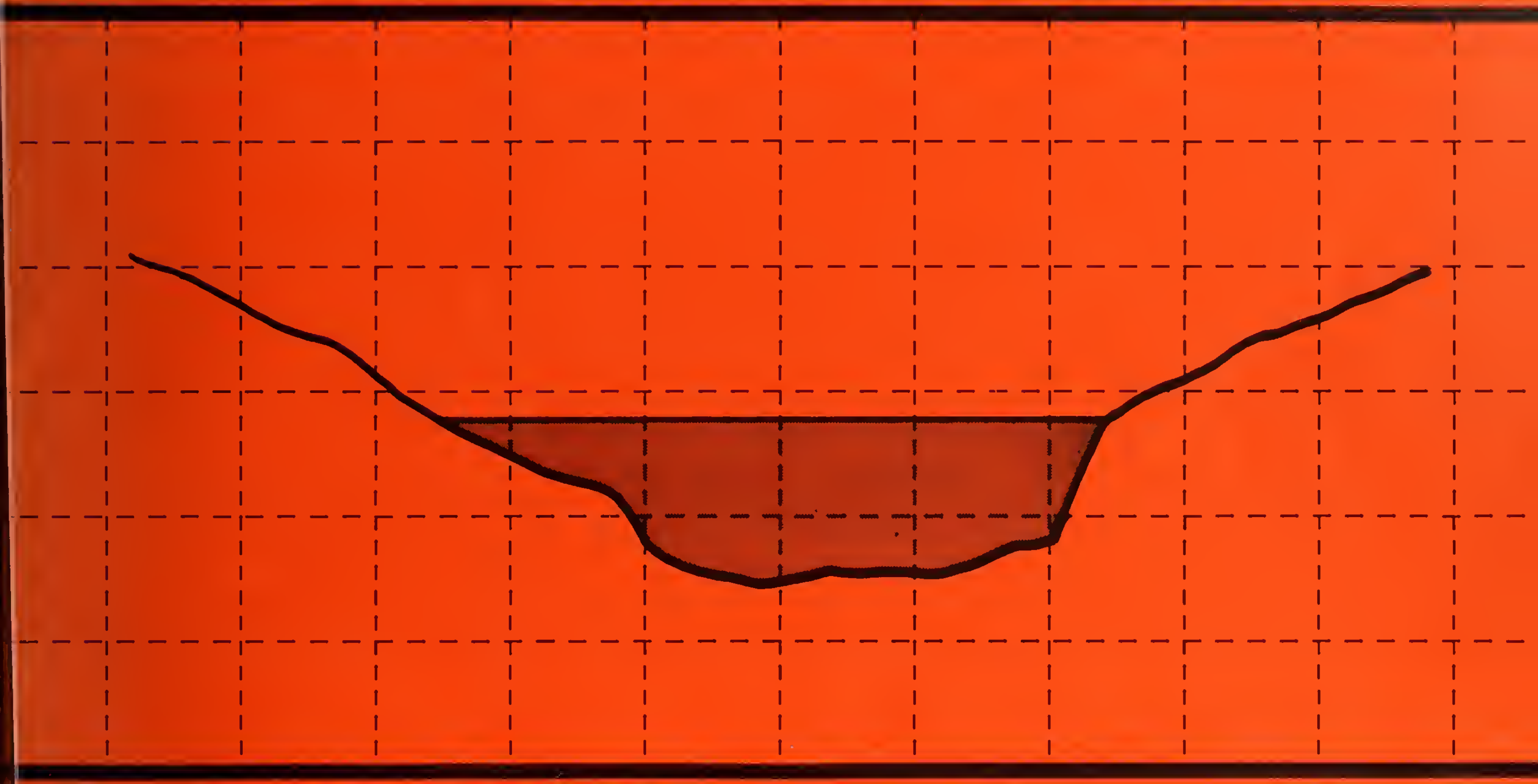
Channel Cross Section Surveys and Data Analysis



By

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CHANL and MCHANL (metric version) are computer programs which reduce and analyze stream channel cross-section survey data collected by either a rod and level survey or a sag tape survey. Data may be entered from the keyboard or a file. Cross sections are plotted on x-y coordinates and discharge rating curves are developed using Manning's equation given a user-supplied value for Manning's "n". Output tables include values for average flow velocity (for each discharge increment), cross-section area, wetted perimeter, and hydraulic radius. Access CHANL or MCHANL on the BLM Honeywell DPS-8 by typing

A403/CHANL or A403/MCHANL.

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Stream Channel Cross Section Surveys and Data Analysis

A Handbook for Using the CHANL and MCHANL Computer Programs and Gathering the Necessary Field Data

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Symbols

A = Cross sectional area (ft^2 or m^2)
$\bar{d}$ = hydraulic or mean depth (ft or m)
$D_{84}(D_{75}, D_{90})$ = The intermediate particle diameter which is greater than or equal to 84 percent (75 or 90 percent) of the particles in stream bed. (in., ft., mm. or m. specified in text)
E = Difference in tape and elevation (ft or m).
Fr = Froude number = $V/(gR)^{1/2}$ (dimensionless).
g = acceleration due to gravity (ft/sec^2 or m/sec^2)
ΔH = difference in water surface elevation along a longitudinal transect. (ft or m)
L = length of survey transect over which H is measured (ft or m)
L_i = Distance along tape from zero stake to location of vertical (ft or m).
L_t = Total length of tape (ft or m).
n = Mannings roughness coefficient (approximately dimensionless).
P = Wetted perimeter (ft or m).
Q = Water discharge (ft^3/sec or m^3/sec).
R = Hydraulic radius = A/P (ft or m).
S = Water surface gradient (dimensionless).
S_f = Gradient of friction energy loss (dimensionless)
T = Width of flow (ft or m).
V = Mean velocity of water (ft/sec or m/sec).
X_i = Distance from zero point to ith point along horizontal axis (ft or m).
Y_i = Distance of the ith point above lowest (surveyed) point in channel (ft or m).

Introduction

Channel geometry surveys provide data for hydrologists, fishery biologists, geomorphologists, engineers, and others to use in computing stream flow, describing instream-flow regimes, monitoring stream channel processes, and providing information on riparian habitats. This handbook will present some existing methods of reducing channel geometry survey data and will introduce two interactive FORTRAN programs, readily available to BLM personnel, that will expedite channel geometric and hydraulic parameter computation.

Survey data from channel cross sections are usually paired horizontal and vertical measurements. There are several methods to obtain this data. The traditional method is with an engineer's level and rod.

The U.S. Forest Service developed sag tape survey methods that correct for the sagging shape (catenary) of a survey tape which occurs when a survey tape is suspended between two stakes. The measured distance between the tape and the ground can then be converted to an elevation above an arbitrary datum (Ray and Megahan, 1979). The Forest Service computer programs are written for batch execution which reduces opportunities to use an iterative approach to problem solving. Two programs modeled after the Forest Service procedures have been developed for the BLM Honeywell DPS-8 computer. The programs are interactive and prompt the user to supply information as it is needed, either to make a computation or to select an option.

Program Description

Survey Data Transformation

The programs, CHANL and MCHANL, perform two basic functions. The programs correct sag tape or rod and level survey data for uneven tape end elevations, tape physical characteristics, and tape sag. After the correction is made, the vertical measurements along the perimeter are converted to points in an X-Y coordinate system in which X equals zero at the zero stake and Y equals zero at the lowest point of the cross section. The location of the channel perimeter at each vertical is defined in this coordinate system. Once the survey data have been converted to Cartesian coordinates, the data can be plotted.

The second part of the programs uses the channel geometry, defined in the first part, along with the gradient and hydraulic roughness (n) of the reach, to compute velocity, discharge, cross sectional area, hydraulic radius, wetted perimeter, mean depth and top width at a given depth of water. Velocity is computed using Manning's equation. Discharge is the product of cross sectional area and velocity. Cross sectional area, wetted perimeter, hydraulic radius, mean depth and top width are computed from the geometry of the channel and the height of the water surface.

The programs have identical form, but differ only in their units. CHANL uses English units of pounds-feet-seconds and MCHANL uses metric units of kilograms-meters-seconds.

Both programs, MCHANL and CHANL, begin by prompting the user for the survey type and how the data will be entered for analysis. In both the sag tape survey and the rod and level survey, data is loaded into matrices. After loading, the horizontal and vertical distance components are corrected as warranted by the survey type.

Rod and level survey data are converted to a set of horizontal distances and elevations relative to a benchmark, without correcting for tape sag. The program was designed to analyze a transect configuration similar to that in Figure 1, but in which the vertical measurement is a foresight. The program corrects for the uneven tape end elevation, then searches the foresight values in the matrix. It locates the largest one, i.e., the lowest point on the cross section and assigns it an elevation of zero. All other elevations are calculated relative to this zero point by subtracting the foresight reading, at each distance, from the foresight value at the zero point. The corrected distance and elevation pairs are stored in another matrix. The geometric calculations use the corrected values. Figure 2 contains the correction formula and a plot of the correction factor for rod and level surveys with uneven stakes.

Correcting sag tape surveys requires more complicated formulae than rod and level surveys. The correction for sag tape surveys requires the tape end elevation difference, the tape weight per unit length, tape tension, and overall tape length (Figure 3). These formulae describe the tape's catenary curve.

In a sag tape survey, the distance from the tape to the channel perimeter is measured repeatedly at intervals along the tape and is referred to as depth. The sag tape survey points are converted to points in a Cartesian (X-Y) coordinate system. This is explained in some detail in Ray and Megahan (1979). As with the rod and level survey, the corrected values are stored in a matrix prior to the geometric calculations.

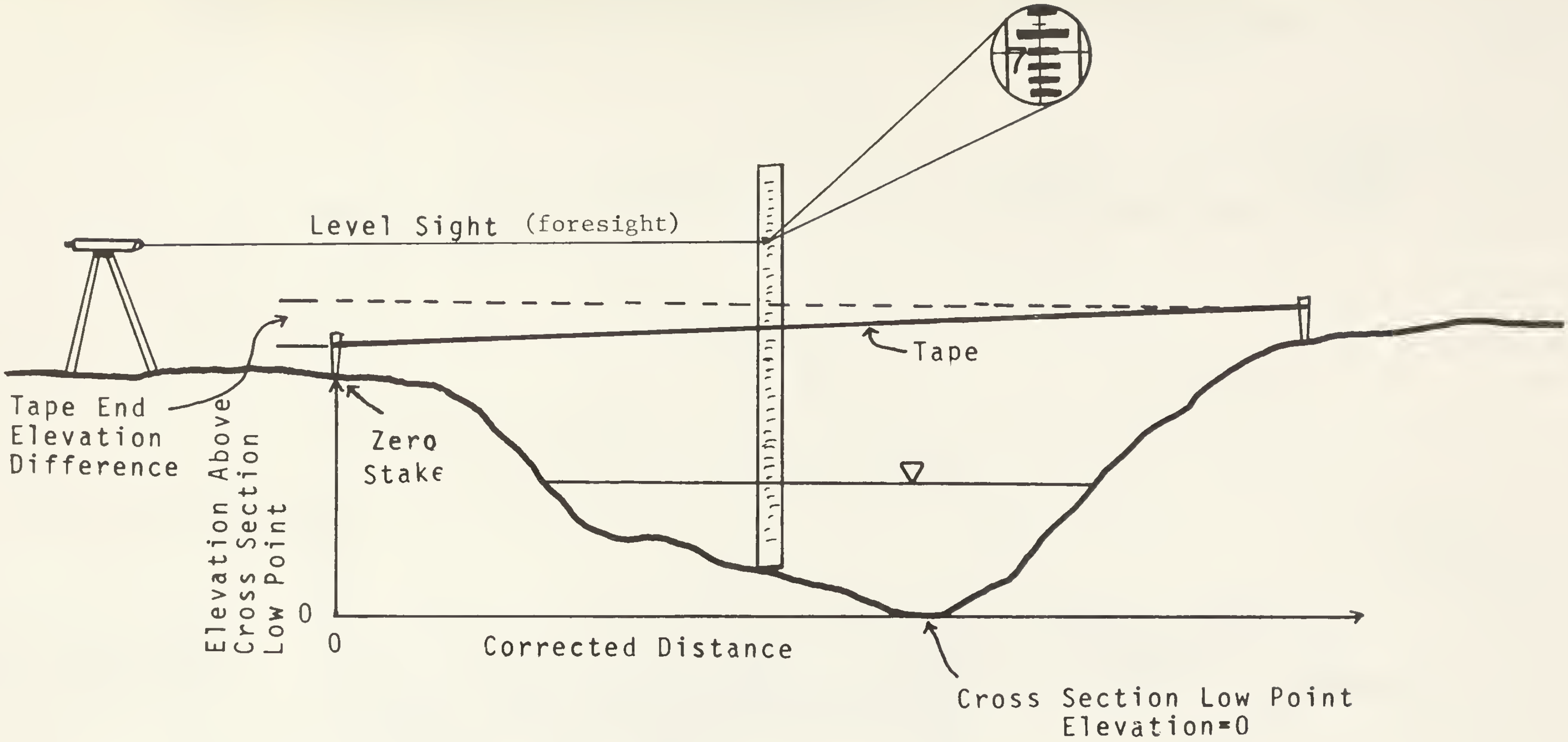


Figure 1: Configuration of rod and level survey.

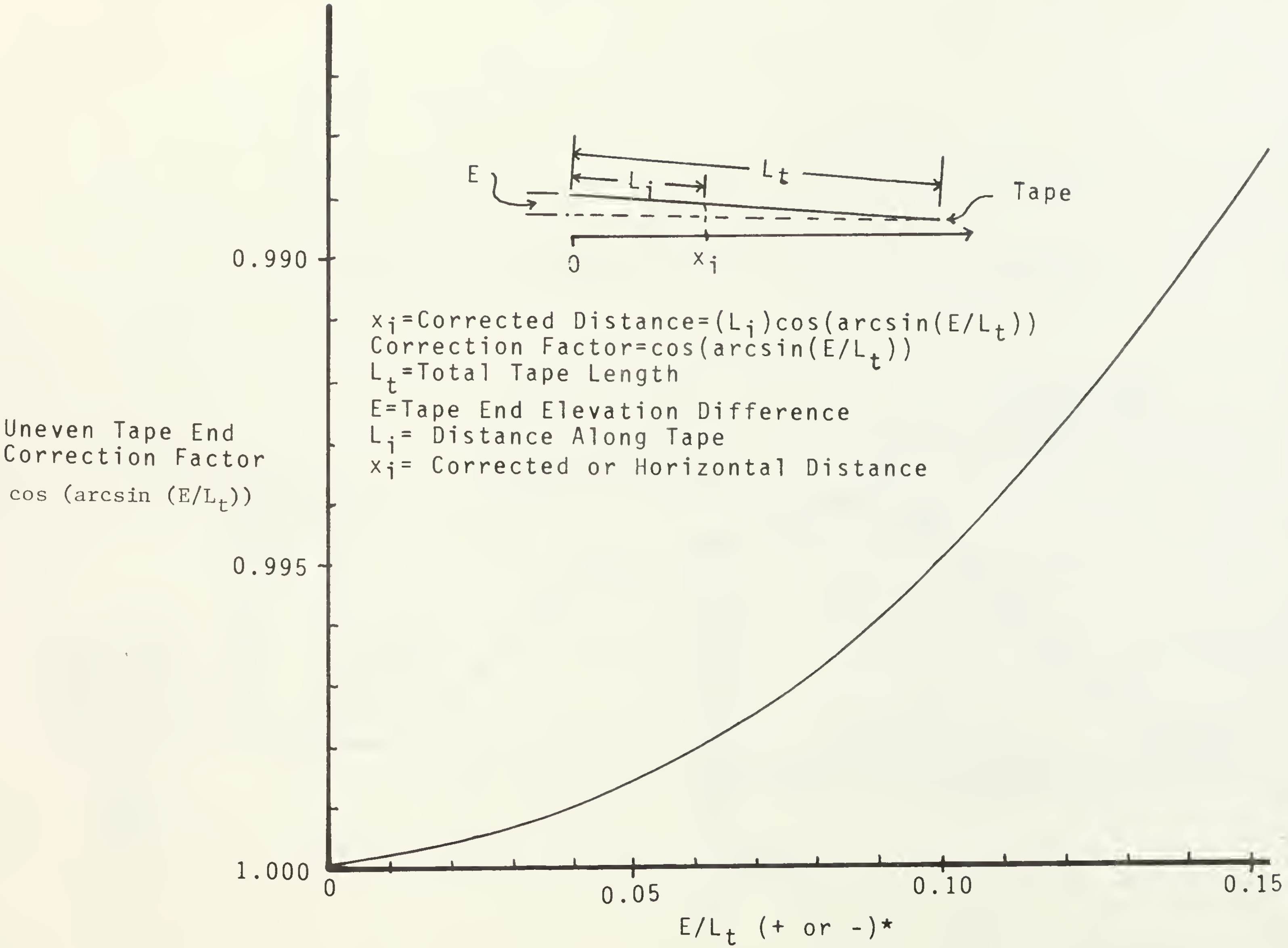
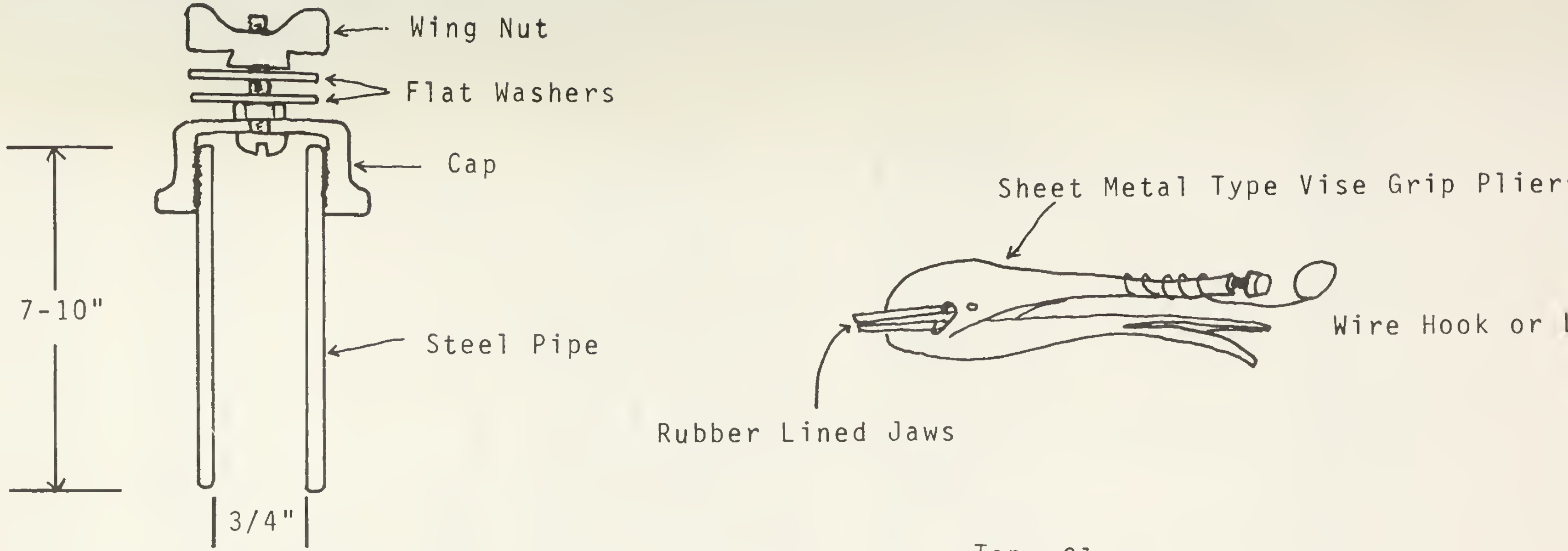


Figure 2: Correction factor for uneven tape ends during a rod and level survey, and explanatory diagram.

* Correction Factor is unaffected by sign of E/L_t.



End Stake Tape Attachment

Tape Clamp

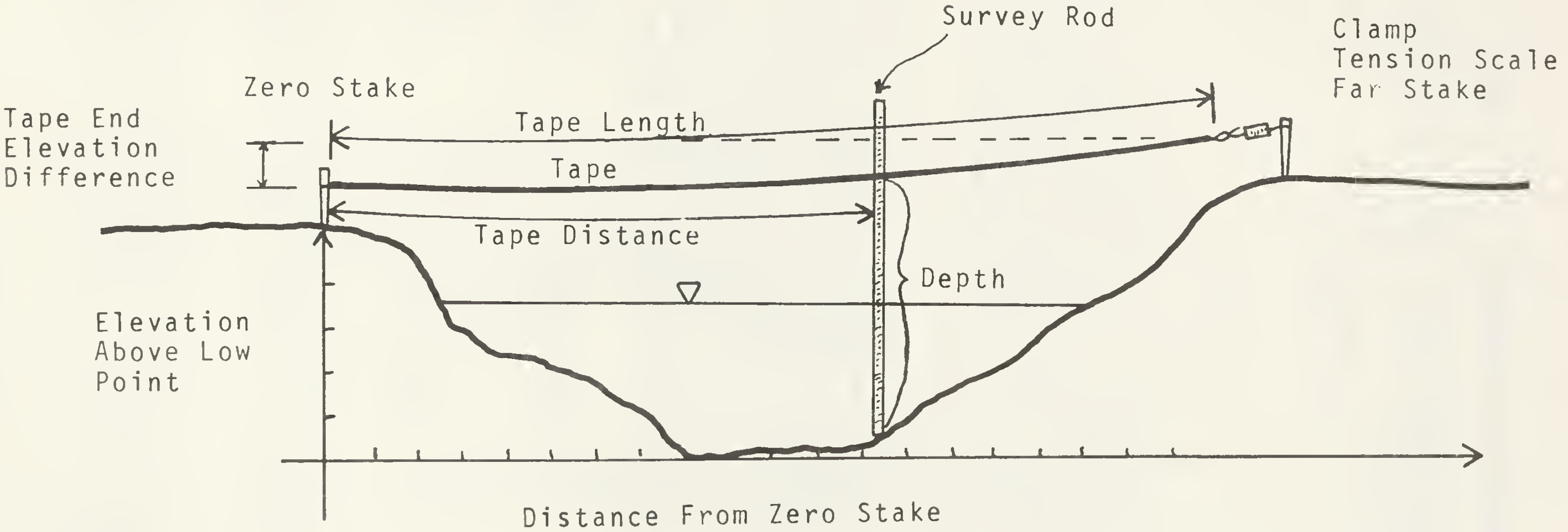


Figure 3: Configuration for sag tape survey and definition of terms.

Hydraulic and Geometric Computations

The hydraulic computations are similar to those used in the Single Transect Method (USDI 1979). The basis of the Single Transect Method is the Manning Equation:

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

or

$$Q = \frac{A\ S^{1/2}\ R^{2/3}}{n} \qquad \text{(Metric Units)}$$

where Q is discharge (L^3/time); A, the cross sectional area (L^2); S_f, the gradient of friction energy loss (dimensionless); R, the hydraulic radius (equal to cross sectional area divided by wetted perimeter, L); and n, the Manning's roughness coefficient (dimensionless). CHANL and MCHANL calculate discharge, Q, using Manning's equation. The equation's geometric components (A and R) are calculated from the corrected survey information, after a water depth is supplied.

The cross sectional area, A, is calculated by summing the areas of the rectangles and triangles created when a water surface elevation is superimposed on the cross section (Figure 4). The wetted perimeter, P, is determined by calculating the distances between adjacent survey points along the channel bottom, and summing (Figure 4). The hydraulic radius R, is equal to A/P. The water surface gradient, S, which is often used in place of the friction slope, and the roughness coefficient, n, are supplied by the user. The Field Procedures and Theory Section discusses several methods to determine S and n. Mean velocity, V, is computed with another form of Manning's Equation:

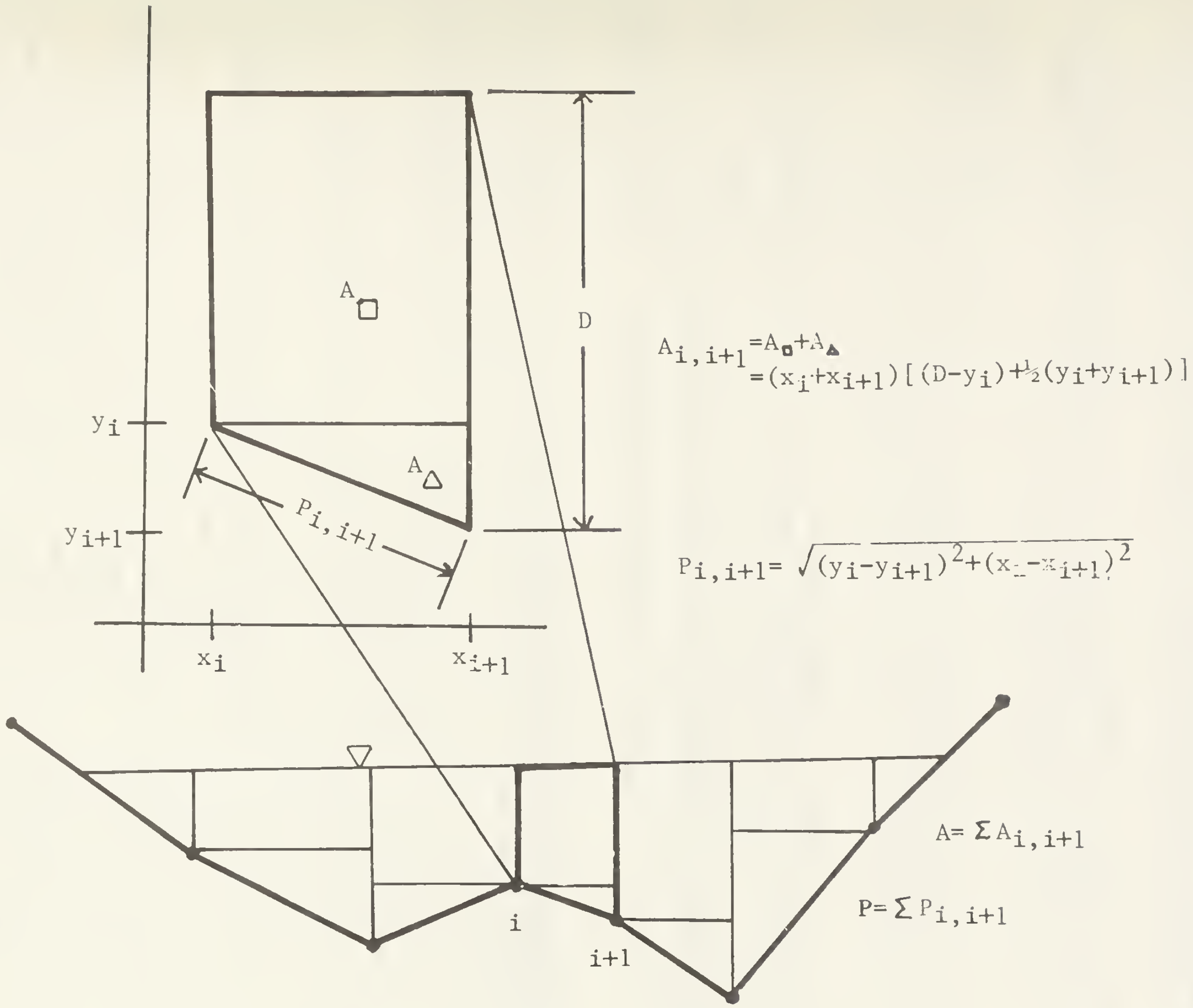
$$V = \frac{1.486\ R^{2/3}\ S^{1/2}}{n} \qquad \text{(English Units)}$$

or

$$V = \frac{R^{2/3}\ S^{1/2}}{n} \qquad \text{(Metric Units)}$$

Manning's equation is applicable to uniform flow conditions. It should not be used for stream reaches with surface discontinuities (e.g., those with waterfalls or channel steps) or in channels with rapidly changing depth or width.

The field form (Appendix A) can be used when data are gathered and also in the office when CHANL or MCHANL is run. The order of the field form data entries is approximately the same order as the interactive program requires them. The field form also provides space to record the computer file name.



$$A_{i,i+1} = A_{\square} + A_{\triangle}$$
$$= (x_i + x_{i+1})[(D - y_i) + \tfrac{1}{2}(y_i + y_{i+1})]$$

$$P_{i,i+1} = \sqrt{(y_i - y_{i+1})^2 + (x_i - x_{i+1})^2}$$

$$A = \Sigma A_{i,i+1}$$

$$P = \Sigma P_{i,i+1}$$

Figure 4: Geometry and equations used to calculate area, A and wetted perimeter, P of surveyed cross section.

Interactive Program Operation

CHANL and MCHANL are interactive, allowing the user to make repeated runs and computations. The programs will read data from a file (usually used with detailed or large cross section surveys) or smaller amounts may be entered from the keyboard. It is easy to re-run a cross section with different hydraulic parameters. In many BLM applications, the hydraulic information for a cross section is limited. Using an iterative approach may allow estimation of parameters, such as Manning's n, without extensive field work.

CHANL and MCHANL prompts are designed to be as self explanatory as possible. The nomenclature is restricted to hydrologic and aquatic biology vocabularies. The user must have a UMC (User Master Catalog) or user number and be able to log on to the BLM Honeywell DPS-8 computer.

The CHANL program uses the English units of feet-pounds-seconds. MCHANL uses the metric units of meters-kilograms(force)-seconds. Neither program has the capability of converting units, so all input data must be consistent with the program used. The procedure to call and run the programs is identical.

To call and run one of these programs, you must log-on to the BLM Honeywell DPS-8. After several lines of preliminary information, you will receive an asterisk (*) prompt. After that prompt, enter:

A403/MCHANL (carriage return, CR) or A403/CHANL (CR).

This will be followed by a heading telling the program name. The first prompt is:

```
ARE THE DATA FROM SAG TAPE OR ROD AND LEVEL SURVEY?
SAG TAPE-0, ROD AND LEVEL-1
=0
```

The prompt for your response is an equals sign (=). Enter your response (0 or 1), then a carriage return. The next prompt is:

```
WAS THE LEFT OR THE RIGHT STAKE THE X-SECTION ZERO POINT?  LEFT-0, RIGHT-1
=1
```

This response plays no part in the computations, but may be useful for results interpretation or as a record of the sag tape survey.

If your response to the survey options was sag tape, the next prompts solicit input of the parameters of the survey tape arrangement. The equations that correct for the sag in the tape (Ray and Megahan, 1979) require the tape end elevation difference, the tape tension, the weight per unit length of the tape, and the total tape length (Figure 3). The tape end elevation difference should be determined to the nearest centimeter (.01m) or 0.03 foot. The tape weight per unit length should be known to the nearest 0.001kg/m or 0.002 pound/ft. The tape weight may be determined by accurately weighing a known length of the tape that has been removed from its case. The weight per unit length is then determined by dividing the weight of the tape section by its length. Tape tension should be measured to the nearest 0.25 kg or the nearest 0.5 pound. The tension is measured using a tape tension scale. The stake to stake distance should be determined to the nearest 0.01m or 0.1 foot. The prompts for this information are:

```
ENTER ELEVATION DIFFERENCE IN METERS, IF THE ZERO STAKE IS HIGHER, ENTER
DIFFERENCE AS A NEGATIVE, IF STAKE ELEVATIONS ARE EQUAL, ENTER 0.
=-.065

ENTER TAPE WT. (KGS/METER).
=.00832

ENTER TAPE TENSION (KGS).
=10.25

ENTER STAKE TO STAKE DISTANCE.(METERS)
=30.1
```

Following this is a statement verifying the above data and an opportunity to correct any errors.

```
VERIFY:  TAPE WT IS 0.0083 KGS/METER, TAPE TENSION IS 10.25 KGS, ELEVATION
DIFFERENCE IS -.065 METERS AND STAKE TO STAKE DISTANCE IS 30.10 METERS.

ARE THE ABOVE DATA CORRECT?  YES-0, NO-1
=0
```

A "no" response to this prompt returns the user to the program beginning to re-enter the correct data values. The new data values replace the original, erroneous entries. Elevation difference between tape ends should be measured between the clamp at the far stake and the elevation of the tape at the zero stake (Figure 3).

If the survey option was rod and level, the tape is assumed to be without sag. The prompts soliciting tape weight per unit length and tape tension are omitted for rod and level surveys. These tape parameters are most important in making the vertical correction of the sag tape survey. If the survey tape is put under a reasonable tension, the horizontal distance will not be far off. A tape end elevation difference of 5 feet (1.5m) in a 100 foot (30.5m) length produces less than 0.125 ft. (0.038m) error in horizontal distance. Tape tension should be at least 20 lbs (9.1 kg) and the tape end elevation difference should be less than 0.5 ft per 100 feet (0.15m per 30.5m) of tape.

At this point, details of the survey parameters are complete. The next prompts identify the number of measurements made and how the data will be entered.

```
ENTER NUMBER OF X-SECTION VERTICALS, INCLUDING ENDS.
=65
WILL THE 65 PAIRS BE ENTERED
VIA THE TERMINAL OR VIA A FILE?
TERMINAL-0, FILE-1
=1
WHAT IS THE CATALOG FILE STRING (FILE NAME) OF THE FILE THE DATA ARE COMING
FROM?  BE SURE TO ENTER THE UMC IF IT IS DIFFERENT FROM THIS ONE AND
SUBCATALOGS IF THERE ARE ANY.
=DATA
```

In this example, "DATA" is the name of a file. The number of verticals must be entered accurately. If the number entered is too low, only that number of verticals will be corrected. Any remaining entries will be ignored. If the number entered is too large, an error messages is written stating the number of records in the file and the program ends.

If data are entered from the keyboard, the prompt is:

```
ENTER X-SECTION MEASUREMENTS.

ENTER DISTANCE, DEPTH  1
=3.6, 1.25
ENTER DISTANCE, DEPTH  2
=5.2,1.41
ENTER DISTANCE, DEPTH  3
=6.3, 1.55
```

(Indicates the beginning of data entry. Your entries follow the equal sign.)

"ENTER DISTANCE, DEPTH" will repeat for each vertical. Data entries are in free format, which means entries for distance and depth (or foresight for rod and level survey) need only be separated by a comma or a space. Values may be entered with as many significant digits as desired. There must be one line for each vertical measured. It is recommended that data be stored on a file if there are a large number of vertical measurements (i.e., lines) or if the analysis requires repeated computations on the same cross section. The keyboard entry option is useful for entering cross sections with small numbers of measurements, such as channels or canals having simple geometries.

The correction algorithms for sag tape surveys and rod and level surveys are different. Ray and Megahan (1979), contains an explanation of the correction procedure for sagging tape. Both correction procedures: 1) convert tape distances and relative elevations to an arbitrary, rectangular coordinate system; 2) determine the location of the cross section low point; and 3) convert all locations from the arbitrary coordinates to a coordinate system in which the horizontal distance is relative to the zero stake and elevation is relative to the lowest point on the cross section.

At this point, the field data reduction is complete and the corrected values are stored. A table is printed containing the uncorrected and corrected values:

ENTRY	TAPE DIST	FORESIGHT OR VERTICAL DIST	CORRECTED HORIZONTAL DIST	ELEV. ABOVE X-SECT LOW PT	
1	0.	0.	0.	2.750	
2	0.500	0.250	0.499	2.500	
3	1.000	0.750	0.999	2.000	
4	1.500	1.500	1.498	1.250	
5	2.000	2.000	1.997	0.750	
6	2.750	2.500	2.747	0.250	
7	3.000	2.750	2.996	0.	(Low Point)
8	3.500	2.500	3.496	0.250	
9	4.000	2.000	3.995	0.750	
10	4.500	1.500	4.494	1.250	
11	5.000	1.750	4.994	1.000	
12	5.500	2.250	5.493	0.500	
13	5.750	2.500	5.743	0.250	
14	6.500	2.250	6.492	0.500	
15	7.000	1.500	6.991	1.250	
16	7.750	1.000	7.740	1.750	
17	8.500	0.750	8.489	2.000	

Note, a "0." is entered in the "ELEV ABOVE X-SECT LOW PT" column at the low point. Stage refers to meters or feet of water above this point. Plotting the corrected coordinates produces a cross section diagram of the survey site. You will have the option to plot the channel after calculations for the last stage have been completed. The cross section has now been defined and hydraulic geometry relationships may be computed. Cross section hydraulic relationships may be defined if the reach gradient, S, and the roughness coefficient, n, are known. Procedures for determining these parameters will be discussed later.

The first program option is calculation of a rating table:

```
DO YOU WISH TO GENERATE A RATING TABLE FOR THIS X-SECTION?  YES-0, NO-1
=0
```

If the response is yes, a table containing fifteen stages between user defined limits and six hydraulic parameters at each stage will be generated. The parameters are discharge (L^3/s), velocity (L/s), cross sectional area (L^2), wetted perimeter (L), hydraulic radius (L), and top width (L). Three entries must be made to permit these computations:

```
ENTER GRADIENT OF REACH (METERS/METER).
=.0066
ENTER MANNINGS 'N' VALUE FOR THIS STAGE
=.035
THE RATING TABLE CONTAINS THE DISCHARGE AND HYDRAULIC PARAMETERS AT 15 STAGES
BETWEEN LIMITS SET BY THE USER.  WHAT ARE THE MINIMUM AND MAXIMUM STAGES OF
THE RATING?  MIN,MAX
=.0001, .4900
```

The value of MIN must be greater than zero and the value of MAX must be less than the lower of the two end stakes. If a value for MAX, greater than one of the end stake elevations, is entered the warning:

```
STAGE CHOSEN EXCEEDS STAGE OF ONE OR BOTH
END STAKES.  TRY A LOWER STAGE.
=.0001, .474
```

will be printed. You must enter both the minimum and maximum stages again. In the above example, the lower end stake elevation was 0.475 meters (not shown).

The rating table carries three decimal places to accommodate precise surveys of small channels. An example of a rating table appears in Table 1.

Table 1. Stream stage-discharge rating table

STAGE	DISCH	VEL	X-SECT AREA	WETTED PERIM	HYDR RADIUS	TOP WIDTH
0.000	0.000	0.003	0.000	0.001	0.000	0.001
0.034	0.001	0.112	0.010	0.959	0.011	0.942
0.068	0.013	0.226	0.057	1.882	0.030	1.839
0.102	0.041	0.300	0.137	2.947	0.046	2.868
0.135	0.083	0.302	0.274	5.829	0.047	5.690
0.169	0.174	0.321	0.543	10.546	0.051	10.319
0.203	0.366	0.379	0.966	14.660	0.066	14.357
0.237	0.678	0.453	1.499	17.412	0.086	17.043
0.271	1.085	0.512	2.118	20.416	0.104	20.004
0.305	1.662	0.589	2.822	22.087	0.128	21.657
0.339	2.364	0.660	3.580	23.602	0.152	23.157
0.372	3.220	0.735	4.383	24.612	0.178	24.151
0.406	4.183	0.801	5.220	25.732	0.203	25.250
0.440	5.296	0.870	6.088	26.535	0.229	26.042
0.474	6.497	0.928	6.997	27.658	0.253	27.157

This example covers a range of flows from about zero to bankfull. Often, a more narrow range of flows is desirable, for example, lower flows in a fisheries evaluation or flows near bankfull for bedload transport analyses. These hydraulic parameters are often plotted against stage or discharge to develop hydraulic geometry relationships (Leopold and Maddock, 1953).

Following the rating table is an opportunity to compute a rating for different limits or conditions:

```
DO YOU WISH TO DO ANOTHER RATING USING A DIFFERENT MANNINGS N, LIMITS, OR
GRADIENT AT THIS X-SECTION?  YES-0, NO-1
=1
```

A yes response at this point will return the program to the initiating prompts for the rating table. Many ratings may be run by responding with a zero to this prompt.

Following the rating table option, you may compute hydraulic parameters at a specified stage.

```
DO YOU WISH TO CALCULATE HYDRAULIC PARAMETERS FOR A GIVEN STAGE?  YES-0, NO-1
=0
ENTER GRADIENT OF REACH (METERS/METER).
=.0066
ENTER MANNINGS 'N' VALUE FOR THIS STAGE.
=.035
ENTER STAGE AS ELEVATION ABOVE LOWEST POINT
=.50
*****THERE ARE MULTIPLE CHANNELS AT THIS STATE.  MANNINGS EQ. MAY NOT APPLY.***
```

The inputs are the same as for the rating table, plus the desired stage. In the example above, a multiple channel warning is printed. Figure 5 illustrates a condition that will generate this warning. In this situation, each channel should be analyzed separately, with its own n and S value, if applicable. The parameters will be calculated despite the warning, thus the user must determine if the computation may be used. Occasionally, a large rock will be above the water surface and produce this warning. The computations will generally be valid in a case like this. An example of computation output is shown below.

```
CROSS SECTIONAL AREA =  7.707           SQ METERS
WETTED PERIMETER =     27.917           METERS
HYDRAULIC RADIUS =      0.276           METERS
GRADIENT =   0.0066    METERS/METER
MANNINGS N =            0.035
MAXIMUM DEPTH =         0.500           METERS
MEAN DEPTH =            0.281           METERS
TOP WIDTH = 27.405     METERS
MEAN VELOCITY =         0.984           METERS/SEC
DISCHARGE =  7.584     CUBIC METERS/SEC
```

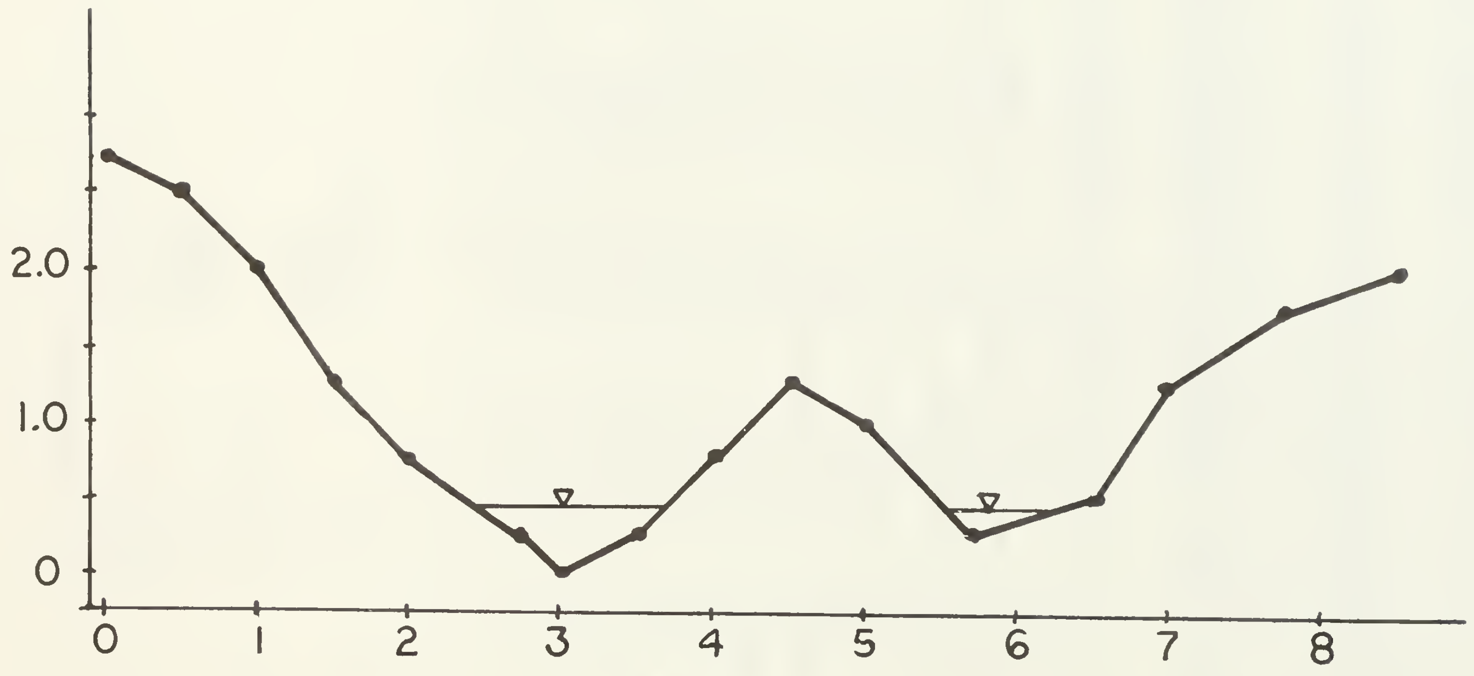


Figure 5: Example of channel configuration that will generate a multiple channel warning. Each channel should be computed separately.

A definition diagram is shown in Figure 6. Hydraulic radius, R, is

$$R = \frac{A}{P},$$

where A is cross sectional area and P is wetted perimeter. Mean (or hydraulic depth), $\overline{d}$, is

$$\overline{d} = \frac{A}{T},$$

where T is top width. Velocity, V, is computed from Manning's equation and discharge, Q is

$$Q = VA.$$

After the calculation of these parameters, you may opt for a list of the horizontal location of each vertical or edge of water, and the depth of water at that stage. For example:

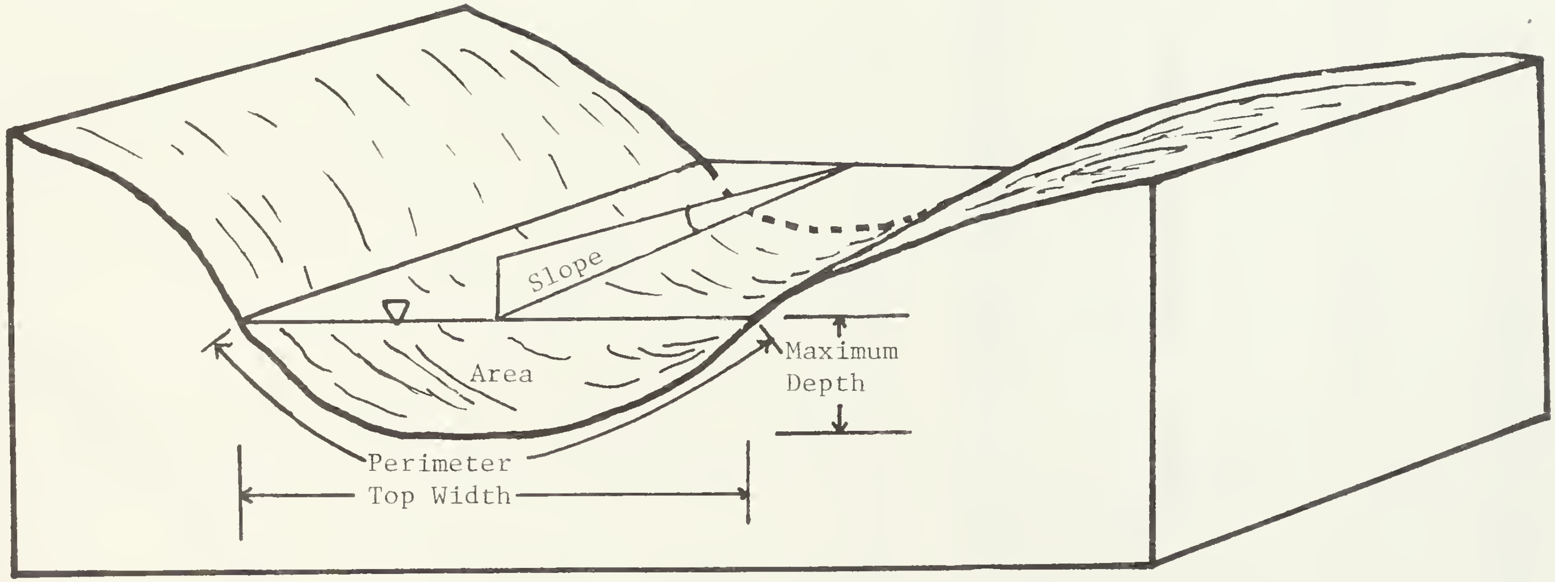


Figure 6: Definition diagram for hydraulic parameters.

```
DO YOU WANT A LISTING OF DEPTHS AND DISTANCES AT THIS STAGE?  YES-0, NO-1
=0

                                   DEPTH OF
     #         DISTANCE            WATER

     1           2.526             0.
     2           3.000             0.058
     3           3.500             0.059
     4           4.000             0.129
     5           4.500             0.045
     6           5.000             0.145
     7           5.500             0.170
     8           6.000             0.240
     9           6.500             0.245
    10           7.000             0.289
    11           7.500             0.173
    12           7.999             0.202
    13           8.499             0.206
    14           8.999             0.240
    15           9.499             0.353
    16           9.999             0.317
    17          10.499             0.300
    18          10.999             0.397
    19          11.499             0.255
    20          11.999             0.307
    21          12.499             0.365
    22          12.999             0.317
    23          13.499             0.423
    24          13.999             0.255
    25          14.499             0.376
    26          14.999             0.373
    27          15.499             0.399
    28          15.999             0.270
    29          16.499             0.375
    30          16.999             0.280
    31          17.499             0.326
    32          17.999             0.481
    33          18.499             0.320
    34          18.999             0.500
    35          19.499             0.339
    36          19.999             0.229
    37          20.499             0.238
    38          20.999             0.406
    39          21.499             0.475
    40          21.999             0.478
    41          22.499             0.406
    42          22.999             0.229
    43          23.499             0.322
    44          23.999             0.380
    45          24.499             0.317
```

```
     46         24.999           0.244
     47         25.499           0.221
     48         25.999           0.368
     49         26.499           0.354
     50         26.999           0.321
     51         27.499           0.352
     52         27.999           0.098
     53         28.499           0.188
     54         28.999           0.159
     55         29.499           0.099
     56         29.899           0.025
     57         29.931           0.
```

Clearly, the depth of water at an edge is zero. If the channel is divided, water depths at each edge of the island will be zero also. Following the listing of depths and distances, you may compute at another stage or plot the channel for this cross section.

```
DO YOU WISH TO CALCULATE FOR ANOTHER STAGE?
YES-0, NO-1
=1

DO YOU WISH TO PLOT THE CHANNEL FOR THIS X-SECTION?  YES-0, NO-1
=0

WHICH PLOT WIDTH DO YOU WANT?

1 - 70 CHARACTER
0 - 100 CHARACTER
= 1
```

Both plots have 30 print positions on the y-axis. The 70-character plot has 70 print positions on the x-axis, while the 100-character plot has 100 print positions on the x-axis. On both plots, tic marks (+) will be placed at every fifth print position on the y-axis, and at every tenth print position on the x-axis. A scale value will be printed at each tic mark. The scale will start at zero for both the x- and y- axes. Thus, the scale value for the first tic mark will be zero for both the x- and y- axes.

```
DO YOU WANT TO DEFINE YOUR OWN AXES, OR DO
YOU WANT TO USE THE DEFAULT?

0 - DEFAULT
1 - YOU DEFINE
= 1
```

In general, the default option will make the plot as large as possible, subject to the following constraints. The sixth, or maximum, y-axis tic value will be the next whole number greater than the largest elevation above the x-section low point. The remaining five y-axis tic marks may or may not have whole number values. All the x-axis tic values will be whole numbers. In order to do this, the program divides the maximum corrected horizontal distance by the number of tic marks (7 or 10 depending on the plot size) and then rounds this value to the next largest whole number to obtain a whole number tic length.

The user defines the axes by choosing the maximum x and y values. Depending on the values chosen, the tic marks may or may not be whole numbers.

```
THERE ARE 70 PRINT POSITIONS ON THE HORIZONTAL (X)
AXIS.  I WILL PUT A PERIOD (.) EVERY OTHER PRINT
POSITION, AND A TIC (+) EVERY 10TH PRINT POSITION.
EACH TIC MARK WILL ALSO HAVE A SCALE VALUE
PRINTED BELOW IT.  SO, WHAT VALUE DO YOU
WANT FOR THE 70TH PRINT POSITION?

= 70

THERE ARE 30 PRINT POSITIONS ON THE VERTICAL (Y)
AXIS.  I WILL PUT A DASH (-) AT EVERY PRINT
POSITION, AND A TIC (+) EVERY 5TH PRINT POSITION.
EACH TIC MARK WILL ALSO HAVE A SCALE VALUE PRINTED
BESIDE IT.  SO, WHAT VALUE DO YOU WANT FOR THE
30TH PRINT POSITION?

= 6
```

See Figure 7 for a plot of the cross-section.

To allow a change of scale, an option to plot the same cross section is presented.

```
DO YOU WANT TO TRY ANOTHER PLOT OF YOUR DATA?
0-YES
1-NO
= 1
```

A no to this prompt will give the following prompt:

```
DO YOU WISH TO ENTER ANOTHER X-SECTION?
YES-0, NO-1
= 1
```

A yes to this prompt returns the user to the beginning of the program to enter another cross section, a no ends the program.

```
***************************************
****** END OF CHANL CALCULATIONS ******
***************************************
```

Figure 7: Plot of the cross section.

Field Procedures and Theory

The most important aspect of a stream reach evaluation is gathering the appropriate information. Several important assumptions must be satisfied before Manning's equation and some of the other equations may be applied. Rarely will all assumptions be met in field situations. Therefore, some idea of how the procedures were derived and how sensitive the procedures are to deviations from the assumptions is important. There is often only one opportunity to gather data at a location, so all necessary information must be gathered at that time. Understanding the development and analytic processes will make data collection more efficient and consistent.

Most methods for determining open-channel discharge have two components: 1) determination of mean velocity, and 2) determination of a cross section area over which the velocity is averaged. The area (or sub-area) and mean velocity are multiplied to compute discharge through that sub-area and then summed (if the area is less than the total cross section area) to compute the total discharge. Computation of cross section area is strictly a geometry problem. There are numerous methods for determining the velocity in a channel. Methods for direct measurement of the fluid velocity include: current meters (rotating cup type and propeller type), electromagnetic meters, drag body meters, velocity head rods, pitot tubes, transit time of a floating object, and transit time of a dye or salt (U.S.D.I., 1975; Smoot, 1978). Each method has its own advantages and disadvantages related to channel characteristics, precision, and available time.

The relationship between channel cross section geometry and velocity has been explored by many authors for many years (Chow, 1959), and has produced numerous empirical relationships. Manning's equation has come to us in its present form with several, mostly cosmetic, changes since its original presentation in 1889 (Chow, 1959). Since hydraulic computations in CHANL and MCHANL use Manning's equation to calculate mean channel velocity, users of CHANL or MCHANL must understand the assumptions made in the derivation of Manning's equation.

Assumptions of the Manning's equation

Manning's equation is one of several formulae empirically defined for uniform flow conditions. Uniform flow conditions require that: 1) depth, cross sectional area, and width do not change downstream; 2) the energy gradient, water surface (friction) gradient, and stream bed gradient are equal; and 3) velocity does not change downstream (Chow, 1959). It is seldom possible to strictly abide by these requirements. The site selection criteria below will help minimize deviation from these requirements.

Site Selection

The main criteria for selecting a suitable cross section is meeting the uniform flow conditions requirement. This may be difficult to do in a natural stream. One feature of uniform flow which may prove useful is that the flow streamlines (the trace of the path that a "particle" of water would follow in the flow" are parallel and straight. Therefore, the observer should look for indications that all parts of the flow move parallel to one another. This can be ascertained by observing the path of floating objects or wading across the stream with a length (20-30') of survey flagging in the flow. The flagging should stretch out about parallel to the banks. The cross section should be within a channel reach of sufficient length to establish the stream gradient. For a reach with approximately uniform flow, this would be about 75 times the mean depth or several channel widths (Barnes and Davidian, 1978; Jarrett, 1983). The reach must have flow characteristics that vary gradually, if at all, and not contain discontinuities of flow, such as water falls, steps or hydraulic jumps. Discontinuities of this type are usually associated with channel constrictions or obstructions. Large roughness elements, such as channel bars, large boulders, or tree trunks, frequently disrupt the flow by creating wakes or diverting streamlines (Figure 8). It is generally obvious from the surface condition of the water how far downstream the wake affects the flow.

Constrictions or debris dams can cause backwater effects that cannot be modeled by CHANL and MCHANL. Channel constrictions, such as at a bedrock gap or a bridge crossing, may have a small influence on a low flow but as discharge increases, flow through the width constriction may become super critical or rapid. (This is as opposed to sub critical or tranquil flow. These conditions are defined by the Froude number, which is a dimensionless number that relates the velocity of the flow to the velocity of a gravity wave. The concentric ripples produced by throwing a pebble into water are gravity waves. A simple field test, though one that requires ideal conditions, for super critical flow is to throw a rock into the flowing water. If the ripples move upstream, relative to a fixed point, the flow is sub critical or tranquil. If the flow is super critical, the ripples will be swept downstream.) At this constriction the water surface slope will differ markedly from the gradient of the energy line, and significantly violate the Manning equation assumptions. Constrictions of depth, such as a bedrock ledge or a submerged diversion dam or log , can also produce a transition to rapid flow. Downstream of the depth constriction the return to tranquil flow will be accomplished with a hydraulic jump (Figure 9). Flows of these types can be modeled, but not with these programs.

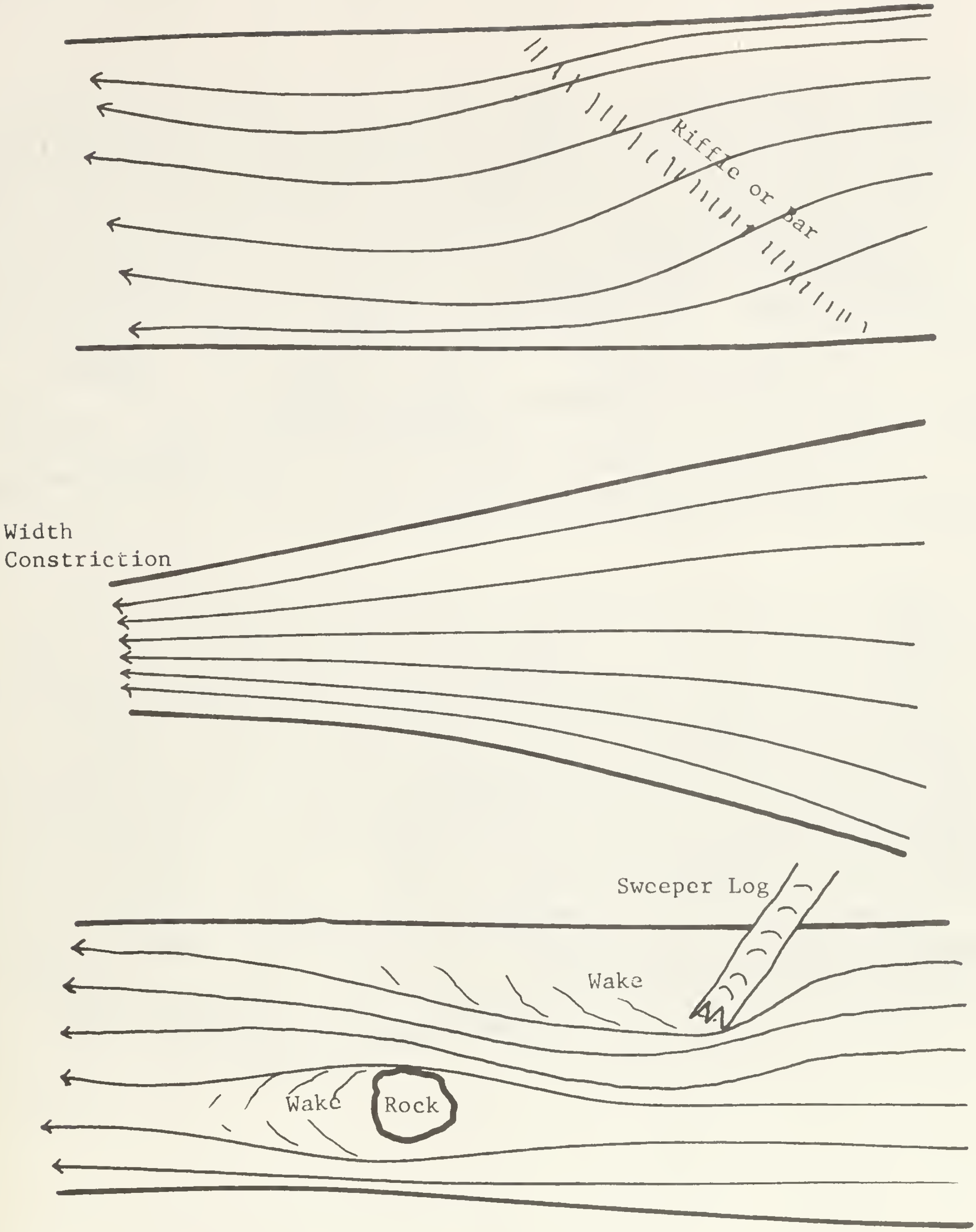


Figure 8 Some typical channel configurations which disrupt uniform flow.

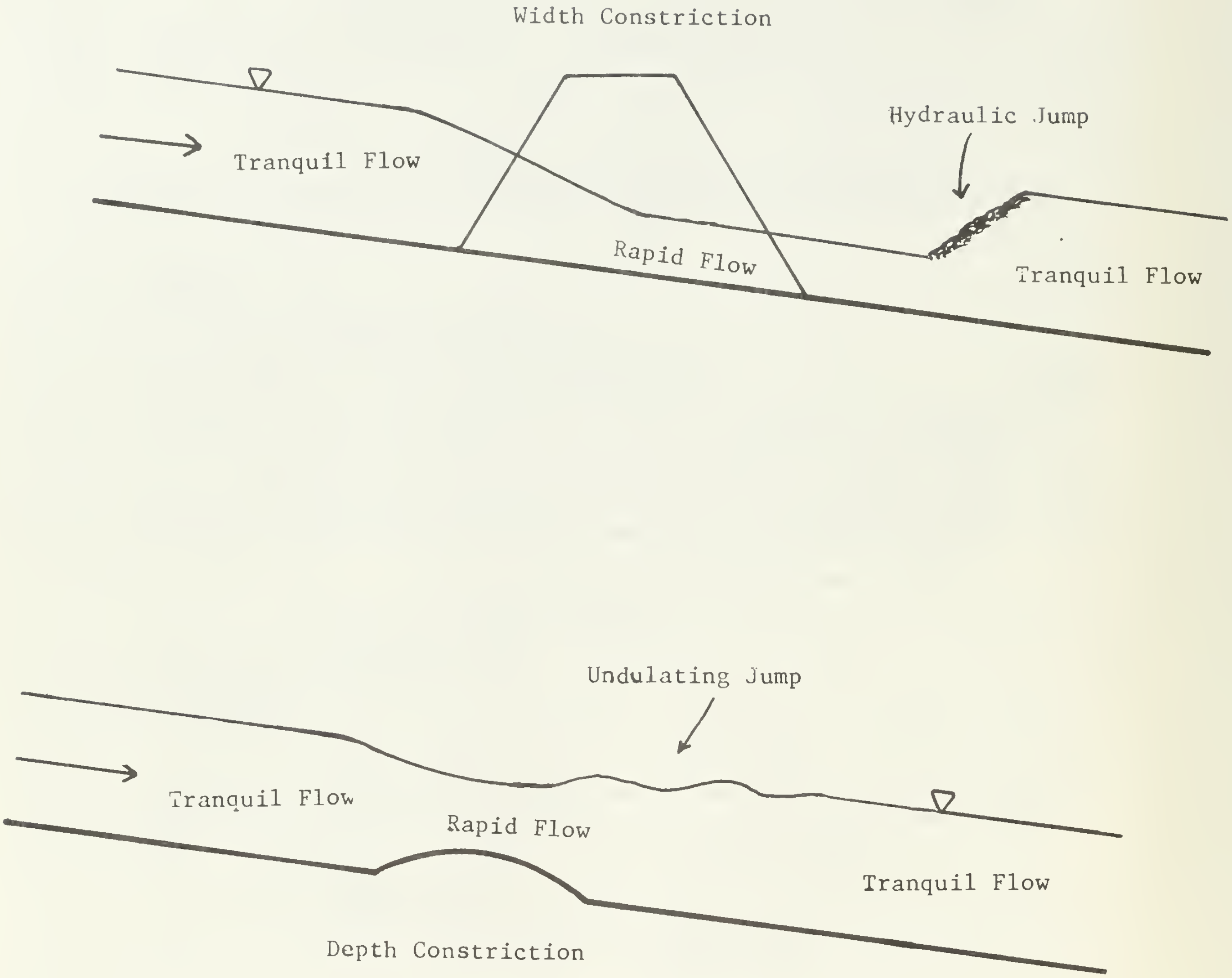


Figure 9: Transition from tranquil to rapid flow at channel constrictions.

Bank stability and bed stability are also important considerations. Alluvial or mobile bed channels are more complex in their response to flow condition than are rigid boundary channels. Alluvial channels may range from sand bed channels, which are very sensitive to changes in flow, (Simons, Li, et al., 1982) to gravel bed channels which may only be mobile at bank full stage (Jackson and Bechta, 1982). Bank sloughing or falling trees can create backwaters and eddies with very low or negative velocities. Measuring velocity at under cut banks is difficult, though in some situations, the undercut bank contributes a sizeable portion of the flow. The selection of a cross section is a vital part of determining discharge.

At this point, it is necessary to consider the computer program's main tasks: 1) convert survey data from one of two types of survey to X-Y coordinates; and 2) use this geometric data to compute velocity and other hydraulic and geometric parameters for the cross section. The method of using this geometric data contains many options and a brief discussion of how to approach problems is warranted.

The entire method is aimed at analysis of a cross section within a rather short reach. It is possible that the programs will be used only to reduce survey data, such as to analyze long term scour or fill. They may define the depth-discharge relationship for fish habitat analysis. The user's intent plays the largest role in locating the cross section. Whether the cross section is to be a critical location or is to be representative of a larger system must be decided. A critical location may be considered the reach most likely to meet (or fail to meet) some important condition or the reach most sensitive to change. A representative cross section will typify a definable portion of the channel system and will be used to describe the whole system. The programs are not restricted to use in channels. They may be used to reduce any rod and level or sag tape survey data. For example, they have been used in reducing data from a horizontal hillslope transect survey for monitoring rill development (Steve Ellis, 1983, BLM, personal communication). But, it must be emphasized that if hydraulic computations are to be made, the programs do use the Manning's equation and its assumptions must be met.

Measuring Stream Gradient

The gradient of the stream reach, S, is one of three additional pieces of data the user must supply before hydraulic computations can be made. If the flow through the cross section is truly uniform, the gradient measurement is quite simple. Strict adherence to the uniform flow condition is nearly impossible in natural channels, so care must be taken to reduce errors due to flow irregularities.

The S in Manning's equation is the gradient of the total energy line of the stream, i.e., the rate at which energy is dissipated through turbulence and boundary friction. In uniform flow, the gravitational forces that drive water downhill are just balanced by the resistance forces, (Simons, Li, et al., 1982) so velocity does not change downstream. For uniform flow conditions, the water surface drops at the same rate downstream as does the energy line. S is typically determined by measuring a change in elevation, ΔH, over a length, L:

$$S = \frac{H}{L}.$$

Length L is measured along a stream line, (Figure 10) rather than simply stretching a tape between two points. Finding a location with streamlines which are approximately straight will avoid overestimating or underestimating S. The length, L, should be as long as possible, especially at low gradients, because short lengths tend to have small changes in elevation. Any survey errors will be a greater percent of a small elevation difference than of a larger elevation difference. However, measuring over a long length must be tempered with measuring a homogeneous reach.

Estimating Manning's n

There are three types of methods for estimating the Manning roughness coefficient, n. They are: 1) comparing the reach to a similar, measured reach, 2) empirical formula, and 3) measuring velocity, V, hydraulic radius, R, gradient, S, and applying the formula,

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

or

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

Comparing the reach to a similar, measured reach is a very rapid way to estimate n. It is also probably the least accurate method and subject to the most variability between individuals making the estimate. Chow (1959, page 110-113), tabulated an extensive listing of ranges of n values for manmade conduits and natural channels. Variations of this table can be found in several hydraulic and hydrology texts (Chow, 1964; Simons and Senturk, 1977; Dunne and Leopold, 1978; Barfield, Warner and Haan, 1983; Henderson, 1966; Simons, Li, et al., 1982; Van Haveren, 1985). Van Haveren's table of

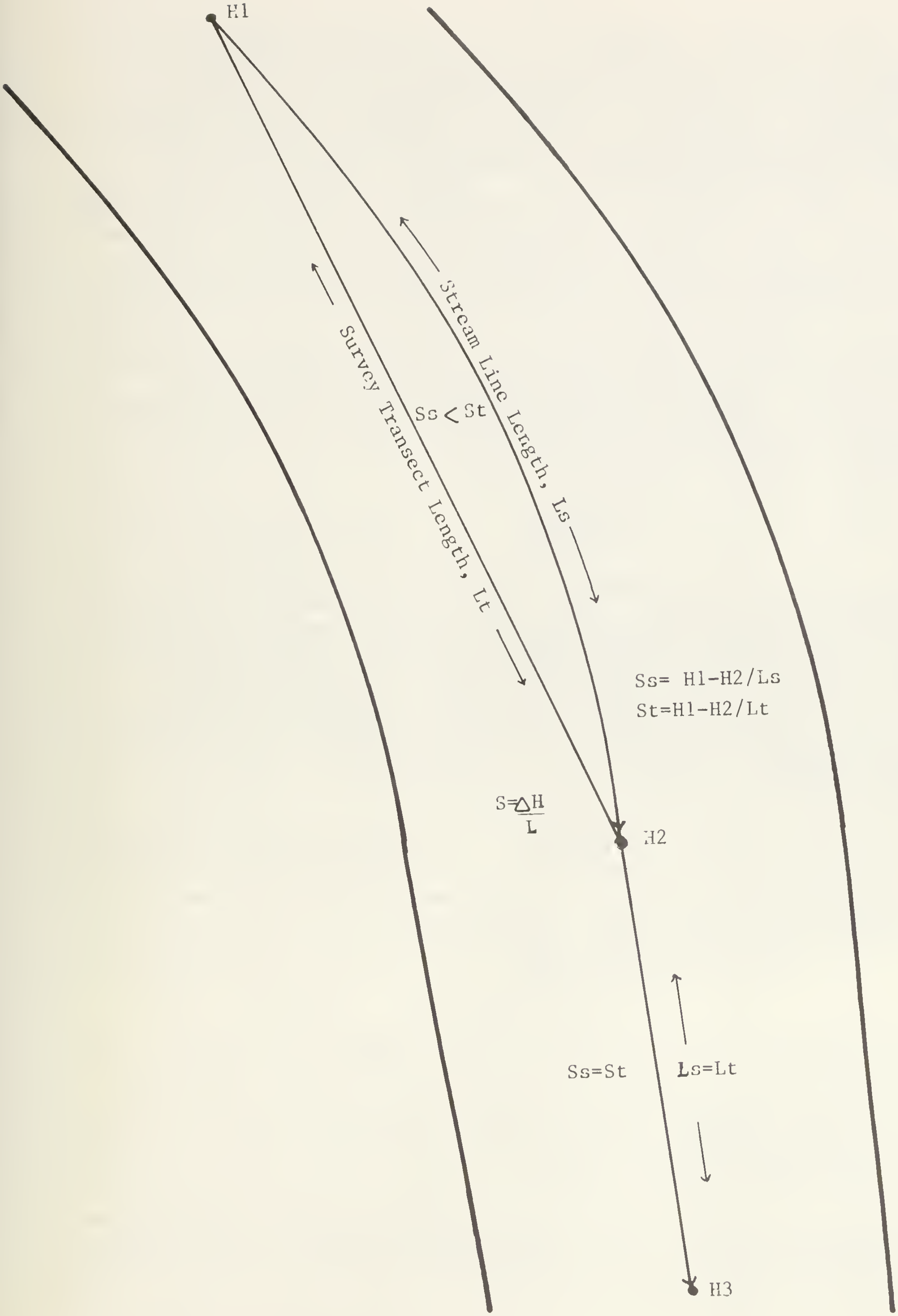


Figure 10: Example of error in S due to not accounting for bending stream line.

Manning's n values is given in Appendix B. Chow (1959) also suggested a method developed by Cowan (1956) which uses a base n value, derived from a table and adds to it additional roughness contributions due to channel pattern, sediment load, vegetation, and seasonal changes. A similar method was adapted by Benson and Dalrymple (1967) for use by USGS personnel when making indirect discharge measurements. This method is explained below.

Chow (1959) and Barnes (1977) have compiled photographs of stream reaches with computed n values. These are used much the same way the tables are; find the photo that best describes the reach in question and use its n value for the base n value in the Cowan method. The USGS also has these photographs as stereo pairs, available for inspection at USGS District offices and libraries.

There are numerous empirical relationships that correlate Manning's n with a statistical index of bed material size composition (Simons and Senturk, 1977). These formulae assume that larger particles in the channel boundary dominate the hydraulic roughness. For example, the Meyer-Peter-Mueller formula, (Simons and Senturk, 1977),

$$n = \frac{D_{90}^{\;1/6}}{26}, \qquad \text{(metric, D in m)}$$

is defined for rigid, sand bed channels, where D_{90} is the intermediate particle diameter which is greater than or equal to the diameter of 90 percent of the particles in the bed. Dunne and Leopold (1978, p. 665-669) describe a field method of collecting and manipulating bed material data that does not require sieving, and will give a size distribution of the bed material. Simons and Senturk (1977) list a number of formulae of this type, which are usually defined for a narrow range of conditions. It is very important that the conditions are met. Lane and Carlson (1953) developed a formula for cobble bedded canals:

$$n = \frac{D_{75}^{\;1/6}}{39}. \qquad \text{(English units, D in inches)}$$

Limerinos (1970) developed a formula for n that incorporates a relative smoothness term, a ratio of R to D_{84}. The equation,

$$n = \frac{(0.0926)\ R^{1/6}}{1.16 + 2.0 \log (R/D_{84})} \quad \text{(R and } D_{84} \text{ in feet)},$$

was developed with data from eleven gravel bedded streams in California. The streams ranged in hydraulic radius from 1.45 to 10.9 feet and in D_{84} from 0.062 to 2.45 feet. The ratio, R/D_{84}, has the effect of reducing the value of n as depth (R) of flow increases, for a give bed material size distribution. Limerinos equation is one of the few using bed material size, that also incorporates the depth of flow.

Jarrett (1983, written communication) has found that for steep, rough streams, n varies rapidly with depth of flow. He developed an equation for 21 streams in Colorado that is a power function of S and R:

$$n = 0.39\ S^{0.38}\ R^{-0.16}. \qquad \text{(R in feet)}$$

This equation applies to stream with gradients in a range of 0.002 to 0.052, and hydraulic radii of 0.5 to 7 feet. The equation applies to channels with stable bed and banks and relatively low suspended sediment load. Jarrett (1983) noted that discharge might be underestimated by a factor of two to three if n were not reduced when the stage increased.

The hydraulics of sand or mobile bed channels are more complex than rigid boundary channels. The value of n changes as bed forms change. Bed forms change with velocity, stream power, and Froude number (Simons, Li, et al., 1982; Benson and Dalrymple, 1967). As velocity and stream power increase, the bed forms evolve from ripples, to dunes, to washed out dunes, to plane bed, to antidunes, to chutes and pools (Simons and Senturk, 1977). The ripples and dunes occur when the Froude number is less than 1.0 (tranquil flow), washed out dunes occur at about Fr=1 (critical flow), and plane bed, antidunes and chutes and pools, occur at rapid flow. The n value is maximum when dune bed forms are present and minimum when ripples and plane bed forms are present. If possible, it is best to select a cross section that does not have a mobile boundary, since scour, as well as variable n values, may create uncertainty in relationships of stage with hydraulic parameters.

Many engineering texts contain empirical relationships of n and various factors (Simons and Senturk, 1977). Most of these equations have limited ranges of application and it is incumbent upon the user to apply them only within these limited ranges. These formulae, including the ones described above, should be considered base values of n that account for only the factors they contain (e.g., Limerinos equation accounts for depth and relative smoothness). In general, the base value of n should be increased if vegetation, sinuosity, channel irregularities, or sediment load warrant it. Chow (1959), contains a table that systemizes adjustment of the base n value for some of these factors. Table 2 is a modified version of Chow's table. To use Table 2, determine the base value (n_0) using one of the aforementioned formulae, and then make adjustments for the remaining five factors. Jarrett (1983) has suggested reducing the amount of the adjustment factors (n_1, n_2, n_3, and n_4) to one half to two thirds of the table values. Inserting the base value and the adjustments in the equation:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)\ m_5,$$

calculates the value of n in the reach.

Manning's n has been documented to vary with many factors including temperature, discharge (or stage), bed material, sediment load, and bed form (Simons, Li, et al., 1982; Vanoni, 1975; Garde and Ranga Ragu, 1977). Velocities and discharges calculated using Manning's equation are quite sensitive to the n value, (Table 3) so it is often worth taking time to make one or more current meter discharge measurements to determine velocity, V, and hydraulic depth, d. (Hydraulic depth, d, is defined by the equation: $d = A/T$ where A is cross sectional area and T is top width of water. For wide channels $R = d$. Hydraulic depth is also called mean depth.) By measuring S, and inserting in the formula:

Table 2: Adjustments to Manning's n for channel conditions.

Channel conditions			Values
Degree of irregularity	Smooth	n_1	0.000
	Minor		0.005
	Moderate		0.010
	Severe		0.020
Variations of channel cross section	Gradual	n_2	0.000
	Alternating occasionally		0.005
	Alternating frequently		0.010-0.015
Relative effect of obstructions	Negligible	n_3	0.000
	Appreciable		0.020-0.030
	Severe		0.040-0.060
Vegetation	Low	n_4	0.005-0.010
	Medium		0.010-0.025
	Very High		0.050-0.100
Degree of meandering	Minor	m_5	1.000
	Appreciable		1.150
	Severe		1.300

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

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

it is possible to solve for n at a particular stage. Since n varies with stage, (Chow, 1959 and others) it is advantageous to calculate n for at least one discharge and then estimate the change of n with stage, perhaps by applying Limerino's (1970) or Jarrett's (1983) equations. Most authors have found that for uniform channel cross sections, n decreases as stage increases up to bankfull stage. If it is possible to make measurements at several stages, the relationship between n and stage can be determined.

At discharge above bankfull, the overbank areas are also transporting water. These areas are usually hydraulically quite different from the channel. Generally, flow in the overbank areas may be treated as a separate channel and added to the main channel portion of the flow to compute total discharge. Yen and Overton (1973) describe a method of sub-dividing the main channel and overbank portions of flood flow that minimizes shear between the sub-sections. CHANL or MCHANL may be used for these computations, if the main channel and overbank sub-sections are entered separately.

Table 3: Example of change in discharge and velocity with change in Manning's n. Data are from a surveyed cross section of the North Fork of the White River, near Buford, Colorado.

Held Constant:

Cross-sectional Area = 7.59 meters
Hydraulic Radius = 0.26 meters
Water Surface Slope = 0.0066
Stage Chosen = 0.47 meters above lowest point

Mannings's n	Discharge (m^3/s)	Velocity (m/s)
.025	10.14	1.34
.030	8.45	1.11
.035	7.24	0.96
.040	6.34	0.84
.045	5.64	0.74
.050*	5.07	0.67
.055	4.61	0.61
.060	4.23	0.56

*The n value computed from a discharge measurement near this stage is 0.050. Jarrett's (1983) equation gives an n value of 0.058.

The computation of hydraulic and geometric parameters, stage, Q, A, R, P, d, and V is the springboard to other analyses. These are the basic hydraulic components of a channel cross section and may be used for further elaboration. The user may relate the parameters one to the other, such as a stage-discharge plot, or compute other parameters such as basal shear or stream power. They may be combined with flow duration data to generate a plot of frequency of inundation or other probability relationships.

Conclusions

Since Manning's equation was developed for a uniform flow condition, it is important that a stream reach approximate that condition, if the hydraulic parameters are to be computed. The three main criteria of uniform flow are: 1) that depth and width remain constant through the reach, 2) that the stream energy line gradient, the water surface gradient and the stream bed gradient are equal, and 3) that lines of flow in the reach are parallel and straight. These criteria are seldom strictly met in field applications, but a site that best approximates them will provide better results.

The programs are not restricted to hydraulic computations. They may be used to reduce any sag tape or rod and level survey data. This capability is especially useful for monitoring changes in surface geometry, such as long-term down-cutting of a stream channel or rill.

The hydraulic and geometric parameters computed by these programs are used commonly in analyses related to sediment transport, channel stability, channel gain/loss, and fishery habitat. These programs should be considered tools that expedite the computation of basic information used for technical investigations.

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Appendix A

Suggested Field Form for Collection of Data to be Used with CHANL and MCHANL

CHANL/MCHANL Data Collection

Date:____________________ Collected by:______________________________

Drainage Name:____

Location or Reach Identification:___________________________________

Reference Gage Height at time of Survey:____________________________

Type of Survey: Rod and Level, Sag Tape (Circle one)

Survey Conditions (e.g., Windy, rain, dim light, etc.):___________________

Benchmark Location and Elevation:___________________________________

Zero Stake is on Right, Left bank facing Upstream, Downstream. (Circle two)

Tape End Elevation Difference (ft or m):____________________________

(If zero end is higher, difference is negative)

Total Tape Length (clamp to clamp, ft or m):____________________________

If Sag Tape Survey, enter next 2 values

Tape Weight (lbs/ft or kgs/m):______________________________________

Tape Tension (lbs or kgs):____

Number of Cross Section Verticals:__________________________________

File Name, if Data are stored on Computer File:_________________________

Gradient of Reach at Cross Section (ft/ft or m/m):_______________________

Manning's n value at this stage:______________________________________

Discharge at this Stage (ft^3/sec or m^3/sec):____________________________

Notes: (e.g., was a pebble count made?; samples taken?; photos taken?; stability rating?; observations of flow, bed or bank character?)

____

____

____

____

____

____

<u>Cross Section Measurements</u>

Distance	Depth or Foresight	Notes	Distance	Depth or Foresight	Notes	Distance	Depth or Foresight	Notes

Appendix B

Table of Manning's n values for natural and manmade channels

Values of the Manning Roughness Coefficient, n

Description of Channel	Minimum	Normal	Maximum
A. Excavated or dredged			
1. Earth, straight and uniform			
a. Clean, recently completed	0.016	0.018	0.020
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
2. Earth, winding, sluggish			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
d. Earth bottom and rubble sides	0.028	0.030	0.035
e. Stony bottom and weedy banks	0.025	0.035	0.040
f. Cobble bottom and clean sides	0.030	0.040	0.050
3. Dragline-excavated or dredged			
a. No vegetation	0.025	0.028	0.033
b. Light brush on banks	0.035	0.050	0.060
4. Rock cuts			
a. Smooth and uniform	0.025	0.035	0.040
b. Jagged and irregular	0.035	0.040	0.050
5. Channels not maintained, weeds and brush not cut			
a. Dense weeds as high as flow depth	0.050	0.080	0.120
b. Clean bottom, brush on sides	0.040	0.050	0.080
c. Same as above at highest stage of flow	0.045	0.070	0.110
d. Dense brush, high stage	0.080	0.100	0.140
B. Natural streams			
1. Minor streams with width at flood stage 100 ft			
a. Streams on plains			
(1) Clean, straight, full stage no rifts or deep pools	0.025	0.030	0.033
(2) Same as above but more stones and weeds	0.030	0.035	0.040
(3) Clean, winding, some pools and bars	0.033	0.040	0.045
(4) Same as above but some weeds and stones	0.035	0.045	0.050
(5) Same as above but lower stages, more ineffective slopes and sections	0.040	0.048	0.055
(6) Same as (4) but more stones	0.045	0.050	0.060
(7) Sluggish reaches, weedy, deep pools	0.050	0.070	0.080

Description of Channel	Minimum	Normal	Maximum
(8) Very weedy reaches, deep pools or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
(1) Bottom consists of gravels, cobbles and few boulders	0.030	0.040	0.050
(2) Bottom consists of cobbles with large boulders	0.040	0.050	0.070
(3) Bottom consists of large boulders and some large organic debris, sinuous flow	0.050	0.070	0.100
2. Floodplains			
a. Pasture, no brush			
(1) Short grass	0.025	0.030	0.035
(2) High grass	0.030	0.035	0.050
b. Cultivated areas			
(1) No crop	0.020	0.030	0.040
(2) Mature row crops	0.025	0.035	0.045
(3) Mature field crops	0.030	0.040	0.050
c. Brush			
(1) Scattered brush, heavy weeds	0.035	0.050	0.070
(2) Light brush and trees in winter	0.035	0.050	0.060
(3) Light brush and trees in summer	0.040	0.060	0.080
(4) Medium to dense brush in winter	0.045	0.070	0.110
(5) Medium to dense brush in summer	0.070	0.100	0.160
d. Trees			
(1) Dense willows, summer, straight	0.110	0.150	0.200
(2) Cleared land, tree stumps no sprouts	0.030	0.040	0.050
(3) Same as above, with heavy sprout growth	0.050	0.060	0.080
(4) Heavy stand of timber, a few downed trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
(5) Same as above but with flood stage reaching branches	0.100	0.120	0.160

Description of Channel	Minimum	Normal	Maximum
3. Major streams with width at flood stage | 100 ft			
a. Streams on plains			
(1) Sand channels	0.025	0.035	0.045
(2) Boulder channels	0.028	0.040	0.045
(3) Vegetation-lined channels at flood stage	0.045	-----	0.120
b. Mountain streams			
(1) Cobbly bottom, no debris jams	0.028	0.035	0.040
(2) Cobbly bottom with debris jams	0.032	-----	0.060
(3) Bottom with large boulders, no debris jams	0.045	0.050	0.070
(4) Bottom with large boulders, debris jams in channel	0.050	-----	0.100
C. Channels in swales with vegetation			
1. Depth of flow up to 0.7 ft			
a. Bermudagrass, bluegrass, buffalograss			
(1) Height 2-4 inches	0.045	-----	0.060
(2) Height 4-6 inches	0.060	-----	0.090
b. Good stand, any grass			
(1) Height 6-12 inches	0.060	-----	0.180
(2) Height 12-24 inches	0.180	-----	0.300
c. Fair stand, any grass			
(1) Height 6-12 inches	0.050	-----	0.140
(2) Height 12-24 inches	0.140	-----	0.250
2. Depth of flow 0.7-1.5 ft			
a. Bermudagrass, bluegrass, buffalograss			
(1) Height 2-4 inches	0.035	-----	0.055
(2) Height 4-6 inches	0.040	-----	0.060
b. Good stand, any grass			
(1) Height 6-12 inches	0.050	-----	0.120
(2) Height 12-24 inches	0.100	-----	0.200
c. Fair stand, any grass			
(1) Height 6-12 inches	0.040	-----	0.100
(2) Height 12-24 inches	0.080	-----	0.170

Appendix C

Glossary of Terms

Glossary of Terms

Page	Term	Definition
2	foresight	In rod and level surveying, the reading on a rod of a horizontal sight through a level or transit of known elevation. (See Figure 1)
2	catenary curve	The curve assumed by a flexible tape or wire under tension, suspended between two points, e.g. a sagging survey tape. A catenary can be described mathematically and thus its deviation from a straight line can be corrected.
14	hydraulic radius	A form of average flow depth equal to the area of flow divided by the wetted perimeter at a cross section. Hydraulic radius is often used as the representative depth in empirical hydraulic relationships such as Manning's equation.
22	supercritical or rapid flow	One of three states of flow (the others are subcritical and critical flow) defined by the Froude number (Fr) of a flow. For supercritical flow Fr exceeds 1, for critical flow Fr = 1, and for subcritical flow, Fr is less than one.
22	Froude number	The ratio of the mean flow velocity (V) to the velocity of a small gravity wave, c, (e.g., a pond ripple). The velocity of the gravity wave is equal to: $c = (gR)^{1/2}$, where g is the acceleration due to gravity and R is the hydraulic radius of flow. Therefore, $Fr = V/c = V/(gR)^{1/2}$. The Froude number is a ratio of the relative effect of inertial forces (V) to the damping effect of gravitational forces ($(gR)^{1/2}$).
22	bedrock ledge	In a stream channel, an outcrop of bedrock that hinders stream erosion and creates a waterfall or rapids.

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22	hydraulic jump	A transition from supercritical to subcritical flow, usually resulting from a change in channel geometry or gradient. Hydraulic jumps may be confined to very short reaches in which flow depth increases dramatically in a turbulent wavelike feature, or move gradually as an undulating increase. (See Figure 9)
Appendix A	gage (gauge) height	Elevation of the water surface relative to a measuring device that usually has an arbitrary reference elevation. For example, a staff gage may measure elevations from zero to 10 feet. Such a staff gage should be tied to a benchmark of known elevation and permanance by surveying.