5.0 DEVELOPMENT OF HABITAT VERSUS FLOW RELATIONSHIPS

5.1 Overview

Following the selection of the study sites, field data were collected for use in calibrating a hydraulic model. The calibrated hydraulic model was used to estimate the amount of habitat available under different flow conditions and also to develop wetted perimeter versus flow graphs. Hydrologic analyses were conducted to develop hydrology for the study sites, and to develop procedures for determining when to dispatch field crews.

In addition, the following studies were conducted:

- Spawning location characterization to verify criteria for transect placement, described in section 5.4; and
- Comparison of alternative types of suitability criteria, described in section 5.8.

There are many interactions among field data collection, hydrologic analyses, and hydraulic model calibration, but each will be discussed separately in the following sections. The field site locations were used to select representative stream gages for hydrologic analyses, and flow measurements at some study sites were used to develop hydrology for those sites. The hydrology was used to help determine when to dispatch field crews to collect additional data. For some streams, the additional data showed the initial gage selection or hydrologic computations were incorrect, and the field data were used to modify the hydrology. Similarly, the hydraulic modeling showed errors in some of the field data, requiring additional field data collection to resolve discrepancies.

The decision to estimate the habitat needs for a study region by analyzing the habitat needs for a number of sites within that region (section 2.0) helped establish the procedures for all aspects of the study, including data collection, hydraulic calibration and modeling, and available habitat analysis.

5.2 Study Site Selection

The segment boundaries were located in the field, and within those boundaries, a study site was selected. The study site was located at an accessible location closest to the midpoint of the segment, unless that location was not representative of the segment. If the location at the midpoint was considered not representative, an alternative study site was selected within the same segment. If the stream was determined to be unsuitable for use in the study (section 4.4), it was deleted from the list, and an alternate stream was selected.

When a study site was identified, the landowner was contacted for permission to enter the site. The landowner was given a letter explaining the project, and a brief explanation of what the crews would be doing, including the use of iron pins to mark the transect end points. If the landowner did not allow access, an alternate site in the same segment was sought, or an alternate stream was selected.

Information regarding the study segments that were selected upon completion of the field data collection stage of the study is summarized in Tables 5.1 through 5.4. These tables show additional detail regarding the streams shown in bold type in Tables 4.2 through 4.5. The number of streams and stream segments in each region at that stage are summarized in Table 5.5, which is comparable to Table 4.6. Four

Table 5.1. Data for Ridge and Valley Freestone Region Study Sites

Study Site Name	County	Drainage Area	Segment Length	Length Characterized	Mesohabitat			Stream Number (Plate 1)
					Riffle	Run	Pool	
		square miles	miles	feet	percent	percent	percent	
Bear Run	Union	2.19	2.5	132	55	0	45	1
Big Fill Run, Seg. 1	Blair	7.98	3.7	314	0	57	43	2
Big Fill Run, Seg. 2	Blair	12.12	3.7	357	40	29	31	3
Big Run	Juniata	2.88	5.0	414	39	47	14	4
E. Br. Raven Creek	Columbia	2.48	2.9	535	28	25	47	90
Fowler Hollow, Seg. 1	Perry	1.81	3.1	795	56	24	20	6
Fowler Hollow, Seg. 2	Perry	5.52	3.1	328	34	32	34	7
Granville Run	Mifflin	2.74	3.4	788	50	34	16	91
Green Creek, Seg. 1	Columbia	2.55	4.0	788	49	33	18	9
Green Creek, Seg. 2	Columbia	9.42	4.0	825	32	32	36	10
Green Creek, Seg. 3	Columbia	33.24	4.0	1,010	17	17	66	11
Horning Run	Juniata	5.26	3.8	263	38	27	35	12
Kansas Valley Run	Perry	2.91	4.0	281	54	19	27	13
Laurel Run	Juniata	2.85	2.7	681	26	48	26	15
Laurel Run	Huntingdon	1.50	2.0	642	30	35	35	92
Mile Run	Union	1.37	1.2	254	22	47	31	16
Mugser Run, Seg. 1	Columbia	4.39	3.9	806	19	52	29	17
Mugser Run, Seg. 2	Columbia	8.92	3.9	655	68	33	0	18
Rapid Run, Seg. 1	Union	3.50	3.7	315	27	33	40	19
Rapid Run, Seg. 2	Union	10.74	3.7	340	35	31	34	20
Rapid Run, Seg. 3	Union	14.53	3.7	635	25	21	54	21
Salem Creek	Luzerne	2.70	4.5	839	56	31	13	22
Sand Spring Run	Union	3.22	4.5	401	26	53	21	23
Swift Run	Mifflin	3.03	2.2	99	59	41	0	24
Vanscoyoc Run	Blair	3.36	5.0	107	43	57	0	26
Wapwallopen Creek, Seg. 1	Luzerne	4.13	4.5	724	80	20	0	27
Wapwallopen Creek, Seg. 2	Luzerne	13.90	4.5	1,031	35	41	24	28
Wapwallopen Creek, Seg. 3	Luzerne	26.82	4.5	1,274	61	27	12	29
Wapwallopen Creek, Seg. 4	Luzerne	33.43	4.5	1,519	35	59	6	30

Table 5.2. Data for Ridge and Valley Limestone Region Study Sites

Study Site Name	County	Drainage Area	Segment Length	Length Characterized	Mesohabitat			Stream Number (Plate 1)
					Riffle	Run	Pool	
		square miles	miles	feet	percent	percent	percent	
Antes Creek	Lycoming	52.00	3.4	982	41	32	27	31
Big Spring Creek	Cumberland	7.30	4.8	530	4	96	0	32
Boiling Spring Run	Blair	6.30	3.4	189	76	24	0	33
Bushkill Creek, Seg. 1	Northampton	59.37	3.5	468	28	72	0	34
Bushkill Creek, Seg. 2	Northampton	79.34	3.5	369	40	60	0	35
Cedar Creek	Lehigh	11.58	4.2	572	41	59	0	36
Cedar Run	Centre	13.94	2.9	1,001	18	66	16	37
Cedar Run	Cumberland	6.08	3.3	401	26	42	32	38
Falling Spring Run	Franklin	4.20	4.7	Not available	0	100	0	39
Honey Creek	Mifflin	91.45	3.8	723	20	41	38	41
Letort Creek, Seg. 1	Cumberland	3.79	4.3	1,000	0	100	0	41
Letort Creek, Seg. 2	Cumberland	17.00	4.3	1,300	0	100	0	42
Lick Creek	Centre	10.20	2.5	1,064	58	23	19	43
Little Fishing Creek	Centre	41.76	1.7	453	26	25	49	44
Long Hollow Run	Mifflin	6.34	1.9	535	23	22	55	45
Monocacy Creek, Seg. 1	Northampton	8.45	4.4	235	58	42	0	46
Monocacy Creek, Seg. 2	Northampton	34.79	4.4	Not available	0	100	0	47
Monocacy Creek, Seg. 3	Northampton	41.56	4.4	581	15	85	0	48
Nancy Run	Northampton	5.85	2.8	260	45	55	0	49
Penns Creek, Seg. 1	Centre	15.10	4.0	1,291	10	64	26	50
Penns Creek, Seg. 2	Centre	63.50	4.0	1,086	37	46	37	51
Penns Creek, Seg. 3	Centre	89.40	4.0	1,708	15	57	28	52
Potter Creek	Bedford	12.55	3.4	280	56	44	0	53
Spring Creek	Berks	19.68	4.7	937	18	34	48	54
Spring Creek, Seg. 1	Centre	29.70	4.7	1,150	28	35	37	55
Spring Creek, Seg. 2	Centre	58.55	4.7	1,093	8	31	61	56
Spring Creek, Seg. 3	Centre	79.10	4.7	1,414	27	64	9	57
Spring Creek, Seg. 4	Centre	86.30	4.7	1,395	54	42	4	58
Trindle Spring Run	Cumberland	19.55	0.9	1,392	49	51	0	59
Trout Creek	Lehigh	7.98	1.6	443	24	32	44	60

Table 5.3. Data for Unglaciated Plateau Region Study Sites

Study Site Name	County	Drainage Area	Segment Length	Length Characterized	Mesohabitat			Stream Number (Plate 1)
					Riffle	Run	Pool	
		square miles	miles	feet	percent	percent	percent	
Beech Run	Clearfield	1.40	4.5	315	49	38	13	61
Benner Run	Centre	4.38	3.7	1,256	40	41	19	62
Bloomster Hollow	McKean	1.52	3.5	804	59	28	13	63
Cherry Run	Forest	3.35	3.2	243	29	40	31	64
Coke Oven Hollow	Somerset	1.22	3.0	226	72	0	28	65
Cush Creek, Seg. 1	Indiana	1.99	1.8	369	65	0	35	66
Cush Creek, Seg. 2	Indiana	4.85	6.1	495	42	58	0	67
Dunlap Run	Clearfield	1.20	2.7	932	24	16	60	68
E. Br. Spring Creek Seg. 2	Elk	11.45	5.7	562	30	37	33	70
Fall Creek, Seg. 1	Somerset	3.41	2.6	381	38	0	62	71
Fall Creek, Seg. 2	Somerset	5.89	2.6	315	83	0	17	72
Findley Run	Indiana	6.17	4.9	Not Available	100	0	0	73
Lower Two Mile Run, Seg. 1	Venango	2.72	3.5	356	42	22	36	74
Lower Two Mile Run, Seg. 2	Venango	8.43	3.5	509	42	29	29	75
Lyman Run	McKean	1.00	2.1	487	25	32	43	76
McClintock Run	Somerset	11.77	4.6	598	48	30	22	77
McEwen Run	Jefferson	2.13	3.1	257	33	46	21	78
Meyers Run	Centre	0.47	0.9	600	37	34	29	79
Mill Run	Clinton	1.70	1.7	945	53	16	31	80
Red Run	Cambria	1.43	2.5	259	62	20	18	82
Seaton Run	Jefferson	2.40	2.4	229	22	51	27	83
Strange Hollow	McKean	0.88	3.1	1,214	57	29	14	84
Tannery Hollow	Cameron	4.25	2.0	1,302	57	26	17	85
Warner Brook	McKean	3.22	3.7	1,109	51	36	13	86
Whites Creek, Seg. 1	Somerset	24.15	4.8	553	64	14	22	88
Whites Creek, Seg. 2	Somerset	31.79	4.8	Not available	0	100	0	89

Table 5.4. Data for Piedmont Upland Region Study Sites

Study Site Name	County	Drainage Area	Segment Length	Length Characterized	Mesohabitat			Stream Number (Plate 1)
					Riffle	Run	Pool	
		square miles	miles	feet	percent	percent	percent	
Baisman Run	Baltimore	1.33	1.7	729	42	40	18	93
Basin Run, Seg. 1	Cecil	2.08	3.2	687	26	14	60	94
Basin Run, Seg. 2	Cecil	9.77	3.2	956	41	30	29	95
Cooks Branch	Baltimore	0.87	2.0	847	20	58	22	96
First Mine Branch	Baltimore	5.07	3.6	1,030	49	32	19	97
Gillis Falls, Seg. 1	Carroll	2.26	4.2	533	42	25	33	98
Gillis Falls, Seg. 2	Carroll	7.79	4.2	1,430	39	37	24	99
Greene Branch	Baltimore	1.14	2.0	564	53	32	15	100
Norris Run	Carroll	2.04	3.0	669	42	27	31	101
Piney Run	Baltimore	5.09	5.0	865	20	31	49	102
Third Mine Branch	Baltimore	0.96	3.4	977	51	31	18	103
Timber Run	Baltimore	0.29	1.7	710	60	21	19	104

Table 5.5. Summary of Study Sites and Segments After Field Data Collection

Study Region	Number of Study Streams					Number of Segments
	One Segment	Two Segments	Three Segments	Four Segments	Total	
Ridge and Valley Limestone	16	2	2	1	21	30
Ridge and Valley Freestone	14	3	2	1	20	30
Unglaciated Plateau	19	5	—	—	24	29
Piedmont Upland	8	2	—	—	10	12
Grand Total					**75**	**101**

of these segments were deleted during the modeling phase, as described in section 5.6.2. The locations of the final study sites are shown in Plate 1.

5.3 Field Data Collection Procedures

Field procedures were designed to collect information necessary to develop a relationship between stage and discharge spanning the flow range of interest, and to model the aquatic habitat, for each study transect. The procedures included determining percentages of each mesohabitat type, locating transects, and collecting field data for model calibration. The necessary field data include: percentages of each mesohabitat type (riffle, run, pool); transect geometry; channel substrate/cover data; depth and water velocity at one flow; and water surface elevation for several flows.

Field data collection forms were developed specifically for this study, and sample forms are shown in Figures 5.1 through 5.4.

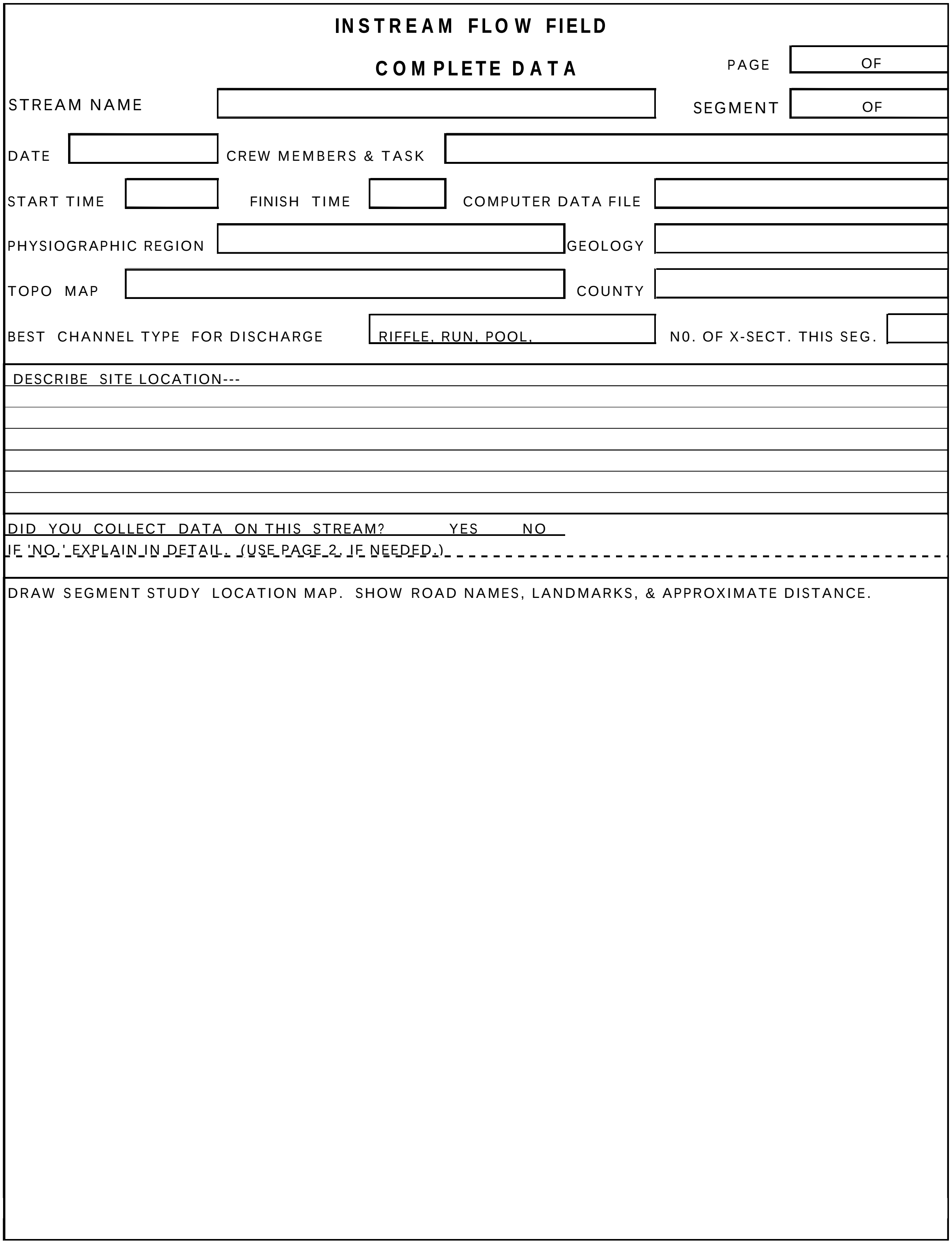
5.3.1 Mesohabitat percentages

The percentages of different mesohabitat types present were determined by defining a reach of stream at the site that contained either three repetitions of each of the mesohabitat types (riffle, run, or pool) present, or 1,000 feet of stream, whichever was greater. Then the lengths of each repetition of each mesohabitat type were measured and recorded on the Channel Type Data Sheet, (Figure 5.2), and the percentages of each mesohabitat type were computed and recorded.

5.3.2 Description of data sets

The calibrated hydraulic model is used to estimate depth and velocity over a range of simulation flows (section 5.7). Generally, the calibration process requires measurements at three flows that span the range of simulation flows. For the purpose of field data collection, the range of flows was assumed to range between the maximum and minimum median monthly flows.

In general, three satisfactory data sets were collected at each study site for hydraulic model calibration. For a number of limestone streams, the difference between the maximum median monthly flow and the minimum median monthly flow was small enough that only two satisfactory data sets were necessary to span that range, based on model extrapolation criteria discussed in section 5.3.3. A data set was considered satisfactory if the flow was in an appropriate range, if there were no irreconcilable errors in the data, and no inconsistencies among data sets. More than three site visits were necessary to collect the



INSTREAM FLOW FIELD

COMPLETE DATA

PAGE ____ OF ____

STREAM NAME ____ SEGMENT ____ OF ____

DATE ____ CREW MEMBERS & TASK ____

START TIME ____ FINISH TIME ____ COMPUTER DATA FILE ____

PHYSIOGRAPHIC REGION ____ GEOLOGY ____

TOPO MAP ____ COUNTY ____

BEST CHANNEL TYPE FOR DISCHARGE RIFFLE, RUN, POOL, ____ N0. OF X-SECT. THIS SEG. ____

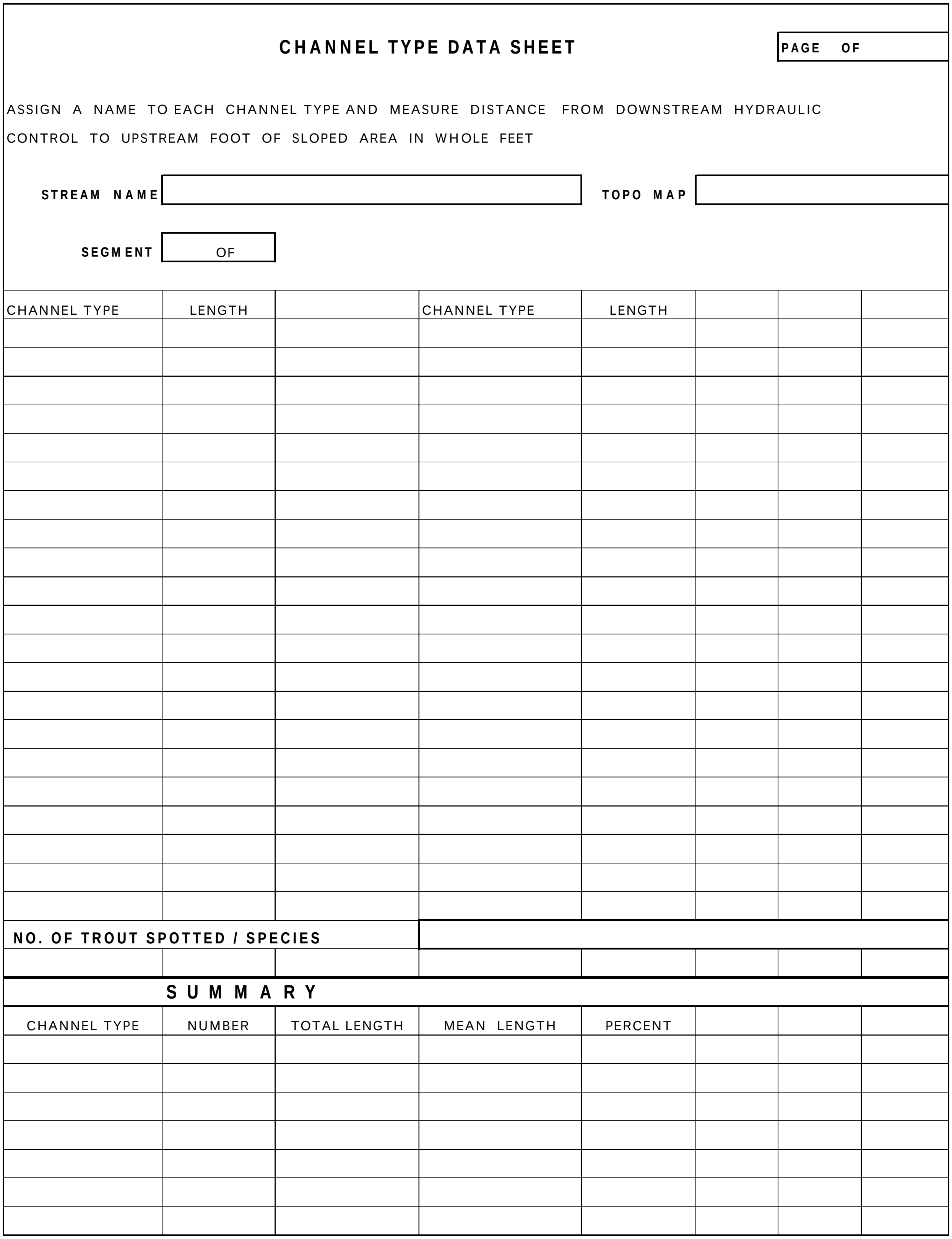
DESCRIBE SITE LOCATION---

DID YOU COLLECT DATA ON THIS STREAM? YES NO

IF 'NO,' EXPLAIN IN DETAIL. (USE PAGE 2, IF NEEDED.)

DRAW SEGMENT STUDY LOCATION MAP. SHOW ROAD NAMES, LANDMARKS, & APPROXIMATE DISTANCE.

Figure 5.1. Sample Pennsylvania-Maryland Instream Flow Field Data Sheet for Complete Data Set



CHANNEL TYPE DATA SHEET

PAGE OF

ASSIGN A NAME TO EACH CHANNEL TYPE AND MEASURE DISTANCE FROM DOWNSTREAM HYDRAULIC CONTROL TO UPSTREAM FOOT OF SLOPED AREA IN WHOLE FEET

STREAM NAME ☐ **TOPO MAP** ☐

SEGMENT ☐ OF

CHANNEL TYPE	LENGTH		CHANNEL TYPE	LENGTH			
NO. OF TROUT SPOTTED / SPECIES							

SUMMARY

CHANNEL TYPE	NUMBER	TOTAL LENGTH	MEAN LENGTH	PERCENT			

Figure 5.2. Sample Pennsylvania-Maryland Instream Flow Channel Type Data Sheet

CROSS SECTION DATA SHEET (FLOW DATA, ELEV. DATA, PHYSICAL DATA) PAGE OF

STREAM NAME **SEGMENT** **OF**

CHANNEL TYPE RUN, RIFFLE, POOL TOPO MAP

BENCH MARK ELEV.= **100.00** B.M. DESCRIPT.

BACKSIGHT READING +

HEIGHT INSTRUMENT(LEVEL)= **DIST. TO CONTROL(POOL)** DISCHARGE

STATION	PT. DESCRIP.	FORESIGHT	ELEV.	DEPTH	REV.	TIME	VEL.	*SUBSTR.	*COVER	
	I.P. LEFT									
	I.P. RIGHT									

LEVEL LOOP CLOSURE

BACKSIGHT + B.S. DESCRIPTION--

HI =

FORESIGHT - = = BM (100.0)

WATER SURFACE ELEV.= **LEFT** **CENTER** **RIGHT**

* FOR SUBSTRATE AND COVER CODES SEE BACK OF PAGE #1 **SEE BACK FOR X-SECTION SKETCH**

Figure 5.3. Sample Pennsylvania-Maryland Instream Flow Cross-Section Data Sheet

INSTREAM FLOW FIELD DATA

PARTIAL DATA SET

PAGE ___ OF ___

STREAM NAME ___

SEGMENT ___ OF ___

DATE ___

CREW MEMBERS & TASK ___

PHYSIOGRAPHIC REGION ___

GEOLOGY ___

TOPO MAP ___

COUNTY ___

CHANNEL TYPE ___

BENCH MARK ELEV. =										
BACKSIGHT READING +										
	HI =									
			FORESIGHT	ELEV.						
LEFT EDGE WATER										
RIGHT EDGE WATER										
I.P. LEFT										
I.P. RIGHT										
LEVEL LOOP CLOSURE										
	BACKSIGHT +									
	HI =									
	FORESIGHT -									
	BM. =									

CHANNEL TYPE ___

BENCH MARK ELEV. =										
BACKSIGHT READING +										
	HI =									
			FORESIGHT	ELEV.						
LEFT EDGE WATER										
RIGHT EDGE WATER										
I.P. LEFT										
I.P. RIGHT										
LEVEL LOOP CLOSURE										
	BACKSIGHT +									
	HI =									
	FORSIGHT -									
	BM. =									

Figure 5.4. Sample Pennsylvania-Maryland Instream Flow Field Data Sheet for Partial Data Set

required number of satisfactory data sets for some streams because measured flows were too close together, or due to measurement errors or inconsistencies.

The three data sets generally included a complete data set (CDS) and two partial data sets (PDS). Ideally, the CDS should be collected at a higher flow than the PDS. Where the CDS flow was greater than, or equal to, the target for the highest flow (section 5.3.3), two low flow partial data sets were collected.

However, in many cases, the CDS was collected at a flow less than necessary to simulate the highest median monthly flow, based on the extrapolation criteria described in section 5.3.3, and in some cases the CDS was within the flow range necessary to simulate the lowest median monthly flow. In those cases, it was necessary to collect one or two additional data sets at flows greater than the complete data set flow. The hydraulic model calibration procedure recommends depth and velocity measurements be made at the highest flow, because the flow submerges the greatest channel width. Therefore, depth and velocity measurements had to be collected as part of any high flow PDS.

The CDS included the following measurements: depths and velocities at each measurement point for each transect; bottom and overbank survey for each transect; water surface elevations; and substrate and cover codes at each measurement point for each transect. Depth and velocity measurements at one of the transects were used to compute the flow rate. Also, the stream reach was photographed.

For high flow PDSs, depth, velocity, and water surface elevation measurements were required at each transect. Again, the depth and velocity measurements at one transect were used to compute flow rate. Depths and velocities were measured at all transects at the same points used for the CDS. Additional points were measured if the increased flow covered cells that were dry during the complete data set measurement. Substrate and cover were not required for this data set.

For low flow PDSs, only water surface elevations at all transects and a flow rate measurement were required. The hydraulic model calibration procedure does not require depth and velocity measurements for this data set. The discharge measurement was normally made at one of the original transects, but changing flow conditions occasionally required the measurement be made at a nearby location.

In some instances, several complete data sets were gathered at a given study site, as a result of:

- Changes in channel bottom configuration;
- Changes caused by construction of a beaver dam, or seasonal variations in aquatic vegetation; or
- Incorrect location of the original study site.

5.3.3 Model calibration and flow range criteria

Usually, field data cannot be collected over the entire range of discharges that need to be simulated, so the calibrated model must extrapolate to flows outside the calibration range. Also, the measured flow rates used in the hydraulic calibration process need to be sufficiently different to obtain a valid hydraulic calibration. As noted in section 5.3.2, for the purpose of data collection, the simulation flows were assumed to range between maximum median monthly flow and minimum median monthly flow.

The hydraulic model can reasonably be extrapolated to a flow equal to 1.5 times the highest calibration flow and 0.6 times the lowest calibration flow. The absolute maximum range for extrapolation is to a flow 2.5 times the highest calibration flow and 0.4 times the lowest calibration flow (U.S. Geological Survey, Biological Resources Division, 1994).

These extrapolation limits are summarized in Table 5.6, along with the target range of measured flows derived from the normal extrapolation limits. To satisfy the normal extrapolation limits shown in the table, the highest measurement flow should equal, or exceed, the target value (column 4) multiplied by the maximum median monthly flow, and the lowest flow measurement should be less than the target value multiplied by the minimum median monthly flow. It was assumed that valid calibration could be obtained if the lower flow is less than 50 percent of the higher flow. These criteria were used to determine the range of flows for field data collection.

Table 5.6. Hydraulic Simulation Limits and Flow Targets

Measurement Flow	Normal Extrapolation Limit	Maximum Extrapolation Limit	Measurement Flow Target*
Highest	1.5 times	2.5 times	0.67
Lowest	0.6 times	0.4 times	1.67

* Based on normal extrapolation limit.

For any study stream, the range between maximum and minimum median monthly flows can be subdivided, based on the extrapolation limits, and the criterion that flows used for calibration should differ by at least 50 percent. The relationship of the complete and partial data set flows to each other, and the criteria for determining targets, are shown in Table 5.7. In this table, Threshold 1 is the highest acceptable value of the lowest measurement flow, and the lowest acceptable value of the intermediate measurement flow. Threshold 2 represents the highest acceptable value of the intermediate measurement flow and the lowest acceptable value of the highest measurement flow.

Table 5.7. Flow Relationships and Target Measurement Flows

	Threshold 1	Threshold 2
Lowest Measurement Flow	Intermediate Flow	Highest Measurement Flow
PDS-1 <= MIN(0.5*PDS-2, 1.67*Minimum MM Flow)	PDS-2 <= 0.5*CDS AND >=2.0*PDS-1	CDS
PDS-1 <=MIN(0.5*CDS, 1.67*Minimum MM Flow	CDS	PDS-2 >= MAX(2.0*CDS, 0.67*Maximum MM Flow)
CDS	PDS-1 >= 2.0*CDS AND <=0.5*PDS-2	PDS-2 >= MAX(2.0*PDS-1, 0.67*Maximum MM Flow)

Key

CDS = Compete data set flow measured
PDS-1 = target flow for lower partial data set
PDS-2 = target flow for higher partial data set
MM= median monthly
MAX = maximum value
MIN = minimum value

5.3.4 Field measurement procedures

For each of the mesohabitat types observed, a representative occurrence of that type was selected, and a transect was established near the midpoint. The transect was located perpendicular to the streamflow.

The placement of transects at the midpoint of the selected mesohabitats resulted in questions regarding whether that location adequately represented habitat for the spawning life stage. A study of spawning locations, described in section 5.4, showed spawning habitat was adequately sampled.

Field data were collected in accordance with procedures described by Bovee (undated). Temporary benchmark(s) was (were) set at each study site and assigned an arbitrary elevation. Transects were marked at both ends with reinforcing bar, and referenced to nearby topographic features.

Velocity and discharge measurements and discharge computations followed the procedures described by Buchanan and Somers (1969). Velocity measurements were made with either rotating cup meters (Price Type AA current meter or pygmy meter), or a Marsh-McBirney electromagnetic meter. Although no direct comparisons of velocity measurements between different meters were made as part of this study, general experience of the study participants is that velocity measurements made with the electromagnetic meter compare very well with measurements made with either of the rotating cup meters. Where substantial vegetation was present, the electromagnetic meter was used, because the cup rotation was restricted. The electromagnetic meter did not work well where velocities were very low.

For most transects, depth and velocity measurements were made at 15 to 25 points across the transect. Measurements were made at points where either bottom contour, velocity, substrate, or cover changed. Generally, flow measurement points were selected so that each partial section of the transect between measurement points included no more than 10 percent of the total flow. The exact number of measurements depended upon flow conditions. Bottom elevations were surveyed at each measurement point during collection of the complete data set.

Water surface elevations were measured at each transect at the left and right edges of water, as a minimum. One or more midstream elevations were measured if the water surface elevation varied across the transect.

Substrate and cover codes were determined at each measurement point, using the coding scheme described in section 3.1.2. These codes were generally determined only once, and assumed constant throughout the study.

In many instances when a revised CDS was collected, the original CDS was utilized as a partial data set during model calibration.

5.3.5 Problems encountered

The problems encountered during the study site selection and field data collection phases of the study are described in Appendix C. Aquatic vegetation frequently caused difficulty in obtaining valid velocity and flow measurements. Seasonal changes in vegetation resulted in changes in depth, velocity and roughness for different measurements, which made hydraulic calibration difficult, and in some cases impossible. For some streams, changes in transect geometry between measurements, usually as a result of high flows, also caused inconsistencies between measurements and required collection of additional data, or in some cases, deletion of a study site. Some study streams in the Piedmont Upland in Maryland showed signs of unstable bed and banks, as discussed in Appendix C. Future hydraulic and habitat conditions for these streams may be different from current conditions, so the habitat analyses should be used with caution. Also, withdrawals from these streams may affect sediment transport and channel morphology, which should be considered further in impact analyses.

5.3.6 Data processing procedures

The field data was logged into a data tracking form as it was received. The form was used to track data processing status.

Field data for the CDSs were checked for completeness. All field calculations were checked, and all other calculations, including the flow rate, were completed and checked. The location of the site was plotted on a USGS quadrangle map using information provided in the field notes. The watershed boundary was delineated, and the drainage area was planimetered and checked. Then all the data were entered into the PHABSIM computer model, as described in section 5.6.1.

PDS field notes were processed in the same way as CDS notes. In addition, benchmark descriptions and end pin elevations were compared with previous data sets to check for discrepancies. Water surface elevations and flow rates were tabulated and checked to ensure that changes in elevations were consistent with changes in discharge.

5.4 Spawning Location Characterization Procedure and Results

The procedures for locating transects for physical habitat measurements (section 5.3.4) placed each transect in the center of each mesohabitat type (i.e., riffles, runs, and pools). This placement of transects could result in missing much of the spawning habitat if the fish do not spawn in the center of the mesohabitat type. PFBC biologists suggested trout redds (nests) are often found in the downstream or tail end of pools. Transects placed in the middle of this mesohabitat type would miss these spawning areas. To determine whether the placement of transects would affect the evaluation of spawning habitat, a study was conducted during the fall spawning period to document the location of redds in each mesohabitat type.

5.4.1 Methods for studying spawning location

The following criteria were used to identify redds:

- Observation of spawning trout occupying redds;
- Identification of areas that had been swept clean of algae and silt, as observed during an October 11, 1994, field trip to Little Fishing Creek in Centre County; and
- Probing the suspected redds with a walking stick to determine if the sediments were loose.

Dr. Robert Carline of the Pennsylvania State University instructed field personnel on how to identify trout redds during the October 11, 1994, field trip to Little Fishing Creek.

The list of all study streams, including the trout species (brook trout or brown trout) inhabiting each stream, was furnished to the field crews. An attempt was made to sample brook trout streams during October, which is the peak spawning period for that species. When possible, brown trout streams were sampled in November, the peak spawning period for that species.

The field crews walked about 300 m. (1,000 ft) of each stream, which corresponded as closely as possible with the area of the stream that was used to determine the percentage of each mesohabitat type (section 5.3.1). Each mesohabitat type was divided into four parts, as shown schematically on the Spawning Data Sheet shown in Figure 5.5. The location of each redd relative to each mesohabitat type was recorded on the diagram. The depth, average column velocity, and substrate type for each redd also were recorded.

5.4.2 Results of spawning location study

A summary of the streams sampled, and the number of redds observed, is shown in Table 5.8. Thirty streams and 31 stream segments were evaluated. Nineteen streams and 20 segments were identified as either exclusively or dominantly inhabited by brook trout. Seven streams and seven stream segments were identified as exclusively or dominantly populated by brown trout. The remaining four streams and four stream segments were inhabited by both brook and brown trout, with neither species clearly dominant. Where brook trout were dominant, redds were assumed to be primarily created by brook trout; where brown trout were dominant, the redds were assumed to be created by brown trout; where neither species was dominant, the species was considered unidentified. One hundred twenty-three redds were located on brook trout streams, 29 redds on the brown trout streams, and 24 redds on the streams where neither species was dominant.

In spite of the field training, crews had difficulty identifying redds. Many of the redds were recorded as “potential” redds because, although they generally met the criteria, the crews did not consider the identification to be definitive. Sixty-five percent of the brook trout redds were listed as “potential”, as were 69 percent of the brown trout redds and 92 percent of the unidentified redds. The following discussion is based on the assumption that all “potential” redds were actual redds.

The locations of the redds in each mesohabitat type for brook trout, brown trout, unidentified species, and for all streams combined, respectively, are shown in Tables 5.9 through 5.12. Most brook trout redds were located either in pools (54.5 percent) or runs (41.5 percent), while the remaining 4.1 percent were located in riffles (Table 5.9). In pools, the proportion of redds increased from the head-end to the tail-end, as expected. However, since the middle half of the pools had a significant percentage of redds, sampling in this portion of the pool should ensure some redd locations were included in the sample. For riffles and runs, the greatest proportions of the redds were located near the center of the mesohabitat types.

Twenty-four of the 29 (82.8 percent) brown trout redds were located in runs, and most of these redds were located in the center of that mesohabitat type (Table 5.10). Only five brown trout redds were located in riffles or pools, so little can be said about their relative location in these mesohabitats.

Twenty-one of the 24 unidentified trout redds also were located in runs (Table 5.11). All were located in the central 50 percent of this habitat type.

The depth, velocity, and substrate measurements for the various redd locations are shown in Table 5.13, and summarized in Table 5.14. Brook trout redds were located at depths ranging from 0.2 to 2.0 ft, with a mean depth of 0.7 ft. Velocities ranged from 0 to 1.03 ft/sec, and the mean velocity was 0.24 feet per second (ft/sec). The primary substrate type in most brook trout redds was gravel (0.12-2.15 inches in diameter). One redd was found in an area of primarily sand (< 0.12 inches in diameter); three were found in substrate predominantly larger than gravel. However, the field notes

PENNSYLVANIA INSTREAM FLOW STUDY
SPAWNING DATA SHEET

STREAM NAME_________________________________ SEGMENT_______OF_______ TOPO MAP____________________________

FLOW DIRECTION
-------------------------------->

POOL	**RIFFLE**	**RUN**

INSTRUCTIONS: DOCUMENT LOCATION OF REDD RELATIVE TO EACH MESOHABITAT TYPE ABOVE USING CONSECUTIVE ORDER NUMBER.
THEN RECORD DEPTH AND SUBSTRATE CODE AT EACH REDD CORRESPONDING WITH ITS ASSOCIATED NUMBER.
REPORT ANY COMMENTS ON BACK OF THIS DATA SHEET.

REDD #	DEPTH	SUBSTR.#		REDD #	DEPTH	SUBSTR.#		REDD #	DEPTH	SUBSTR.#	
1				13				25			
2				14				26			
3				15				27			
4				16				28			
5				17				29			
6				18				30			
7				19				31			
8				20				32			
9				21				33			
10				22				34			
11				23				35			
12				24				36			

Figure 5.5. Sample Spawning Data Sheet

Table 5.8. Streams Evaluated for Redd Locations, October–November 1994

Stream	Study Region	County	Subbasin	Seg. No.	Species (* = Dominant)	Date	No. of Redds
Brook Trout or Brook Trout-Dominant Streams							
Cherry Run	Unglaciated Plateau	Forest	16E	1	Brook Trout	10/21/94	2
McEwen Run	Unglaciated Plateau	Jefferson	17A	1	Brook Trout	10/20/94	3
Lyman Run	Unglaciated Plateau	McKean	16C	1	Brook Trout	10/18/94	2
Strange Hollow	Unglaciated Plateau	McKean	16C	1	Brook Trout	10/18/94	5
Tannery Hollow Run	Unglaciated Plateau	Cameron	8A	1	Brook Trout	10/19/94	3
Meyers Run	Unglaciated Plateau	Centre	9C	1	Brook Trout	10/19/94	1
Dunlap Run	Unglaciated Plateau	Clearfield	8C	1	Brook Trout	10/19/94	1
Mill Run	Unglaciated Plateau	Clinton	9B	1	Brook Trout	10/18/94	8
Coke Oven Hollow	Unglaciated Plateau	Somerset	19E	1	Brook Trout	10/14/94	7
Broad Run	Ridge and Valley Freestone	Franklin	13C	1	Brook Trout	11/17/94	14
Fowler Hollow Run	Ridge and Valley Freestone	Perry	7A	1	Brook Trout	11/03/94	6
Fowler Hollow Run	Ridge and Valley Freestone	Perry	7A	2	Brook Trout	11/18/94	20
Bear Run	Ridge and Valley Freestone	Union	6A	1	Brook Trout	10/12/94	9
Mile Run	Ridge and Valley Freestone	Union	10C	1	Brook Trout	10/13/94	9
Lower Two Mile Run	Unglaciated Plateau	Venango	16G	1	Brook Trout*, Brown Trout	11/15/94	5
Whitehead Run	Unglaciated Plateau	Cameron	8A	1	Brook Trout*, Brown Trout	10/18/94	6
Benner Run	Unglaciated Plateau	Centre	8D	1	Brook Trout*, Brown Trout	10/19/94	2
Kansas Valley Run	Ridge and Valley Freestone	Perry	12B	1	Brook Trout*, Brown Trout	11/18/94	14
Salem Creek	Ridge and Valley Freestone	Luzerne	5D	1	Brook Trout*, Brown Trout	10/20/94	3
Rapid Run	Ridge and Valley Freestone	Union	10C	1	Brook Trout*, Brown Trout	11/09/94	3
Subtotal							**123**

Table 5.8. Streams Evaluated for Redd Locations, October–November 1994—Continued

Stream	Study Region	County	Subbasin	Seg. No.	Species (* = Dominant)	Date	No. of Redds
Brown Trout or Brown Trout-Dominant Streams							
Cush Creek	Unglaciated Plateau	Indiana	8B	2	Brown Trout	11/04/94	1
Honey Creek	Ridge and Valley Limestone	Mifflin	12A	1	Brown Trout	11/04/94	6
Long Hollow Run	Ridge and Valley Limestone	Mifflin	12C	1	Brown Trout	11/04/94	3
Spring Creek	Ridge and Valley Limestone	Centre	9C	3	Brown Trout	10/20/94	2
Cedar Run	Ridge and Valley Limestone	Centre	9C	1	Brown Trout	11/10/94	4
Falling Spring Branch	Ridge and Valley Limestone	Franklin	13C	1	Brown Trout, Rainbow Trout	11/02/94	11
Wapwallopen Creek	Ridge and Valley Freestone	Luzerne	5B	4	Brown Trout*, Brook Trout	10/21/94	2
Subtotal							**29**
Streams With Neither Species Dominant							
Horning Run	Ridge and Valley Freestone	Juniata	12A	1	Brook Trout, Brown Trout	10/26/94	1
Little Fishing Creek	Ridge and Valley Limestone	Clinton	9C	1	Brown Trout, Brook Trout	11/04/94	3
Potter Creek	Ridge and Valley Limestone	Bedford	11D	1	Brown Trout, Brook Trout	11/01/94	11
Big Spring Creek	Ridge and Valley Limestone	Cumberland	7B	1	Brown Trout, Brook Trout	11/02/94	9
Subtotal							**24**
Grand Total							**176**

Table-5.9. Location of 123 Brook Trout Redds in 19 Streams Evaluated as Part of the Pennsylvania-Maryland Instream Flow Study
(The number of redds in each location is given in a schematic plan view of a stream along with the percentages of redds in the various categories.)

FLOW DIRECTION
→

Right Bank		2	4			1	1		2	4	2	
	3	5	6	8					4	5	4	1
	5	4	6	8		1	1		5	3	3	5
Left Bank		1	3	1		1				8	4	1
Total %	6.5	9.8	15.4	22.8		2.4	1.6		8.9	16.3	10.6	5.7

POOL
67 Redds
(54.5%)

RIFFLE
5 Redds
(4.1%)

RUN
51 Redds
(41.5%)

Table 5.10. ***Location of 29 Brown Trout Redds in Seven Streams Evaluated as Part of the Pennsylvania-Maryland Instream Flow Study***
(The number of redds in each location is given in a schematic plan view of a stream along with the percentages of redds in the various categories.)

FLOW DIRECTION
→

Right Bank										4	2	
			1	1							3	1
	2					1				2	4	1
Left Bank										6		1
Total %	6.9		3.4	3.4		3.4				41.3	31.0	10.3
	POOL 4 Redds (13.9%)				RIFFLE 1 Redd (3.4%)				RUN 24 Redds (82.8%)			

Table-5.11. Location of 24 Unidentified Trout Redds in Four Streams Evaluated as Part of the Pennsylvania-Maryland Instream Flow Study
(The number of redds in each location is given in a schematic plan view of the stream along with the percentages of redds in the various categories.)

FLOW DIRECTION
→

Right Bank							1			1	2	
			1			1				4	1	
										3		
Left Bank										7	3	
Total %			4.2			4.2	4.2			62.5	25.0	
	POOL 1 Redd (4.2%)				RIFFLE 2 Redds (8.3%)				RUN 21 Redds (87.5%)			

Table 5.12. Location of 176 Trout Redds (Brook Trout, Brown Trout, and Unidentified Trout Combined) in 30 Streams Evaluated as Part of the Pennsylvania-Maryland Instream Flow Study
(The number of redds in each location is given in a schematic plan view of a stream along with the percentages of redds in the various categories)

FLOW DIRECTION
→

Right Bank		3	4	10		1	2		2	9	6	
	3	5	8	9		1			4	9	8	2
	7	3	6	9		2	1		5	7	7	6
Left Bank		1	3	1			1			21	7	2
Total %	5.7	6.9	12.0	16.6		2.3	2.3		6.3	26.3	16	5.7
	POOL 72 Redd (41.1%)				RIFFLE 8 Redds (4.6%)				RUN 96 Redds (54.3%)			

Table 5.13. Depths, Velocities, and Substrate Types for Trout Redds

Stream Name	Redd Number	Depth (ft)	Velocity (ft/sec)	Substrate
Brook Trout Redds				
Cherry Run	1	0.40	0.419	Gravel
	2	0.30	1.029	Gravel
McEwen Run	3	0.55	0.050	Gravel
	4	0.35	0.121	Gravel
	5	0.25	0.432	Gravel
Lyman Run	6	0.35		Gravel
	7	0.40		Gravel
Strange Hollow	8	0.60		Gravel
	9	0.40		Gravel
	10	0.30		Gravel
	11	0.50		Gravel
	12	0.50		Gravel
Tannery Hollow	13	0.22		Gravel
	14	0.55		Gravel
	15	0.64		Gravel
Meyers Run	16	0.56		Gravel
Dunlap Run	17	0.50		Gravel
Mill Run	18	0.60		Gravel
	19	0.80		Gravel
	20	0.16		Gravel
	21	0.55		Gravel
	22	0.65		Gravel
	23	1.15		Gravel
	24	0.60		Gravel
	25	0.55		Gravel
Coke Oven Hollow	26	0.60	0	Gravel
	27	0.75	0	Gravel
	28	0.90	0	Gravel
	29	1.30	0	Gravel
	30	0.40	0	Gravel
	31	0.50	0	Gravel
	32	0.15	0	Gravel
Broad Run	33	0.60	0.565	Gravel
	34	0.60	0.100	Gravel
	35	0.55	0.218	Gravel
	36	0.85	0.383	Gravel
	37	1.05	0.188	Gravel
	38	1.00	0.334	Gravel
	39	0.60	0.256	Gravel
	40	0.80	0.217	Gravel
	41	0.50	0.050	Gravel
	42	0.60	0.177	Gravel
	43	0.70	0.425	Gravel
	44	0.85	0.262	Gravel
	45	0.70	0.169	Gravel
	46	0.80	0.266	Gravel

Table 5.13. Depths, Velocities, and Substrate Types for Trout Redds—Continued

Stream Name	Redd Number	Depth (ft)	Velocity (ft/sec)	Substrate
Brook Trout Redds—Continued				
Fowler Hollow Run Segment 1	47	0.45	0.514	Gravel
	48	0.80	0.356	Gravel
	49	0.55	0.050	Gravel
	50	0.50	0.106	Gravel
	51	0.90	0.291	Gravel
	52	0.85	0.378	Sand
Fowler Hollow Run Segment 2	53	1.10	0.530	Gravel
	54	0.90	0.133	Gravel
	55	0.30	0.267	Gravel
	56	0.90	0.469	Gravel
	57	0.40	0.267	Gravel
	58	0.40	0.953	Gravel
	59	0.40	0.176	Gravel
	60	0.60	0.381	Gravel
	61	0.60	0.168	Gravel
	62	0.70	0.050	Gravel
	63	0.90	0.355	Gravel
	64	0.70	0.050	Gravel
	65	1.10	0.325	Rock
	66	1.20	0.050	Gravel
	67	0.50	0.050	Gravel
	68	0.50	0.206	Gravel
	69	0.60	0.050	Rock
	70	1.50	0.282	Gravel
	71	1.30	0.453	Rock
	72	0.70	0.076	Gravel
Bear Run	73	0.85	0.340	Gravel
	74	0.40	0.000	Gravel
	75	0.20	0.299	Gravel
	76	1.60	0.255	Gravel
	77	1.20	0	Gravel
	78	1.80	0.042	Gravel
	79	1.90	0.042	Gravel
	80	2.00	0.042	Gravel
	81	2.00	0.042	Gravel
Mile Run	82	0.35	0.419	Gravel
	83	0.40	0.321	Gravel
	84	0.30	0.101	Gravel
	85	0.40	0.462	Gravel
	86	0.40	0.144	Gravel
	87	0.40	0.150	Gravel
	88	0.45	0.240	Gravel
	89	0.40	0.255	Gravel
	90	0.50	0.118	Gravel

Table-5.13. Depths, Velocities, and Substrate Types for Trout Redds—Continued

Stream Name	Redd Number	Depth (ft)	Velocity (ft/sec)	Substrate
Brook Trout Redds—Continued				
Lower Two Mile Run	91	1.10	0.401	Sand
	92	0.85	0.050	Gravel
	93	1.40	0.153	Gravel
	94	0.40	0.625	Gravel
	95	1.10	0.164	Gravel
Whitehead Run	96	0.18		Gravel
	97	0.41		Gravel
	98	0.37		Gravel
	99	0.64		Gravel
	100	0.77		Gravel
	101	0.98		Gravel
Benner Run	102	0.76		Gravel
	103	0.33		Gravel
Kansas Valley Run	104	0.75	0.077	Gravel
	105	0.70	0.314	Gravel
	106	0.55	0.659	Gravel
	107	0.40	0.320	Gravel
	108	0.50	0.308	Gravel
	109	0.40	0.304	Gravel
	110	0.45	0.202	Gravel
	111	0.50	0.050	Gravel
	112	0.60	0.050	Gravel
	113	0.45	0.050	Rock
	114	0.30	0.050	Gravel
	115	0.50	0.268	Gravel
	116	0.40	0.401	Gravel
	117	0.60	0.296	Gravel
Salem Creek	118	0.36		Gravel
	119	0.30		Gravel
	120	0.30		Gravel
Rapid Run	121	0.62	0.761	Gravel
	122	0.70	0.435	Gravel
	123	0.45	0.516	Gravel
Brown Trout Redds				
Cush Creek	1	0.62	0.860	Gravel
Honey Creek	2	0.60	0.061	Gravel
	3	0.40	0	Gravel
	4	1.10	0.524	Sand
	5	0.70	0.168	Gravel
	6	0.75	0.509	Gravel
	7	0.75	1.080	Gravel
Long Hollow Run	8	0.80	0.445	Gravel
	9	0.50	0.397	Gravel
	10	0.80	0.253	Gravel
Spring Creek	11	1.20		Gravel
	12	1.20		Gravel

Table 5.13. Depths, Velocities, and Substrate Types for Trout Redds—Continued

Stream Name	Redd Number	Depth (ft)	Velocity (ft/sec)	Substrate
Brown Trout Redds—Continued				
Cedar Run	13	0.50	0.332	Gravel
	14	0.90	0.117	Gravel
	15	1.05	0.338	Gravel
	16	1.35	0.167	Gravel
Falling Spring Branch	17	0.90	1.636	Gravel
	18	1.30	0.929	Gravel
	19	0.60	0.473	Gravel
Falling Spring Branch	20	0.65	0.285	Gravel
	21	1.25	1.947	Gravel
	22	0.70	1.120	Gravel
	23	1.30	0.690	Gravel
	24	1.20	0.486	Gravel
	25	1.40	1.073	Gravel
	26	1.10	0.602	Gravel
	27	1.60	0.432	Gravel
Wapwallopen Creek	28	1.35	1.660	Gravel
	29	1.10	1.690	Gravel
Both Species				
Horning Run	1	1.35	0.165	Gravel
Little Fishing Creek	2	1.10	0.114	Gravel
	3	1.50	0.343	Gravel
	4	0.50	0.404	Gravel
Potter Creek	5	0.45	0.560	Gravel
	6	0.50	0.874	Gravel
	7	0.70	0.705	Sand
	8	0.80	1.140	Sand
	9	0.70	1.270	Gravel
	10	0.45	0.753	Gravel
	11	0.55	0	Sand
	12	0.95	0.712	Sand
	13	0.90	0.384	Sand
	14	0.75	0.727	Gravel
	15	0.80	1.464	Gravel
Big Spring Creek	16	1.30	0.997	Gravel
	17	1.55	0.614	Gravel
	18	1.55	0.540	Gravel
	19	1.30	1.324	Gravel
	20	1.40	0.650	Gravel
	21	1.85	1.012	Gravel
	22	1.60	0.818	Gravel
	23	1.90	1.053	Gravel
	24	1.90	1.026	Gravel

Table 5.14. Summary of Depths, Velocities, and Substrate Types at Redd Locations for Brown Trout and Brook Trout

	Depth (ft)				Velocity (ft/sec)				Substrate Type (%)			
	# Redds	**Mean**	**Maximum**	**Minimum**	**# Redds**	**Mean**	**Maximum**	**Minimum**	**# Redds**	**Sand/Silt**	**Gravel**	**Rock**
Brook Trout	123	0.7	2.0	0.15	90	0.24	1.03	0	129	0.8	88.4	10.7
Brown Trout	29	1.0	1.6	0.40	27	0.68	1.96	0	29	3.4	96.6	0
Unidentified Trout	24	1.1	1.9	0.45	24	0.74	1.46	0	24	21.0	79.2	0
Total	176	0.8	2.0	0.15	141	0.41	1.95	0	176	4.0	88.5	7.4

indicated gravel was probably present in these areas, between the larger substrate, so the actual redds may have been in the gravel.

Brown trout redds were located at depths ranging from 0.4 to 1.6 ft, with a mean of 1.0 ft. Velocities ranged from 0 to 1.9 ft/sec, with a mean of 0.68 ft/sec. Gravel substrate was dominant for all except one of the redds, which was located in sand.

Unidentified trout redds were found in depths ranging from 0.5 to 1.9 ft, with a mean of 1.1 ft. Velocities ranged from 0 to 1.46 ft/sec, with a mean of 0.74 ft/sec. These redds were primarily found in gravel (79.2 percent), with the remaining 20.8 percent of redds found in sand.

5.4.3 Conclusion

The reason for studying spawning location was to document the relative position of redds in the various mesohabitats sampled. The primary concern was whether sampling in the midpoint of the riffles, runs, or pools would adequately represent the areas used for spawning.

Analysis and interpretation of the data are problematic because of the uncertainty regarding redd identification. Future studies of redd location should include procedures for verification of redd identification such as that used in the transferability study (section 3.4.2). The following conclusions are based on the assumption that all redds listed as “potential” on the field data forms were actual redds**.**

Although the number of brook trout redds in the pools increased in a downstream direction, the proportion of redds in the middle half of the pools (25.2 percent) was about the same as in the downstream quarter of the pool (22.8 percent). Therefore, transects placed in the center of the pools should be representative of trout spawning habitat. In future studies, it would be desirable to also include a transect in the tail of the pools in order to include the area that has the highest proportion of redds.

In runs, which had 41.5 percent of the brook trout redds (compared to 54.5 percent in the pools), and the majority of both the brown trout (82.8 percent) and unidentified trout redds (83.3 percent), the center of the mesohabitat was the most likely place to find redds. This also was true for riffles, although there were very few redds found in riffles.

These results show that the procedure for locating transects will adequately represent spawning habitat.

5.5 Hydrologic Analyses

5.5.1 Hydrologic analysis concepts

To apply the IFIM methodology to any specific stream, hydrology must be developed to describe the flows that occur there. The flows were estimated using data for certain nearby existing or discontinued USGS stream gages. The stream gage data also were used to monitor existing flow conditions. These monitoring flow levels were very important in determining when to dispatch field crews to sample the stream in a specific flow range.

Criteria for determining when to dispatch field crews were necessary due to different target flow levels required for hydraulic calibration, and rapidly changing conditions at the various sites. These criteria were necessary to increase the probability of field crews visiting sites at times when the streamflow was in an appropriate range.

The hydrology developed for the study sites included:

- Median monthly flows for all sites for the entire period-of-record;
- Annual mean and median flows for all sites for the entire period-of-record;
- Annual and seasonal flow duration data for all sites for the entire period-of-record; and
- Median monthly flow time series.

5.5.2 Stream gage selection

Stream gages were selected to develop hydrology for study sites, and to determine when to dispatch field crews. To select gages, the study sites were plotted on a stream map (Ings and Simmons, 1991), along with certain long-record gages known to be in the area. These gages were evaluated further, based on drainage area size, proximity, geology, and judgment, to select gages located on streams believed to have hydrology similar to the study sites. Most of the selected gages are currently in operation, but a few have been discontinued. In most cases, one gage was selected for each study site. In a few cases, more than one gage was selected, because of uncertainty regarding the representativeness of the gage, and to provide a backup in the event of an outage.

For certain streams, the hydrology did not correspond with flows measured in the field. As a result, certain changes were made in the original gage selections to provide reasonable correspondence with the flows measured in the field.

In most cases, satellite data transmission equipment was available at the gages selected to generate study site hydrology, and could be used to determine when to dispatch field crews. If the gage used to determine hydrology for a study stream did not have satellite data transmission equipment, additional gages in the area were selected for monitoring current flow conditions to determine when to dispatch field crews.

A list of gages selected for each study stream is shown in Table 5.15.

5.5.3 Hydrology for study sites

In general, the hydrology for each study site was determined using the gage selected, as described. Study site hydrology was generally derived by multiplying streamflows at the appropriate gage by the ratio of drainage area at the site to drainage area at the gage.

For the following study sites, the hydrology procedures were more complex due to mixed or unusual geology, water supply withdrawals, or wastewater treatment plant (WWTP) discharges.

- Monocacy Creek and Bushkill Creek, Northampton County;
- Cedar Creek and Trout Creek, Lehigh County;
- Nancy Run and Spring Creek, Berks County;
- Letort Spring Run, Trindle Spring Run, and Big Spring Creek, Cumberland County;
- Falling Spring Run, Franklin County;
- Spring Creek and Penns Creek, Centre County;
- Honey Creek and Long Hollow Run, Mifflin County;

Table 5.15. Study Sites and Gages

Study Stream	No. Seg.	Seg. No.	Region	County	Gage	Use	
						Hydrology*	Tracking Flows/ Dispatching Crew
Spring Creek	4	1	Ridge and Valley Limestone	Centre	Spring Creek at Houserville	X	X
		2	Ridge and Valley Limestone	Centre	Spring Creek at Houserville	X	X
		3	Ridge and Valley Limestone	Centre	Spring Creek at Houserville	XC	X
		4	Ridge and Valley Limestone	Centre	Spring Creek at Houserville	XC	X
		4	Ridge and Valley Limestone	Centre	Spring Creek at Axemann	XC	
Penns Creek	3	All	Ridge and Valley Limestone	Centre	Penns Creek at Penns Creek	XC	X
Lick Creek	1		Ridge and Valley Limestone	Centre	Spring Creek at Houserville	X	X
Antes Creek	1		Ridge and Valley Limestone	Lycoming	Spring Creek at Houserville	X	X
Cedar Run	1		Ridge and Valley Limestone	Centre	Spring Creek at Houserville	X	X
Boiling Spring Run	1		Ridge and Valley Limestone	Blair	Frankstown Br. at Williamsburg	X	X
Falling Spring Run	1		Ridge and Valley Limestone	Franklin	Letort Spring Run near Carlisle	XC	X
Potter Creek	1		Ridge and Valley Limestone	Bedford	Spring Creek at Houserville	X	X
Big Spring Creek	1		Ridge and Valley Limestone	Cumberland	Letort Spring Run near Carlisle	XC	X
Long Hollow Run	1		Ridge and Valley Limestone	Mifflin	Dunning Creek at Belden	X	X
Honey Creek	1		Ridge and Valley Limestone	Mifflin	Kishacoquillas Creek at Reedsville	XC	X
Little Fishing Creek	1		Ridge and Valley Limestone	Clinton	Spring Creek at Houserville	X	X
Monocacy Creek	3	All	Ridge and Valley Limestone	Northampton	Monocacy Creek at Bethlehem	C	X
Bushkill Creek	2	All	Ridge and Valley Limestone	Northampton	Monocacy Creek at Bethlehem	C	X
Cedar Creek	1		Ridge and Valley Limestone	Lehigh	Monocacy Creek at Bethlehem	XC	X
Trout Creek	1		Ridge and Valley Limestone	Lehigh	Monocacy Creek at Bethlehem	C	X
Spring Creek	1		Ridge and Valley Limestone	Berks	Monocacy Creek at Bethlehem	C	X
Spring Creek	1		Ridge and Valley Limestone	Berks	Maiden Creek at Virginville		X
Trindle Spring Run	1		Ridge and Valley Limestone	Cumberland	Letort Spring Run near Carlisle	XC	X
Letort Spring Run	2	All	Ridge and Valley Limestone	Cumberland	Letort Spring Run near Carlisle	XC	X
Nancy Run	1		Ridge and Valley Limestone	Northampton	Monocacy Creek at Bethlehem	XC	X
Cedar Run	1		Ridge and Valley Limestone	Cumberland	Yellow Breeches at Camp Hill	X	X

* Hydrology Key:
X Hydrology based on drainage area ratio
XC Hydrology based on gage shown, but more complex than drainage area ratio
C Complex synthesis procedure, multiple gages

Table-5.15. Study Sites and Gages —Continued

Study Stream	No. Seg.	Seg. No.	Region	County	Gage	Use	
						Hydrology*	Tracking Flows/ Dispatching Crew
Wapwallopen Creek	4	All	Ridge and Valley Freestone	Luzerne	Wapwallopen Creek near Wapwallopen	XC	
Wapwallopen Creek	4	All	Ridge and Valley Freestone	Luzerne	Fishing Creek near Bloomsburg		X
Salem Creek	1	All	Ridge and Valley Freestone	Luzerne	Wapwallopen Creek near Wapwallopen	XC	
Salem Creek	1	All	Ridge and Valley Freestone	Luzerne	Fishing Creek near Bloomsburg		X
Mugser Run	2	All	Ridge and Valley Freestone	Columbia	Wapwallopen Creek near Wapwallopen	XC	
Mugser Run	2	All	Ridge and Valley Freestone	Columbia	Fishing Creek near Bloomsburg		X
E. Branch Raven Creek	1		Ridge and Valley Freestone	Columbia	Wapwallopen Creek near Wapwallopen	XC	
E. Branch Raven Creek	1		Ridge and Valley Freestone	Columbia	Fishing Creek near Bloomsburg		X
Green Creek	3	All	Ridge and Valley Freestone	Columbia	Fishing Creek near Bloomsburg	X	X
Big Run	1		Ridge and Valley Freestone	Juniata	Shermans Creek at Shermans Dale	X	X
Laurel Run	1		Ridge and Valley Freestone	Juniata	Shermans Creek at Shermans Dale	X	X
Laurel Run	1		Ridge and Valley Freestone	Juniata	Kishacoquillas Creek at Reedsville		X
Granville Run	1		Ridge and Valley Freestone	Mifflin	Shermans Creek at Shermans Dale	X	X
Laurel Run	1		Ridge and Valley Freestone	Huntingdon	Aughwick Creek near Three Springs	X	X
Kansas Valley Run	1		Ridge and Valley Freestone	Perry	Shermans Creek at Shermans Dale	X	X
Fowler Hollow Run	2	All	Ridge and Valley Freestone	Perry	Shermans Creek at Shermans Dale	X	X
Broad Run	1		Ridge and Valley Freestone	Franklin	Shermans Creek at Shermans Dale	X	X
Horning Run	1		Ridge and Valley Freestone	Juniata	Shermans Creek at Shermans Dale	X	X
Sand Spring Run	1		Ridge and Valley Freestone	Union	Sand Spring Run near White Deer	X	
Sand Spring Run	1		Ridge and Valley Freestone	Union	Penns Creek at Penns Creek		X
Rapid Run	3	All	Ridge and Valley Freestone	Union	Sand Spring Run near White Deer	X	
Rapid Run	3	All	Ridge and Valley Freestone	Union	Penns Creek at Penns Creek		X
Swift Run	1		Ridge and Valley Freestone	Mifflin	Sand Spring Run near White Deer	X	
Swift Run	1		Ridge and Valley Freestone	Mifflin	Penns Creek at Penns Creek		X
Big Fill Run	1		Ridge and Valley Freestone	Blair	Bald Eagle Creek at Tyrone	X	
Big Fill Run	2	All	Ridge and Valley Freestone	Blair	Frankstown Branch at Williamsburg		X
Bear Run	1		Ridge and Valley Freestone	Union	Sand Spring Run near White Deer	X	
Bear Run	1		Ridge and Valley Freestone	Union	Penns Creek at Penns Creek		X
Vanscoyoc Run	1		Ridge and Valley Freestone	Blair	Bald Eagle Creek at Tyrone	X	
Vanscoyoc Run	1		Ridge and Valley Freestone	Blair	Frankstown Branch at Williamsburg		X
Mile Run	1		Ridge and Valley Freestone	Union	Sand Spring Run near White Deer	X	
Mile Run	1		Ridge and Valley Freestone	Union	Penns Creek at Penns Creek		X

* Hydrology Key: X Hydrology based on drainage area ratio
XC Hydrology based on gage shown, but more complex than drainage area ratio
C Complex synthesis procedure, multiple gages

Table 5.15. Study Sites and Gages—Continued

Study Stream	No. Seg.	Seg. No.	Region	County	Gage	Use	
						Hydrology*	Tracking Flows/ Dispatching Crew
Tannery Hollow	1		Unglaciated. Plateau	Cameron	Driftwood Branch at Sterling Run	X	X
Whitehead Run	1		Unglaciated Plateau	Cameron	Driftwood Branch at Sterling Run	X	X
Benner Run	1		Unglaciated Plateau	Centre	Marsh Creek at Blanchard	X	
Benner Run	1		Unglaciated Plateau	Centre	Bald Eagle Creek at Milesburg		X
Benner Run	1		Unglaciated Plateau	Centre	Clearfield Creek at Dimeling		X
Meyers Run	1		Unglaciated Plateau	Centre	Marsh Creek at Blanchard	X	
Meyers Run	1		Unglaciated Plateau	Centre	Bald Eagle Creek at Milesburg		X
Meyers Run	1		Unglaciated Plateau	Centre	Clearfield Creek at Dimeling		X
Mill Run	1		Unglaciated Plateau	Clinton	Marsh Creek at Blanchard	X	
Mill Run	1		Unglaciated Plateau	Clinton	Bald Eagle Creek at Milesburg		X
Strange Hollow	1		Unglaciated Plateau	McKean	Potato Creek at Smethport	X	X
Lyman Run	1		Unglaciated Plateau	McKean	Potato Creek at Smethport	X	X
Dunlap Run	1		Unglaciated Plateau	Clearfield	Clearfield Creek at Dimeling	X	X
Bloomster Hollow	1		Unglaciated Plateau	McKean	Potato Creek at Smethport	X	X
Warner Branch	1		Unglaciated Plateau	McKean	Potato Creek at Smethport	X	X
E. Branch Spring Creek	2	All	Unglaciated Plateau	Elk	W. Branch Clarion at Wilcox	X	X
Cherry Run	1		Unglaciated Plateau	Forest	W. Branch Clarion at Wilcox	X	X
Seaton Run	1		Unglaciated Plateau	Jefferson	W. Branch Clarion at Wilcox	X	X
Lower Two Mile Run	2	All	Unglaciated Plateau	Venango	Oil Creek at Rouseville	X	X
Beech Run	1		Unglaciated Plateau	Clearfield	Mahoning Creek at Punxsutawney	X	X
McEwen Run	1		Unglaciated Plateau	Jefferson	Mahoning Creek at Punxsutawney	X	X
Rattlesnake Run	1		Unglaciated Plateau	Jefferson	Mahoning Creek at Punxsutawney	X	X
Coke Oven Hollow	1		Unglaciated Plateau	Somerset	Laurel Hill Creek at Ursina	X	X
Whites Creek	2	All	Unglaciated Plateau	Somerset	Laurel Hill Creek at Ursina	X	X
Red Run	1		Unglaciated Plateau	Cambria	Blacklick Creek at Josephine	X	X
Findley Run	1		Unglaciated Plateau	Indiana	Blacklick Creek at Josephine	X	X
Fall Creek	2	All	Unglaciated Plateau	Somerset	Laurel Hill Creek at Ursina	X	X
McClintock Run	1	All	Unglaciated Plateau	Somerset	Laurel Hill Creek at Ursina	X	X
Cush Creek	2	All	Unglaciated Plateau	Indiana	W. Branch Susquehanna River at Bower	X	X

* Hydrology Key: X Hydrology based on drainage area ratio
XC Hydrology based on gage shown, but more complex than drainage area ratio
C Complex synthesis procedure, multiple gages

Table 5.15. *Study Sites and Gages—Continued*

Study Stream	No. Seg.	Seg. No.	Region	County	Gage	Use	
						Hydrology*	Tracking Flows/ Dispatching Crew
Baisman Run	1		Piedmont Upland	Baltimore	Little Falls at Blue Mount	X	
Basin Run	2		Piedmont Upland	Cecil	Basin Run at Liberty Grove	X	
Cooks Branch	1		Piedmont Upland	Baltimore	Beaver Run near Finksburg	X	
First Mine Branch	1		Piedmont Upland	Baltimore	Little Falls at Blue Mount	X	
Gillis Falls	2		Piedmont Upland	Carroll	North Br. Patapsco River at Cedarhurst	X	
Greene Branch	1		Piedmont Upland	Baltimore	Little Falls at Blue Mount	X	
Norris Run	1		Piedmont Upland	Carroll	Beaver Run near Finksburg	X	
Piney Run	1		Piedmont Upland	Baltimore	North Br. Patapsco River at Cedarhurst	X	
Third Mine Branch	1		Piedmont Upland	Baltimore	Little Falls at Blue Mount	X	
Timber Run	1		Piedmont Upland	Baltimore	Beaver Run near Finksburg	X	

* Hydrology Key:
X Hydrology based on drainage area ratio
XC Hydrology based on gage shown, but more complex than drainage area ratio
C Complex synthesis procedure, multiple gages

- Boiling Spring Run, Blair County;
- Potter Creek, Bedford County;
- Wapwallopen Creek and Salem Creek, Luzerne County;
- Mugser Run and East Branch Raven Creek, Columbia County; and
- Red Run, Cambria County.

The procedures for developing hydrology used for these sites are described in Appendix D.

5.5.4 Criteria for dispatching field crews

The determination of when to send out field crews was complicated by:

- The flow range criteria described in section 5.3.3; and
- Different flow conditions occurring in different study streams at a given time, e.g., one study stream in an area might be at a high flow, another stream at a low flow.

The flow relationships and targets shown in Table 5.7 were used to determine which data set(s) had been collected and which remained to be collected. Then the current flows at the tracking gage (Table 5.15) were compared to the appropriate threshold flow to determine whether to dispatch field crews to a particular study stream.

A spreadsheet was developed to facilitate tracking flows, to determine what flows remained to be measured, and when to dispatch field crews. The computation of target measurement flows, the determination of whether the target flow had been measured, the current flows at the study site, and the determination of whether the current flows were in the appropriate range were all programmed into the spreadsheet. The determination of whether flows were in the appropriate range was generally based on real-time data for the appropriate gage and a drainage area ratio.

5.6. Hydraulic Modeling

The PHABSIM computer programs, described by Milhous and others (1989), were used in the hydraulic model calibration and habitat modeling.

5.6.1 Data input and checking procedures

The purpose of the data input checking process was to ensure that the data collected and recorded in the field were accurately entered into the computer file used for hydraulic and habitat modeling.

CDS information (channel and overbank geometry, substrate and cover, flow rate and associated average water surface elevation, and velocity distribution) for each transect at all study sites was manually keyed into a computer data file using the PHABSIM data input routine. Then another PHABSIM routine was used to insure all information was properly located and formatted in the file, and that the data were consistent. A formatted listing of the input file was then manually compared to the original field data sheets to insure the data were correct.

In general, the field data for the PDSs were not entered into the computer file. However, velocity distribution data for the high flow partial data sets were entered and checked.

5.6.2 Hydraulic model calibration

Various hydraulic modeling options are available within PHABSIM, including a routine that uses Manning's equation to simulate water surface elevations (MANSQ) and a routine that uses a rating curve to estimate mean velocity at different flows from water surface elevations (IFG4). In this study, these routines were used to develop a representative hydraulic model for each study site. The hydraulic model(s) were then used to compute water surface elevations and associated velocity distributions at each study site for any flow that was chosen for habitat modeling.

The MANSQ routine develops a stage-discharge curve at each transect, based on a form of Manning's equation (Chow, 1959; Bovee, 1982):

$$Q = \frac{1.49}{n} S^{1/2} AR^{2/3} = KAR^{2/3}$$

where: n = roughness factor;
A = wetted area of the transect;
R = hydraulic radius (area divided by wetted perimeter);
S = slope of stream; and
K = conveyance factor.

The program utilizes the water surface elevation and discharge measured as part of the CDS, and computes other water surface elevations at selected discharges. The computed water surface elevations are based on the channel conveyance factor. The appropriate conveyance factor for each transect is developed by iteratively attempting to match the computed water surface elevations with measured water surface elevations and discharges collected as part of the PDSs (section 5.3.2).

The iterative process to determine the value of the conveyance factor that best fit the computed and observed water surface elevations required numerous computer simulations. In general, three sets of observed water surface elevations at significantly different flows were used for calibration purposes whenever possible. However, because of small differences between maximum and minimum median monthly flows (section 5.3.2) for some streams in the Ridge and Valley Limestone study region, only two data sets were used in the calibration for those streams.

The goal of the calibration process was to match computed and observed water surface elevations exactly. However, because that goal was often unattainable, the calibration process resulted in the value of the conveyance factor that minimized the difference between calculated and observed water surface elevations at each transect. Differences less than, or equal to, 0.1 ft were considered acceptable; differences greater than 0.1 ft required additional analyses to either reduce the difference or explain the reason for the difference.

Field data were collected for a total of 101 study segments in the four study regions (Table 5.5). During the calibration process, the following study sites were eliminated due to insufficient consistent field data to develop an adequate hydraulic model: Broad Run (Franklin County); East Branch Spring Creek (Elk County), segment 1; Rattlesnake Run (Jefferson County); and Whitehead Run (Cameron County). The first stream is in the Ridge in Valley Freestone study region, and the remaining streams are in the Unglaciated Plateau study region.

After the remaining study streams were calibrated, an acceptable hydraulic model was available for 254 individual transects, located at 97 different study sites. Sixteen transects out of a total of 254 were calibrated, although one of the calibration elevations did not match the observed field data within 0.1 ft. The differences ranged from 0.11 ft to 0.31 ft, with an average of 0.18 ft. These 16 transects were considered acceptable, and were used, even though one field data point was not within 0.1 ft of the calibrated flow.

Possible explanations for these discrepancies include:

- Leaf accumulation in the stream channel could have affected the observed water surface elevation;
- Undetected survey errors may have occurred;
- Benchmarks may have been disturbed;
- Seasonal variations in aquatic vegetation may have impacted the flow regime; or
- High water conditions, or other factors, occurring between the collection of data sets, may have caused changes in stream geometry.

Aquatic vegetation problems were acute in the Ridge and Valley Limestone study region, where 50 percent of the unresolved calibration problems occurred. The aquatic vegetation effect was not discovered until well into the data collection and calibration phases of the study.

A summary of the sites remaining after completion of the model calibration phase is shown in Table 5.16. This table is comparable to Table 5.5, which shows a summary of sites prior to the modeling phase. However, the data are compiled differently. The number of study streams with a certain number of segments are shown in Table 5.5, but the number of segments in each segment class are shown in Table 5.16. For example, a three-segment stream is counted as such, and included only in column four of Table 5.5. A three-segment stream has one segment in each of the first three classes, and is shown in each of columns 2 through 4 of Table 5.16. The reason for this change is that subsequent analyses group all segments in a given class.

Table 5.16. Summary of Study Sites After Hydraulic Calibration

Study Region	Number of Final Study Sites				Total Number of Segments
	Segment Class One	Segment Class Two	Segment Class Three	Segment Class Four	
Ridge and Valley Limestone	21	5	3	1	30
Ridge and Valley Freestone	19	6	3	1	29
Unglaciated Plateau	21	5	—	—	26
Piedmont Upland	10	2	—	—	12
Grand Total	**71**	**18**	**6**	**2**	**97**

5.7 Physical Microhabitat Estimation

The PHABSIM protram includes several habitat modeling routines. In this study, the HABTAE routine was used. This routine computes WUA per 1,000 feet of stream length for each transect, for each level of flow, and for each evaluation species and life stage. The amount of WUA is computed from HSC, transect geometry, mean column velocity, and transect reach lengths expressed as a percent of each mesohabitat type, determined as described in section 5.3.1.

After the hydraulic models were calibrated for the 97 study sites (section 5.6.2), the available habitat was estimated using the HABTAE routine. WUA was computed for adult, juvenile, fry, and spawning life stages for each evaluation species, brook trout, brown trout and combined brook and brown trout.

The habitat modeling included the following steps:

- Selection of flows to be simulated for each study site;
- Simulation of water surface elevations and velocity distributions for each flow at each study site and transect; and
- Computation of the available habitat for each flow at each study site and transect for each evaluation species and life stage, using the HABTAE routine in PHABSIM.

Eighteen different simulation flows were selected at each site, based on statistical analysis of the 12 median monthly flows at each site, estimated as described in section 5.5. This statistical analysis gave values for the minimum, maximum, and 25th, 50th, and 75th percentile median monthly flows at each site. Thirteen additional values were calculated from these five values, emphasizing the lower end of the expected flow range, as follows:

- Three simulation flows less than the minimum median monthly flow;
- Four flows between the minimum median monthly flow and the 75 percent probability of exceedance value;
- Two flows between the 75 and 50 percent probability of exceedance;
- Two flows between the 50 and 25 percent probability of exceedance;
- One flow between the 25 percent probability of exceedance and the maximum median monthly flow; and
- One flow greater than the maximum median monthly flow.

These 18 flows were checked to insure they were within the acceptable model flow range discussed in section 5.3.3. If any simulation flows fell outside the model flow range, the simulation values were modified to insure they would not violate the maximum extrapolation limits described in section 5.3.3.

The previously-calibrated hydraulic models for each cell of each transect were used to simulate water surface elevations for each flow selected, using the MANSQ routine. The computed water surface elevations were used to calculate a velocity distribution for each simulation flow across each transect, using the IFG4 routine. That routine adjusts the observed water surface elevation and associated velocity distribution across the transect (collected as part of the CDS) to determine a velocity distribution that corresponds to each simulated flow and water surface elevation. The result is a water surface elevation and velocity distribution table for each transect for each of the 18 simulation flows.

The input to the HABTAE routine included the following:

- The water surface elevation/velocity distribution table;
- Percentage length of each mesohabitat type determined from the length of each mesohabitat type, collected as part of the complete data set (section 5.3.1);
- HSC for the evaluation species and life stage being analyzed, developed as described in sections 3.7; and
- All of the original transect geometry and substrate data.

The HABTAE routine generates a table of WUA versus discharge for the study site for each species and life stage. An example of these tables is shown in Table 5.17. The simulation is repeated for each life stage of each evaluation species being considered.

5.8 Comparison of Univariate and Binary Suitability Criteria

5.8.1 Purpose of comparing alternative criteria

Because univariate habitat suitability criteria such as described in sections 3.7 may result in protecting low quality habitat, Bovee and others (1994) recommend consideration of the use of binary, rather than univariate curves, in microhabitat simulations. The difference between the two types of criteria is that univariate criteria can have values that range from 1 to 0, as shown in Figures 3.9 through 3.16, but binary criteria can only have a value of either 1 or 0. Univariate curves have been almost universally used in IFIM studies involving brook and brown trout. No binary criteria for brook or brown trout were identified for transferability testing at the time this study was initiated.

Binary criteria were developed from the new univariate HSC (section 3.7), and a pilot study was performed to evaluate the potential effects of using binary criteria for this study

5.8.2 Development of binary criteria

There are no established methods for converting univariate criteria to binary criteria. The shape of the univariate curves shown in Figures 3.9 through 3.16 was examined to establish the cutoff for optimum habitat for use in developing binary criteria. Some of the univariate curves have sharp peaks, resulting in only a narrow range of depths or velocities for the greater HSC index values. For that reason, binary criteria for depth and velocity were developed by assigning the binary criteria value of 1 to all univariate suitability index values equal to, or greater than, 0.7. All univariate suitability index values less than 0.7 were assigned the binary criteria value of 0. The same procedure was used to develop binary substrate/cover criteria for brook and brown trout juveniles, spawning, and fry.

If the same procedure had been used to develop binary substrate/cover criteria for adults, the only habitat with any value (binary criteria value of 1) would have been that associated with undercut objects along stream banks. As shown in Table 3.7, all other habitat would have been assigned the binary criteria value of 0. Because brook and brown trout adults in the transferability study streams used other types of cover when it was available, cover types 2 (object cover), 3 (undercut object along bank), 4 (aquatic vegetation), and 5 (terrestrial vegetation less than 1 foot above water surface) were assigned the binary criteria value of 1. Cover type 1 (no cover) was assigned the binary criteria value of 0 for brook and brown trout adults.

5.8.3 Pilot study procedures and results

The purpose of the pilot study was to compare the difference in habitat (WUA) values resulting from the different types of criteria. The pilot study was conducted at four study sites in each of three study regions, with a range of drainage areas to minimize bias. WUA versus discharge relationships for both sets of criteria were plotted, and evaluated subjectively. In all cases, the univariate criteria produced a smooth, steadily increasing or decreasing plot of habitat versus flow, whereas the binary criteria plots showed significant variability, sometimes a saw-tooth pattern. Comparisons of the WUA curves for Bloomster Hollow (Unglaciated Plateau study region) for each type of criteria and each life stage are

Table 5.17. Example of Habitat Output, Green Creek, Segment 1, Ridge and Valley Limestone Study Region

```
        DISCHARGE           AREA
*  1       0.42          9275.05
*  2       0.53          9506.83
*  3       0.65          9762.35
*  4       0.76         10023.77
*  5       0.86         10104.15
*  6       0.97         10160.23
*  7       1.07         10259.48
*  8       1.18         10330.73
*  9       1.28         10411.09
*10        1.80         10708.92
*11        2.32         10962.97
*12        2.84         11087.59
*13        3.10         11130.77
*14        3.37         11192.94
*15        3.63         11246.69
*16        4.91         11490.02
*17        6.18         11648.83
*18        7.42         11826.97
***************
BROOK TROUT
        DISCHARGE          ADULT       JUVENILE      SPAWNING          FRY
*  1       0.42           664.72        1766.67       1001.39      1726.70
*  2       0.53           721.55        1878.57       1066.90      1710.23
*  3       0.65           796.02        2031.52       1155.62      1723.81
*  4       0.76           849.33        2158.53       1236.56      1743.60
*  5       0.86           892.00        2234.56       1290.77      1716.47
*  6       0.97           939.83        2318.00       1328.13      1683.01
*  7       1.07           990.77        2428.81       1379.91      1685.53
*  8       1.18          1018.35        2496.07       1412.77      1662.13
*  9       1.28          1060.61        2578.90       1450.34      1637.70
*10        1.80          1205.83        2909.19       1551.68      1553.12
*11        2.32          1336.82        3175.69       1635.44      1511.73
*12        2.84          1433.29        3356.81       1672.94      1392.18
*13        3.10          1456.89        3400.47       1676.07      1360.04
*14        3.37          1505.50        3484.10       1692.68      1329.86
*15        3.63          1536.59        3547.27       1706.22      1302.04
*16        4.91          1656.49        3640.53       1754.76      1234.77
*17        6.18          1740.94        3680.77       1693.78      1203.68
*18        7.42          1849.11        3742.42       1643.97      1143.86
```

shown in Figure 5.6, and illustrate the behavior of the different types of criteria. All 12 study sites used in this pilot study showed similar behavior.

Although the concept of using only the optimum habitat seems intuitively reasonable, the shapes of the curves, and the low amount of habitat available on streams with excellent trout populations, made interpretation of the binary curves difficult. The WUA curves based on univariate criteria appeared to be more consistent with expected flow versus habitat relationships. Perhaps the reason is that suboptimal habitat is very important to the populations. For that reason, the analysis of habitat impacts was based on univariate criteria.

5.9 Wetted Perimeter Analysis

As discussed in section 2.1.1.2, the wetted perimeter method is usually applied to riffle transects, because those transects are considered most critical for protecting macroinvertebrate populations. The wetted perimeter method was applied to each riffle transect measured during the study. Because some study sites did not have any riffle habitat, only 91 riffle transects were analyzed, 12 in the Piedmont Upland study region, 25 in the Unglaciated Plateau study region, 26 in the Ridge and Valley Limestone study region, and 28 in the Ridge and Valley Freestone study region.

For each riffle transect, wetted perimeter at the simulation discharges was plotted versus flow, and the inflection point was determined visually. In effect, this procedure assumes that the inflection point is within the range of the simulation flows.

Definite inflection points could be identified for only 47 study sites and transects. Examples of definite inflection points are shown in Figures 5.7 and 5.8. The graphs for the remaining transects showed one of the following:

- Either a straight line or a smooth curve with no discernible inflection points, as illustrated in Figures 5.9 and 5.10;
- A slight change in curvature, resulting in a marginal selection of the inflection point, as illustrated in Figure 5.11; or
- Two distinct inflection points, as illustrated in Figure 5.12.

A summary of the number of segments showing each type of plot is shown in Table 5.18.

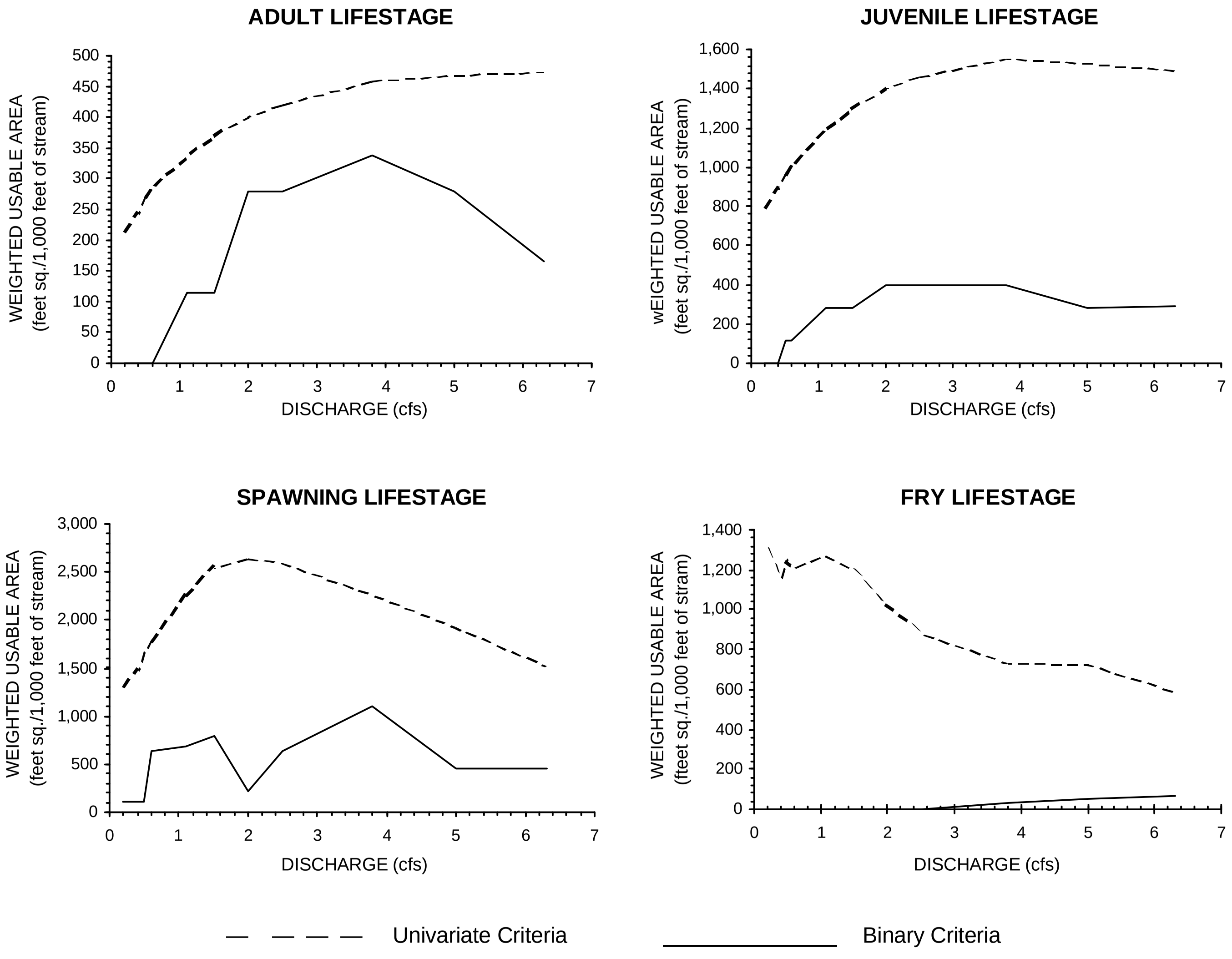


Figure 5.6. Comparison of Weighted Usable Area for Alternative Habitat Suitability Criteria

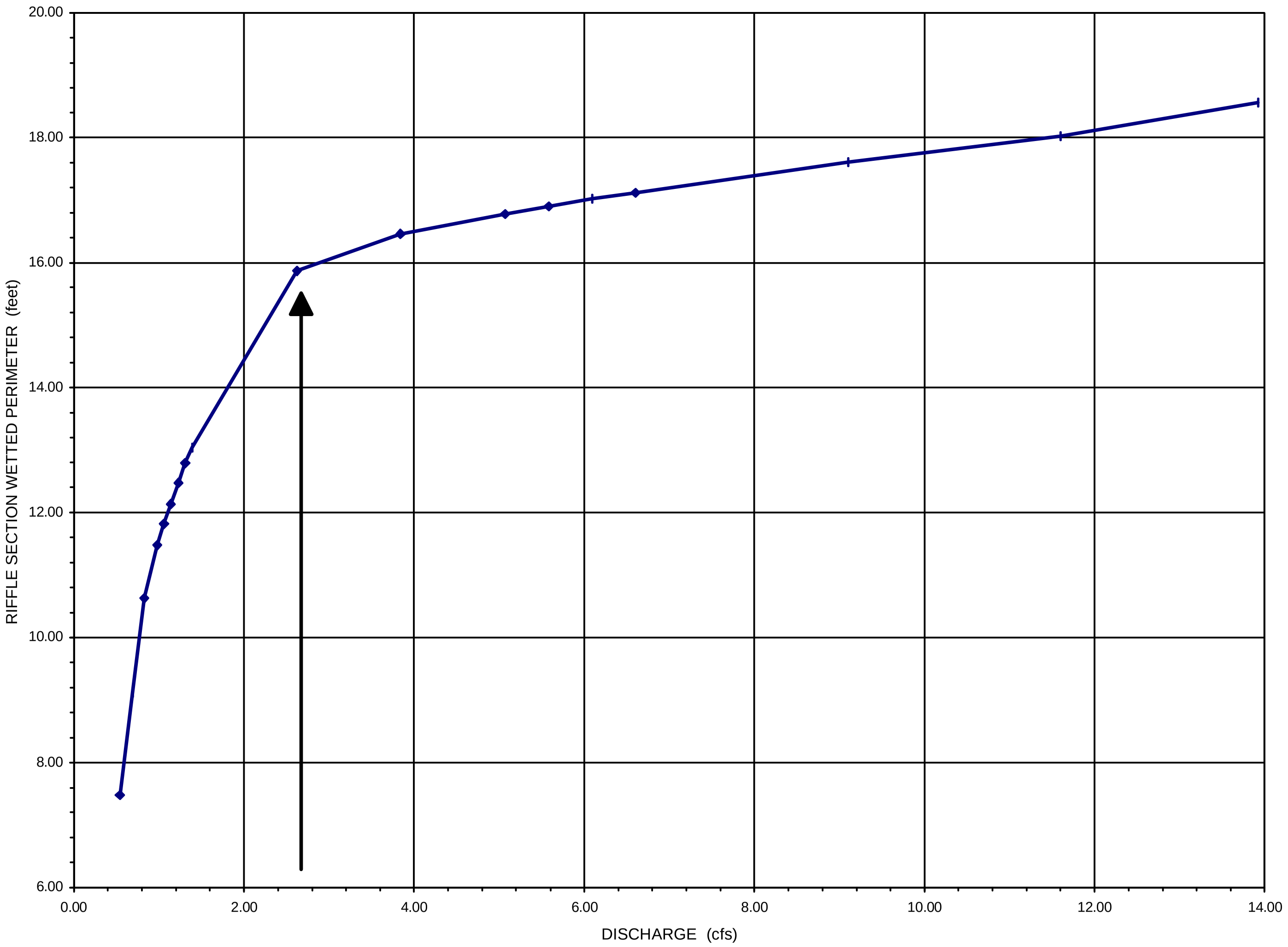


Figure 5.7. Typical Wetted Perimeter Plot With Definite Inflection Point (Unglaciated Plateau Study Region, Fall Creek, Segment 1)

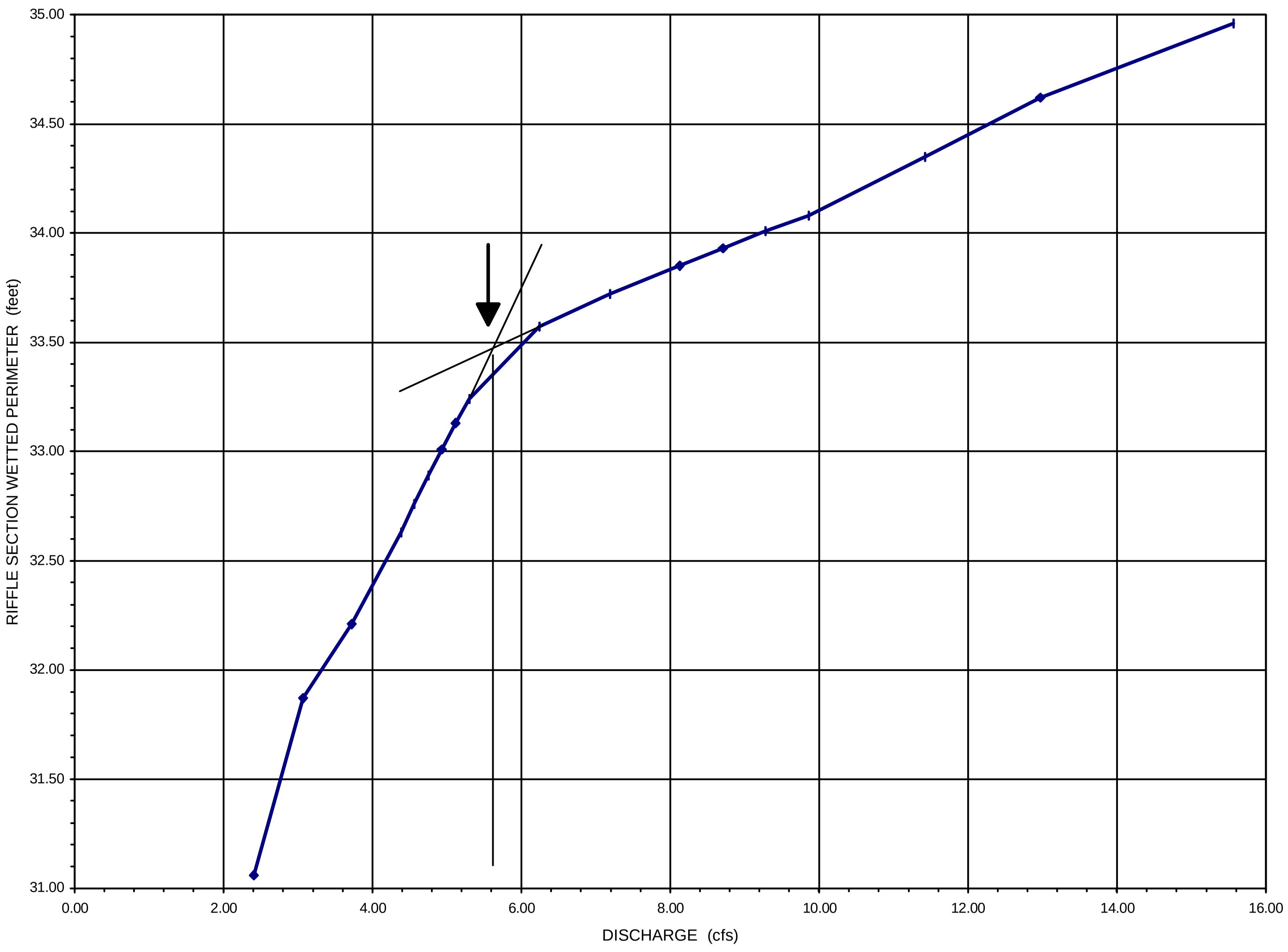


Figure 5.8. Typical Wetted Perimeter Plot With Definite Inflection Point (Piedmont Upland Study Region, Basin Run, Segment 2)

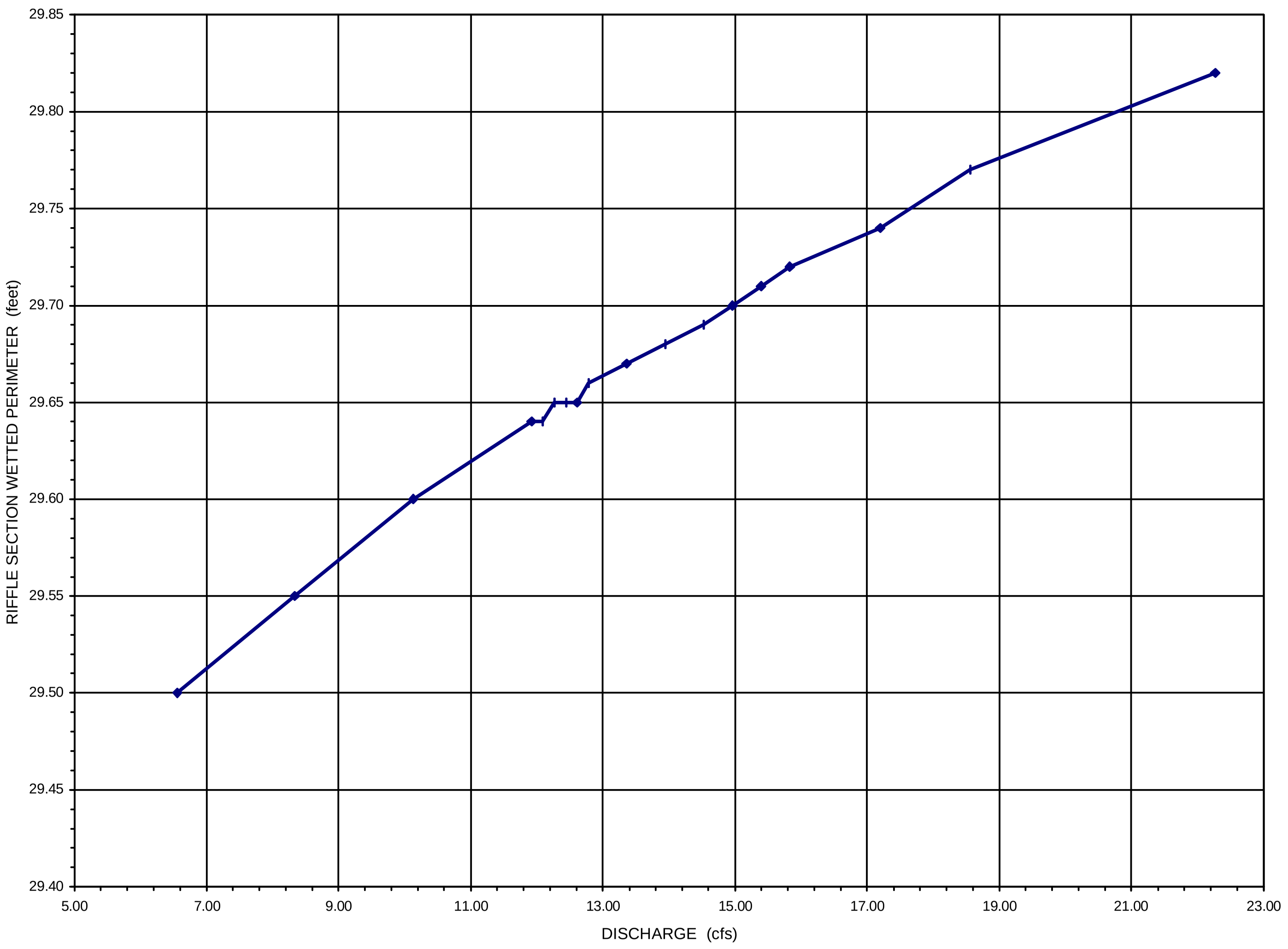


Figure 5.9. Typical Wetted Perimeter Plot With No Inflection Point (Ridge and Valley Limestone Study Region, Cedar Creek, Lehigh County, Segment 1)

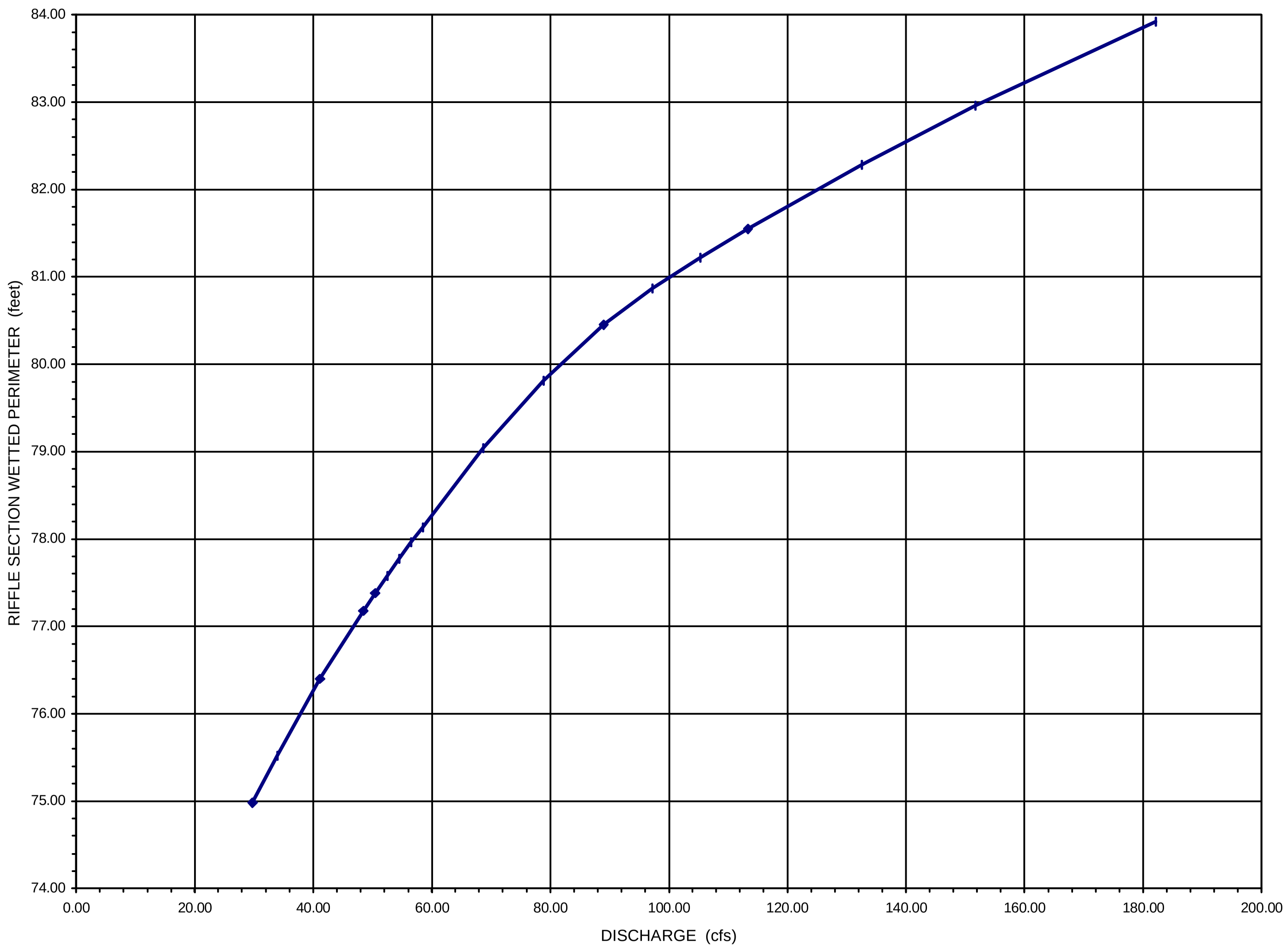


Figure 5.10. Typical Wetted Perimeter Plot With No Inflection Point (Ridge and Valley Limestone Study Region, Bushkill Creek, Segment 2)

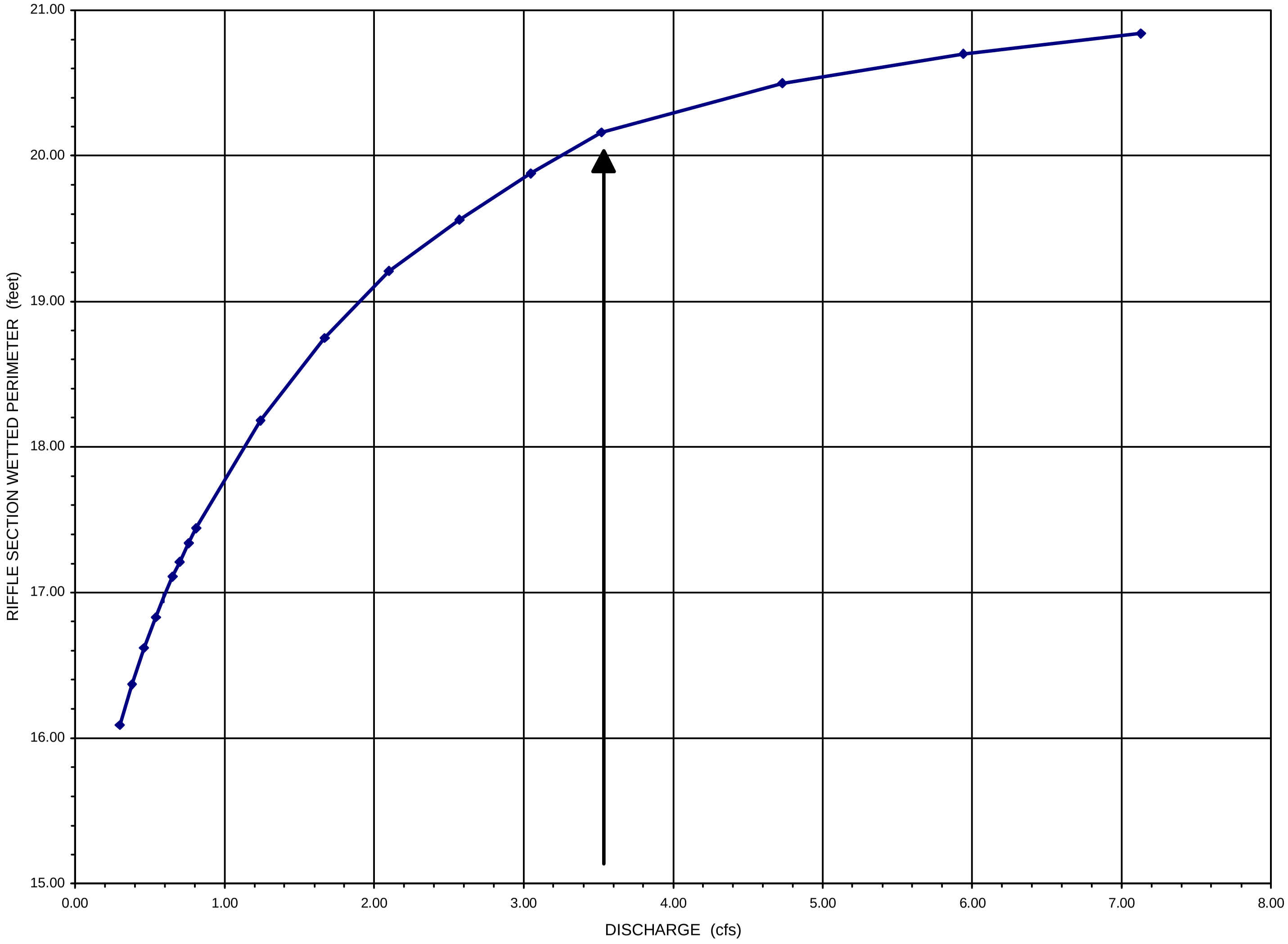


Figure 5.11. Typical Wetted Perimeter Plot With Marginal Inflection Point (Ridge and Valley Freestone Study Region, Big Run, Segment 1)

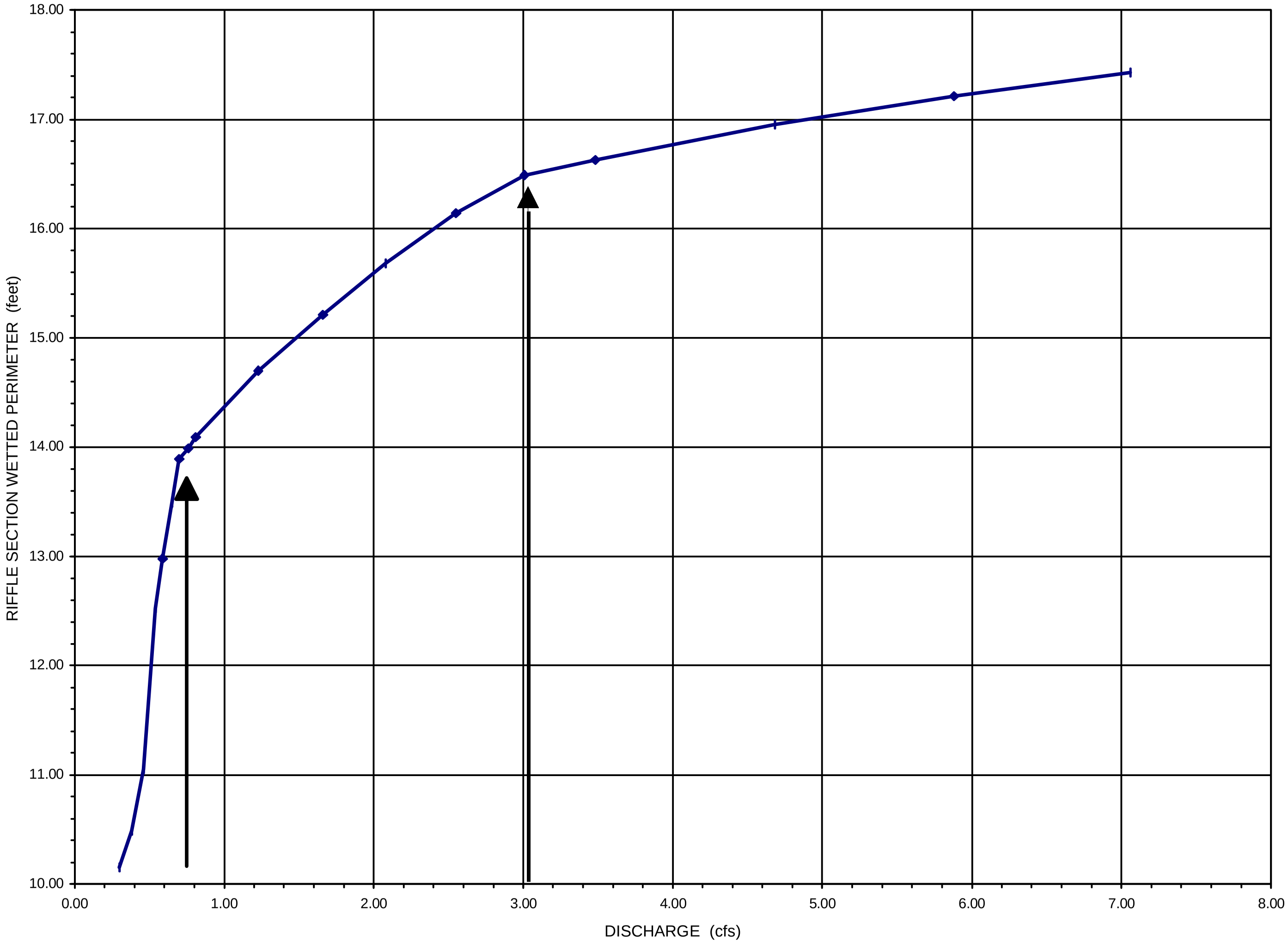


Figure 5.12. Typical Wetted Perimeter Plot With Two Inflection Points (Ridge and Valley Freestone Study Region, Laurel Run, Juniata County, Segment 1)

Table 5.18. Number of Sites Showing Different Wetted Perimeter Curve Types

Wetted Perimeter Curve Type	All Study Regions	Ridge and Valley Limestone	Ridge and Valley Freestone	Unglaciated Plateau	Piedmont Upland
Definite Inflection Point	47	14	14	15	4
No Inflection Point	23	9	5	4	5
Marginal Inflection Point	12	2	3	4	3
Double Inflection Point	9	1	6	2	0
Total	**91**	**26**	**23**	**25**	**12**

The flows at the inflection points were tabulated by region and expressed as a unit flow rate (csm) and as a percent of ADF. For transects where two inflection points were identified, the lower flow value was included in the table. The averages and standard deviations of both the unit flow rates and the percent ADF values were computed for all the transects within a region where inflection points could be identified. These tabulations are shown in Tables 5.19 through 5.22.

The averages and standard deviations of the unit flow rates and the percent ADF values also were computed for only the transects that displayed definite inflection points. These computations are not included in this report. However, comparison of this case with the results shown in Tables 5.19 through 5.22 showed that excluding study sites with no definite inflection point changed the regional average of the unit flow rates (csm) at the inflection point by as much as 0.12 csm, depending on region. Also, the regional average percentage of ADF changed by as much as 6.3 percent, depending on region. Since these changes were well within one standard deviation of the inflection point values for the respective regions, shown in Tables 5.19 through 5.22, they were considered insignificant. Also, there was no consistency in direction of change.

Because these wetted perimeter plots were developed only for the range of simulation flows, they did not include zero flow. The curves were extended to include the point at zero wetted perimeter and zero flow, as illustrated in Figures 5.13 and 5.14. These figures show that including the “zero-zero” point in the wetted perimeter versus flow plot changes the graph substantially, and usually introduces a lower inflection point, depending on channel geometry. The resulting inflection points for the Ridge and Valley Freestone, Unglaciated Plateau, and Piedmont Upland study regions are summarized in Table 5.23 through 5.25.

The conclusion was that wetted perimeter data developed from the limited range of simulation flows are not adequate to allow selection of inflection points. Therefore, comparisons with the results of the IFIM method are not possible without collecting additional extreme low flow data.

Table 5.19. Wetted Perimeter Summary, Ridge and Valley Freestone Study Region (Simulated Flows)

Study Site	**Segment Class**	**Drainage Area**	**Average Daily Flow**	**Inflection Point**			
		sq. mi.	**cfs**	**cfs**		**csm**	**% ADF**
Bear Run	1	2.19	4.12	1.50		0.68	36.41
Big Fill Run	2	12.12	20.91	None			
Big Run	1	2.88	4.10	3.50	M	1.22	85.37
E. Branch Raven Creek	1	2.48	3.63	None			
Fowlers Hollow Run	1	1.81	2.58	1.15		0.64	44.57
Fowlers Hollow Run	2	5.52	7.87	4.40		0.80	55.91
Granville Run	1	2.74	3.90	0.78		0.28	20.00
Green Creek	1	2.55	4.44	0.78	D	0.31	17.57
Green Creek	2	9.42	16.40	3.20	D	0.34	19.51
Green Creek	3	33.24	57.87	10.00	D	0.30	17.28
Horning Run	1	5.26	7.50	2.55		0.48	34.00
Kansas Valley Run	1	2.91	4.15	0.80		0.27	19.28
Laurel Run (Huntingdon County)	1	1.50	1.76	0.17	D	0.11	9.66
Laurel Run (Juniata County)	1	2.85	4.06	0.72	D	0.25	17.73
Mile Run	1	1.37	2.58	2.22		1.62	86.05
Mugser Run	1	4.39	6.42	2.35	M	0.54	36.60
Mugser Run	2	8.92	13.05	5.00		0.56	38.31
Rapid Run	1	3.50	6.59	3.50		1.00	53.11
Rapid Run	2	10.74	20.22	14.50		1.35	71.71
Rapid Run	3	14.53	27.35	8.80	D	0.61	32.18
Salem Creek	1	2.70	3.95	None			
Sand Spring Run	1	3.22	6.06	None			
Swift Run	1	3.03	5.70	3.05		1.01	53.51
Vanscoyoc Run	1	3.36	5.80	2.07		0.62	35.69
Wapwallopen Creek	1	4.13	2.76	None			
Wapwallopen Creek	2	13.90	17.06	12.30		0.88	72.10
Wapwallopen Creek	3	26.82	39.75	28.00	M	1.04	70.44
Wapwallopen Creek	4	33.43	49.42	21.50		0.64	43.50
					Average	0.68	42.20
					Standard Deviation	0.39	22.86

M = Marginal inflection point
D = Double inflection points (lower value shown)

Table 5.20. Wetted Perimeter Summary, Ridge and Valley Limestone Study Region (Simulated Flows)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point			
		sq. mi.	cfs	cfs		csm	% ADF
Antes Creek	1	52.00	51.91	None			
Big Spring Creek	1	7.30	35.74	None			
Boiling Spring Run	1	6.30	8.53	1.62		0.26	18.99
Bushkill Creek	1	59.37	85.26	61.00		1.03	71.55
Bushkill Creek	2	79.34	118.21	None			
Cedar Creek (Lehigh)	1	11.58	16.38	None			
Cedar Run (Centre)	1	13.94	13.92	None			
Cedar Run (Cumberland)	1	6.08	8.11	7.05		1.16	86.93
Honey Creek	1	91.45	68.93	28.00		0.31	40.62
Lick Creek	1	10.20	10.18	4.82		0.47	47.35
Little Fishing Creek	1	41.76	41.69	None			
Long Hollow Run	1	6.34	8.40	1.18	D	0.19	14.05
Monocacy Creek	1	8.45	12.13	3.45		0.41	28.44
Monocacy Creek	3	41.56	43.32	21.00		0.51	48.48
Nancy Run	1	5.85	8.62	None			
Penns Creek	1	15.10	19.90	9.98		0.66	50.15
Penns Creek	2	63.50	90.86	34.00		0.54	37.42
Penns Creek	3	89.40	128.79	103.00	M	1.15	79.98
Potter Creek	1	12.55	12.53	5.20	M	0.41	41.50
Spring Creek (Berks)	1	19.68	29.33	14.95		0.76	50.97
Spring Creek (Centre)	1	29.70	29.65	19.60		0.66	66.10
Spring Creek (Centre)	2	58.55	58.45	None			
Spring Creek Centre)	3	79.10	79.47	48.50		0.61	61.03
Spring Creek (Centre)	4	86.30	58.45	89.00		1.03	152.27
Trindle Spring Run	1	19.55	18.92	None			
Trout Creek	1	7.98	12.00	5.30		0.66	44.17
					Average	0.64	55.29
					Standard Deviation	0.30	31.79

M = Marginal inflection point
D = Double inflection points (lower value shown)

Table 5.21. Wetted Perimeter Summary, Unglaciated Plateau Study Region (Simulated Flows)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point			
		sq. mi.	cfs	cfs		csm	% ADF
Beech Run	1	1.40	2.45	1.17		0.84	47.76
Benner Run	1	4.38	5.78	2.00		0.46	34.60
Bloomster Hollow	1	1.52	2.90	None			
Cherry Run	1	3.35	6.70	6.82		2.04	101.79
Coke Oven Hollow	1	1.22	2.68	None			
Cush Creek	1	1.99	3.51	1.20	D	0.60	34.19
Cush Creek	2	4.85	8.56	12.60	M	2.60	147.20
Dunlap Run	1	1.20	1.87	1.85		1.54	98.93
E. Branch Spring Creek	2	11.45	22.90	11.20		0.98	48.91
Fall Creek	1	3.41	7.50	2.65		0.78	35.33
Fall Creek	2	5.89	12.95	5.80		0.98	44.79
Findley Run	1	6.17	11.86	15.00	M	2.43	126.48
Lower Two Mile Run	1	2.72	4.91	2.38		0.88	48.47
Lower Two Mile Run	2	8.43	15.20	4.00		0.47	26.32
Lyman Run	1	1.00	1.91	None			
McClintock Run	1	11.77	25.87	10.20		0.87	39.43
McEwen Run	1	2.13	3.73	1.88	M	0.88	50.40
Meyers Run	1	0.47	0.62	0.16		0.33	25.00
Mill Run	1	1.70	2.24	0.69		0.41	30.80
Red Run	1	1.43	1.99	0.69		0.48	34.67
Seaton Run	1	2.40	4.80	None			
Strange Hollow	1	0.88	1.68	0.49		0.56	29.17
Tannery Hollow	1	4.25	7.09	0.80	D	0.19	11.28
Warner Brook	1	3.22	6.14	2.05		0.64	33.39
Whites Creek	2	31.79	69.89	24.50	M	0.77	35.06
					Average	0.94	51.62
					Standard Deviation	0.67	35.63

M = Marginal inflection point
D = Double inflection points (lower value used)

Table 5.22. Wetted Perimeter Summary, Piedmont Upland Study Region (Simulated Flows)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point			
		sq. mi.	cfs	cfs		csm	% ADF
Baisman Run	1	1.33	1.69	1.47	M	1.11	86.98
Basin Run	1	2.08	2.64	None			
Basin Run	2	9.77	12.40	5.70		0.58	45.97
Cooks Branch	1	0.87	0.94	None			
First Mine Branch	1	5.07	6.44	3.65		0.72	56.68
Gillis Falls	1	2.26	2.51	None			
Gillis Falls	2	7.79	8.66	9.25		1.19	106.81
Greene Branch	1	1.14	1.45	0.93		0.82	64.14
Norris Run	1	2.04	2.21	None			
Piney Run	1	5.09	5.66	4.45	M	0.87	78.62
Third Mine Branch	1	0.96	1.22	None			
Timber Run	1	0.29	0.31	0.23	M	0.79	74.19
Average						0.87	73.34
Standard Deviation						0.21	20.19

M = Marginal inflection point
D = Double inflection points (lower value shown)

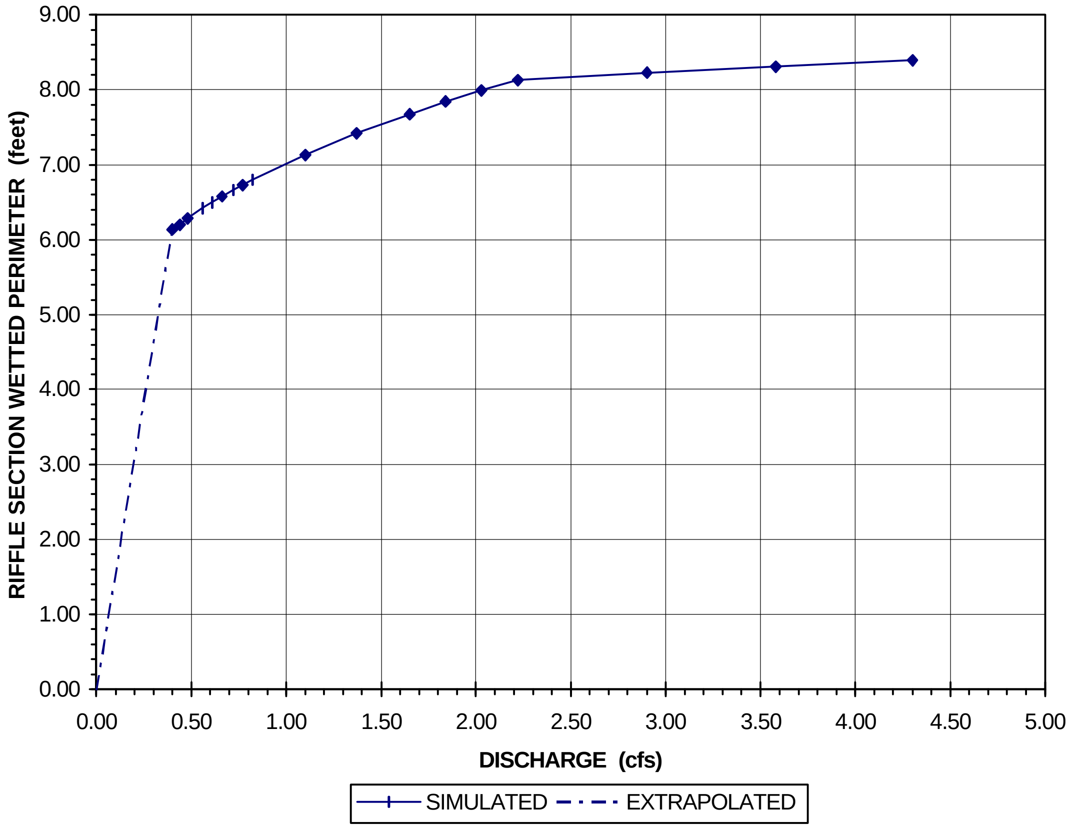


Figure 5.13. Wetted Perimeter Graph Showing Effect of Extrapolation, Mile Run, Segment 1

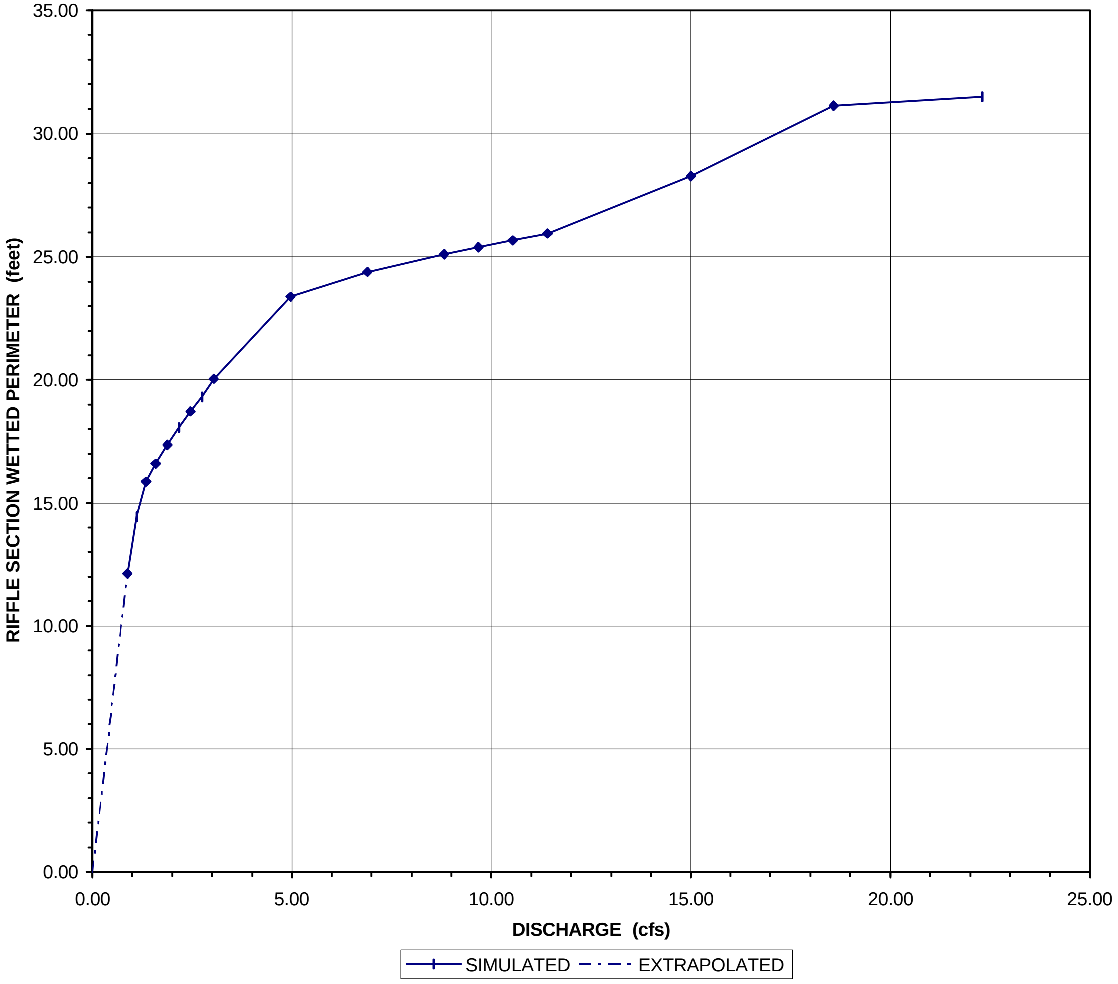


Figure 5.14. Wetted Perimeter Graph Showing Effect of Extrapolation, Mugser Run, Segment 2

Table 5.23. Wetted Perimeter Summary, Ridge and Valley Freestone Study Region (Extrapolated to Zero Flow)

Study Site	**Segment Class**	**Drainage Area**	**Average Daily Flow**	**Inflection Point**		
		sq. mi.	**cfs**	**cfs**	**csm**	**% ADF**
Bear Run	1	2.19	4.12	0.60	0.27	14.56
Big Fill Run	2	12.12	20.91	1.80	0.15	8.61
Big Run	1	2.88	4.10	0.30	0.10	7.31
E. Branch Raven Creek	1	2.48	3.63	0.25	0.10	6.89
Fowlers Hollow Run	1	1.81	2.58	0.35	0.19	13.57
Fowlers Hollow Run	2	5.52	7.87	0.60	0.11	7.62
Granville Run	1	2.74	3.90	0.30	0.11	7.69
Green Creek	1	2.55	4.44	0.78	0.31	17.57
Green Creek	2	9.42	16.40	3.00	0.32	18.29
Green Creek	3	33.24	57.87	5.50	0.17	9.50
Horning Run	1	5.26	7.50	1.00	0.19	13.33
Kansas Valley Run	1	2.91	4.15	0.70	0.24	16.87
Laurel Run (Huntingdon County)	1	1.50	1.76	0.17	0.11	9.66
Laurel Run (Juniata County)	1	2.85	4.06	0.72	0.25	17.73
Mile Run	1	1.37	2.58	0.40	0.29	15.50
Mugser Run	1	4.39	6.42	0.70	0.16	10.90
Mugser Run	2	8.92	13.05	1.30	0.15	9.96
Rapid Run	1	3.50	6.59	0.80	0.23	12.14
Rapid Run	2	10.74	20.22	3.00	0.28	14.84
Rapid Run	3	14.53	27.35	3.20	0.22	11.70
Salem Creek	1	2.70	3.95	0.35	0.13	8.86
Sand Spring Run	1	3.22	6.06	0.75	0.23	12.38
Swift Run	1	3.03	5.70	0.70	0.23	12.28
Vanscoyoc Run	1	3.36	5.80	0.45	0.13	7.76
Wapwallopen Creek	1	4.13	2.76	0.46	0.11	16.67
Wapwallopen Creek	2	13.90	17.06	1.70	0.12	9.96
Wapwallopen Creek	3	26.82	39.75	6.00	0.22	15.09
Wapwallopen Creek	4	33.43	49.42	9.50	0.28	19.22
				Average	0.19	12.37
				Standard Deviation	0.07	3.77

Table 5.24. Wetted Perimeter Summary, Unglaciated Plateau Study Region (Extrapolated to Zero Flow)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point		
		sq. mi.	cfs	cfs	csm	% ADF
Beech Run	1	1.40	2.45	0.22	0.16	8.98
Benner Run	1	4.38	5.78	1.60	0.37	27.68
Bloomster Hollow	1	1.52	2.90	0.30	0.20	10.34
Cherry Run	1	3.35	6.70	0.60	0.18	8.95
Coke Oven Hollow	1	1.22	2.68	0.30	0.25	11.19
Cush Creek	1	1.99	3.51	0.40	0.20	11.40
Cush Creek	2	4.85	8.56	0.80	0.17	9.35
Dunlap Run	1	1.20	1.87	0.15	0.13	8.02
E. Branch Spring Creek	2	11.45	22.90	4.00	0.35	17.47
Fall Creek	1	3.41	7.50	0.80	0.24	10.67
Fall Creek	2	5.89	12.95	2.30	0.39	17.76
Findley Run	1	6.17	11.86	1.30	0.21	26.48
Lower Two Mile Run	1	2.72	4.91	0.92	0.34	18.74
Lower Two Mile Run	2	8.43	15.20	2.00	0.24	13.16
Lyman Run	1	1.00	1.91	0.20	0.20	10.47
McClintock Run	1	11.77	25.87	4.80	0.41	18.55
McEwen Run	1	2.13	3.73	1.35	0.63	36.19
Meyers Run	1	0.47	0.62	0.06	0.13	9.68
Mill Run	1	1.70	2.24	0.60	0.35	26.79
Red Run	1	1.43	1.99	0.10	0.07	5.03
Seaton Run	1	2.40	4.80	0.50	0.21	10.42
Strange Hollow	1	0.88	1.68	0.18	0.21	10.71
Tannery Hollow	1	4.25	7.09	0.80	0.19	11.28
Warner Brook	1	3.22	6.14	2.00	0.62	32.57
Whites Creek	2	31.79	69.89	8.00	0.25	11.45
				Average	0.27	15.31
				Standard Deviation	0.14	8.33

Table 5.25. Wetted Perimeter Summary, Piedmont Upland Study Region (Extrapolated to Zero Flow)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point		
		sq. mi.	cfs	cfs	csm	% ADF
Baisman Run	1	1.33	1.69	0.48	0.36	28.40
Basin Run	1	2.08	2.64	0.50	0.24	18.94
Basin Run	2	9.77	12.40	2.40	0.25	19.35
Cooks Branch	1	0.87	0.94	0.20	0.23	21.28
First Mine Branch	1	5.07	6.44	1.80	0.36	27.95
Gillis Falls	1	2.26	2.51	0.60	0.27	23.90
Gillis Falls	2	7.79	8.66	2.00	0.26	23.09
Greene Branch	1	1.14	1.45	0.63	0.55	43.45
Norris Run	1	2.04	2.21	0.45	0.22	20.36
Piney Run	1	5.09	5.66	1.30	0.17	22.97
Third Mine Branch	1	0.96	1.22	0.35	0.37	28.69
Timber Run	1	0.29	0.31	0.07	0.24	22.58
				Average	0.29	25.08
				Standard Deviation	0.10	6.70