Designation: D5130 – 95(Reapproved 2008)

Standard Test Method for Open-Channel Flow Measurement of Water Indirectly by Slope-Area Method[1]

This standard is issued under the fixed designation D5130; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the computation of discharge (the volume rate of flow) of water in open channels or streams using representative cross-sectional characteristics, the water-surface slope, and coefficient of channel roughness as input to gradually-varied flow computations.[2]

1.2 This test method produces an indirect measurement of the maximum discharge for one flow event, usually a specific flood. The computed discharge may be used to help define the high-water segment of a stage-discharge relation.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D1129 Terminology Relating to Water

D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water

D3858 Test Method for Open-Channel Flow Measurement of Water by Velocity-Area Method

2.2 *ISO Standards:*[4]

ISO 748 Liquid Flow Measurements in Open Channels—Velocity-Area Method

ISO 1070 Liquid Flow Measurements in Open Channels—Slope-Area Method

3. Terminology

3.1 *Definitions:* For definitions of terms used in this test method, refer to Terminology D1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 Several of the following terms are illustrated in Fig. 1:

3.2.2 *alpha* (α)*—*a velocity-head coefficient that represents the ratio of the true velocity head to the velocity head computed on the basis of the mean velocity. It is assumed equal to 1.0 if the cross section is not subdivided. For subdivided sections, α is computed as follows:

$$\alpha = \frac{\sum\left(\frac{k_i^{\,3}}{A_i^{\,2}}\right)}{\frac{K_T^{\,3}}{A_T^{\,2}}}$$

where:

K and A = the conveyance and area of the subsection indicated by the subscript i, and
K_T and A_T = the conveyance and area of the entire cross section.

3.2.3 *conveyance (K)*—a measure of the carrying capacity of a channel and has dimensions of cubic feet per second or cubic metres per second. Conveyance is computed as follows:

$$K = \frac{1.486}{n} AR^{2/3}$$

where:

n = the Manning roughness coefficient,
A = the cross-section area, ft^2 (m^2), and

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[1] This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

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[2] This test method is similar to methods developed by the U.S. Geological Survey and described in documents referenced in Footnotes 5, 6, and 7.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

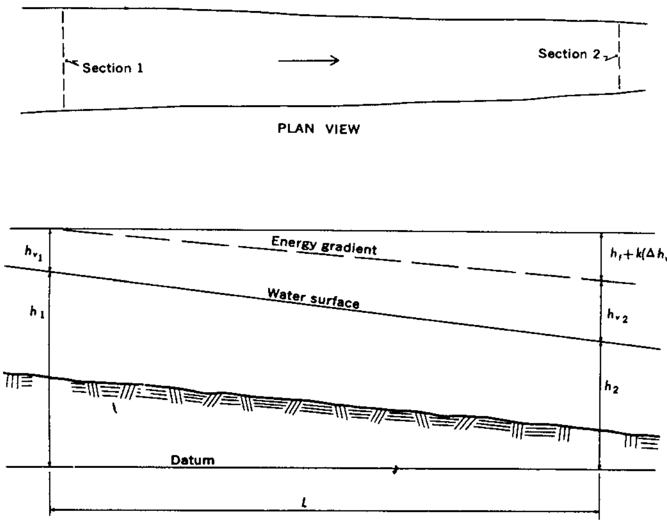

FIG. 1 Definition Sketch of a Slope-Area Reach

R = the hydraulic radius, ft (m).

NOTE 1—1.486 = 1.00 SI unit.

3.2.4 *cross sections (numbered consecutively in downstream order)*—representative of a reach of channel and are positioned as nearly as possible at right angles to the direction of flow. They must be defined by coordinates of horizontal distance and ground elevation. Sufficient ground points must be obtained so that straight-line connection of the coordinates will adequately describe the cross-section geometry. If major breaks in the high-water profile are evident, cross sections should be located at the breaks.

3.2.5 *cross-section area (A)*—the area of the water below the high-water surface elevations that are computed by assuming a straight-line interpolation between elevations on each bank. The area is computed as the summation of the products of mean depth multiplied by the width between stations of the cross section.

3.2.6 *friction loss (h_f)*—the loss due to boundary friction in the reach and is equivalent to the following:

$$\Delta h + \Delta h_v - k(\Delta h_v)$$

where:

Δh = the fall in the reach,
Δh_v = the upstream velocity head minus the downstream velocity head,
$(k\Delta h_v)$ = the energy loss due to acceleration or deceleration and to eddies in a contracting or expanding reach, where k is a coefficient for energy losses.

All of the equations presented in this standard are based on the assumption that k is zero for contracting reaches and 0.5 for expanding reaches.

3.2.7 *fall (Δh)*—the drop in the water-surface computed as the difference in the average water-surface elevation at adjacent cross sections.

3.2.8 *friction slope (S_f)*—the energy loss divided by the length of the reach or:

$$S_f = \frac{h_f}{L}$$

that becomes:

$$S_f = \frac{\Delta h + \Delta h_v}{L}$$

when Δh_v is negative (for a contracting reach), or:

$$S_f = \frac{\Delta h + \frac{\Delta h_v}{2}}{L}$$

when Δh_v is positive (for an expanding reach).

3.2.9 *Froude number (F)*—an index to the state of flow in the channel. In a prismatic channel, the flow is tranquil or subcritical if the Froude number is less than 1.0 and is rapid or supercritical if it is greater than 1.0. The Froude number is computed as follows:

$$F = \frac{V}{\sqrt{g d_m}}$$

where:

V = the mean velocity in ft/s (m/s),
d_m = the average depth in the cross section in feet, and
g = the acceleration of gravity in ft/s/s (m/s/s).

3.2.10 *high-water marks*—the evidence of the highest stage reached by a flood. Debris, stains, foam lines, and scour marks are common types of high-water marks. Water-surface slopes are determined by the elevations of these marks.

3.2.11 *hydraulic radius (R)*—defined as the area of a cross section or subsection divided by the corresponding wetted perimeter.

3.2.12 *roughness coefficient (n)*—or Manning's n is used in the Manning equation. Roughness coefficient or Manning's n is a measure of the resistance to flow in a channel. The factors that influence the magnitude of the resistance to flow include the character of the bed material, cross section irregularities, depth of flow, vegetation, and alignment of the channel. A reasonable evaluation of the resistance to flow in a channel depends on the experience of the person selecting the coefficient and reference to texts and reports that contain values for similar stream and flow conditions.[5,6] (See 9.3).

3.2.13 *velocity head (h_v)*—computed as follows:

$$h_v = \frac{\alpha V^2}{2g}$$

where:

α = the velocity-head coefficient,
V = the mean velocity in the cross section in ft/s (m/s), and

[5] Benson, M. A., and Dalrymple, T., "General Field and Office Procedures for Indirect Discharge Measurements," *Techniques of Water Resources Investigations*, Book 3, U.S. Geological Survey, 1967.

[6] Matthai, Howard F., "Measurement of Peak Discharge at Width Contractions by Indirect Methods," *Techniques of Water Resources Investigations*, Book 3, Chapter A4, U.S. Geological Survey, 1984.

g = the acceleration of gravity in ft/s/s (m/s/s).

3.2.14 *wetted perimeter (WP)*—the total length of the boundary between the channel bed and the water for a cross section. It is computed as the sum of the hypotenuse of the right triangle defined by the distance between adjacent stations of the cross section and the difference in bed elevations.

4. Summary of Test Method

4.1 The slope-area method is used to indirectly determine the discharge through a reach of channel, usually after a flood, using evidence left by the event and the physical characteristics of the channel reach. A field survey is made to determine distances between and elevations of high-water marks and to define cross sections of the stream. These data are used to compute the fall in the water surface between sections and selected properties of the sections. This information is used along with Manning's n in the Manning equation to compute the discharge, Q. The Manning equation in terms of discharge, Q, is as follows:

$$Q = \frac{1.486}{n} AR^{2/3} S_f^{\ 1/2} \text{ or } Q = KS_f^{\ 1/2}$$

The symbols on the right sides of the equations are defined in Section 3.

5. Significance and Use

5.1 This test method is particularly useful for determining the discharge when it cannot be measured directly by some type of current meter to obtain velocities and with sounding weights to determine the cross section.

5.2 Even under optimum conditions, the personnel available cannot cover all points of interest during a major flood. Field personnel cannot always obtain reliable results by direct methods if the stage is rising or falling very rapidly, if flowing ice or debris interferes with depth or velocity measurements.

5.3 Under the worst conditions, access roads are blocked, cableways and bridges may be washed out, and knowledge of the flood frequently comes too late to obtain direct measurements of flow. Therefore, some type of indirect measurement is necessary. The slope-area method is a commonly used method.

6. Apparatus

6.1 The equipment generally used for a "transit-stadia" survey is recommended. An engineer's transit, a self-leveling level with azimuth circle, newer equipment using electronic circuitry, or other advanced surveying instruments may be used. Standard level rods, a telescoping, 25-ft (7.6 m) level rod, rod levels, hand levels, steel and metallic tapes, tag lines (small wires with markers fixed at known spacings), vividly colored flagging, survey stakes, a camera (preferably stereo) with color film, light meter, and ample note paper are necessary items.

6.2 Additional equipment that may expedite a survey include axes, shovels, a portable drafting machine, a boat with oars and motor, hip boots, waders, rain gear, nails, sounding equipment, two-way radios, ladder, and rope.

6.3 Safety equipment should include life jackets, first aid kit, drinking water, and pocket knives.

7. Sampling

7.1 Sampling as defined in Terminology D1129 is not applicable in this test method.

8. Calibration

8.1 The surveying instruments, levels and transits, etc., should have their adjustment checked before each use and possibly daily when in continuous use or after some occurrence that may have affected the adjustment.

8.2 The standard check is the "two-peg" or" double-peg" test. If the error is over 0.03 ft in 100 ft (0.9 cm in 30.5 m), the instrument should be adjusted. The two-peg test and how to adjust the instrument are described in many surveying textbooks and in instructions provided by the manufacturer. Refer to manufacturer's manual for the electronic instruments.

8.3 If the "reciprocal leveling" technique is used in the survey, it is the equivalent of the two-peg test between each of the two successive hubs.

8.4 Sectional and telescoping level rods should be checked visually at frequent intervals to be sure sections are not separated. A proper fit at each joint can be quickly checked by measurements across the joint with a steel tape.

8.5 All field notes of the transit-stadia survey should be checked before proceeding with the computations.

9. Procedure

9.1 Selection of a reach of channel is the first and probably the most important step to obtain reliable results. Ideal reaches rarely exist; so the various elements in a reach must be evaluated and compromises made so that the best reach available is selected.[7] Selection soon after the flood event is recommended because livestock, humans, heavy rain, and bank sloughing can destroy high-water marks.

9.1.1 Good high-water marks are essential for good results. At times a reach with poor quality marks must be used because of other complicating factors such as inflow, proximity to a gaging station, etc. List high-water marks in a format such as shown in Fig. 2.

9.1.2 The nearer the reach to a uniform channel the better. Marked changes in channel shape should be avoided because of uncertainties regarding the value of the expansion/contraction loss coefficient (k) and the friction losses in the reach. Changes in channel conveyance should 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 conveyances at the end sections.

9.1.3 A reach with flow confined to a roughly trapezoidal channel is desirable because roughness coefficients have been determined for such shapes. However, compound channels, those with overbank flow, for example, can be used if they are properly subdivided into subareas that are approximately trapezoidal.

[7] Benson, M. A., and Dalrymple, Tate, "Measurement of Peak Discharge by the Slope-Area Method," *Techniques of Water Resources Investigations*, Book 3, U.S. Geological Survey, 1967.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

File No. Washington ______ District ______

Snake Creek near Connell, Wash. – flood of Feb. 21, 1956

High water marks

Left bank Sta.	Elev.	Sta.	Elev.	Right bank Sta.	Elev.	Sta.	Elev.
47	17.80	423	14.58	0	19.18	372	15.07
63	17.60	449	14.85	24	18.81	388	14.99
80	17.17	478	14.05	36	18.54	401	(sec 3)
97	16.81	502	13.46	67	17.40	402	14.96
120	16.53	510	13.84	84	17.22	412	14.88
142	16.48	517	(sec 4)	103	16.99	428	14.87
165	16.37	517	13.76	127	16.65	454	14.47
190	(sec 1)	548	13.63	141	16.56	476	14.35
190	16.29	578	13.44	167	16.39	496	13.99
218	16.15	600	13.41	188	(sec 1)	516	13.49
237	15.91	638	13.04	188	16.40	521	13.67
267	15.71	654	12.90	215	16.31	522	(sec 4)
284	15.62	678	12.73	239	15.93	524	13.75
312	(sec 2)	689	12.64	264	15.76	536	13.73
312	15.66	707	12.62	281	15.58	561	13.87
338	15.16			300	15.53	585	13.27
365	14.93			308	15.51	604	13.12
380	14.77			309	(sec 2)	627	13.00
401	(sec 3)			318	15.48	644	12.92
402	14.71			345	15.41	668	12.55
						684	12.39

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FIG. 2 Sample Slope-Area Computation, Listing of High-Water Marks

9.1.4 A straight reach that contracts is preferred, but both conditions seldom exist in the same reach. Whether or not a reach is contracting or expanding depends solely upon the difference in velocity head (Δh_v) between sections. The reach is contracting if the difference in the velocity head is negative. The reach is expanding if the velocity-head difference is positive.

9.1.5 Cross sections are assumed to be carrying water in accordance with the conveyance for each part of the section. Therefore, the channel for some distance upstream should be similar to that of the reach. Then the discharge will be distributed in relation to depths, roughness, and shape. If the upstream section is located too close to a sharp bend, a bridge that constricts the width, or a natural constriction, slack water, or even an eddy may occupy part of the section; and the section will not be effective in carrying water downstream in proportion to the computed conveyance.

9.1.6 Channels in mountainous areas may be very rough and steep and may have free fall over riffles and boulders. The Manning equation is not applicable when free fall exists. However, free fall may or may not be indicated by the high-water profiles or by inspection of the reach. Cross sections can be located to eliminate any part of a reach in which free fall is indicated. If the reach includes stretches in which free fall might have occurred, the computed discharges are not reliable.

9.1.7 The reach should be long enough to develop a fall that is well beyond the range of error in the surveying method, in alternative interpretations of the high-water profile, or in uncertainties related to the computation of the velocity head. One suggested criteria is that the fall in the reach should be 0.5 ft (0.15 m) or greater than the velocity head in the reach, or both.

9.2 Cross sections represent the geometry of a reach of channel. For example: section 2 should be typical of the reach from halfway upstream to section 1 to halfway downstream to section 3. A minimum of three cross sections is highly recommended.

9.2.1 Locate cross sections at major breaks in the high-water profiles. To do so, the high-water marks should be plotted in the field, and a profile for each bank drawn before sections are located and surveyed. Several high-water marks near the ends of the sections are desirable to define the high-water elevations at these points.

9.3 The roughness coefficient, n , is assigned to a cross section or to subdivisions of a section, but the n selected should represent conditions in the partial reach for which the section is typical. Several factors affect the selection of an n value for a channel. The most important factors are the type and size of the materials that compose the bed and banks of a channel and the shape of the channel. Techniques of determining values of

Number of cross sections	
2	$Q=K_2\sqrt{\dfrac{\Delta h}{\dfrac{K_2}{K_1}L+\dfrac{K_2^2}{2gA_2^2}\left[-\alpha_1\left(\dfrac{A_2}{A_1}\right)^2(1-k)+\alpha_2(1-k)\right]}}$
3	$Q=K_3\sqrt{\dfrac{\Delta h}{\dfrac{K_3}{K_2}\left(\dfrac{K_3}{K_1}L_{1\text{-}2}+L_{2\text{-}3}\right)+\dfrac{K_3^2}{2gA_3^2}\left[-\alpha_1\left(\dfrac{A_3}{A_1}\right)^2(1-k_{1\text{-}2})+\alpha_2\left(\dfrac{A_3}{A_2}\right)^2(k_{2\text{-}3}-k_{1\text{-}2})+\alpha_3(1-k_{2\text{-}3})\right]}}$
Multiple (n)	$Q=K_n\sqrt{\dfrac{\Delta h}{A+B}}$, where

$$A=K_n^2\frac{L_{1\text{-}2}}{K_1K_2}+K_n^2\frac{L_{2\text{-}3}}{K_2K_3}+\ldots\frac{K_n^2L_{(n-2)\text{-}(n-1)}}{K_{(n-2)}K_{(n-1)}}+\frac{K_n^2L_{(n-1)\text{-}n}}{K_{(n-1)}K_n}$$

$$B=\frac{K_n^2}{A_n^2 2g}\left[-\alpha_1\left(\frac{A_n}{A_1}\right)^2(1-k_{1\text{-}2})+\alpha_2\left(\frac{A_n}{A_2}\right)^2(k_{2\text{-}3}-k_{1\text{-}2})+\alpha_3\left(\frac{A_n}{A_3}\right)^2(k_{3\text{-}4}-k_{2\text{-}3})+\ldots\right.$$
$$\left.+\alpha_{(n-1)}\left(\frac{A_n}{A_{(n-1)}}\right)^2(k_{(n-1)\text{-}n}-k_{(n-2)\text{-}(n-1)})+\alpha_n(1-k_{(n-1)\text{-}n})\right].$$

FIG. 3 Discharge Equations for Use in Slope-Area Measurements

n are given in most texts on hydraulics. One particularly helpful reference uses photographs and descriptive stream channel data to describe values of n.[8] Cowan developed a procedure for estimating the effects of these factors to determine the value of n for a channel.[9] In this procedure, the value of n may be computed by the following:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

where:

n_b = a base value of n for a straight, uniform, smooth channel in natural materials,
n_1 = a value added to correct for the effect of channel-bed irregularities,
n_2 = a value for variations in shape and size of the channel cross section,
n_3 = a value for obstructions,
n_4 = a value for vegetation and flow conditions, and
m = a correction factor for channel meanders.

9.3.1 The n-value is determined by first selecting a base value for a straight, uniformly shaped channel reach with existing bed material forming the wetted perimeter and then adjusting it for other conditions influencing the flow.

9.3.2 Bank irregularities might add as much as 0.020 to the base n. Gradual changes have a minimal effect on n.

9.3.3 Vegetation may cause an increase in n of as much as 0.040 depending upon the percentage of the cross section occupied by the vegetation, its type and density, and height of growth in relation to depth of flow.

9.3.4 Depth of flow usually does not affect the base value of n. For streams with cobble or boulder beds, n may decrease with an increase in stage if the bank roughness is less than that of the bed.

9.3.5 Obstructions such as irregularly spaced or isolated boulders will retard the flow more than ones fairly uniformly distributed, hence a higher value of n is implied.

9.3.6 Curves and bends in a channel probably increase n less than 0.003 unless they are sharp ones. Sharp bends should be avoided.

9.3.7 Flow characteristics in meandering flow situations change abruptly when overbank flows cross the meanders and follow the general direction of the valley. The value of n is subject to large increases, depending on intervening overbank conditions. According to Chow,[10] meanders can increase n values as much as 30 % where flow is totally confined within a channel.

9.3.8 *For Example*—The range in the base n for a stream with a clean gravel bed is 0.028 to 0.035. Assuming a value of 0.030 for this example, 0.003 is added because of bank irregularities, 0.010 is added to account for vegetation in the channel, and nothing is added because the channel alignment is almost straight and the depth of flow has no effect. The n value used is 0.043.

9.3.9 When two or more field personnel select n values, the values should never be arbitrarily averaged. Discussion of the bases for each one's selection should be held in the field and a consensus value agreed upon.

10. Computations

10.1 A number of computations must be performed manually before the data are ready for input to a computer program or for continuing with manual computations. Computations to three significant figures are all that are warranted in this test method. Discharge computations for use in slope-area measurements are given in Fig. 3.

10.1.1 After the field notes are checked, the plan view (see Fig. 4) and cross-sections (see Fig. 5) plotted, the profiles

[8] Barnes, H. H., Jr., "Roughness Characteristics of Natural Streams," *U.S. Geological Survey Water Supply Paper 1849*, 1967.

[9] Cowan, W. L., "Estimating Hydraulic Roughness Coefficients," *Agricultural Engineering*, July 1956, pp. 473-475.

[10] Chow, V. T., *Open Channel Hydraulics*, McGraw-Hill, 1959, pp. 108–109.

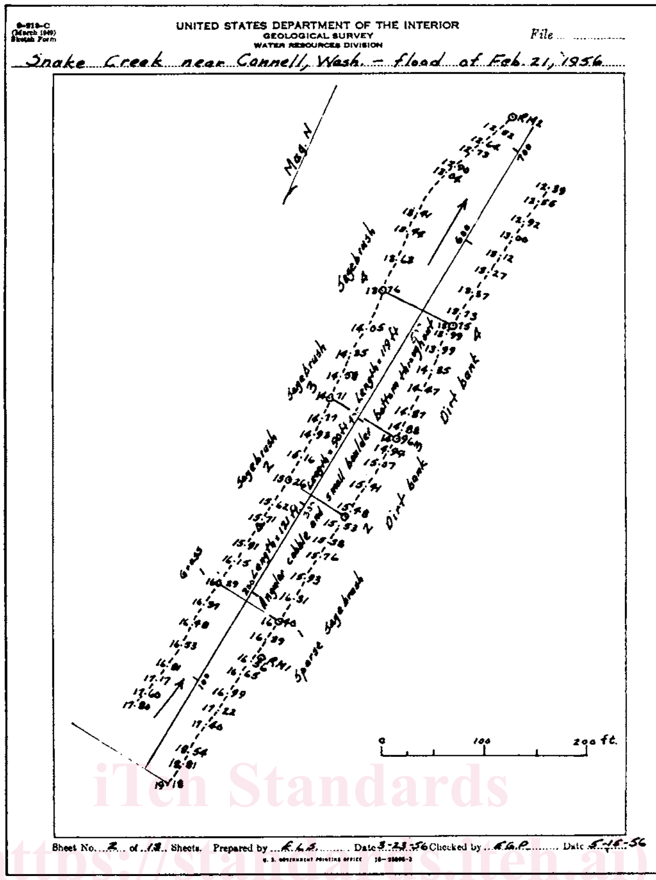

FIG. 4 Sample Slope-Area Computation, Plan View of Reach

drawn (see Fig. 6), and the cross-sections located thereon, the fall, Δ *h*, between cross-sections is computed. The water-surface elevations are determined by averaging elevations for both banks at each cross section. The upstream average elevation minus the downstream average elevation is the fall within the reach. Computations of fall are shown on a profile sheet.

10.1.2 The length of the reach between cross sections is computed from the stationing of the ends of the sections or by scaling the length on the plan provided the channel is straight or nearly so. If the channel is curving and of nearly uniform depths, measure the length on the curved line along the center of the channel. Where the main channel is closer to the outside of the curve, use the length along the center of the deep channel. Computations of length should also be shown on a profile sheet.

10.2 Manual computation of discharge is neither efficient nor economical. However, thorough knowledge of manual computation techniques will give the user added insight into the interrelationships of the various factors and a good basis for a reliable evaluation of computer output.

10.2.1 Computations of cross-section properties—area, wetted perimeter, hydraulic radius, conveyance, and the velocity-head coefficient—can be standardized by using forms similar to those in Fig. 7.

10.2.1.1 The area of a cross section is computed by the mean-section method to facilitate computer computations. This test method uses partial sections having an area equal to the mean of two adjacent depths multiplied by the horizontal distance between them. See Fig. 8.

10.2.1.2 The summation of the areas for all of the partial sections is the total area of the cross section.

10.2.1.3 The wetted perimeter or slope distance between two ground points is computed as the hypotenuse of a right triangle with sides equal to the distance between stations and the difference in bed elevations. For example: the wetted perimeter between stations 11 and 12 of section 2 in Fig. 7 is the square root of the sum of the squares of (12-11) and (14.0-11.6) or $(1^2 + 2.4^2)^{1/2} = (6.76)^{1/2} = 2.6$. It is more convenient to use a table listing the increase of the slope distance over the horizontal distance to compute the wetted perimeter. In Table 1 for the above example, the width of the section is 1 (12-11) and the difference in bottom elevations is 2.4 (14.0-11.6), the increase in slope distance over horizontal distance is 1.6. The wetted perimeter is therefore (1 + 1.6) or (1 + 2.6).

10.2.1.4 The hydraulic radius, *R*, equals the area divided by the wetted perimeter as shown in Fig. 9.

10.2.1.5 A form similar to that of Fig. 9 expedites the computation of the conveyance, *K*, and the velocity head coefficient *a*. Computations are straightforward as indicated on the form in Fig. 9. To avoid handling very large numbers when computing the factor K^3/a^2 move the decimal point one, two, or three places to the left. In Fig. 9, it was moved two places for