IS-8
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MONTANA DEPARTMENT OF FISH AND GAME

ENVIRONMENT AND INFORMATION DIVISION

GUIDELINES FOR USING WATER SURFACE PROFILE PROGRAM TO DETERMINE INSTREAM FLOW NEEDS FOR AQUATIC LIFE

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Prepared in cooperation with
U.S. Department of Interior
Bureau of Reclamation
Billings, Montana

Helena, Montana

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ACKNOWLEDGEMENTS AND PREFACE

These guidelines are the culmination of efforts by Department of Fish and Game and Bureau of Reclamation personnel to arrive at a method of establishing stream resource maintenance flows for Montana aquatic life which is practical and requires a minimum of field work. Thanks are extended to Allen Elser and Dennis Workman of the Department of Fish and Game, to John Keys, John Dooley, Rick DeVore and Eley Denson of the Bureau of Reclamation's regional office in Billings, Montana and to the other Department personnel who were helpful in developing the guidelines. The guidelines were adapted from a Water Surface Profile workshop presented by the Bureau to Montana and Wyoming aquatic biologists in Billings on January 22, 1975.

The Bureau's Technical Assistance Program allows the Bureau to share its technical expertise and computer capability with a state agency when the need arises. Final arangements for this help were made in late 1973 and early 1974.

The program itself is practical and straightforward. The greatest difficulty we currently face is the lack of specific biological/streamflow criteria which can be applied to the program results. Such criteria will, hopefully, be forthcoming from all workers faced with establishing instream flows for aquatic life. It is hoped these guidelines will be useful to those workers. Comments or suggestions for improvement of the guidelines will be welcome.

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INTRODUCTION

The Montana Department of Fish and Game is attempting to identify the stream resource maintenance flows needed by aquatic life. This information is needed to establish water reservations under the 1973 Montana Water Use Act and aid in the evaluation of proposed future diversions. Physical data needed to determine these needs include velocities, water depths, and channel characteristics at various flows. These interrelated factors can be determined by actual field measurements at many flows, which are time consuming and often impossible, or can be computed using the WSP (Water Surface Profile) computer program and one set of field measurements.

DESCRIPTION OF THE WSP PROGRAM

The WSP Program is a computer adaptation of the Bureau of Reclamation's (hereafter called the Bureau) Water Surface Profile Computation Method B. The WSP Program was written to computerize computations necessary to determine tailwater and backwater elevations. These are the water surface elevations below dams and control structures and above reservoirs.

WSP is adaptable to instream applications. The program allows the users, after sufficient field work, to predict and/or study various changes in stream characteristics at many different flows without having to make numerous field observations at these flows. The program (model) is calibrated to a specific stream section using one or two observed flows, the corresponding water surface elevations, and channel profile data at various locations, or transects, in a stream section. The characteristics of the stream determine the number of transects needed to obtain data on various types of aquatic habitat being measured, and channel configuration determines the number of elevation measurements needed along a transect. A minimum of four transects are needed to properly describe the stream for use in the WSP Program.

The predicted values from the program are within the accuracy of the field data, i.e., if water surface elevations are measured within $\pm$ 0.1 foot, the predicted water surface elevations at other flows will be within $\pm$ 0.1 foot.

The computer program utilizes "Manning's equation" to predict hydraulic values at each of the streamflows requested. Manning's equation is

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where V = velocity, R = hydraulic radius, S = slope, and n is a roughness coefficient.

FIELD DATA REQUIREMENTS

Field data needed for input to the WSP Program comprise a physical description of the stream section being investigated. The quality of this data determines the accuracy of the computed results. The data requirements for the program include:

1. Map or aerial photograph showing stream section being studied and transect locations in that section.

2. Elevation data at each transect.

3. Distance between transects.

4. Measured flow in cubic feet per second (cfs).

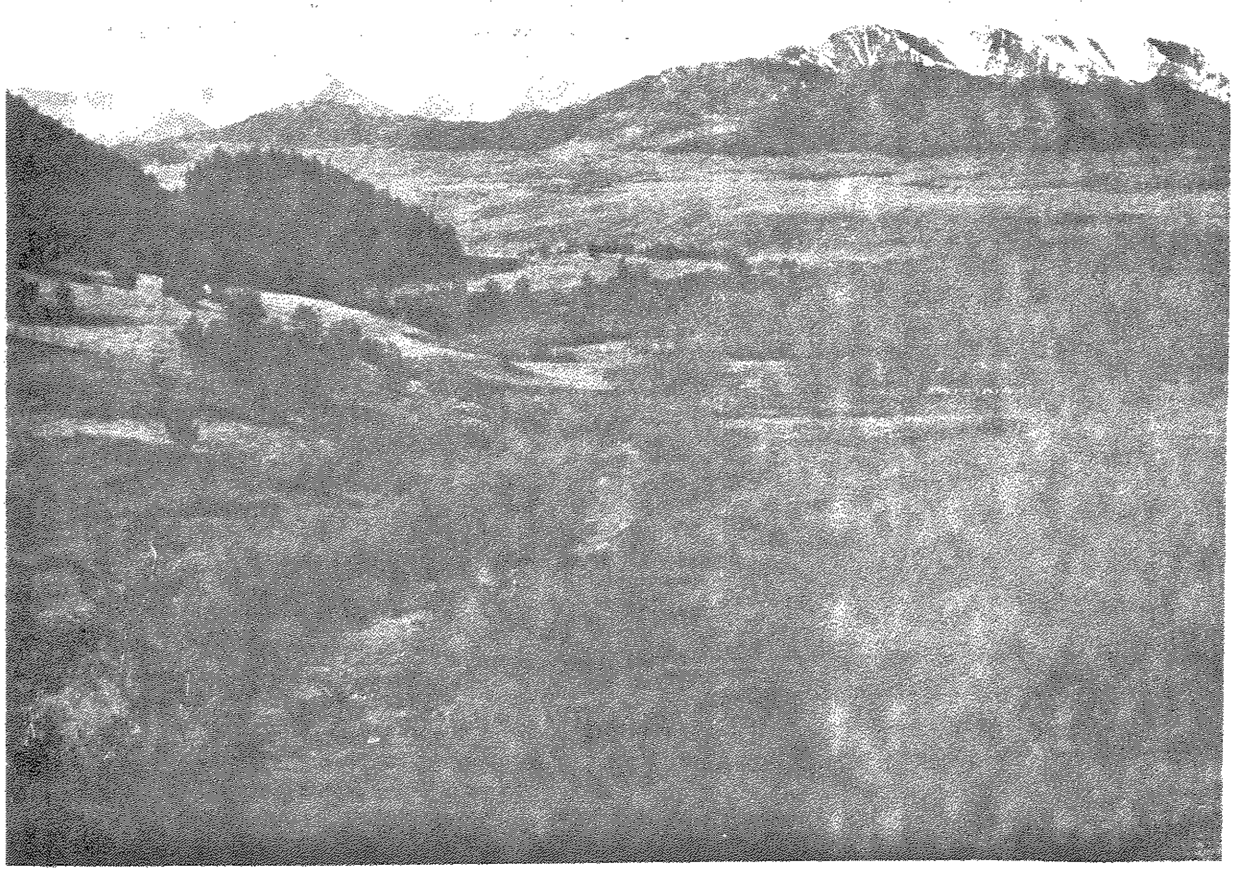
5. Water surface elevation at each transect at the measured flow.

6. Photographs of the stream reach and each transect.

7. Description of the type of streambed materials along each transect (sand, gravel, cobbles, boulders, muck, etc.).

8. Identification of points where the type of streambed materials change along a transect.

9. Description of bank and overbank material and vegetation (trees, brush, grass, logs, etc.) at each transect.



FIELD METHODS

Equipment

- Transit or level
- Stadia or Philadelphia Rod
- Measuring tape calibrated in feet and 1/10 foot
- Survey stakes
- Engineer's field notebook
- Hip boots or waders
- Camera
- marking pencil
- Current meter
- Wading Rod
- Head set
- Stop watch
- Discharge Measurement Notes
- Slide rule or pocket calculator (optional)
- Axe or hatchet
- nails

Picking a Location

Habitat Condition

Pick a stream study reach which contains the type of habitat you want to study, such as for spawning, rearing, passage, etc. The types of habitat you measure should reflect the seasonal requirements of the species you are most concerned about. Mark the location of these habitat transects with survey stakes. It is a good idea to mark the water's edge with a stake as you establish your transects.

Flow Control Points

Transects must be established across all flow control points (riffles, rapids, log jams, channel constrictions) even though you may not want any habitat information on them.

The farthest downstream transect must be at a flow control point. The farthest upstream transect can be at any location.

Stations should be numbered from downstream to upstream as shown in Figure 1.

Benchmarks

Establish a benchmark, or elevation reference point, at the downstream end of the study reach. If a surveyed benchmark (mean sea level elevation marker) is not available near the study reach, you can use an arbitrary, or "planned," elevation, such as 1,000 feet, as a beginning point and relate all other elevations to the planned elevation. Establish a benchmark by using a survey stake, or a large spike or metal rod fastened to a painted metal disc and driving it into the ground. Mark another object which can be readily seen near the benchmark with spray paint so the benchmark can be easily relocated. Benchmarks can also be established by driving a nail into a tree, marking a spot on a bridge abutment, etc., i.e., using a point which is not likely to be disturbed or moved.

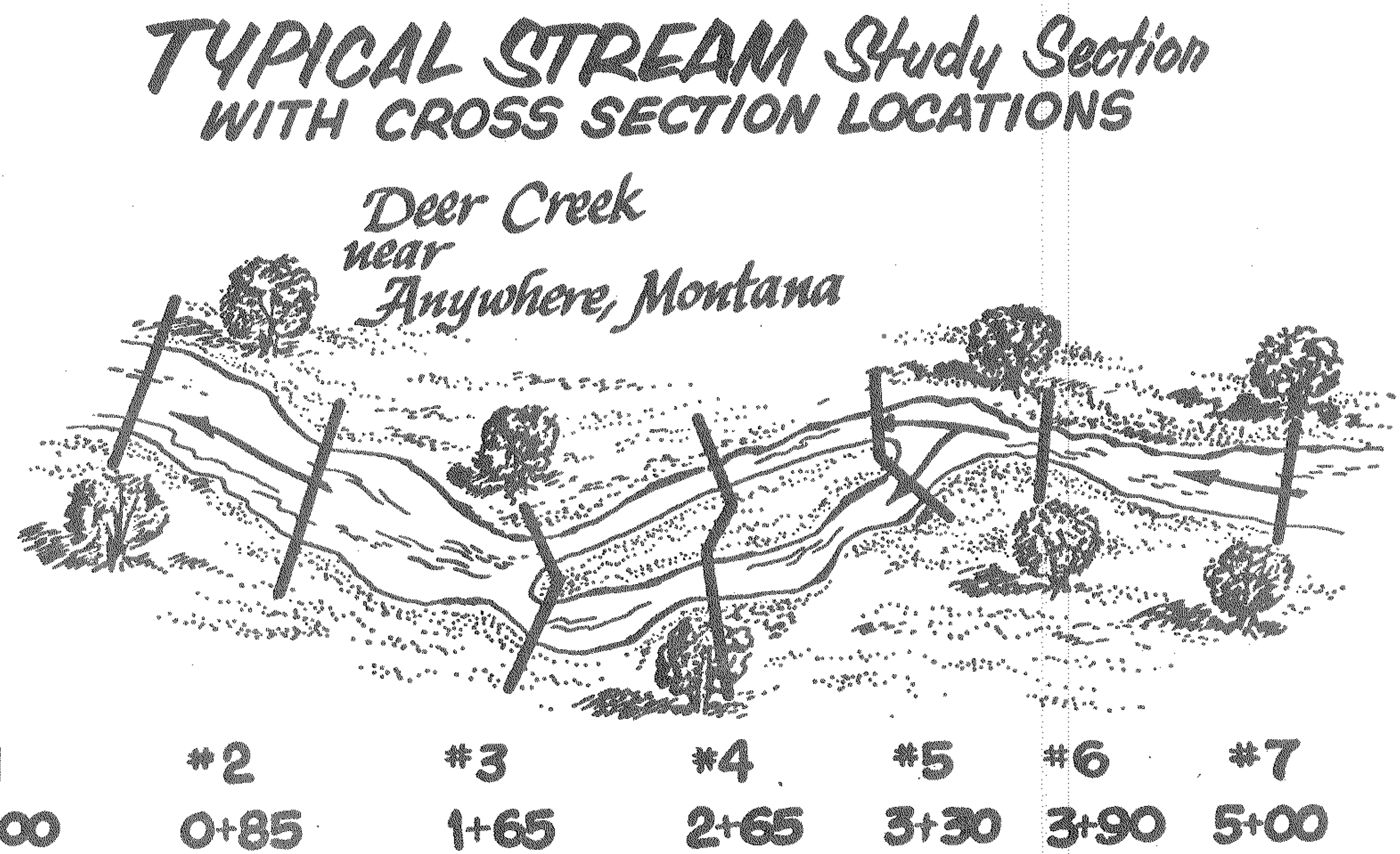


Figure 1. Example of study section layout.

Making the Measurements

USE GOOD SURVEYING TECHNIQUES!

Consistency

An important point to consider when taking field data is to be consistent in the manner in which data is collected and recorded. Transect measurements should originate from the same side of the stream, if possible. Right and left streambanks are always specified as though you are looking downstream.

Transects can be measured in any order as long as the elevation data is submitted to BuRec in the proper order. Data should be submitted in order beginning with transect 1 and continuing upstream to the uppermost transect.

It is convenient to determine benchmark elevations at each of the other transects if you begin at transect 1 and work upstream. However, field conditions often preclude this, and you will have to make your own adjustments. Just be sure to keep your field data straight.

Stream Discharge

Water surface elevations at all transects must be recorded at the time stream discharge is determined. One way to do this is to stake the water's edge at all transects and then make a discharge measurement. Transect measurements can then be made later, and if the stream discharge increases or decreases slightly the water's edge at the measured discharge can still be determined from the position of the stakes. It is best to do your surveying during the time when streamflow is stable and wadeable, because flow measurement is more difficult during periods of increasing or decreasing flow.

Make a discharge measurement near the downstream transect at a good measuring site. If possible, take another discharge measurement near the upstream transect to verify the earlier discharge. Discharge measurements should be made according to methods recommended by the U.S. Geological Survey. Figure 2 is an example of a completed Department of Fish and Game Discharge Measurement Note form.

Equipment Setup

After you have established benchmarks, BM, at all habitat and control transects you are ready to make elevation measurements. Set up and level the instrument (transit or level) at a point where you have a clear view of all or most of the transect. Be sure to set the tripod on firm ground. On snow-covered ground, dig down to solid ground and set the tripod legs on it. This will preclude instrument settling during the survey which could introduce errors into your surveyed elevation data.

If the distance between transects is less than 50 feet, you can measure more than one transect from the same instrument location as long as the rod can be seen and read. However,

DISCHARGE MEASUREMENT NOTES

Department of Fish & Game

eam Deer Creek near Anywhere, mont.

cation 200 ft. upstream from Hiway 10 bridge

te 9-28 1975 Party J. Smith

dth 37.5 Area 40.95 Avg. Vel. 1.98 Disch. 81.1 G.H. .79

ter Type AA Meter No. 59404

sp. Rod Method .6 No. Secs. 26 Hor. Angle Coef. Noted

in Before Measurement 3:15 Spin After Measurement 2:45

GAGE READINGS				
me		Recorder	Inside	Outside
10	Start			.79
45	Finish			.79
eighted mean G.H.				—

H. change 0 in 1/2 hrs.

Air Temp. 63 F @ 1655

Water Temp. 54 F @ 1655

Weather Sunny, clear, warm

Maximum discharge in partial section: 6.3 cfs = 7.8 % of total flow

nditions at measuring site: Cross-section small rubble and gravel. Good measuring site. Gage pool clear.

ow Even, deepest in center of X-section

marks Turbidity sample collected.

quatic Habitat Notes: Water very low and clear. Algae growth on streambed. Side channel 100' upstream barely flowing. main channel Too shallow to float. Most undercut banks exposed, over hanging brush providing minimal cover. Not a suitable long-term flow.

H. of zero flow .18 ft.*

* complete only when installing gage

lew 1/75) Sheet 1 of 1 Sheets

River at—

Angle coefficient	Dist. from initial point	Width	Depth (RB 1610)	Observation depth	Revolutions	Time in seconds	Velocity: At point	Velocity: Mean in vertical	Adjusted for hor. angle or	Area	Discharge
	3	.75	0		0	—	0			0	0
	4.5	1.5	.15		5	62	.196			.225	.044
	6.0		.3		7	40	.401			.45	.180
	7.5		.45		10	44	.515			.675	.348
	9.0		.6		20	47	.948			.9	.853
	10.5		.8		20	43	1.03			1.2	1.236
	12.0		1.0		25	46	1.2			1.5	1.80
	13.5		1.2		30	42	1.58			1.8	2.844
	15.0		1.4		40	48	1.84			2.1	3.864
	16.5		1.6		30	40	1.65			2.4	3.96
	18.0		1.6		50	48	2.29			2.4	5.496
	19.5		1.6		50	46	2.39			2.4	5.736
	21.0		1.5		40	44	2.0			2.25	4.50
	22.5		1.45		50	41	2.64			2.175	5.829
⊙	24.0		1.6		40	51	1.73			2.4	4.152
	25.5		1.5		40	42	2.1			2.25	4.725
	27.0		1.4		50	50	2.2			2.1	4.62
	28.5		1.4		50	44	2.5			2.1	5.25
	30.0		1.5		50	44	2.5			2.25	5.625
	31.5		1.5		60	47	2.8			2.25	6.3
	33.0		1.45		50	47	2.34			2.175	5.089
	34.5		1.3		50	50	2.2			1.95	4.29
	36.0		1.1		40	49	1.8			1.65	2.97
	37.5		.6		20	42	1.06			.9	.954
	39.0	1.5	.3		20	48	.928			.45	.418
	40.5	.75	0		0	—	0			0	0
	37.5	37.5								40.95	81.083
			LB 1645								

Figure 2. Example of completed discharge measurement note form.

for transect distances greater than 50 feet, the instrument should be moved to the next transect. This procedure helps avoid errors in reading the rod and subsequently in the elevation data.

Note: 50 feet is an arbitrary distance. The intent here is to insure best accuracy and promote good surveying techniques. Judgment will be required by the investigator in some situations.

On wadeable streams, attach the measuring tape at the beginning of the transect (transect station 0+00) by attaching the end of the tape to a small nail driven into the top of the wooden survey stake or to the metal rod, or spike which has been driven into the ground at the beginning of the transect. This method reduces manpower needs by allowing the rod man to also measure the distance of each elevation measurement along the transect as he crosses the channel. On larger, unwadeable streams a tape will not be feasible unless used from a boat. In this situation, you can also use the stadia hairs in a transit to measure distances along the transect (see page

Surveying Mechanics

This section describes a field situation you may experience and will serve as a guide to the mechanics of making transect measurements. Refer to Figures 3 and 4 in this discussion.

Transect 1 has been established across a stream channel. The total length of the transect is 90.9 feet between points A and N (Figure 3). Elevation measurements in this example begin from the left streambank. To determine the elevations between points A and N, it is necessary to set up the level several times such as at B, D, M, and to establish intermediate points such as C, E, L, etc. These are the conditions commonly met with in practice, and will serve as an illustration of the general methods of direct leveling (from DeGroot 1954).

Let the elevation of point A be assumed as 1,000.00 feet. This is the "planned" elevation. The level is first set up at point B so that a rod held at A will be visible through the telescope. The reading of the rod is found to be 0.50 feet. The height of instrument, abbreviated H.I., is found by adding this reading to the elevation of point A. Thus H.I. = 1,000.00 + 0.50 = 1,000.50 feet. Since the rod reading at A is taken by directing the line of sight back toward the start of the line, it is called a backsight reading, or simply a backsight, and is abbreviated B.S. A better definition of a backsight, however, is a rod reading which is taken on a point of known elevation to find the height of instrument, H.I. Since a backsight is usually added to the elevation of the point on which the rod is held, a backsight is often called a plus sight, writen +S.

After the H.I. has been determined by a backsight on A, a point C is selected which will allow a rod reading to be made and a reading is taken on a rod held at C. If this reading is 12.32 feet, the point C is 12.32 feet below the line of sight, and the elevation of C is 1,000.50 – 12.32 = 988.18 feet. This reading is called a foresight reading, or foresight, and is abbreviated F.S. A foresight is taken on a point of unknown elevation in order to determine that elevation from the height of instrument. Since the reading for a foresight is subtracted from the height of instrument to get the elevation of the point on which the rod is held, a foresight is sometimes called a minus sight and is written –S.

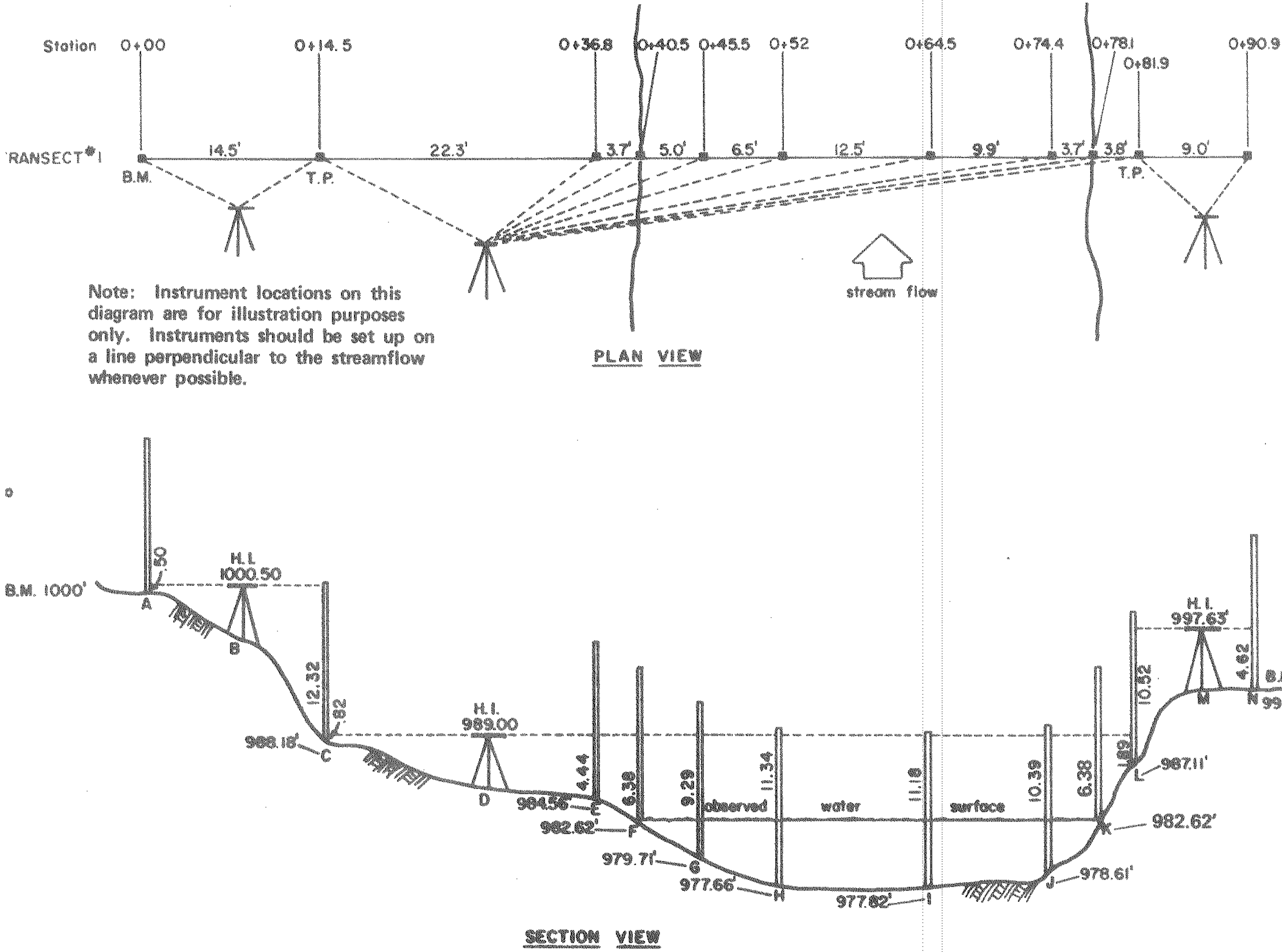
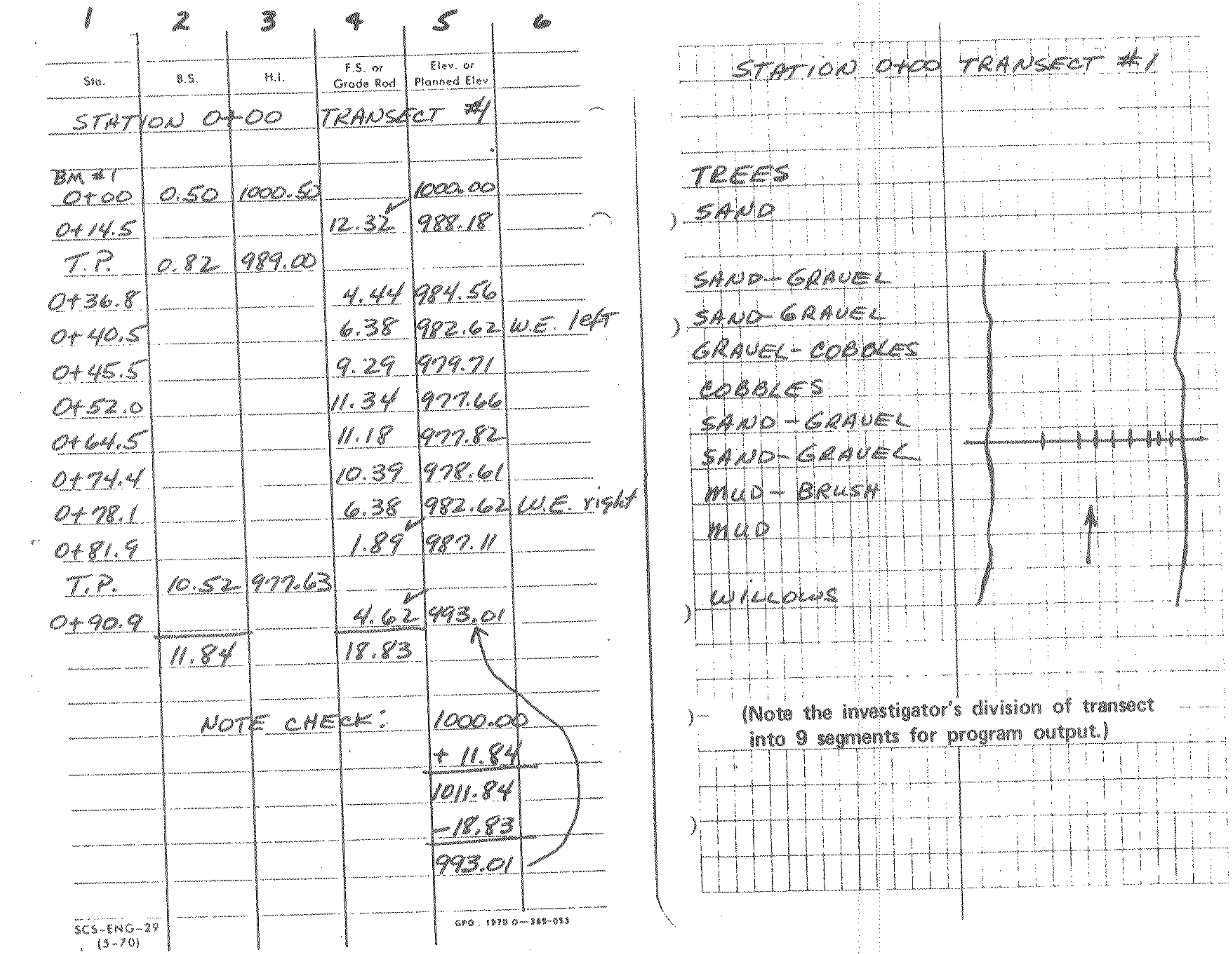


Figure 3. Mechanics of transect surveying.



1 Sta.	2 B.S.	3 H.I.	4 F.S. or Grade Rod	5 Elev. or Planned Elev.	6
STATION 0+00			TRANSECT #1		
BM #1 0+00	0.50	1000.50		1000.00	
0+14.5			12.32	988.18	
T.P.	0.82	989.00			
0+36.8			4.44	984.56	
0+40.5			6.38	982.62	W.E. left
0+45.5			9.29	979.71	
0+52.0			11.34	977.66	
0+64.5			11.18	977.82	
0+74.4			10.39	978.61	
0+78.1			6.38	982.62	W.E. right
0+81.9			1.89	987.11	
T.P.	10.52	977.63			
0+90.9			4.62	993.01	
	11.84		18.83		
	NOTE CHECK:			1000.00	
				+ 11.84	
				1011.84	
				– 18.83	
				993.01	

SCS-ENG-29 (5-70)

GPO . 1970 O—385-053

STATION 0+00 TRANSECT #1

TREES
SAND
SAND-GRAVEL
SAND-GRAVEL
GRAVEL-COBBLES
COBBLES
SAND-GRAVEL
SAND-GRAVEL
MUD-BRUSH
MUD
WILLOWS

(Note the investigator's division of transect into 9 segments for program output.)

Figure 4. Example of entries in engineer's field notebook.

While the rodman remains at C, the instrument is moved to D and set up, but not so low that the line of sight will go under the bottom of the rod when it is again held at C. After the instrument is releveled, the reading 0.82 is taken as a backsight to point C, and the H.I. at D is 988.18 + 0.82 = 989.00 feet. When this reading is taken, it is important that the rod should be held on exactly the same point that was used for the foresight when the instrument was at B. The point C on which the rod is held should be some stable object, so that the rod can be removed and put back in the same place as many times as may be necessary. For this purpose, a sharp-pointed rock, or a well-defined projection on some permanent object, is preferable, but if nothing better is available, a stake or peg can be driven firmly in the ground and the rod held on top of it. Such a point as C, on which both a foresight and a backsight are taken, is called a turning point, abbreviated T.P.

When the H.I. at D is known, another point, E, is chosen and a foresight of 4.44 feet is obtained. Then the elevation of E is 989.00 – 4.44 = 984.56 feet.

Since points E through L are all along the line of sight from point D, elevations can all be read from point D. Each of these point elevations is determined by subtracting the rod reading from 989.00 feet, which is the H.I. at point D. Points M and N are above the line of sight from point D. Therefore, the instrument must be moved to a higher location and another turning point (M) established. The instrument is moved to point M and releveled. Then the backsight on L is 10.52 feet. The new H.I. at M is 987.11 + 10.52 = 997.63 feet. The foresight to N is 4.62 feet and the elevation of N is 997.63 – 4.62 = 993.01 feet. Since point N is the other end of the transect, it is established as another benchmark, BM. Instead of moving the instrument to point M, it could also have been moved back to point B, as long as the rod held at points L and N was in the line of sight and could be read.

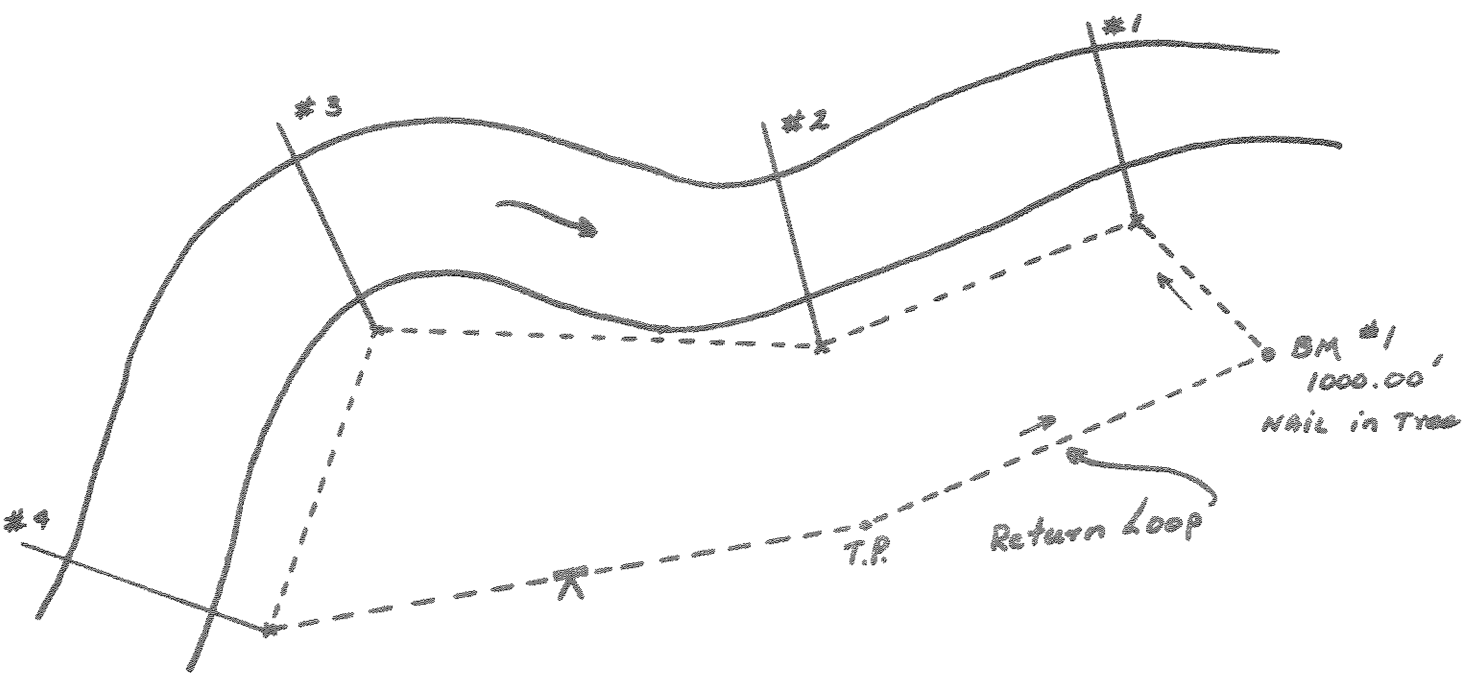
Each of the backsights, instrument heights, front sights, and point elevations is recorded in the field notebook as shown in Figure 4. It is important to record each type of rod reading in the proper column; i.e. backsight under B.S., etc. Otherwise, elevation data cannot be calculated correctly.

The following method of checking field notes affords a reliable check on the elevations of turning points and heights of instrument, which in a general way is a check on the line of levels as a whole, since all other elevations are determined from them. The method is based on the fact that all the backsights are additive or (+) quantities and all the foresights are subtractive or (–) quantities. Therefore, if the sum of all the backsights in a line of levels, or any portion of it, is added to the elevation of the starting point, and from this sum all of the foresights on turning points in the same portion are subtracted, the remainder is the last height of instrument or the elevation of the last turning point, depending upon whether the last sight is a backsight or a foresight. Thus in our example, the sum of all backsights is 11.84, the sum of all foresights at turning points is 18.83, and the beginning elevation is 1,000.00 feet. Thus 1,000.00 + 11.84 – 18.83 = 993.01 feet, the elevation at point N. It is important to include only the foresights at turning points, not those at intermediate points, in these calculations. The checking procedure can be done at the bottom of the field notes.

The difference in elevation from the BM of one transect to the BM of the next transect must be determined so you have a starting point elevation at each transect, and so all transects are tied together by elevation. These elevations are used in computing the energy slope of the stream reach. Elevation differences between transects can be determined by setting the instrument up at a location where both the preceding transect BM and the next transect BM upstream can be seen. For example, place the rod at transect 1 BM (1,000.00 feet elevation) and take a rod reading or backsight. Add this reading to 1,000.00 to determine the H.I. Then take a rod shot at transect 2 BM (foresight) and subtract the reading from the H.I. This is the elevation of the starting point for transect 2. For example, if the elevation of BM 1 is 1,000.00 feet, the backsight to BM 1 is 7.29, and the foresight to BM 2 is 4.38 feet, the elevation of BM 2 is 1,000.00 + 7.29 – 4.38 = 1,002.91 feet.

The elevation to BM 3 is determined in the same manner except you can use the elevation of BM 2 (1,002.91) as the beginning elevation. Also, any time there is not a line of sight between two benchmarks or the distance is too great to read the rod, you will have to establish one or more intermediate benchmarks, or turning points, to reach the next transect BM and find its elevation.

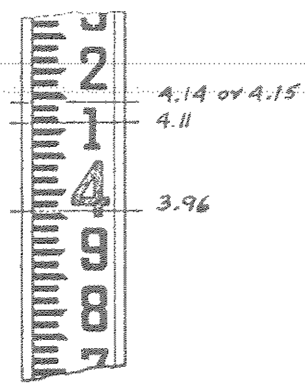
If time permits the best check on your elevation data is to run a "level loop" from your last transect BM back to the beginning elevation in the study section (such as 1,000.00). You do this in the same manner as you tied the transects together, i.e., continue to establish turning points until you reach the beginning elevation. If you began with an elevation of 1,000.00 you should end up at elevation 1,000.00 at your starting point. If you do not, a mistake has been made. In running a level loop, do not return along the same line you went up. The diagram below illustrates how to run a level loop.



The principal sources of error in leveling are (1) defects in the instrument, (2) failure to properly level the instrument, (3) failure of the rod man to hold the rod plumb, (4) mistakes in reading the rod, and (5) improperly recording the rod readings or recording them in the wrong columns.

For purposes of the WSP, all rod readings should be read to hundredths of a foot and elevations calculated to tenths of a foot.

An example of how to read a Philadelphia rod is shown below. The number 4 on the rod will be in the color red. All other numbers are black. When the hairline falls midway between the graduations the number may be rounded either up or down. When it falls other than midway between graduations the reading should be rounded to the graduation nearest the hairline.



Each angled graduation represents a whole number, i.e., 4.0, a tenth, i.e. 4.10, or a hundredth, i.e. 4.05, and allows easier reading of the rod.

When using an instrument with stadia hairs for leveling, be sure and make the foresight reading with the center hairline, not the top or bottom hairline.

If you use stadia to make your distance measurements the procedure is as follows: Read the point elevation of the rod with the center hairline. Then set the bottom hairline on an even foot mark by adjusting the level of the telescope up or down. Make a rod reading with the bottom hair and the top hair. Subtract the bottom reading from the top reading and multiply the difference by 100. For example, if the bottom hairline is set on 4.00 feet and the top hairline reads 4.92 on the rod, the distance from the instrument to the rod is 4.92 – 4.00 = 0.92 x 100 = 92 feet. Note: It is not a requirement to put the bottom hairline on an even foot mark, but it is more convenient and accurate to do so.

Most instruments have a stadia constant of 1.0, which means for each 1.00 foot difference between the top and bottom hairlines the distance is 100 feet. If an instrument does not have a stadia constant of 1.0, the difference in rod readings would have to be multiplied by the constant x 100. For example, if the stadia constant is 0.99, the distance in the previous example would be 4.92 – 4.00 = .92 x 0.99 x 100 = 91.08 feet.

Be sure and relevel the telescope before taking the next level shot if you use the stadia as described above.

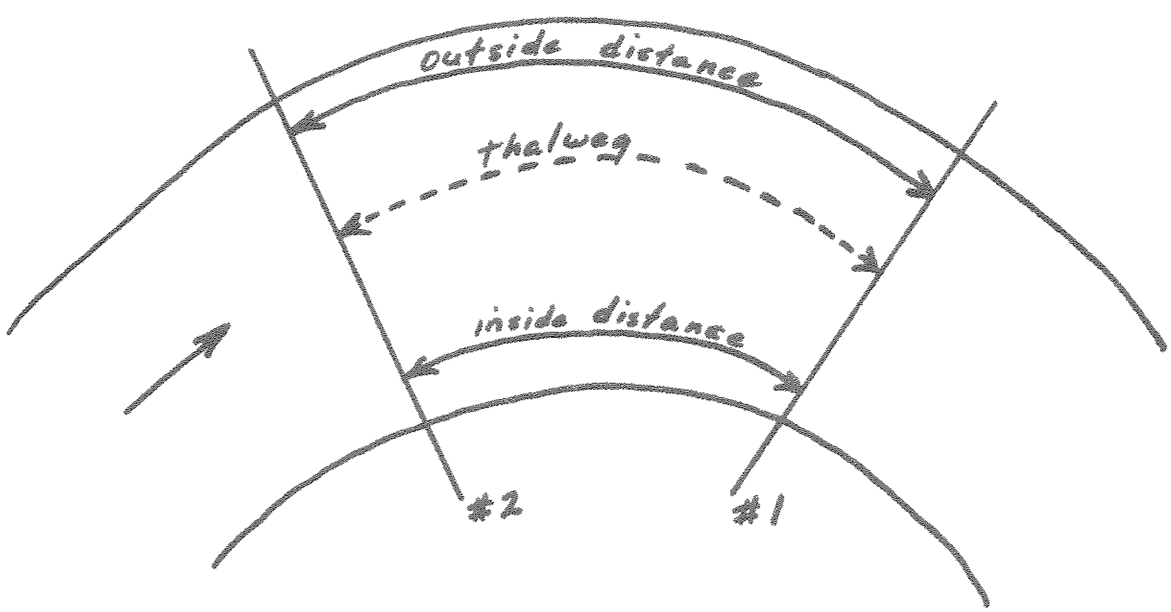
Special Considerations

Elevation shots need not be made along the transect at regular intervals, but only where changes in channel configuration occur. A flat channel will not require as many measurements as an irregular channel, but the deepest part of the channel (thalweg) should be located.

If you are interested in flood flows, it is useful to determine elevations of high water marks and include them in the transect elevation data. This will give another set of elevations to firm up the field data and to help determine the proper energy slope of the stream reach under study. However, if you are not concerned with flood flows which leave the main stream channel, you need only confine your measurements to the portion of the channel where the flows of interest will occur. However, it is convenient to measure from the top of one bank to the top of the other for data plotting purposes.

Always take a shot at water's edge on both banks and mark these on the field notes as W.E. left, and W.E. right (see Figure 4). If rod readings at both water's edge are different, the cross section has not been taken perpendicular to the flow or an error has been made.

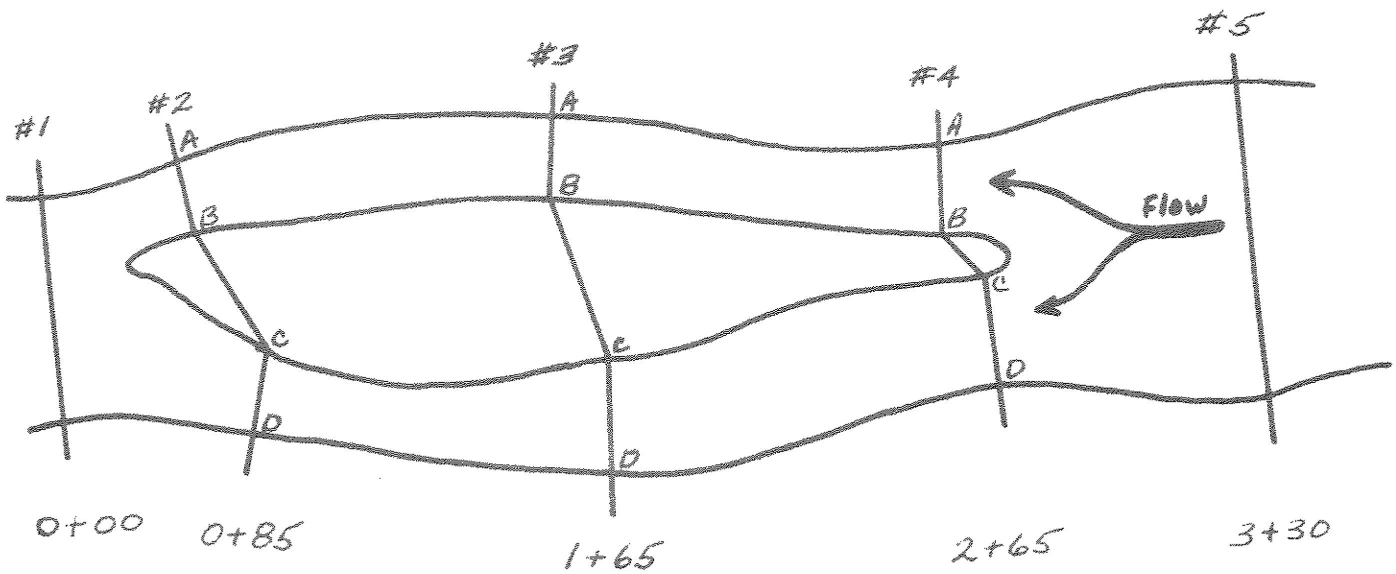
Measure distance between transects along line of flow or along the thalweg (deepest part of the channel). If a meander occurs between two transects, measure inside and outside distances plus the thalweg distance as shown below.



If a bridge is included in the stream reach, three transects must be made: one at the bridge site, one 50 feet upstream and one 50 feet downstream from the bridge. A bridge normally acts as a flow control point.

If log jams or debris dams occur in the study reach, transects should be taken above and below these areas, since they will provide some form of flow control for at least part of the study reach. Submit a photo of the log or debris dams or bridge.

When an island is included in a reach, transects must be taken upstream and downstream from the island and where the channels around the island begin and end (shown in the figure below as transects 1, 2, 4 and 5). As many other transects may be made across the island as desired by the investigator (such as transect 3 in the figure below).



A transect across an island should begin and end at the same water surface elevation. These elevations will not necessarily be on the same line. For example, at each transect in the figure above, points A, B, C, and D are all at the same water surface elevation. Elevation readings must be made across the island to tie the two parts of the transect together, i.e., part AB must be tied to part CD, forming a continuous transect.

Streambed Materials

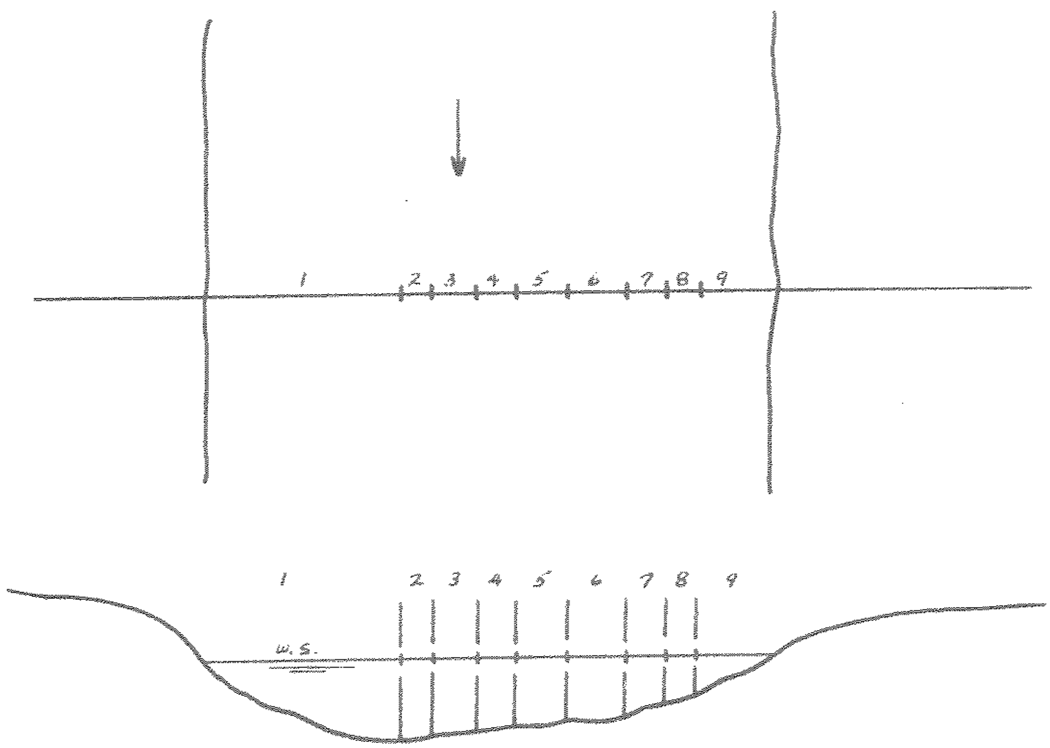
As you make elevation measurements along a transect, be sure to note where streambed materials (bottom types) change. This is important in determining roughness coefficients, n, for each transect segment. To assist in determining bottom types, the following material sizes should be described:

Bedrock — large mass of solid rock
Boulders — rocks over 12 inches in diameter
Cobbles (rubble) — rocks 3.0 to 11.9 inches in diameter
Gravel — rocks 0.1 to 2.9 inches in diameter
Sand, silt, clay — particles less than 0.1 inches in diameter
Vegetation — describe type (weeds, moss, etc.) and thickness of mat above streambed

Materials should be described in survey notes as gravel, or gravel-sand, or rubble-gravel-sand, etc. Be sure and describe the types of materials found generally at the transect site, not just those lying beneath the transect line. Also note location and point of change of bottom types along the transect.

Transect Division

As you are surveying a transect, it is important to note which portions of the transect are of most importance to you. The WSP Program output can give you specific data on up to nine (9) separate segments of a transect. For example, if the center half of the transect is the most suitable for brown trout spawning, and this is what you are interested in, you can request program output data for the nine segments as shown below (there is no sense collecting data on less important parts of the transect).



Division of the transect can be done by marking your plotted cross-section at the desired transect distances as shown in Figure 5. The Bureau will segment the output data from the transect distance you indicate. This division of the transect does not have to be done in the field, i.e., point elevations do not have to be made at the divisions you select. However, it is important to make field notes on the portions of the transect you will later want specific data on (see Figure 4). By reducing the width of each segment, you can relate velocities and depths more specifically to the criteria for the species. Velocities predicted by WSP for each segment at different flows are averages based on bottom types (roughness coefficients), the energy slope, transect configuration and stream section. By reducing the width of each segment you narrow the range of the predicted average velocity and can relate it more precisely to the biological requirements of the fish.

Photographs

A photo should be taken across each transect, preferably from both directions. Either color or black and white photos are acceptable. Photos showing overall views of the stream reach should also be taken. These photos should be submitted to the Bureau with the transect data and will be used by them to help interpret field data you submit. A convenient way to submit photos is to attach them to the plotted cross-section sheet for each transect.

Field Notes

Figure 4 shows how field notes should be completed. Columns 1 through 4 are completed in the field. Column 5 is completed from the data in columns 1 through 4. Column 6 can be used for showing water's edge, remarks, etc. The facing grid sheet can be used to describe bottom types. Also use the grid sheet for any notes or sketches necessary to describe the stream section or transect layout, how you made the measurements, or how you want the transects divided in the computer output analysis.

OFFICE METHODS

Processing the Field Data

Plotting Transect Data

When field data collection is completed, elevation data from individual transects should be plotted by the investigator on cross-section paper. The scale used is not particularly important, but should be large enough to allow easy interpretation. Horizontal and vertical scales do not necessarily have to be the same. The plotted data should show location of bottom types along the transect, types of vegetation on the overbank, and identify left and right streambanks (see Figure 5).

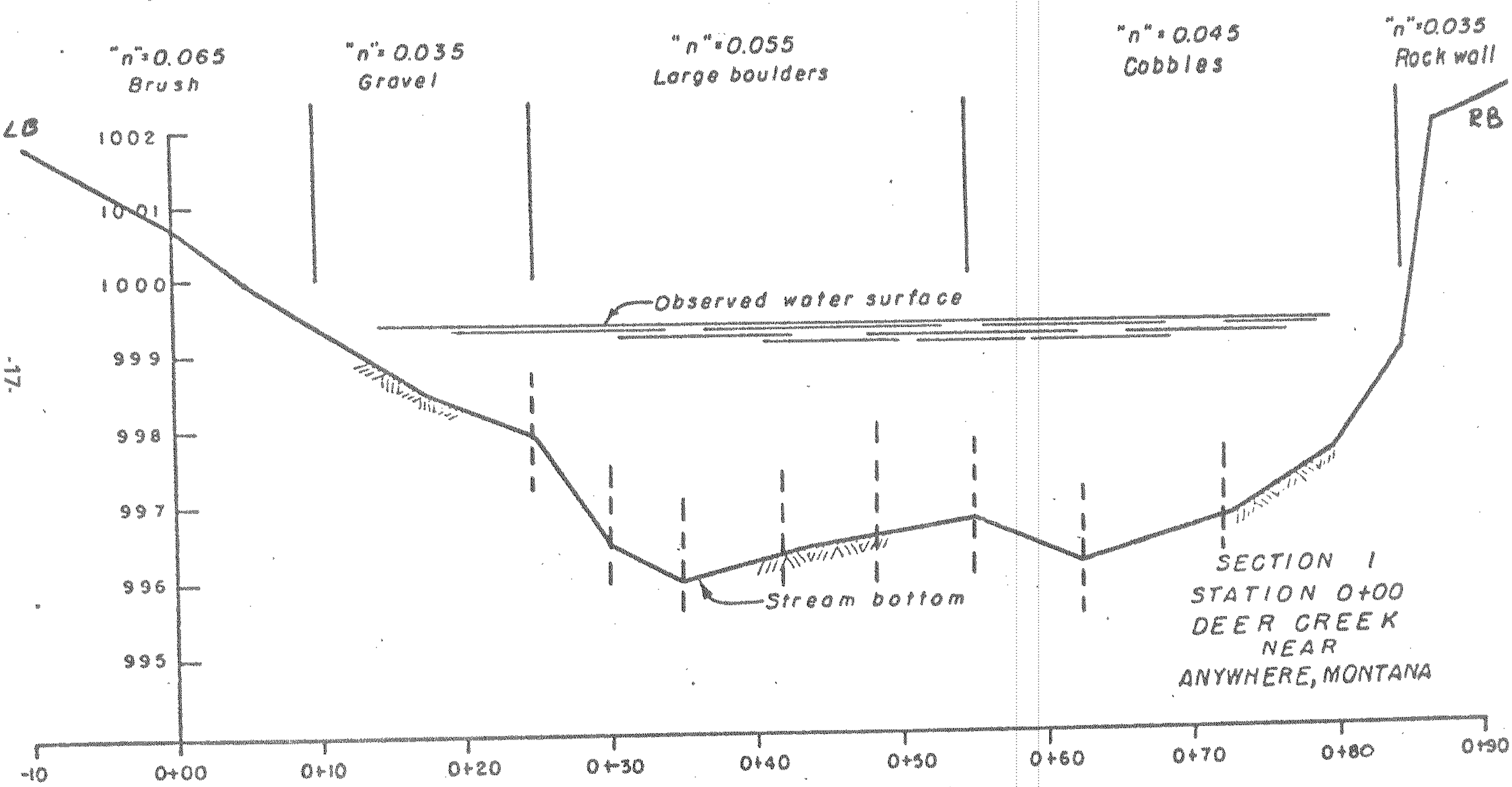


Figure 5. Example of plotted cross-section with segment divisions (vertical dotted lines).

Submission of Data to the Bureau

The package of data which should be submitted to BuRec includes:

(1) Photocopies of original field survey notes
(2) Plotted cross sections
(3) Photos of transects and overview of stream reach
(4) A map or aerial photo of stream reach with transects located on it
(5) Stream discharge measurement notes
(6) Name and phone number of the investigator

Again, all data and photos should be submitted in order beginning with transect 1. Also, be sure to specify the segments of the transects you want specific data on.

Computer Analysis

After data is received at the Bureau, it is readied for keypunching and processing through the computer. An edit routine is used to check the keypunched data for errors. Roughness coefficients are determined from the field observations and photographs. An energy slope is determined from the streambed thalweg and observed water surface elevations. These observed water surface elevations must be correlated to one specific streamflow as previously mentioned. The WSP Program processes the data from the most downstream transect through the most upstream transect.

The computer output for the observed flow is examined to determine if predicted water surface elevations match observed values. If necessary, adjustments are made in roughness coefficients, transects, and station distances to bring predicted values within ± 0.1 foot of the observed values. After these adjustments have been made, a series of flows that includes a probable low flow and a flood flow (if desired) are set up. This series of flows is combined with the observed flow and transect data and run on WSP.

If you have specific flows you would like to have run through the program, you may request them when you submit the data to the Bureau. Otherwise the Bureau will run various flows through WSP based on gage records or comparable data.

Available output from the WSP Program includes specific data for each transect and summary tables of data for all flows run. Output includes transect measurements, main channel distances, water surface elevations, main channel discharges, flow velocities across the transect, roughness coefficients, tractive force (amount of force exerted upon stream bottom), conveyance areas and widths, and hydraulic radii. Examples of program output summary tables are shown in Appendix A.

From the output data the Bureau will plot a water surface profile showing water surface elevations, streambed thalweg, and transect locations by station for each discharge (Figure 14), and a rating curve for the most downstream transect (Figure 15). The investigator plots, the predicted water surface elevations on the previously plotted cross-section for each transect (Figure 16).

The computer output data and all data submitted by the investigator are returned to the investigator for analysis, and for recommendations as to the required stream resource maintenance flow.

Analysis of Data section to be added.

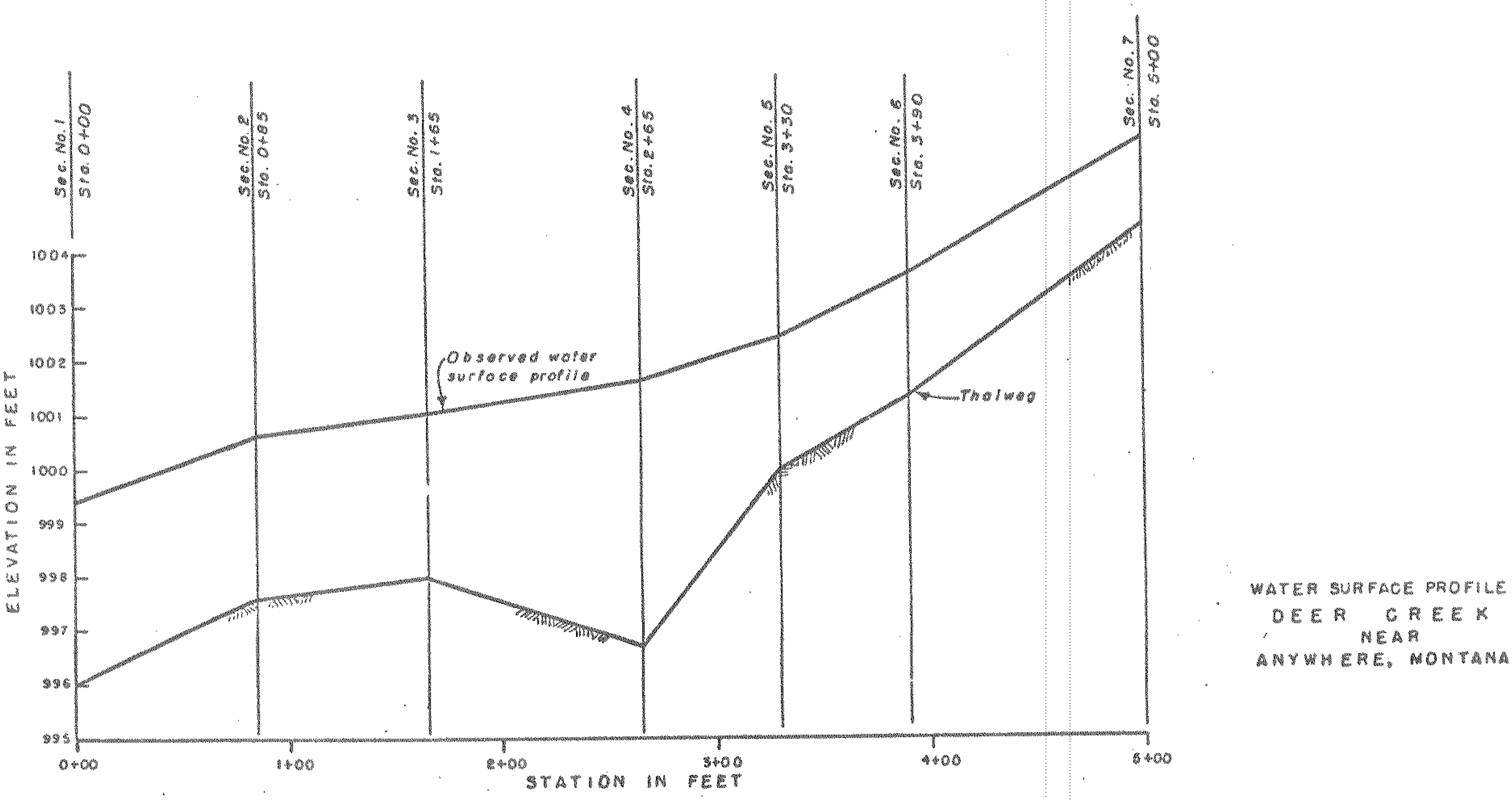


Figure 14. Example of water surface profile plotted by Bureau of Reclamation.

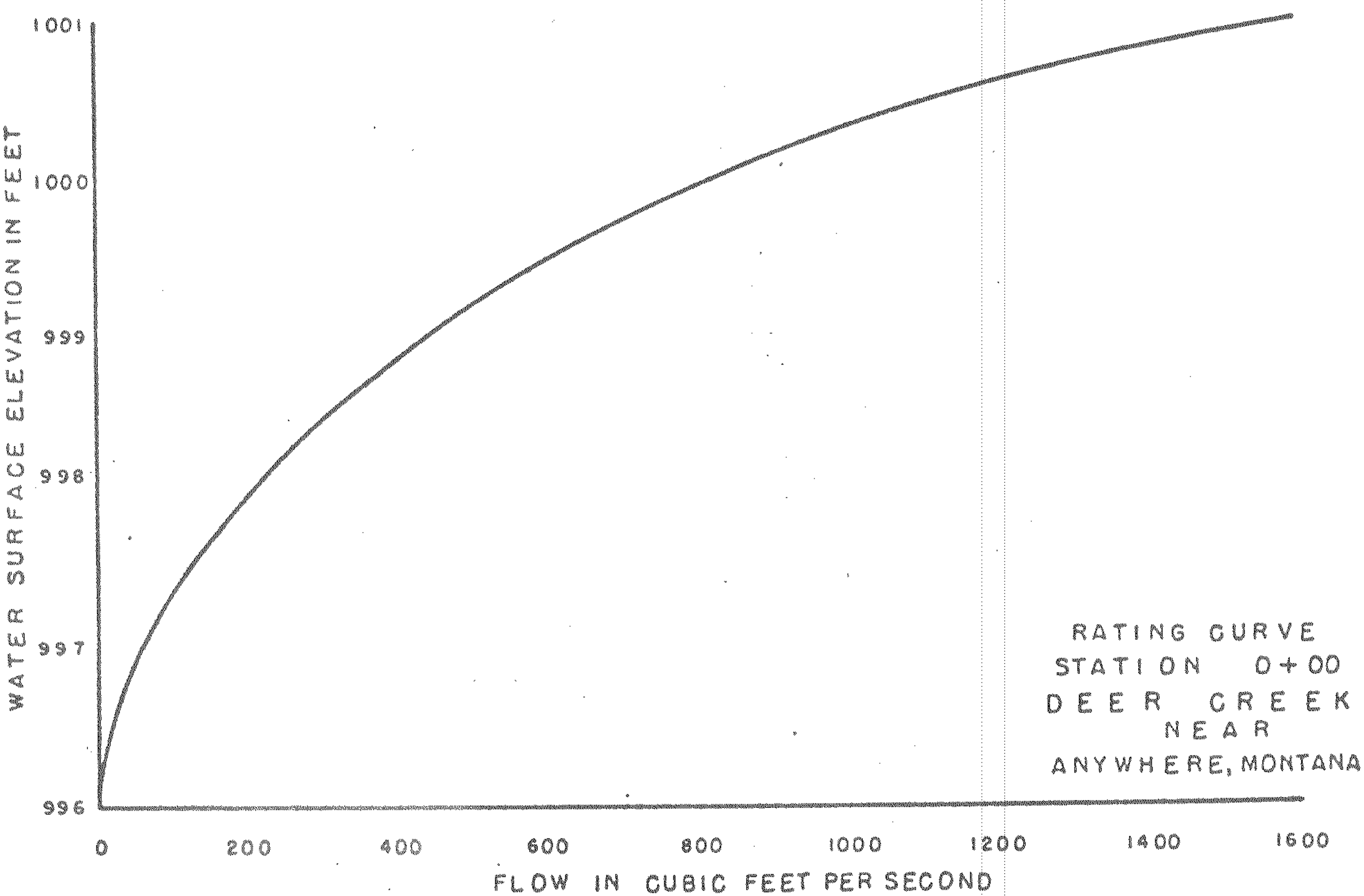
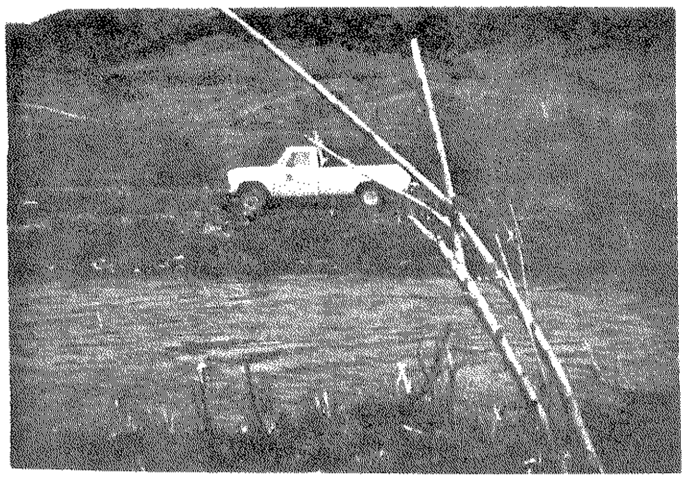
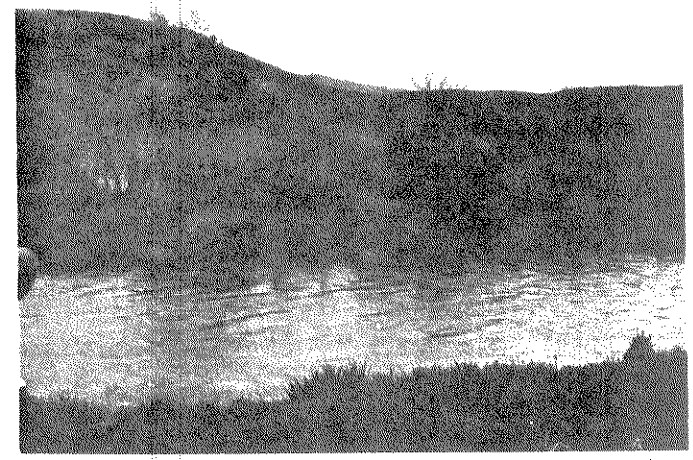


Figure 15. Example of rating curve plotted by Bureau of Reclamation.



View of transect from right bank to left bank.



View of transect from left bank to right bank.

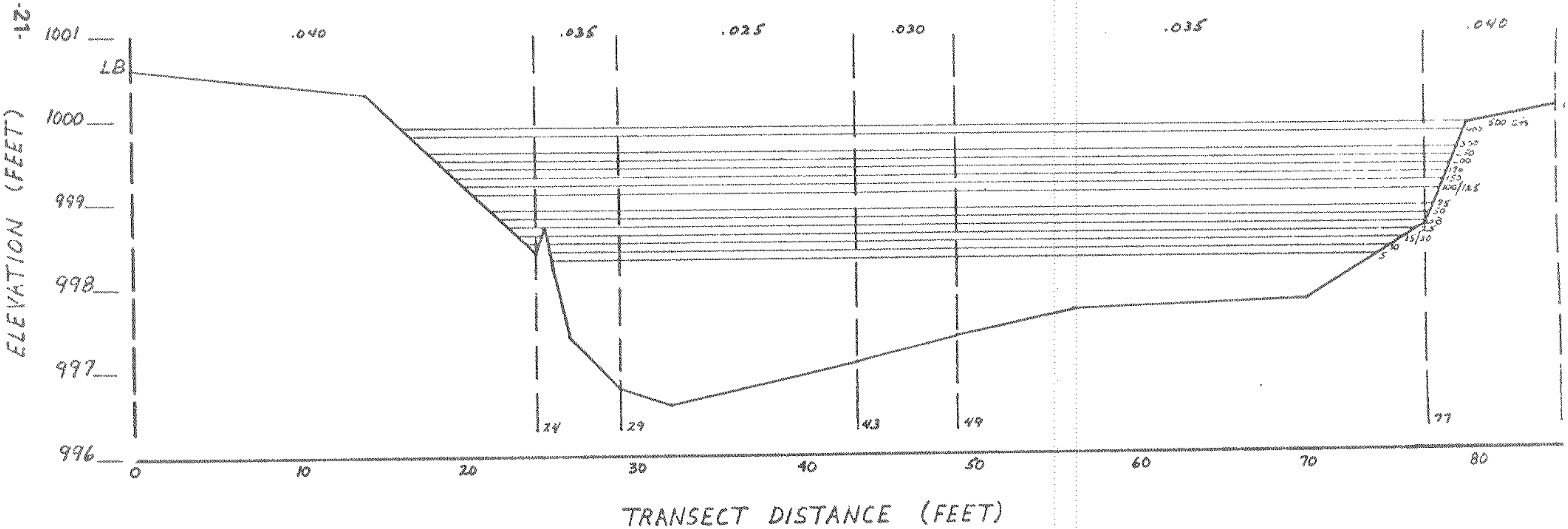


Figure 16. Plot of predicted water surface elevations at transect 0+36, Sixteenmile Creek, Montana.

REFERENCES

U.S. DEPARTMENT OF INTERIOR, BUREAU OF RECLAMATION. 1975 Paper on use of WSP in Montana Department of Fish and Game Fishery studies. Presented at Water Surface Profile Workshop, Billings, Montana on January 22, 1975.

DeGROOT, A. 1954. Leveling. International Correspondence Schools, Scranton, Pennsylvania. Serial 3068-5. 2nd ed. International Textbook Co., Great Britain. 83 pp.

APPENDIX A

Examples of WSP Program Output Summary Tables

TABLE A-1

SUMMARY OF PROFILE DATA

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS RM 1-40

Discharge Table

DISCHARGE	BEGINNING ELEVATION	ROUGHNESS MODIFIERS FOR OVERBANK	ROUGHNESS MODIFIERS FOR MAIN CHANNEL	ESTIMATED BEGINNING HYDRAULIC GRADIENT
5.	REDUNDANT	1.00	1.00	.01640
10.	REDUNDANT	1.00	1.00	.01640
15.	REDUNDANT	1.00	1.00	.01640
20.	REDUNDANT	1.00	1.00	.01640
25.	REDUNDANT	1.00	1.00	.01640
50.	REDUNDANT	1.00	1.00	.01640
75.	REDUNDANT	1.00	1.00	.01640
100.	REDUNDANT	1.00	1.00	.01640
125.	REDUNDANT	1.00	1.00	.01640
150.	REDUNDANT	1.00	1.00	.01640
176.	998.80	1.00	1.00	REDUNDANT
200.	REDUNDANT	1.00	1.00	.01640
250.	REDUNDANT	1.00	1.00	.01640
300.	REDUNDANT	1.00	1.00	.01640
400.	REDUNDANT	1.00	1.00	.01640
500.	REDUNDANT	1.00	1.00	.01640

TABLE A-2

SUMMARY OF OPTION AND COORDINATE DATA

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

Table of Cross Section Data

STATION	36.	NUMBER OF ROUGHNESS SEGMENTS IN SECTION	ELEVATION OF SEDIMENT DELTA	ELEVATION OF OBSERVED PROFILE	INCREMENTAL DISCHARGE
		6	0.0	0.0	0.

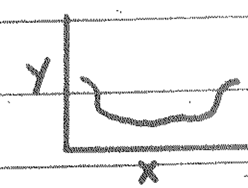
NUMBER OF COORDINATE PAIRS = 15
OPTION PARAMETERS OF ZERO INDICATE A REDUNDANCY

RIGHT MOST COORDINATE	ROUGHNESS COEFFCIENT	REACH LENGTH OF CENTROID
24.	.040	36.
29.	.035	36.
43.	-.025	36.
49.	.030	36.
77.	.035	36.
85.	.040	36.

This is "n" for each segment in the transect.

X COORDINATES	0.0	14.0	24.0	24.5	25.0	26.0	29.0	32.0	43.0	49.0
Y COORDINATES	1000.6	1000.3	998.4	998.7	998.2	997.4	996.8	996.6	997.1	997.4
X COORDINATES	56.0	70.0	77.0	79.0	85.0					
Y COORDINATES	997.7	997.8	996.7	999.9	1000.1					

This is data used to plot cross-section profile.



i.e., 0-24 ft
24-29 ft
29-43 ft
43-49 ft
49-77 ft
77-85 ft

These are positions and lengths of segments along the transect beginning at 0+00 (See Figure 16). There are six segments in this Transect.

TABLE A-3

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

TABLE OF MAIN CHANNEL DISTANCES

STATION	DISTANCE BETWEEN CROSS SECTIONS	CUMULATIVE DISTANCE
0.		0.
	36.	
36. (Station 0+36)		36.
	64.	
100.		100.
	57.	
157.		157.
	21.	
178.		178.
	84.	
262.		262.
	122.	
384.		384.
	117.	
501.		501.
	26.	
527.		527.
	73.	
600.		600.
	65.	
665.		665.
	133.	
798.		798.
	136.	
934.		934.
	46.	
980.		980.
	92.	
1072.		1072.
	53.	
1125.		1125.
	81.	
1206.		1206.
	35.	
1241.		1241.
	19.	
101260.		1260.
	40.	
201300.		1300.
	41.	
1341.		1341.
	25.	
1366.		1366.
	48.	
1414.		1414.

This Table shows station numbers and distances between stations, or Transects.

TABLE A-4

SIXTFENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

TABLE OF WATER SURFACE ELEVATIONS

STATION	THALWEG	FLOWS IN CFS: 5. / 200.	10. / 250.	15. / 300.	20. / 400.	25. / 500.	50.	75.	100.	125.	150.	176.
		WATER SURFACE ELEVATIONS----FEET										
0.	997.8	998.0	998.1	998.1	998.2	998.2	998.4	998.5	998.6	998.7	998.7	998.8
		998.9	998.9	999.0	999.2	999.4						
36.	996.6	998.3	998.4	998.5	998.5	998.6	998.8	998.9	999.0	999.1	999.2	999.2
		999.3	999.4	999.5	999.7	999.8						
100.	995.7	998.3	998.4	998.5	998.5	998.6	998.8	998.9	999.0	999.1	999.2	999.3
		999.3	999.4	999.5	999.7	999.9						
157.	993.6	998.3	998.4	998.5	998.5	998.6	998.8	998.9	999.1	999.2	999.3	999.4
		999.4	999.6	999.8	1000.0	1000.3						
178.	996.1	998.3	998.4	998.5	998.5	998.6	998.8	998.9	999.1	999.2	999.3	999.4
		999.5	999.6	999.8	1000.1	1000.4						
262.	996.7	998.3	998.4	998.5	998.5	998.6	998.8	999.0	999.1	999.2	999.3	999.4
		999.5	999.6	999.8	1000.1	1000.4						
384.	997.3	998.3	998.4	998.5	998.6	998.6	998.8	999.0	999.2	999.3	999.4	999.5
		999.6	999.8	1000.0	1000.3	1000.6						
501.	996.6	998.4	998.4	998.5	998.6	998.6	998.9	999.1	999.3	999.4	999.5	999.6
		999.8	1000.0	1000.2	1000.5	1000.8						
527.	997.3	998.4	998.4	998.5	998.6	998.6	998.9	999.1	999.3	999.4	999.5	999.7
		999.8	1000.0	1000.2	1000.5	1000.8						
600.	993.4	998.4	998.5	998.5	998.6	998.7	999.0	999.2	999.4	999.5	999.7	999.8
		1000.0	1000.2	1000.4	1000.8	1001.2						
665.	997.2	998.4	998.5	998.6	998.6	998.7	999.0	999.2	999.4	999.6	999.8	999.9
		1000.0	1000.3	1000.5	1000.9	1001.3						

The rating curve (Figure 15) is plotted from these data.
The predicted water surface elevations are also plotted from these data.

TABLE A-5

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

TABLE OF MAIN CHANNEL DISCHARGES AND VELOCITIES

FLOWS IN CFS

DISCHARGES IN CFS -/- VELOCITIES IN FT./SEC.

STATION	5. / 200.	10. / 250.	15. / 300.	20. / 400.	25. / 500.	50.	75.	100.	125.	150.	176.
0.	4. / 1.70	7. / 2.13	10. / 2.41	11. / 2.64	14. / 2.82	23. / 3.51	29. / 3.99	37. / 4.33	43. / 4.49	50. / 4.74	53. / 4.91
	60. / 5.17	70. / 5.53	79. / 5.85	97. / 6.39	113. / 6.83						
36.	5. / .15	8. / .28	12. / .39	13. / .50	16. / .60	30. / 1.04	43. / 1.40	54. / 1.72	67. / 2.05	79. / 2.34	92. / 2.64
	102. / 2.88	124. / 3.37	146. / 3.82	190. / 4.65	231. / 5.41						
100.	5. / .13	10. / .25	15. / .36	20. / .47	25. / .57	50. / 1.00	75. / 1.38	100. / 1.72	125. / 2.05	150. / 2.36	176. / 2.67
	200. / 2.93	250. / 3.45	299. / 3.93	395. / 4.81	491. / 5.62						
157.	5. / .07	10. / .13	15. / .19	20. / .25	25. / .30	50. / .56	75. / .80	100. / 1.02	125. / 1.23	150. / 1.43	176. / 1.64
	200. / 1.81	250. / 2.15	300. / 2.46	398. / 3.02	495. / 3.52						
178.	5. / .07	10. / .13	15. / .19	20. / .24	25. / .29	50. / .52	75. / .72	100. / .90	125. / 1.07	150. / 1.23	176. / 1.38

This means That at Station 0+36, at a flow of 5 cfs, The entire flow is in The main channel and has an average velocity of 0.15 fps. The remainder of The flow is in The overbank portion of The transect. The main channel is That segment of The transect with a negative roughness coefficient (See Tables A-6 & A-7).

This means That at Station 0+36, at a flow of 200 cfs, 102 cfs is in The main channel and has an average velocity of 2.88 fps.

TABLE A-6

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

TABLE OF ROUGHNESS COEFFICIENTS

STATION									
0.	.040	.035	.035	-.035	.035	.035	.040	.050	→ There are 8 segments in This Transect
36.		.040	.035	-.025	.030	.035	.040		→ There are 6 segments in This Transect.
100.			.040	-.025	.045				
157.			.040	-.025	.040				This is The main channel!
178.			.040	-.025	.050				
262.			.040	-.025	.040				
384.			.040	-.025	.050				
501.			.040	-.025	.040				
527.			.040	-.025	.040				
600.			.040	-.035	.040				
665.			.040	-.040	.040				
798.			.040	-.040	.050				
934.			.040	-.040	.040				
980.			.040	-.040	.040				
1072.			.040	-.040	.040				
1125.			.040	-.040	.040				
1206.			.040	-.035	.040				
1241.			.040	-.035	.040				
101260.			.040	-.035	.040				
201300.			.040	-.035	.040				
1341.			.040	-.035	.040				
1366.			.040	-.040	.040				
1414.			.040	-.035	.040				

TABLE A-7

Table of Flow Data

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

Indicates main channel!

STATION 0 + 36 ENGLISH UNITS — ASSUMED ELEV. 0.00 — THALWEG ELEV. 996.6 — THALWEG SLOPE -.0333

COMPUTATION LINE HF1 = .56 HV1 = .04 — AVG OVERBANK REACHES - LEFT = 36. RIGHT = 24.

LENGTH OF CENTROID	CONVEYANCE AREAS (sq')	TOP WIDTHS (ft)	HYDRAULIC RADII	ROUGHNESS COEFFICIENTS	CONVEYANCE FACTORS	VELOCITIES (fps)	DISCHARGES (cfs)
36	4	4	.9	.03500	175	.08	0
36	21	14	1.5	.02500	1682	.15	5
36	6	6	1.1	.03000	345	.10	0
36	15	25	.6	.03500	451	.06	0
SUM OR AVG	46	49			2653	.13	5

Shows entire flow of 5 cfs is in main channel.

Data in this Table is for this flow only

THIS SECTION HAS 6 ROUGHNESS SEGMENT OR SEGMENTS. 4 SEGMENT OR SEGMENTS USED FOR THIS DISCHARGE
COMPUTATION LINE HF2= .00 HV2= .00 SF VOIDED TOTAL HEAD= .32 CRIT. FLOW= 210 W.S. ELEV.= 998.34

This is the total number of segments in the Transect.

This indicates that only 4 of the 6 segments are covered by water at a flow of 5 cfs.

$$\text{Wetted perimeter} = \frac{\text{Conveyance Area}}{\text{hydraulic radius}}$$

TABLE A-7 continued

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

STATION 0 + 36 ENGLISH UNITS ASSUMED ELEV. 0.00 THALWEG ELEV. 996.6 THALWEG SLOPE -.0333

COMPUTATION LINE HF1 = .54 HV1 = .05 AVG OVERBANK REACHES - LEFT = 36. RIGHT = 24.

LENGTH OF CENTROID	CONVEYANCE AREAS	TOP WIDTHS	HYDRAULIC RADII	ROUGHNESS COEFFICIENTS	CONVEYANCE FACTORS	VELOCITIES	DISCHARGES
36	0	0	.0	.04000	0	.01	0
36	4	4	1.0	.03500	193	.14	0
36	22	14	1.6	-.02500	1828	.28	8
36	7	6	1.2	.03000	387	.19	1
36	17	25	.7	.03500	546	.11	1
SUM OR AVG	50	49			2954.	.23	10

(8) Shows 8 cfs is in main channel at a flow of 10 cfs.

THIS SECTION HAS 6 ROUGHNESS SEGMENT OR SEGMENTS. 5 SEGMENT OR SEGMENTS USED FOR THIS DISCHARGE
COMPUTATION LINE HF2= .00 HV2= .00 SF VOIDED TOTAL HEAD= .33 CRIT. FLOW= 235 W.S. ELEV.= 998.42

* * *

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

STATION 0 + 36 ENGLISH UNITS ASSUMED ELEV. 0.00 THALWEG ELEV. 996.6 THALWEG SLOPE -.0333

COMPUTATION LINE HF1 = .49 HV1 = .18 AVG OVERBANK REACHES - LEFT = 36. RIGHT = 24.

LENGTH OF CENTROID	CONVEYANCE AREAS	TOP WIDTHS	HYDRAULIC RADII	ROUGHNESS COEFFICIENTS	CONVEYANCE FACTORS	VELOCITIES	DISCHARGES
36	0	2	.2	.04000	9	.21	0
36	6	5	1.2	.03500	336	.70	4
36	29	14	2.1	-.02500	2829	1.40	43
36	9	6	1.7	.03000	686	1.00	9
36	30	28	1.1	.03500	1344	.64	19
36	0	0	.1	.04000	0	.10	0
SUM OR AVG	74	55			5204	1.15	75

THIS SECTION HAS 6 ROUGHNESS SEGMENT OR SEGMENTS. (6) SEGMENT OR SEGMENTS USED FOR THIS DISCHARGE
COMPUTATION LINE HF2= .01 HV2= .02 SF VOIDED TOTAL HEAD= .42 CRIT. FLOW= 417 W.S. ELEV.= 998.90

* * * All segments covered by water at a flow of 75 cfs.

TABLE A-8

SIXTEENMILE CREEK NEAR THE FRANCIS RANCH AND SCHOOL
THIS IS SECTION 3 OF THE CROSS SECTIONS BM 1-40

TABLE OF IN CHANNEL TRACTIVE FORCES

FLOWS IN CFS

STATION	5. / 200.	10. / 250.	15. / 300.	20. / 400.	25. / 500.	50.	75.	100.	125.	150.	176.
	TRACTIVE FORCE---LBS/SQ. FT.										
0.	.2680	.3738	.4947	.4359	.5550	.7002	.7132	.8336	.8271	.9425	.8935
	1.0292	1.1263	1.1919	1.3247	1.4034						
36.	.0008	.0019	.0040	.0043	.0062	.0172	.0300	.0421	.0597	.0771	.0984
	.1133	.1506	.1908	.2785	.3656						
100.	.0003	.0010	.0021	.0034	.0050	.0153	.0285	.0441	.0618	.0806	.1024
	.1216	.1659	.2115	.3069	.4105						
157.	.0001	.0002	.0005	.0008	.0012	.0041	.0082	.0132	.0192	.0258	.0336
	.0409	.0568	.0737	.1083	.1434						
178.	.0001	.0003	.0005	.0009	.0013	.0039	.0073	.0112	.0156	.0203	.0256
	.0302	.0403	.0505	.0706	.0897						
262.	.0006	.0019	.0038	.0061	.0086	.0228	.0377	.0536	.0712	.0885	.1060
	.1214	.1517	.1819	.2335	.2776						
384.	.0013	.0030	.0071	.0106	.0140	.0312	.0483	.0655	.0839	.1015	.1200
	.1352	.1670	.1974	.2522	.3021						
501.	.0010	.0031	.0057	.0087	.0118	.0281	.0447	.0615	.0790	.0959	.1121
	.1271	.1570	.1845	.2370	.2831						
527.	.0026	.0073	.0124	.0175	.0223	.0452	.0664	.0871	.1066	.1266	.1455
	.1611	.1952	.2263	.2840	.3345						
600.	.0008	.0027	.0052	.0082	.0113	.0290	.0480	.0672	.0869	.1060	.1243
	.1414	.1728	.2007	.2545	.3010						
665.	.0034	.0105	.0192	.0290	.0390	.0928	.1442	.1962	.2494	.3015	.3560
	.4037	.4985	.5910	.7623	.9201						
798.	.0166	.0665	.0122	.0219	.0737	.2565	.2988	.3252	.3507	.3783	.3998
	.4140	.4431	.4704	.5193	.5701						
934.	.0105	.0231	.0230	.0382	.0747	.1193	.1808	.2326	.2721	.3117	.3453
	.3766	.4247	.4670	.5373	.5957						
980.	.0291	.1165	.2621	.4660	.7023	.7637	.8896	.9837	1.0448	1.0875	1.1165
	1.1206	1.1020	1.0946	1.0449	.9985						
1072.	.0054	.0123	.0124	.0086	.0060	.0225	.0491	.0850	.1303	.1833	.2458
	.3102	.4551	.6209	.9644	1.2278						
1125.	.0012	.0029	.0031	.0024	.0019	.0070	.0150	.0256	.0384	.0527	.0686
	.0641	.1161	.1480	.2023	.2421						

APPENDIX A

Examples of WSP Program Output Summary Tables

APPENDIX B

Interim Streamflow Criteria for Aquatic Life

To be added