

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Rocky Mountain Research Station

October 2000

Multimedia Training in the Measurement of Stream Discharge

by K. Michael Nolan and Ronald R. Shields

The U. S. Geological Survey (USGS) makes at least 50,000 stream discharge measurements during most years. Over 75% of those measurements are made by wading the stream using the velocity-area method. Other Federal, State and local agencies make an unknown number of additional wading measurements. These measurements are thus a fundamental source of water resources data nationwide.

Goal is to provide cost-effective training on an "as needed" basis

Because wading measurements are such an important activity of the Water Resources Division of the USGS, we chose wading measurements as the subject for the first in a series of CD-ROM based multimedia training classes (Figure 1). The USGS goal is to provide interesting and informative training materials that could be used on an "as needed" basis in offices around the country. Although this course will provide a strong training foundation, we caution that it must be combined with actual field work and some "on-the-job" training to be completely effective.

This training course is available as a formal USGS report and is, therefore, available to other agencies responsible for collecting streamflow data. We hope these agencies will be able to use the information contained in the training course to help them collect data using standard USGS procedures. If all agencies collect data using consistent standards, we will improve our ability to assess the Nation's water resources.

CD-ROM is narrated and contains numerous video clips

The training course, which was developed using Microsoft PowerPoint, is narrated and contains numerous MPEG video clips. Users who do not have PowerPoint or the ability to view MPEG videos can take advantage of the PowerPoint Viewer and Microsoft Media Player contained on the CD-ROM. The presentation works best on Windows-based personal computers. Computers must have a sound card and speakers to take advantage of narrations and video sound.

STREAM NOTES is produced quarterly by the Stream Systems Technology Center, Rocky Mountain Research Station, Fort Collins, Colorado. Larry Schmidt, Program Manager

The PRIMARY AIM is to exchange technical ideas and transfer technology among scientists working with wildland stream systems.

CONTRIBUTIONS are voluntary and will be accepted at any time. They should be typewritten, single-spaced, and limited to two pages. Graphics and tables are encouraged. E-Mail: jpotyondy@fs.fed.us

Ideas and opinions expressed are not necessarily Forest Service policy. Citations, reviews, and use of trade names does not constitute endorsement by the USDA Forest Service.

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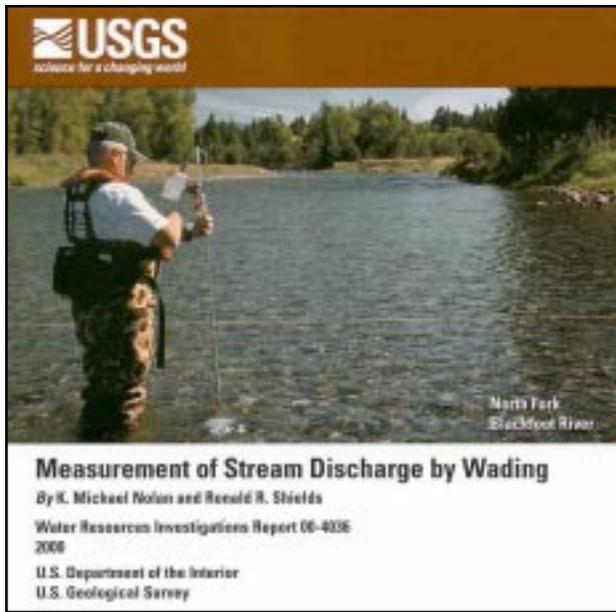


Figure 1. Water Resources Investigations Report 00-4036 in CD-ROM format.

The course contains 106 slides and can be taken at the student's own pace. Most students will take between one and two hours to complete the course. Navigation buttons allow students to move from slide to slide or return to the course agenda from which they can navigate to other parts of the course. Each slide is accompanied by a narration that describes concepts covered by the slide. Figure 2 shows a typical slide. MPEG videos are surrounded by TV-like boxes to alert students that a video is available.



Figure 2. Typical slide from training CD-ROM.

Contains links to reference materials

The course contains numerous links to reference materials contained on the CD. In addition, students can take advantage of multiple links to resources on the World Wide Web when their computers are linked to the Internet (Figure 3).

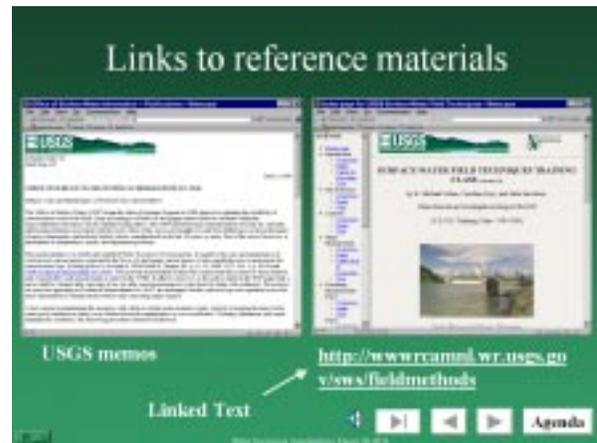


Figure 3. Example of links to World Wide Web Internet resources.

Additional courses planned

This is the first of a series of planned courses. Courses on "Stream Discharge Measurements Under Ice Cover" and "Discharge Measurements from Cableways" are currently under production. Support from the USGS Water Resources Division Safety Committee has been essential to producing these training materials.

The last page of this newsletter contains information about how to obtain a copy of the CD-ROM.

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Solving for Streamflow Without Using Manning's Equation

by John F. Orsborn, PE, and Jeanne Stypula, PE

In the April 2000 issue of *Stream Notes* Douglas J. Trieste asked, "Can no better equation than the Manning equation be developed, or are the concepts and principles used in 1889 still the best today?" (Trieste, 2000). The answers are yes and yes; we just have to apply the principles using different concepts.

In 1768, Chezy completed his calculations for the channel of the new Paris water supply. Chezy was the first to consider the wetted perimeter of channels as an analog of boundary resistance (Rouse and Ince, 1957). Chezy's equation has the form of $V = C R^{1/2} S_c^{1/2}$ that uses a resistance coefficient C , the hydraulic radius ($R=A/P$) and the slope of the channel, S_c . In English units, Chezy's $C = (1.49/n)R^{1/6}$ in Manning's equation, where n is a resistance factor (Roberson, Cassidy and Chaudhry, 1988). Manning's n , when used as a roughness coefficient, should be applied to channels with a uniform surface roughness such as concrete.

The Manning equation requires the estimation of a resistance coefficient n when sizing a channel or estimating a stream flow. There are two ways to avoid using n . The first is to make sufficient discharge measurements at a site so that n can be measured as a function of Q , then written in terms of Q and substituted into Manning's equation. The resistance coefficient, n , varies inversely with Q , so $n = (x/(Q)^y)$ where x and y are the coefficient and exponent determined from the data for n versus Q . But, these calculations also require the measurement of the water surface slope and the calculation of the energy gradient to determine Manning's n . The best stream gaging accuracy is plus or minus 5%.

The second way to eliminate Manning's n is to use two equations. One equation comes from the hydraulic geometry relationships. The other equation describes the shear-shape relations developed by Stypula (1986) and applied to some Oregon coastal streams by Orsborn and Stypula (1987). Usually the

traditional analysis of hydraulic geometry is applied to streams based on the continuity equation: $Q = AV = WDV$; and $W = aQ^b$, $D = cQ^d$ and $V = eQ^f$ where W is the water surface width; D the mean depth; and V the mean velocity (Leopold and Maddock, 1953). We know from Chezy's and Manning's works that V is a function of the hydraulic radius (R), which is the flow area (A) divided by the wetted perimeter (P). Including these two factors in the suite of hydraulic geometry equations, we have $A = gQ^h$ and $P = iQ^j$. Wetted perimeter accounts for two influences; the resistance to flow (shear), and a measure of available habitat for certain life-stages of fish.

Stypula (1986) developed the dimensionless relationships shown in Figure 1 for rectangular channels and natural channels from the sources listed in the legend. The streams are located in Washington, Idaho, Montana, Wyoming, Arizona, Nevada, Vermont, and Alaska. The widths (W) ranged from over 1,500 feet in the Columbia River to 2 inches for erosion rills in the Palouse Hills. Mean depths (D) ranged from 27 feet to 2 inches. The curves can be calculated at any level of flow above which the flow is in a single channel, or for a dry channel. As shown in Figure 1, the natural, non-rectangular channels tend to follow a line defined by

$$W/D = P^2/A - (2+2D/W) \quad (1)$$

until they approach W/D of less than 2. Then they shift to the shear-shape line for rectangular channels defined by

$$W/D = P^2/A - (4 + 4D/W) \quad (2)$$

The P^2/A terms give a positive number from which the factor inside the parentheses can be subtracted to compare with W/D . The P^2/A terms are the same as P/R .



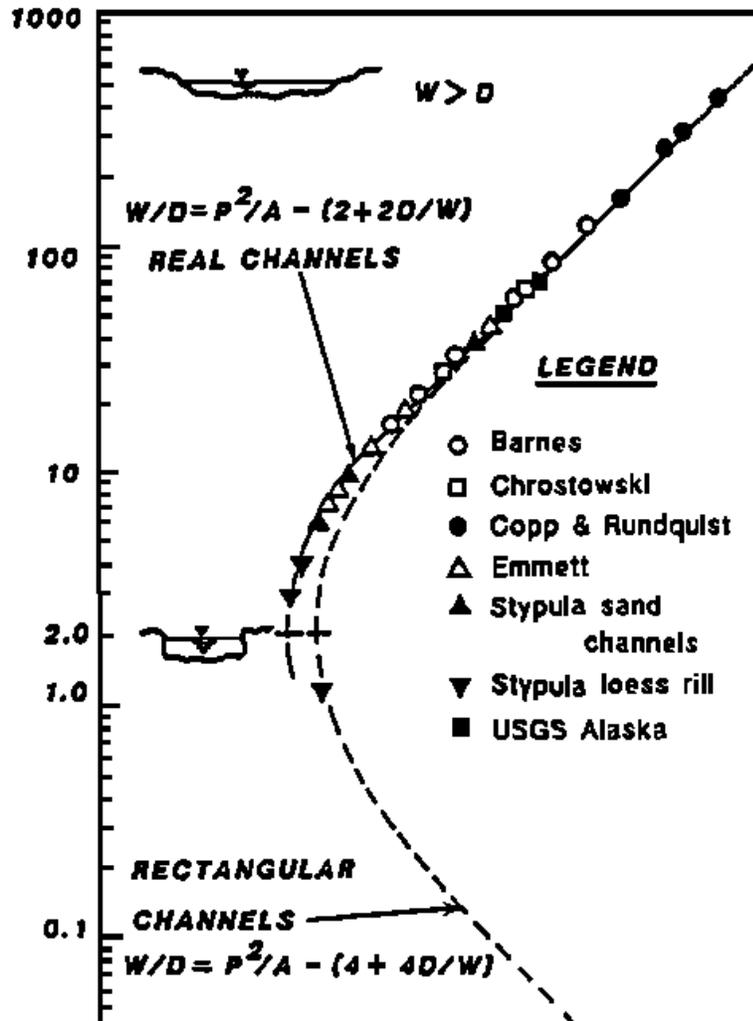


Figure 1. Shear-shape relationships for natural (real) and rectangular stream channels (Stypula 1986).



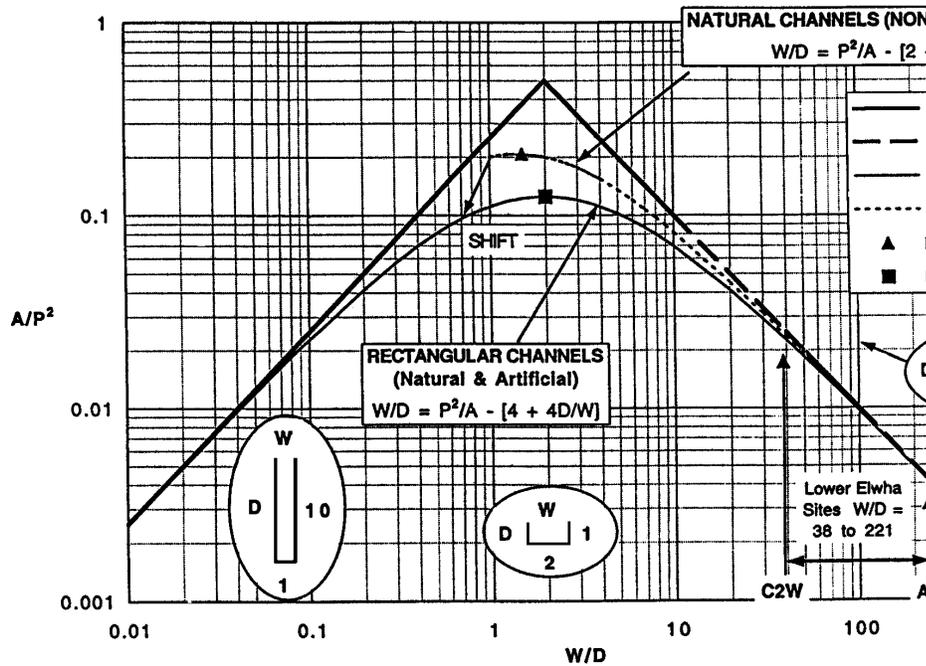


Figure 2. Comprehensive shear-shape relationships (Orsborn and Orsborn 1999).

A more complete analysis of the conditions in Figure 1 is shown in Figure 2, which was developed as part of a low flow study below the dams on the lower Elwha River on the Olympic Peninsula in Washington (Orsborn and Orsborn, 1999). Note that: (1) the lines for non-rectangular channels and rectangular channels coincide when W/D is 40 or more (this is the basis for the “wide” channel assumption used in open channel flow calculations when R approaches D); (2) rectangular channels have a maximum value of A/P^2 at $W/D = 2$, which fits the assumption of hydraulic efficiency when a semicircular radius of $1/2 W$ just fits in a rectangular channel and $W = 2D$; and (3) for natural, non-rectangular channels the maximum value of A/P^2 occurs at $W/D = 1.5$, and beyond that point, all natural channels coincide with rectangular channels because the wetted perimeter (P) dominates the geometric relationships. These narrow channels are hydraulically inefficient, but are good for upstream fish passage (Denil 1937; Ziemer 1962).

To combine the hydraulic geometry with the shear-shape equation, one must merely substitute $W = a(Q)^b$ (or $D = c(Q)^d$) into Eqs. (1) or (2), which gives

$$aQ^b / D = P^2 / A - (2 + 2D/W) \quad (1a)$$

for natural, non-rectangular channels, and

$$W/cQ^d = P^2 / A - (4 + 4D/W) \quad (2a)$$

for both natural and artificial rectangular channels. **And, Manning’s resistance coefficient has been eliminated.**

The variable $-(4 + 4D/W)$ for rectangular channels is easily determined by assigning a depth of 1 ft and various bottom widths from 1 to say 40 ft. For $W = 1$ ft and $D = 1$ ft, $W/D = 1$, $P = 3$ ft, $P^2 = 9$ ft², $A = 1$ ft² and $P^2/A = 9$. The correction variable is $-(4 + 4(1)/1) = 8$, and $W/D = 1$. The natural channel variable, $-(2 + 2D/W)$, was determined for average conditions in numerous cross sections. If a natural,



non-rectangular channel does not fit Eq. 1a, it is probably out of balance (not at grade). For narrower channels, the wetted perimeter (side resistance) becomes dominant and all channels follow the rectangular channel graph in Figure 2. The correction factor $-(4 + 4D/W)$ still holds.

For a planning level investigation at an ungaged stream site, the hydraulic geometry can be measured at a low and an intermediate flow, and graphically projected to bankfull flow. A detailed cross-section at the site will provide the channel geometric characteristics to combine with the two flow measurements and complete the analysis.

Conclusion

We have developed equations for streamflow without Manning's n by combining channel hydraulic geometry and a dimensionless shear-shape relationship of channel characteristics. We have verified the relationships for some Oregon coastal streams (Orsborn and Stypula 1987) and elsewhere in the states covered in Figure 1. The Oregon results given in Table 1 demonstrate some of the benefits of using a morphological approach to find Q .

People have been using Manning's n for such a long time it may be difficult for some to embrace the concept that shape controls flow. Shape is the result of bed and bank material and slope.

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Table 1. Measured and estimated values of average annual flow, width, depth and velocity for Deer, Fall and Flynn Creeks in the Oregon mid-coast region (Orsborn and Stypula 1987).

USGS Number	Gaging Station Name	Average Flow, Q_a (m^3s^{-1})	Top Width (m)	Average Depth (m)	Average Velocity (ms^{-1})
14306300	Deer Creek	0.08			
	Est. eq. (2a) ^a	0.19			
	Est. eq (1a) ^b	0.19			
	Actual sizes ^c		3.26	0.16	0.34
	Est. sizes ^d		3.20	0.17	0.34
14306300	Fall Creek	4.67			
	Est. eq. (2a) ^a	4.14			
	Est. eq (1a) ^b	4.60			
	Actual sizes ^c		15.16	0.46	0.67
	Est. sizes ^d		16.20	0.50	0.58
14306800	Flynn Creek	0.12			
	Est. eq. (2a) ^a	0.18			
	Est. eq (1a) ^b	0.14			
	Actual sizes ^c		3.14	0.13	0.30
	Est. sizes ^d		2.60	0.14	0.32

NOTES:

- ^a Assumes $P = W + 2D$, rectangular section.
- ^b Assumes $P = W + D$ in natural channels, and $P = W$ for Flynn Creek.
- ^c Actual sizes are based on hydraulic geometry at the gaging stations.
- ^d Estimated from equations for W , D and V based on Q_a of record at 10 Regional USGS gaging stations.

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October 2000

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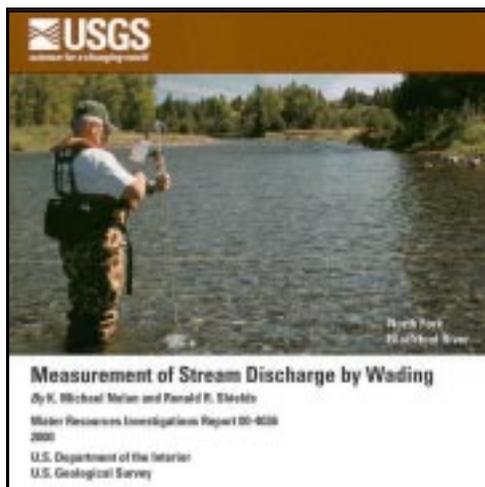


How to Obtain a Copy of the CD

The Stream Systems Technology Center believes that everyone making streamflow measurements on the National Forests should have the benefit of this useful training aid. Accordingly, STREAM has worked with the USGS to produce a special edition of Water Resources Investigations Report 00-4036.

Readers desiring a copy of the CD should direct an e-mail to K. Michael Nolan at the U.S. Geological Survey (kmnolan@usgs.gov).

Note: The Stream Systems Technology Center has mailed a copy of the CD to each National Forest. Forest Service personnel may request additional copies from STREAM. Send e-mail request to pswilliams01.fs.fed.us or a FAX to STREAM at (970) 295-5988 and include your mailing address.



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