (1985), little *n* verification has been done in compound channels, with the exception being the work of Arcement and Schneider (1984) in densely vegetated flood plains in the Southeastern United States. If an opportunity becomes available to verify *n* values in compound channels, the following procedure can be used.

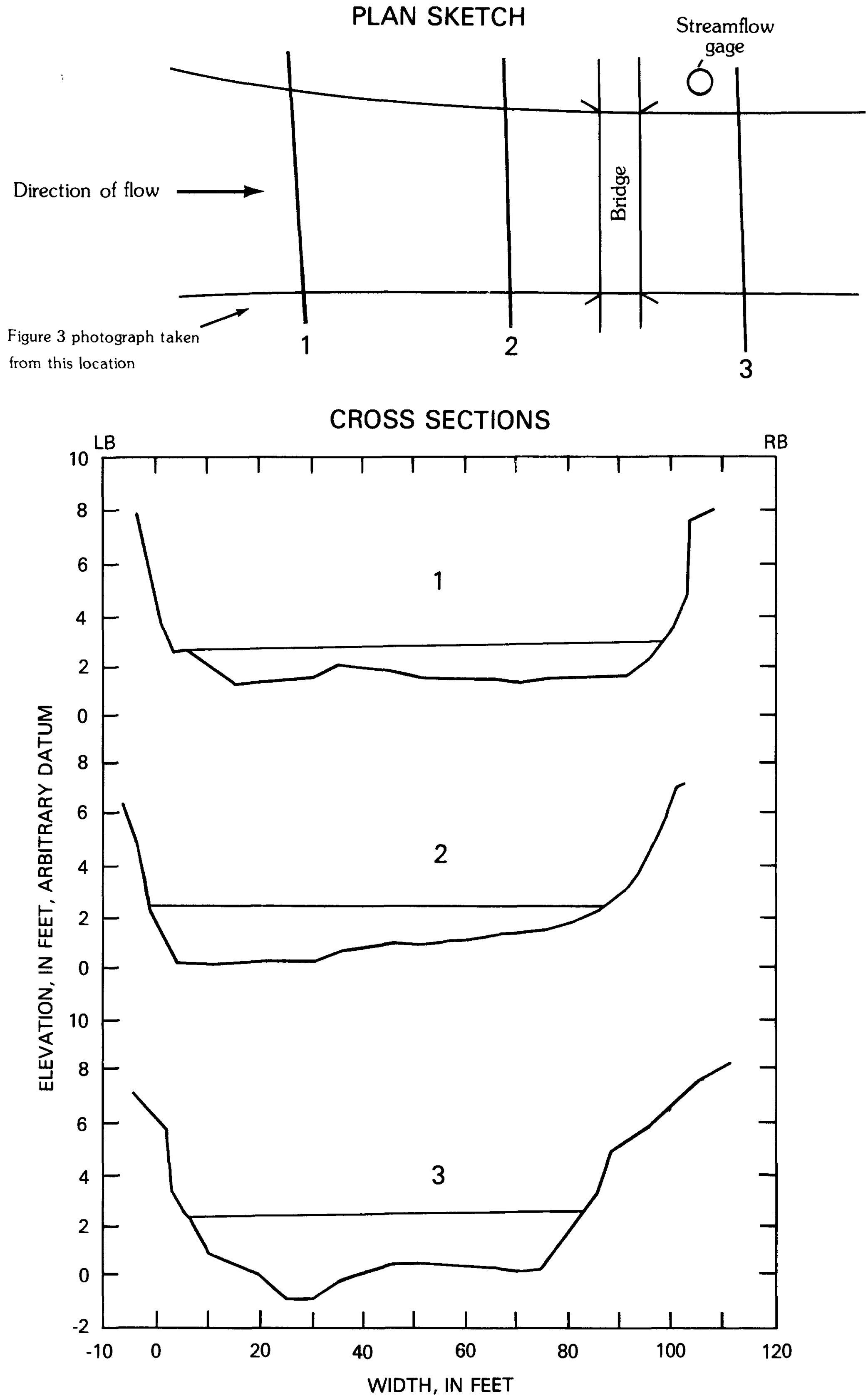

Figure 4.--Plan sketch and cross sections, White River above Coal Creek near Meeker, Colorado.

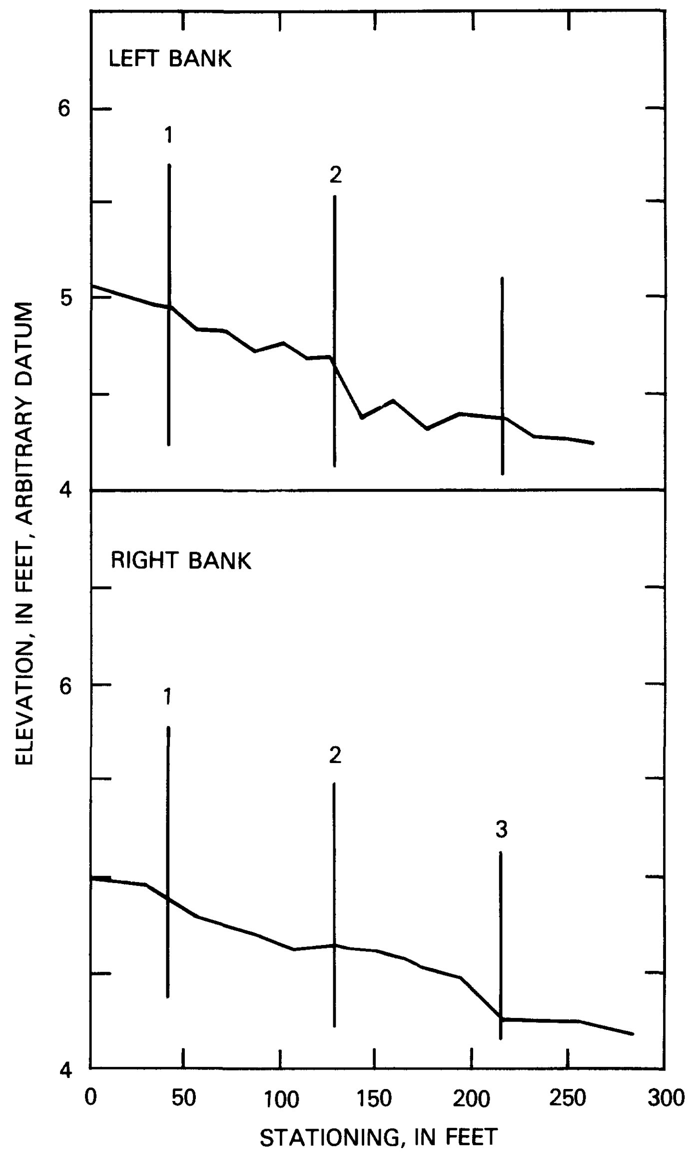

Figure 5.--Water-surface profiles, White River above Coal Creek near Meeker, Colorado.

LISTED BY *RDJ* CHECKED BY *HEP*

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SOLUTION FOR N

STREAM HEADING CARD (1)

STREAM IDENTIFICATION (1–51)	GAGING STATION NO. (54–61)	DATE OF FLOW (64–69)	TOTAL NO. SECS. (71–72)	SEQUENCE (74–78)	CARD (80)
WHITE RIVER AB COAL CREEK NR MEEKER	09304200	062080	03	160	1

CROSS-SECTION PARAMETER CARD (2)

SECTION (3–6)	NO. OF STATIONS (8–10)	REF. DISTANCE (20–26)	Q (29–36)	S (41–50)	SEQUENCE (74–78)	CARD (80)
1	24	57	1740.	.0034	162	2

BASE DATA CARDS (3)

STATION (1–4)	SA (6–7)	GROUND ELEV. (9–13)	STATION (15–18)	SA (20–21)	GROUND ELEV. (23–27)	STATION (29–32)	SA (34–35)	GROUND ELEV. (37–41)	STATION (43–46)	SA (48–49)	GROUND ELEV. (51–55)	STATION (57–60)	SA (62–63)	GROUND ELEV. (65–69)	SEQUENCE (74–78)	CARD (80)
-5		80	-4		80	0		40	5		28	15		14	164	3
20		15	25		15	30		16	35		20	40		19	166	3
45		18	50		15	65		15	70		13	75		15	168	3
80		16	85		15	90		16	95		22	97		29	170	3
100		36	102		47	103		76	107		79				172	3
																3
																3
																3
																3
																3
																3
																3
																3
																3
																3
																3

WATER-SURFACE ELEVATION CARD (5)

4–8	11–15	18–22	25–29	32–36	39–43	46–50	53–57	60–64	67–71	SEQUENCE (74–78)	CARD (80)
490										176	5

COMPUTATION CARD (6)

TYPE (1)

SEQUENCE (74–78) CARD (80) 6

OPTIONAL COMBINATIONS CARD (7)

NO. 8 CARDS (1–4)

SEQUENCE (74–78) CARD (80) 7

OPTIONAL COMPUTATIONS CARD (8)

NO. COMB. (1–4) CROSS-SECTION PAIRS (5–24)

SEQUENCE (74–78) CARD (80) 8

Note: There is no card type 4.

Figure 6.--Completed data-form solution for *n* for White River above Coal Creek near Meeker, Colorado.

LISTED BY RDJ   CHECKED BY HEP

SOLUTION FOR N

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STREAM HEADING CARD (1)

STREAM IDENTIFICATION (1–51)	GAGING STATION NO. (54–61)	DATE OF FLOW (64–69)	TOTAL NO. SECS. (71–72)	SEQUENCE (74–78)	CARD (80)
					1

CROSS-SECTION PARAMETER CARD (2)

SECTION (3–6)	NO. OF STATIONS (8–10)	REF. DISTANCE (20–26)	Q (29–36)	S (41–50)	SEQUENCE (74–78)	CARD (80)
2	28	128	1740	.0027	178	2

BASE DATA CARDS (3)

STATION (1–4)	SA (6–7)	GROUND ELEV. (9–13)	STATION (15–18)	SA (20–21)	GROUND ELEV. (23–27)	STATION (29–32)	SA (34–35)	GROUND ELEV. (37–41)	STATION (43–46)	SA (48–49)	GROUND ELEV. (51–55)	STATION (57–60)	SA (62–63)	GROUND ELEV. (65–69)	SEQUENCE (74–78)	CARD (80)
-7		6.5	-4		4.9	-3		2.1	-2		2.5	0		1.6	180	3
5		0.4	10		0.3	15		0.4	20		0.5	25		0.4	182	3
30		0.5	35		0.9	40		1.1	45		1.2	50		1.1	184	3
55		1.3	60		1.3	65		1.6	70		1.6	75		1.8	186	3
80		2.1	85		2.5	90		3.3	92		3.9	95		5.1	188	3
97		6.0	99		7.2	101		7.4							190	3
																3
																3
																3
																3
																3
																3
																3
																3
																3
																3

WATER-SURFACE ELEVATION CARD (5)

4–8	11–15	18–22	25–29	32–36	39–43	46–50	53–57	60–64	67–71	SEQUENCE (74–78)	CARD (80)
4.68										192	5

COMPUTATION CARD (6)

TYPE (1)	SEQUENCE (74–78)	CARD (80)
		6

OPTIONAL COMBINATIONS CARD (7)

NO. 8 CARDS (1–4)	SEQUENCE (74–78)	CARD (80)
		7

OPTIONAL COMPUTATIONS CARD (8)

NO. COMB. (1–4)	CROSS-SECTION PAIRS (5–24)	SEQUENCE (74–78)	CARD (80)
			8

Note: There is no card type 4.

Figure 6.--Completed data-form solution for *n* for White River above Coal Creek near Meeker, Colorado--Continued.

LISTED BY RDJ   CHECKED BY HEP

SOLUTION FOR N

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STREAM HEADING CARD (1)

STREAM IDENTIFICATION (1–51)	GAGING STATION NO. (54–61)	DATE OF FLOW (64–69)	TOTAL NO. SECS. (71–72)	SEQUENCE (74–78)	CARD (80)
					1

CROSS-SECTION PARAMETER CARD (2)

SECTION (3–6)	NO. OF STATIONS (8–10)	REF. DISTANCE (20–26)	Q (29–36)	S (41–50)	SEQUENCE (74–78)	CARD (80)
3	26	212	1740.	.0023	194	2

BASE DATA CARDS (3)

STATION (1–4)	SA (6–7)	GROUND ELEV. (9–13)	STATION (15–18)	SA (20–21)	GROUND ELEV. (23–27)	STATION (29–32)	SA (34–35)	GROUND ELEV. (37–41)	STATION (43–46)	SA (48–49)	GROUND ELEV. (51–55)	STATION (57–60)	SA (62–63)	GROUND ELEV. (65–69)	SEQUENCE (74–78)	CARD (80)
-5		7.1	2		5.7	3		3.4	5		2.6	7		2.3	196	3
10		0.9	15		0.5	20		0.1	25		-0.8	30		-0.7	198	3
35		0.0	40		0.3	45		0.6	55		0.6	60		0.5	200	3
65		0.4	70		0.3	75		0.5	83		2.7	85		3.3	202	3
86		3.7	88		5.1	90		5.3	95		5.9	100		6.8	204	3
105		7.9													206	3
																3
																3
																3
																3
																3
																3
																3
																3
																3
																3

WATER-SURFACE ELEVATION CARD (5)

4–8	11–15	18–22	25–29	32–36	39–43	46–50	53–57	60–64	67–71	SEQUENCE (74–78)	CARD (80)
4.32										208	5

COMPUTATION CARD (6)

TYPE (1)	SEQUENCE (74–78)	CARD (80)
7	210	6

OPTIONAL COMBINATIONS CARD (7)

NO. 8 CARDS (1–4)	SEQUENCE (74–78)	CARD (80)
0	212	7

OPTIONAL COMPUTATIONS CARD (8)

NO. COMB. (1–4)	CROSS-SECTION PAIRS (5–24)	SEQUENCE (74–78)	CARD (80)
			8

Note: There is no card type 4.

Figure 6.--Completed data-form solution for *n* for White River above Coal Creek near Meeker, Colorado--Continued.

```
                    ***** PROGRAM NCALC *****

          *** INPUT PRINTOUT AND CROSS-SECTION PROPERTIES ***



                WHITE RIVER AB COAL CREEK NR MEEKER                 09304200  062080

 DATA FOR SECTION    1

WHITE RIVER AB COAL CREEK NR MEEKER                   09304200  062080  3       1

   1  24            57.   1740.00   .0034                                       2
 -5.      8.0  -4.      8.0   0.      4.0   5.      2.8  15.       1.4          3
 20.      1.5  25.      1.5  30.      1.6  35.      2.0  40.       1.9          3
 45.      1.8  50.      1.5  65.      1.5  70.      1.3  75.       1.5          3
 80.      1.6  85.      1.5  90.      1.6  95.      2.2  97.       2.9          3
100.      3.6 102.      4.7 103.      7.6 107.      7.9                         3
  4.90                                                                          5

PROPERTIES FOR SECTION     1
         AREA      TOP WIDTH     WETTED     HYDRAULIC     HEAD      AVERAGE
                               PERIMETER     RADIUS                 VELOCITY
        311.06      102.97      104.28        2.98        4.90        5.59

  ALPHA = 1.0000  FROUDE NUMBER = 0.5672  VELOCITY HEAD = 0.4866
                WHITE RIVER AB COAL CREEK NR MEEKER                 09304200  062080

 DATA FOR SECTION    2

   2  28           128.   1740.00   .0027                                       2
 -7.      6.5  -4.      4.9  -3.      2.1  -2.      2.5   0.       1.6          3
  5.      0.4  10.      0.3  15.      0.4  20.      0.5  25.       0.4          3
 30.      0.5  35.      0.9  40.      1.1  45.      1.2  50.       1.1          3
 55.      1.3  60.      1.3  65.      1.6  70.      1.6  75.       1.8          3
 80.      2.1  85.      2.5  90.      3.3  92.      3.9  95.       5.1          3
 97.      6.0  99.      7.2 101       7.4                                       3
  4.68                                                                          5

PROPERTIES FOR SECTION     2
         AREA      TOP WIDTH     WETTED     HYDRAULIC     HEAD      AVERAGE
                               PERIMETER     RADIUS                 VELOCITY
        325.70       97.87      100.47        3.24        4.68        5.34

  ALPHA = 1.0000  FROUDE NUMBER = 0.5161  VELOCITY HEAD = 0.4439
```

Figure 7.--Input data and hydraulic properties output, White River above Coal Creek near Meeker, Colorado.

WHITE RIVER AB COAL CREEK NR MEEKER 09304200 062080

DATA FOR SECTION 3

3 26			212.	1740.00	.0023					2
-5.	7.1	2.	5.7	3.	3.4	5.	2.6	7.	2.3	3
10.	0.9	15.	0.5	20.	0.1	25.	-0.8	30.	-0.7	3
35.	0.0	40.	0.3	45.	0.6	55.	0.6	60.	0.5	3
65.	0.4	70.	0.3	75.	0.5	83.	2.7	85.	3.3	3
86.	3.7	88.	5.1	90.	5.3	95.	5.9	100.	6.8	3
105.	7.9									3
4.32										5

PROPERTIES FOR SECTION 3

AREA	TOP WIDTH	WETTED PERIMETER	HYDRAULIC RADIUS	HEAD	AVERAGE VELOCITY
305.52	84.29	86.22	3.54	4.32	5.70

ALPHA = 1.0000 FROUDE NUMBER = 0.5272 VELOCITY HEAD = 0.5044

Figure 7.--Input data and hydraulic properties output, White River above Coal Creek near Meeker, Colorado--Continued.

Collect the onsite data as outlined in the section on "Onsite Investigations" for the compound-flow conditions. Also collect onsite data for several flows, where the flows are confined to the main channel. Compute the *n* values for within-bank flows. Develop an *n* value versus stage (or water-surface elevation) relation for this data. Plot a line of best fit through the data point and extend the relation to the stage of the compound-channel flow measurement. Code the data into the U.S. Geological Survey slope-area-method program (O.G. Lara and J.S. Davidian, U.S. Geological Survey, written commun., 1970) and enter the *n* value corresponding to the compound channel stage for the main-channel subarea. By trial-and-error solution, enter *n* values for the overbank areas, until the measured discharge for the reach is obtained in the slope-area calculation. If the left and right overbank areas have different resistance characteristics, their *n* values would be weighted subjectively, relative to each other. Ideally try to find channels with only one overbank so the subjective weighting is not required.

*** COMPUTATIONS OF REACH AND FRICTION-HEAD WEIGHTED ROUGHNESS COEFFICIENTS ***

WHITE RIVER AB COAL CREEK NR MEEKER 09304200 062080

DISCHARGE = 1740.00

CROSS-SECTIONS	DELTA VELOCITY HEAD	FRICTION HEAD	ROUGHNESS COEFFICIENT	LENGTH
1 - 2	0.0428	0.2414	0.0338	71.00
2 - 3	-0.0606	0.2994	0.0363	84.00
1 - 3	-0.0178	0.5408	0.0351	155.00

FRICTION-HEAD WEIGHTED N = 0.0352

*** COMPUTATIONS OF REACH AND FRICTION-HEAD WEIGHTED ROUGHNESS COEFFICIENTS ***

WHITE RIVER AB COAL CREEK NR MEEKER 09304200 062080

DISCHARGE = 1740.00

CROSS-SECTIONS	DELTA VELOCITY HEAD	FRICTION HEAD	ROUGHNESS COEFFICIENT	LENGTH
1 - 2	0.0428	0.2414	0.0338	71.00

FRICTION-HEAD WEIGHTED N = 0.0338

*** COMPUTATIONS OF REACH AND FRICTION-HEAD WEIGHTED ROUGHNESS COEFFICIENTS ***

WHITE RIVER AB COAL CREEK NR MEEKER 09304200 062080

DISCHARGE = 1740.00

CROSS-SECTIONS	DELTA VELOCITY HEAD	FRICTION HEAD	ROUGHNESS COEFFICIENT	LENGTH
1 - 3	-0.0178	0.5622	0.0348	155.00

FRICTION-HEAD WEIGHTED N = 0.0348

*** COMPUTATIONS OF REACH AND FRICTION-HEAD WEIGHTED ROUGHNESS COEFFICIENTS ***

WHITE RIVER AB COAL CREEK NR MEEKER 09304200 062080

DISCHARGE = 1740.00

CROSS-SECTIONS	DELTA VELOCITY HEAD	FRICTION HEAD	ROUGHNESS COEFFICIENT	LENGTH
2 - 3	-0.0606	0.2994	0.0363	84.00

FRICTION-HEAD WEIGHTED N = 0.0363

*** CROSS-SECTION ROUGHNESS COEFFICIENTS ***
** COMPUTED USING LOCAL WATER-SURFACE SLOPE **

WHITE RIVER AB COAL CREEK NR MEEKER 09304200 062080

DISCHARGE = 1740.00

SECTION	WATER SLOPE	N
1	0.0034000	0.0321
2	0.0027000	0.0317
3	0.0023000	0.0291

Figure 8.--*n*-verification results output, White River above Coal Creek near Meeker, Colorado.

n-VERIFICATION RESEARCH NEEDS

Most flow-resistance verification work in open channels has been done in uniform, relatively trapezoidal-shaped channels, with flow confined to the main channel and with relatively clear water. Additional *n*-verification work is needed for a variety of additional conditions, including the following:

1. The work by Barnes (1967) and Jarrett (1984) on higher-gradient streams generally has been for depths less than 10 ft. Many streams in the Pacific Northwest have higher gradients and large depths of flow.
2. Minimal *n*-verification work in natural stream channels has been for supercritical flow, that is, flow with Froude numbers greater than 1.0 (Jarrett, 1984).
3. Very little *n*-verification work has been done in higher-gradient sand-bed channels. Many streams have these characteristics in the Central and Western United States.
4. Minimal information is available on flow resistance of sediment-laden streams. Vanoni and Nomicos (1960) provide qualitative evidence that *n* values decrease slightly with small-suspended sediment concentrations. Nationwide, however, streams and rivers may carry large amounts of suspended sediment and bed load that affect flow resistance, particularly for larger flows and floods.
5. Existing *n* verifications are for channels with flow resistance primarily resulting from the size of the stream-bed particles. Total flow resistance is a function of a number of other factors, including channel vegetation, obstructions, channel alignment, cross-section irregularities, and channel meandering where their influence only is known qualitatively. Stream reaches need to be studied to further quantify the effects of these factors on flow resistance. Essentially all natural channels contain these factors.
6. Additional *n* verification is needed where flow exceeds the capacity of the main channel. In addition to the relatively qualitative information and guidelines available for assessing *n* values in flood plains, the effect of the interaction of flow from the main channel to the flood plain, and that interaction in reverse has an increased effect on flow resistance, as discussed by Wormleaton and others (1982). Most streams and rivers have flood-plain flow during periods of high flow or floods.

Comprehensive studies are needed to quantify the processes of flow resistance in main channels, with varying influencing factors, and for flood-plain flows and their interactive processes. Predictive tools can be developed to improve the estimating ability for flow resistance, particularly as it varies with depth of flow in open channels.

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