Validity of the wetted-perimeter method for recommending instream flows for rainbow trout in a small stream

by Christopher L Randolph

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fish and Wildlife Management
Montana State University

Abstract:

Validation of a method estimating minimum instream flow needs for fish is a prerequisite to its application. The validity of the average-riffle-wetted-perimeter method was investigated through study of the relationship between artificially supplemented rainbow trout populations and flow-related decreases in habitat in three sections of Ruby Creek, Madison County, Montana. Low summer flow had a regulating influence on trout numbers and biomass in the study sections. Factors other than short-term summer low flow may also have limited the trout, populations.

Numerical abundance and biomass of trout decreased as flow decreased in all study sections. Emigration from two study sections influenced by irrigation diversions correlated better with average daily flow than did emigration from a section with natural flow. Following flow reduction, trout emigration lagged 11 to 15 days in two of the three stream sections. Emigration from all study sections was primarily in an up stream direction. Average riffle wetted perimeter was not a consistent index of summer habitat suitability for trout. In a pool-riffle section, average-wetted' perimeter of riffles was highly correlated with trout numbers and biomass, and the inflection point on the wetted perimeter curve corresponded closely with the flow at which the rate of trout emigration increased substantially. Correlation between average wetted perimeter of riffles and trout numbers in two run-riffle sections was poor. Most habitat variables were highly correlated with flow and with each other. Variables estimating riffle surface width associated with depth greater than 15 cm changed in a pattern similar to percentage change in trout numbers and biomass.

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A thesis submitted in partial fulfillment
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APPROVAL

of a thesis submitted by

Christopher Lee Randolph

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Validation of a method estimating minimum instream flow needs for fish is a prerequisite to its application. The validity of the average-riffle-wetted-perimeter method was investigated through study of the relationship between artificially supplemented rainbow trout populations and flow-related decreases in habitat in three sections of Ruby Creek, Madison County, Montana. Low summer flow had a regulating influence on trout numbers and biomass in the study sections. Factors other than short-term summer low flow may also have limited the trout populations. Numerical abundance and biomass of trout decreased as flow decreased in all study sections. Emigration from two study sections influenced by irrigation diversions correlated better with average daily flow than did emigration from a section with natural flow. Following flow reduction, trout emigration lagged 11 to 15 days in two of the three stream sections. Emigration from all study sections was primarily in an upstream direction. Average riffle wetted perimeter was not a consistent index of summer habitat suitability for trout. In a pool-riffle section, average-wetted perimeter of riffles was highly correlated with trout numbers and biomass, and the inflection point on the wetted perimeter curve corresponded closely with the flow at which the rate of trout emigration increased substantially. Correlation between average wetted perimeter of riffles and trout numbers in two run-riffle sections was poor. Most habitat variables were highly correlated with flow and with each other. Variables estimating riffle surface width associated with depth greater than 15 cm changed in a pattern similar to percentage change in trout numbers and biomass.

INTRODUCTION

Water demand for agricultural, industrial, and domestic use has resulted in partial or total dewatering of many trout streams within the western United States. To protect and restore stream fisheries, biologists must be able to reliably estimate how much stream flow is needed for that resource. Methods of estimating and recommending adequate instream flows for aquatic life range from subjective inference, based on little or no field data, to detailed quantification and interpolation of the ecological requirements of the species of concern. The assumption of a habitat-standing crop relationship is implicit to all methodologies.

Several investigators have found correlations between physical habitat parameters and fish numbers and biomass in streams. Wesche (1974), Nickelson (1976), Nickelson and Reisenbichler (1977), Nickelson and Hafele (1978), and Binns (1979) developed and implemented models explaining the variation in fish numbers and biomass found in numerous streams. Inconsistencies within these models were assumed to be due to unmeasured physical habitat parameters.

Nelson (1980) evaluated the adequacy of four methods (single transect wetted-perimeter method, multiple wetted-perimeter transect method, non-field method, and instream flow group incremental method, IFG) for recommending instream flow on large rivers. He found that the wetted-perimeter methods provided acceptable absolute minimum flow recommendations when compared to long-term standing crop - flow relationships (Table 1). Based on Nelson's study, the Montana Department of Fish, Wildlife and Parks (MDFWP) chose wetted perimeter as the preferred method for recommending minimum flows for Montana streams. The wetted-perimeter method assumes that a stream's trout carrying capacity is proportional to its food production area, which is in turn proportional to the riffle-wetted perimeter (MDFWP 1981). Collings (1972), Collings and Hill (1973) and White and Cochnauer (1975) used methods based upon this concept to predict the quantity of water preferred by fish for rearing. MDFWP (1981) states that riffle-wetted perimeter may also provide an index of other factors limiting fish populations including spawning sites and cover.

The wetted-perimeter method uses the relationship between wetted perimeter and discharge for riffle cross-sections to derive flow recommendations. Wetted perimeter is the distance along the bottom and sides of a channel cross-section in contact with the water (Figure 1). As discharge increases, wetted perimeter increases, but not at a constant rate. Wetted perimeter increases rapidly with increasing discharge up to the point where the

Table 1. Comparison of the minimum instream flow recommendations derived from the single and multiple-wetted perimeter methods and trout standing crop and flow data for five reaches of the Madison, Beaverhead, Gallatin and Big Hole rivers (from Nelson 1980).

	Instream flow recommendations (liters/sec x 100)[a]			
	Single transect method	Multiple transect method	Trout standing-crop flow data	
Reach (site)	Minimum flow	Minimum flow	Absolute min. flow	Most desirable min. flow
Madison (#1)	312	255 and 396	255-312	340-390
Madison (#3)	170	142	184	326
Beaverhead (#2)	64	28	42	85
Gallatin (#2)	113	--	71	148
Big Hole (#1)	127	113 and 198	113	--

a: cfs = liters/sec x 0.0351

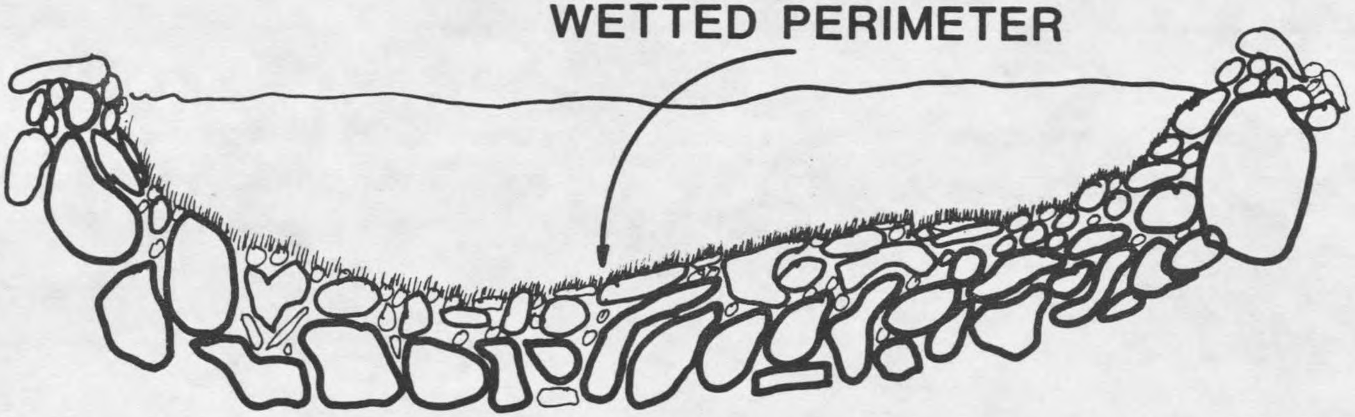

Figure 1. Diagrammatic representation of wetted perimeter in a typical stream cross section.

water covers the entire stream channel. Beyond this point, wetted perimeter increases less rapidly as discharge increases due to the more vertical sides of the channel. Points on wetted perimeter-discharge curves where there are abrupt changes in wetted perimeter with small changes in discharge, are referred to as inflection points.

There are generally one or two inflection points, depending on the channel cross section shape (Figure 2). An instream flow recommendation for a section of stream is made by averaging wetted perimeters from 3 to 10 riffle transects and plotting them against discharge. When there is only one inflection point, the corresponding flow is selected as the low flow recommendation. When there are two inflection points, the method provides a range of flows (between the lower and upper inflection points) from which a single instream flow can be recommended. The wetted perimeter-discharge curve for each riffle cross-section is derived using a wetted perimeter computer model (WETP) developed by the MDFWP (Nelson 1980). The WETP model uses 2 to 10 sets of water surface elevations surveyed at different known discharges at each cross-section. Water surface elevations (stages) are then used to establish a least-square fit of log-stage versus log-discharge. This rating curve, coupled with a surveyed cross-sectional

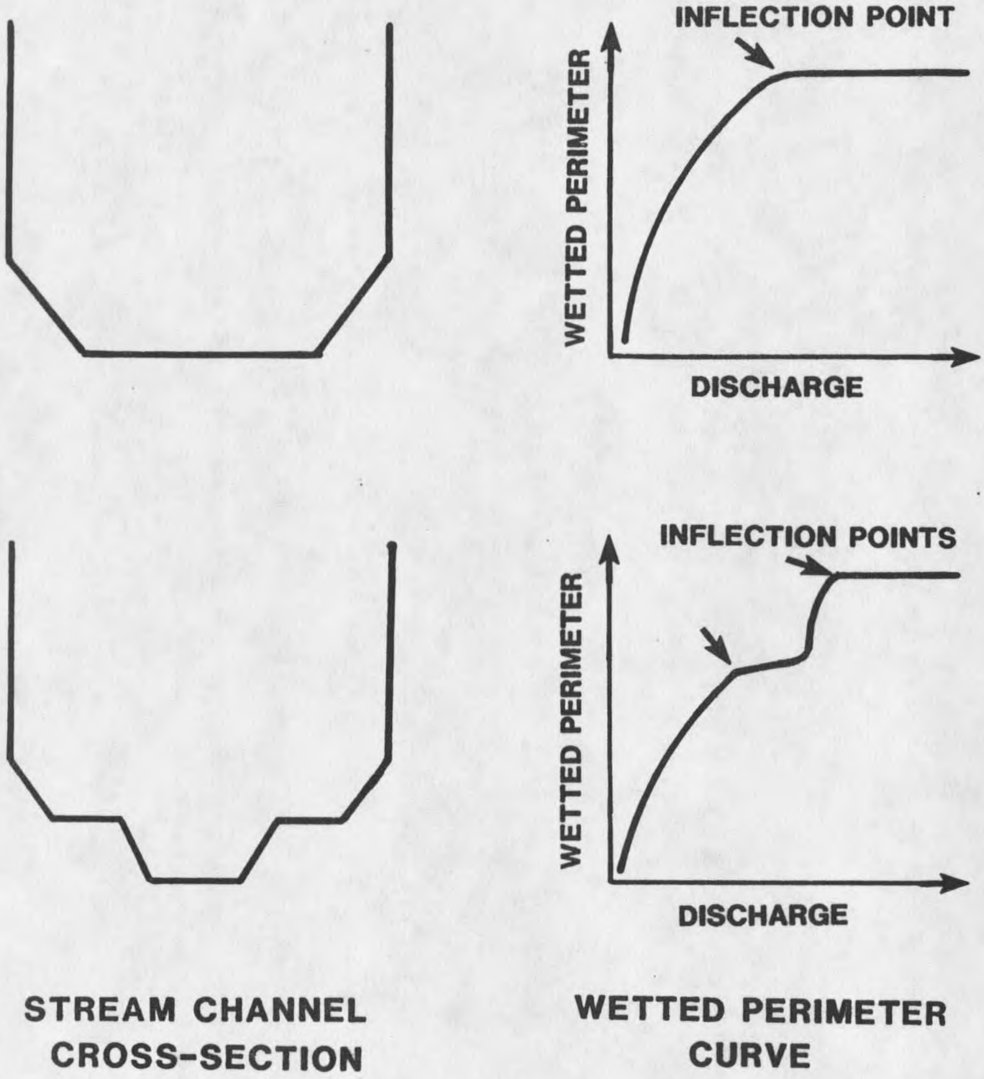

Figure 2. Diagrammatic representation of how stream channel cross section can influence the number of inflection points on corresponding wetted perimeter-discharge plots.

profile of the stream bed, is all that is needed to predict the wetted perimeter for each flow of interest.

The wetted-perimeter method is presently being applied to Montana streams, though its validity has only been shown on rivers with average annual discharge above 12,000 liters/sec (424 cubic feet per second, cfs). The goal of this study was to examine the validity of the wetted perimeter method of recommending minimum instream discharge for small streams of less than 1,400 liters/sec (50 cfs) average annual discharge. Objectives of the study were to test the following hypotheses: 1. salmonid abundance in small streams is regulated by low summer flow, 2. decreases in flow and flow-related reductions in habitat availability are accompanied by decreases in trout abundance, and 3. average wetted perimeter based on riffle cross sections can be used as a general index of adult salmonid habitat suitability in small streams.

DESCRIPTION OF STUDY AREA

Field studies were conducted on Ruby Creek, in Madison County, Montana (T9S, R1W, Sec. 10-12, Figure 3). Ruby Creek flows down the east slope of the Gravelly Mountain Range. Elevation of the 85 square kilometer (km^2) drainage ranges from 1682 meters (m) to 2682 m. The Ruby Creek drainage has a annual average precipitation of 53 centimeters (cm, MDFWP 1981).

Ruby Creek was chosen as the study area for several reasons. The stream was small, with discharge during the study ranging from 822 to 351 liters/sec (29 to 12 cfs). Average annual discharge was reported by MDFWP (1981) to be less than 1,400 liters/sec (50 cfs). These flows allowed efficient electrofishing and permitted construction of semipermanent fish weirs. Also Ruby Creek had adequate numbers of rainbow trout for use in experimental supplementation of the trout populations present in each study section. Rainbow trout (<u>Salmo</u> <u>gairdneri</u>) was the preferred experimental species because of its greater sensitivity to flow reductions compared to other trout species in southwest Montana. Ruby Creek also was reported to have light fishing pressure. This reduced the chance of anglers removing fish from the study sections (MDFG 1976). Finally, the presence of successive irrigation

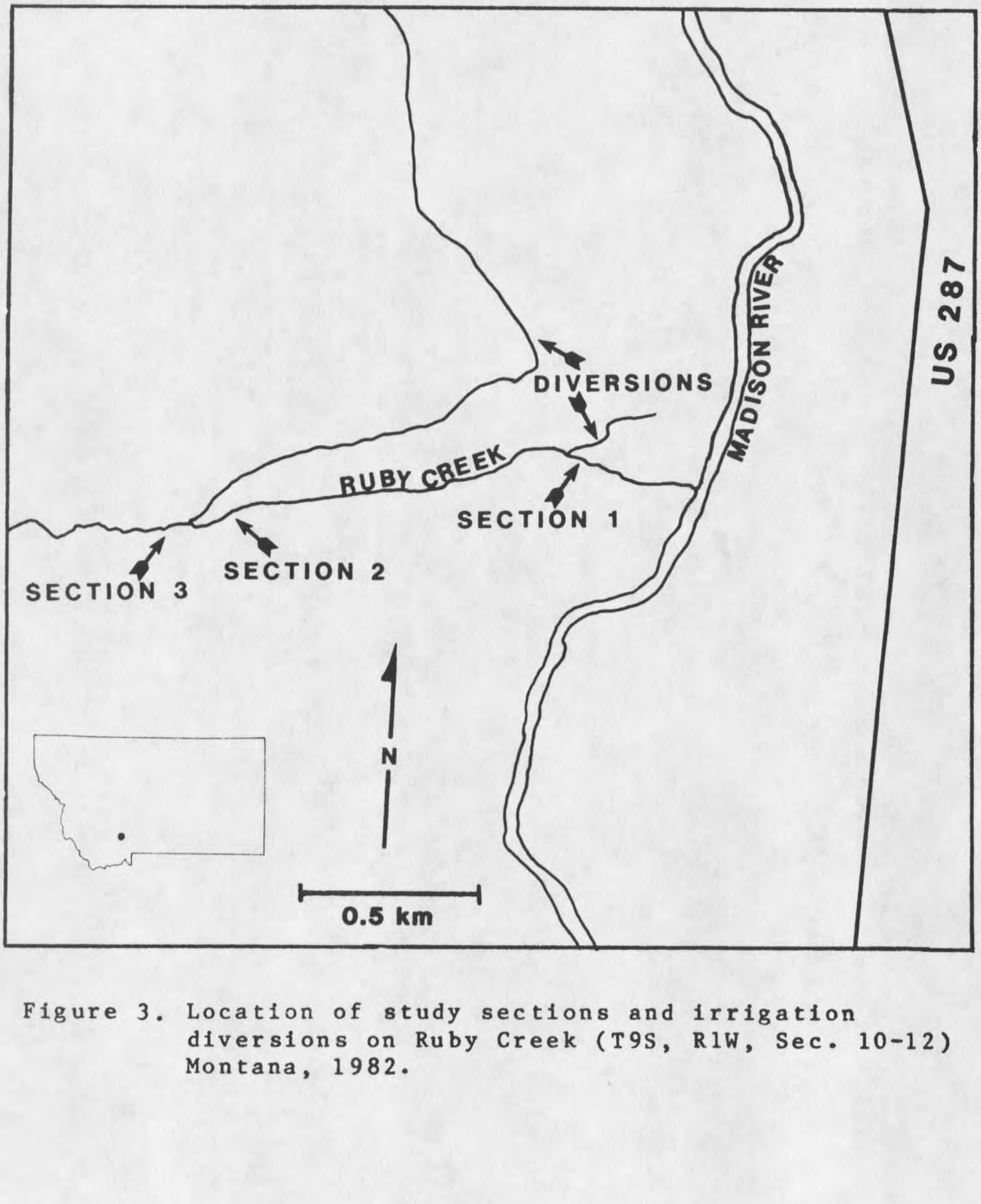

Figure 3. Location of study sections and irrigation diversions on Ruby Creek (T9S, R1W, Sec. 10-12) Montana, 1982.

diversions provided different levels of reduced discharges in two sections of the stream.

Three study sections, numbered consecutively in an upstream direction, were established along the course of Ruby Creek at 0.64 kilometer (km), 2.54 km and 3.34 km above the mouth. Sections 2 and 1 were below successive irrigation diversions while section 3 was above diversions and had no artificial flow control. Section 1 was characterized by a pool-riffle channel structure while sections 2 and 3 had a predominance of riffle-run habitat. Study sections differed in length, gradient, average width, sinuosity, and predominant particle size of streambed material (Table 2).

Table 2. General description of study sections, Ruby Creek, Montana, 1982.

Section	Thalweg distance (m)	Gradient (%)	Average width (m)	Sinuosity	Predominant particle size of streambed material
1	123.7	2.2	2.48	1.29	8-20 cm
2	106.7	1.6	3.14	1.22	8-20 cm
3	133.1	1.3	4.12	1.41	4-15 cm

METHODS

Fish Population Manipulation

Emigration of rainbow trout from study sections of Ruby Creek was measured by placing a weir and box trap (Figure 4) at the upstream and downstream ends of each section. The V-shaped weirs were constructed of 1.3 square centimeter (cm^2) mesh hardware cloth, supported by steel fence posts. After the weirs and traps were in place, resident fish (fish present in each study section before the start of the experiment) were removed from each study section by electrofishing with a 110-volt direct-current unit. For each experimental stream section, the resident rainbow trout >100 millimeter (mm), were removed by electrofishing and held in tubs. To the resident fish then were added trout electrofished from Ruby Creek above the study sections. The supplemented group of fish was then returned into the same experimental section from which the resident fish had been taken. Before stocking, fish total length, measured to the nearest millimeter, and weight, to the nearest gram (g), were recorded. Resident and supplemental fish were given different pelvic fin clips. The fish were held in live buckets until they recovered from handling and were then released in the middle of study sections.

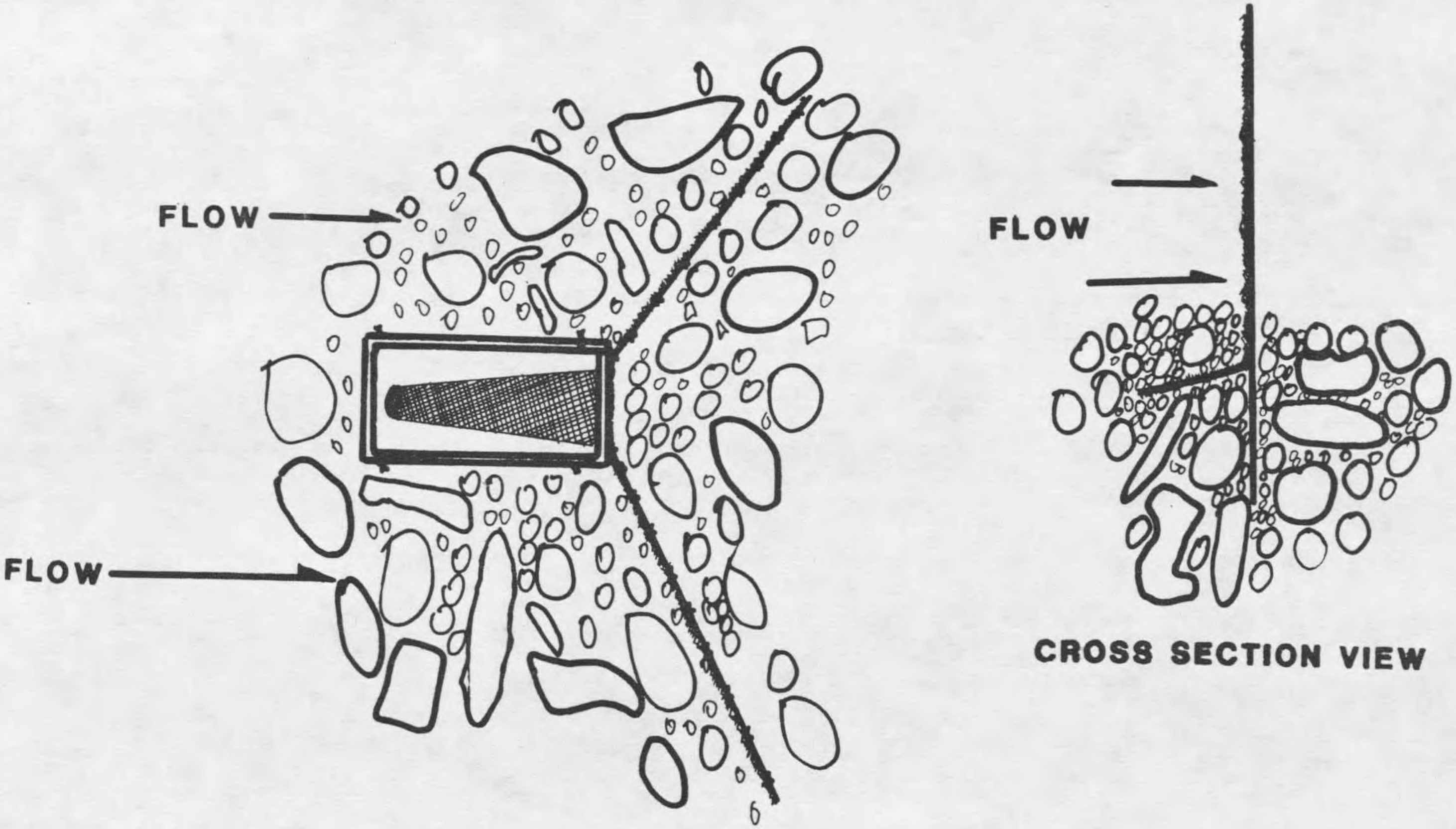

Figure 4. Diagrammatic representation of an upstream fish weir and trap used on Ruby Creek, Montana, 1982.

Fish were allowed to acclimate to test sections for 6 days, during which time all emigrants were returned to the study sections. Fish captured in the traps after the acclimation period, were measured and checked for marks before being released below sections 1 and 2, and above section 3. Abundance of fish remaining in the study sections was defined as the difference between the total cumulative trap counts and the initial number and biomass of fish stocked into the sections at the start of the study. At the end of the 63-day experiment (July 17-September 17), fish remaining in the study sections were removed by repeated electrofishing passes on 2 consecutive days. Electrofishing was discontinued when no fish were captured on two consecutive passes. Length and condition factors of fish emigrating from the study sections were regressed against flow (nearest 28 liters/sec or 1 cfs) to determine if there was a differential response among size classes to decreases in flow. Condition factors, weights and lengths of fish before and after the experiment were statistically compared using the Mann-Whitney test. Condition factor (K) was computed using the equation:

$$K = \text{weight} \times 10^{5} / \text{length}^{3}.$$

Habitat Evaluation

Physical characteristics of the study sections (depth, velocity, and channel width) were mapped at four discharges in sections 1 and 2 and at two discharges in section 3. Habitat cross sections were established perpendicular to the flow at 2-4 m intervals and marked with wooden stakes on each bank. Study sections 1 and 2 contanined 54 and 44 cross sections, respectively; 32 cross sections were established in section 3. A mapping baseline was established by recording the distance and compass bearing between cross section headstakes. The distance from the cross section headstakes to the water's edge was recorded at different flows (nearest 0.01 m) at each cross section.

In each cross section, the distance along the streambank having overhanging plant material or overhanging bank was measured, as well as the distance from this overhanging material to the water surface and its width overhanging the stream. Submerged undercut bank and plant material was also recorded as overhanging bank.

Alternate cross section transects were used for depth and velocity mapping. Depth, velocity and predominant particle size of streambed material measurements were made along transects at 10 equally spaced points. These same points were used during all subsequent measurements. Depth and velocities were measured with a top setting rod and Marsh McBurney electronic current meter. Depth was recorded to the nearest 1 cm and velocity at 0.6 of the water's depth was recorded to the nearest 0.3 centimeter per second (cm/s, 0.1 feet per second, ft/sec). Predominant particle size of the streambed material was estimated with the aid of a meter stick.

Quantity of the following habitat variables was determined for each study section at each flow:

1. Surface area (SA)-total area of water surface.
2. Depth area (DA)-surface area associated with water depths of 15 cm or more.
3. Velocity area (VA)-surface area with mean water velocity of 0.3 cm/s (0.1 ft/sec) or less.
4. Overhanging vegetation area (OHV)-surface area of the study section having vegetation within 30 cm of the water's surface, water depth of 15 cm or more beneath it and overhang width of at least 10 cm.
5. Overhanging bank (OHB)-surface area associated with overhanging bank within 30 cm of the water's surface, having depth of

at least 15 cm and minimum overhang width of 10 cm.

Habitat criteria were based on the results of studies evaluating habitat utilized by trout (Wesche 1974, Stewart 1970, Kennedy and Strange 1982).

Areal habitat variables were measured from habitat maps by extrapolating between transects, using a Tektronic digitizer pad and Geoscan computer program. Linear interpolation between known values of habitat variables was used to obtain estimates between measured flows.

Discharge measurements were made at the start and end of the experiment in each study section and following major changes in discharge. Staff gauges were placed in each section, and stage was recorded twice daily. These data and known discharges were used in developing stage-discharge relationships for each section, which were used to predict average daily flows in each section (Figures 5, 6, and 7). Daily maximum and minimum water temperatures were measured with maximum-minimum registering mercury thermometers in the upper and lower study sections.

Computer Modeling of Wetted Perimeter

Wetted perimeter transects (8 each in sections 1 and 2 and 9 in section 3) were established in typical riffles. Each transect water surface elevation was surveyed at three to four flows, according to Nelson (1980). Water

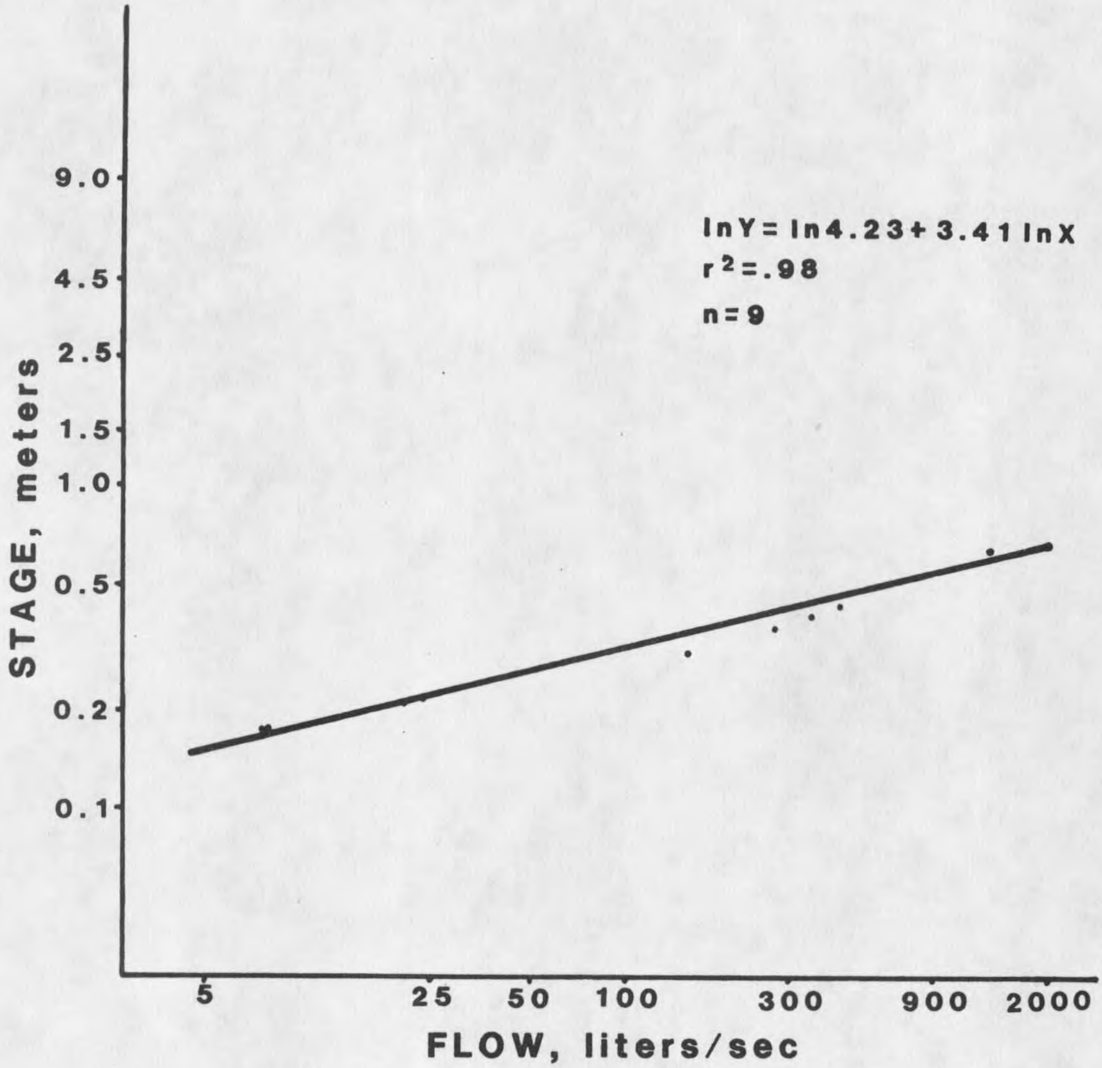

Figure 5. Stage-discharge relationship section 1, Ruby Creek, Montana, 1982.

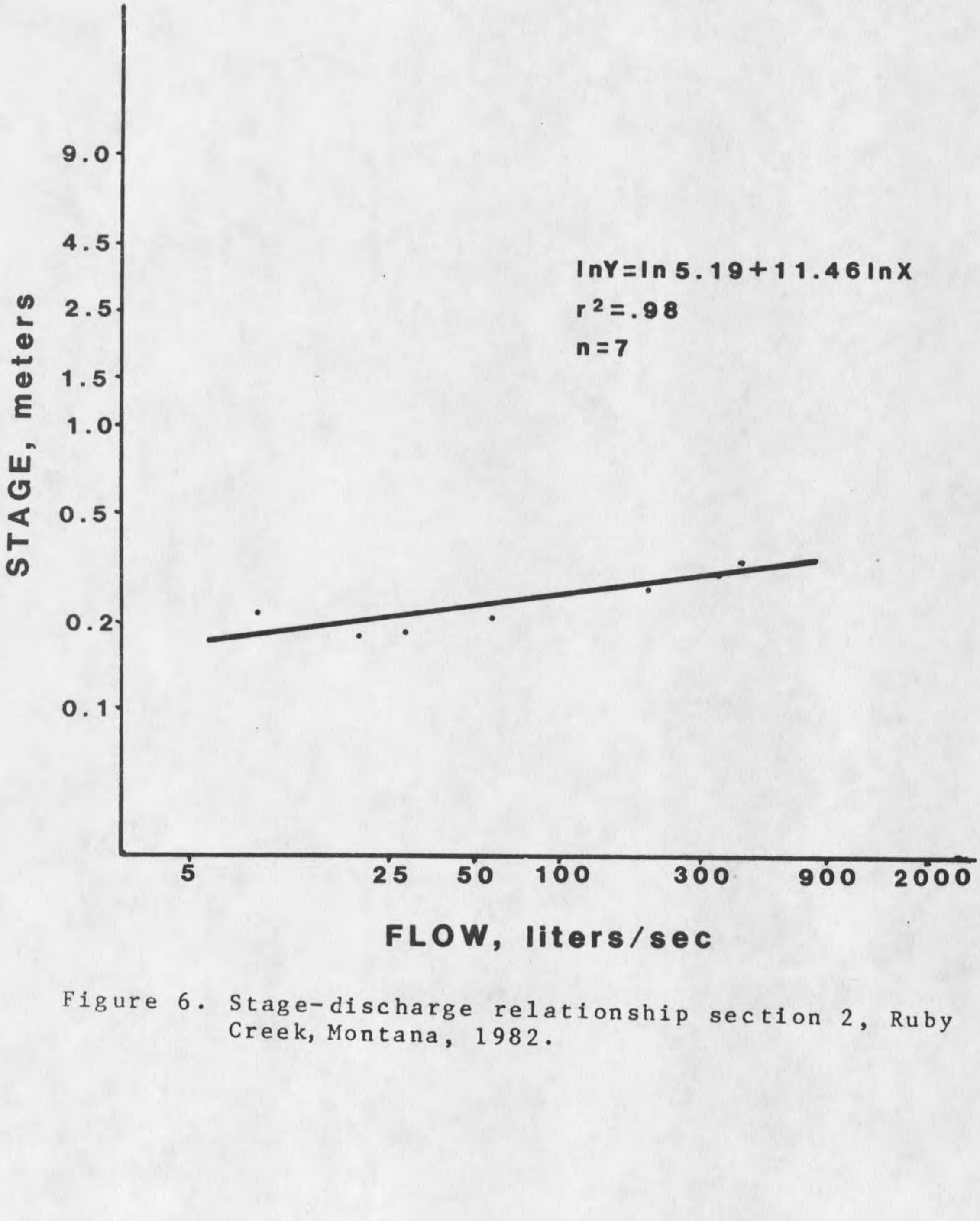

Figure 6. Stage-discharge relationship section 2, Ruby Creek, Montana, 1982.

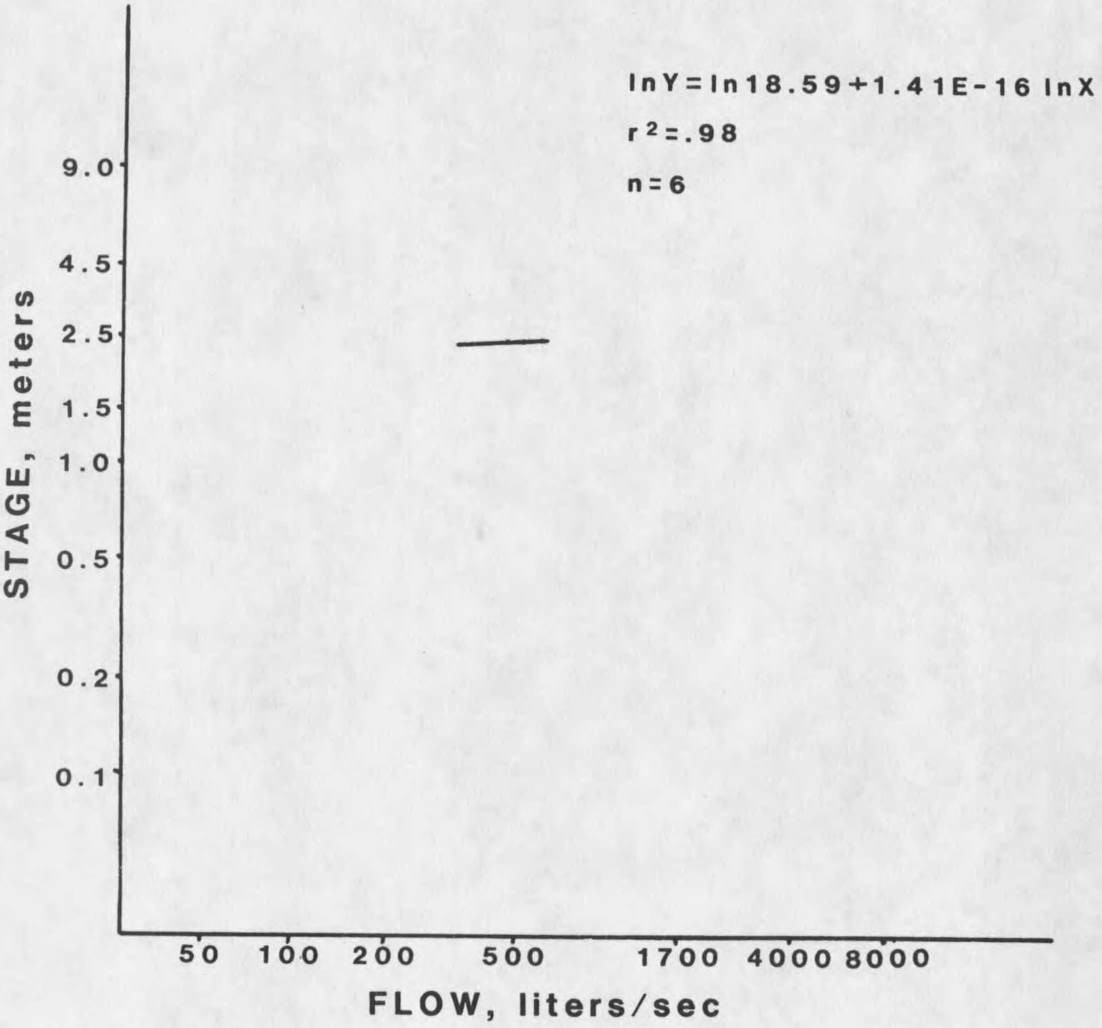

Figure 7. Stage-discharge relationship section 3, Ruby Creek, Montana, 1982.

surface elevation data were used to calibrate the wetted perimeter computer program (Table 3, Nelson 1983). Model output included:

1. Wetted perimeter (WETP)
2. Average water depth (DBAR)
3. Average water velocity in the transect cross-section area (VBAR)
4. Top width of transect (WDTH)
5. Cross sectional area of transect (AREA)
6. Maximum water depth (DMAX)
7. Total top width associated with depth of at least 15 cm (WTOT)
8. Longest continuous top width associated with water depth of at least 15 cm (WMAX).

Within each section, physical characteristics of all wetted perimeter transects were computed according to the wetted perimeter model and then averaged. The hypothesis that riffle wetted perimeter can be used as a general index of salmonid habitat suitability in small streams was examined by relating fish abundance and various habitat variables to flow-related changes in cross sectional wetted perimeters. This was done by visual comparison of plots of habitat variables versus flow and fish abundance versus flow.

All statistical anaylses were done on a Honeywell CP6 (Level 66/DPS 8) computer with the Biomedical Computer

Table 3. Calibration data (S= stage in meters, Q= discharge in liters/sec, and r= correlation coefficients) used in the wetted perimeter model (WETP) for three study sections on Ruby Creek, Montana, 1982.

	Riffle Cross Section											
	1		2		3		4		5		6	
Section	Q	S	Q	S	Q	S	Q	S	Q	S	Q	S
1	2319	28.74	2319	29.06	2319	29.16	2319	29.62	2319	30.59		
	105	28.54	105	28.87	105	28.93	105	29.41	105	30.34		
	23	28.47	23	28.78	23	28.83	23	29.32	23	30.26		
	8	28.43	8	28.75	8	28.80	8	29.31	8	30.24		
r	0.995		0.991		0.990		0.980		0.972			
2	360	28.33	360	28.63	360	28.75	360	28.99	360	29.15		
	54	28.20	54	28.50	54	28.61	54	28.89	54	29.06		
	28	28.18	28	28.46	28	28.58	28	28.86	28	29.01		
r	0.983		0.998		0.989		1.000		0.992			
3	813	29.85	813	30.09	813	30.32	813	30.12	813	30.60	813	30.68
	360	29.79	360	30.03	360	30.25	360	30.37	360	30.52	360	30.62
	309	29.77	309	30.03	309	30.24	309	30.37	309	30.52	309	30.60
r	0.998		0.989		0.994		0.977		0.977		0.997	

Programs (Dixon et al. 1983), Statistical Package for the Social Sciences (Nie et al. 1975) and MSUSTAT (Lund 1983) statistical analysis packages. Paired-comparison statistical tests were made using the nonparametric Mann-Whitney test (Snedecor and Cochran 1980).

RESULTS

Abundance Regulation by Low Summer Flow

Population Manipulation

Supplementing the trout populations in the study sections increased the density of rainbow trout from 0.05 to 1.43, 0.07 to 1.30, and 0.22 to 1.05 fish/meter in sections 1, 2, and 3, respectively (Table 4). Biomass densities were increased by a similar magnitude (Table 5). Length of experimental fish ranged from 104 to 315 mm (Table 6) and length frequency distribution was similar between sections.

Acclimation Flow and Trout Emigration

During a 6-day acclimation period, flow in all sections generally increased and trout emigration decreased (Table 7). In sections 1 and 2 (each below an irrigation diversion) flow fluctuated from 71 to 274 liters/sec (2.5 to 9.7 cfs) and 140 to 524 liters/sec (4.9 to 18.5 cfs), respectively. Discharge in the natural flow control section (section 3) increased from 462 to 674 liters/sec (16.3 to 23.8 cfs) during the same period. During the acclimation period, the number of fish emigrating each day varied but generally decreased. Although density was highest and flow was lowest in

Table 4. Number and density (fish/meter) of trout in each section before and after the study on Ruby Creek, Montana, 1982.

		Numerical abundance						
		Pre-study		Test		Post-study		
Section	Trout species	Number	Density (fish/meter)	Number	Density (fish/meter)	Number	Density (fish/meter)	% Density increase Pre- to Post-study
1	Rainbow	6	0.05	177	1.43	42	0.34	180
2	Rainbow	8	0.07	141	1.32	37	0.35	400
3	Rainbow	29	0.22	140	1.05	67	0.50	127

Table 5. Biomass (g) and density (g/m) of trout in each section before and after the study on Ruby Creek, Montana, 1982.

		Biomass (g)						
		Pre-study		Test		Post-study		
Section	Trout species	Weight	Density (g/meter)	Weight	Density (g/meter)	Weight	Density (g/meter)	% Density increase pre- to post-study
1	Rainbow	826	6.68	14755	119.28	2389	19.31	8
2	Rainbow	584	5.47	11829	110.86	2195	20.57	276
3	Rainbow	2857	21.47	16066	120.7	6857	51.52	140

Table 6. Size range (mm) of trout found in study sections 1, 2 and 3 before, during and after the experiment on Ruby Creek, Montana, 1982.

Section	Trout species	Pre-study (mm)	Start (mm)	Post-study (mm)
1	Rainbow	102-182	104-315	113-248
2	Rainbow	141-273	118-295	128-290
3	Rainbow	117-302	117-310	131-295

Table 7. Emigration of rainbow trout captured during the acclimation period in sections 1, 2 and 3, Ruby Creek,

Section	Date	Number captured upstream	Number captured downstream	Total number	Flow[a] (liters/sec)
1	7/20	4	0	4	144
	7/21	8	10	18	71
	7/22	6	5	11	77
	7/23	3	2	5	109
	7/24	9	2	11	274
	7/25	6	2	8	232
2	7/19	19	0	19	249
	7/20	19	6	25	277
	7/21	6	0	6	167
	7/22	16	5	21	140
	7/23	14	0	14	308
	7/24	8	1	9	524
3	7/19	31	5	36	---
	7/20	26	6	32	---
	7/21	11	3	14	462
	7/22	8	3	11	---
	7/23	6	0	6	674
	7/24	3	0	3	614

a: cfs = liters/sec x 0.0351

section 1, fewer fish attempted to emigrate from this section during the acclimation period (Table 7). Similar numbers attempted to emigrate from sections 2 and 3. A larger number of emigrants moved in an upstream direction.

Flow-Related Changes in Trout Abundance

Rainbow trout responded to flow reductions by emigrating from experimental sections of Ruby Creek. Emigration from the two study sections influenced by irrigation diversions correlated better with average daily flow than did emigration from the natural flow section. Visual evaluation of the plots of numbers and biomass remaining, and flow in sections 1, 2 and 3, indicated that the trout population in section 1 and 3 did not respond immediately to flow reductions (Figures 8, 9 and 10). Delayed response was accounted for by lagging flow, which increased correlations from 0.85 to 0.99 with an 11-day lag in section 1 and from 0.09 to 0.72 with a 15-day lag in the control section. Lagging the data resulted in the loss of one data pair for each day lagged (Table 8). These lags were used in all subsequent analyses. Lagging flow in section 2 increased the correlation by only 1% and was considered to be biologically unimportant. Therefore, data were not lagged before evaluation. In all sections, flow-associated change in trout biomass paralleled observations of change in numbers (Figures 8, 9 and 10).

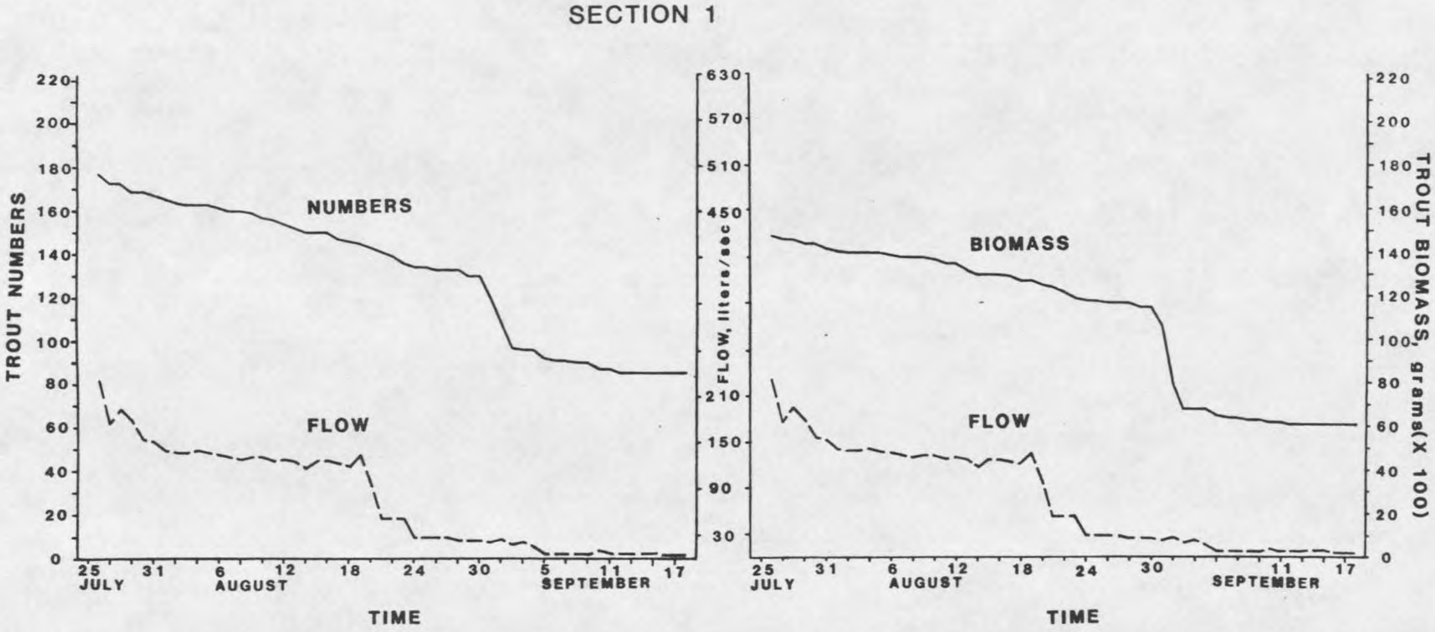

Figure 8. Response of rainbow trout (numbers and biomass) to decreases in discharge in section 1, Ruby Creek, Montana, 1982.

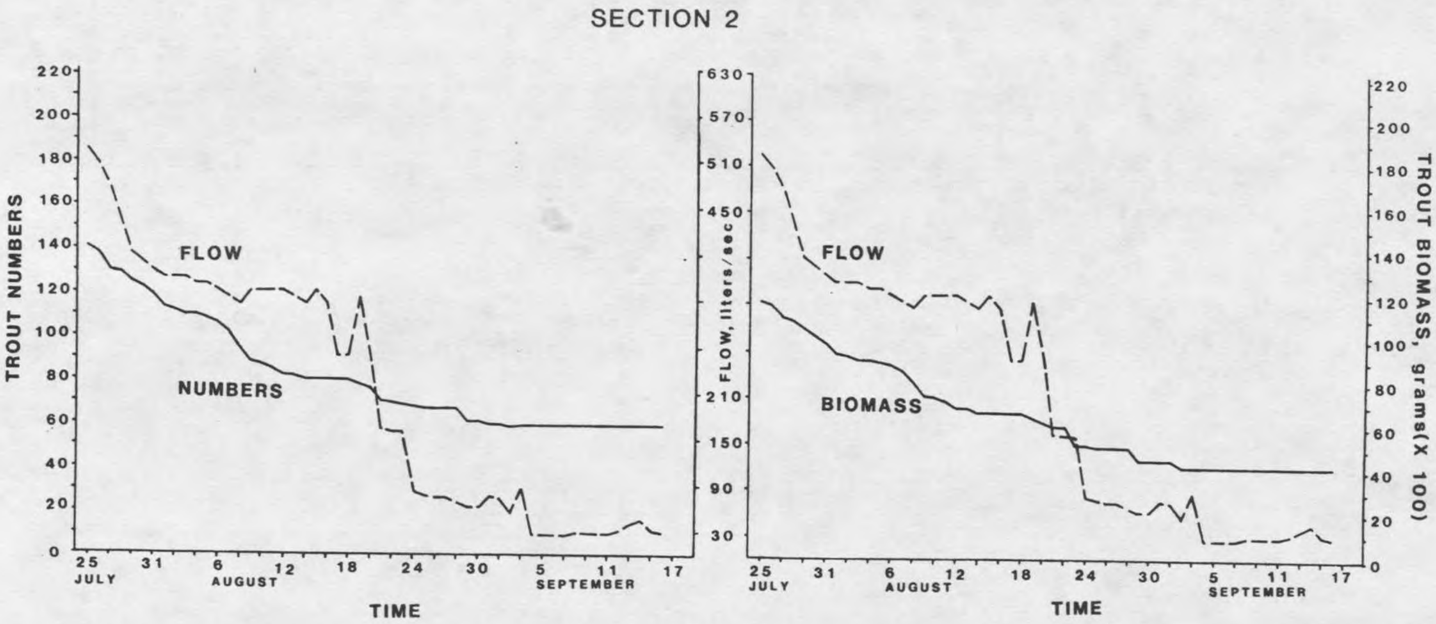

Figure 9. Response of rainbow trout (numbers and biomass) to decreases in discharge in section 2, Ruby Creek, Montana, 1982.

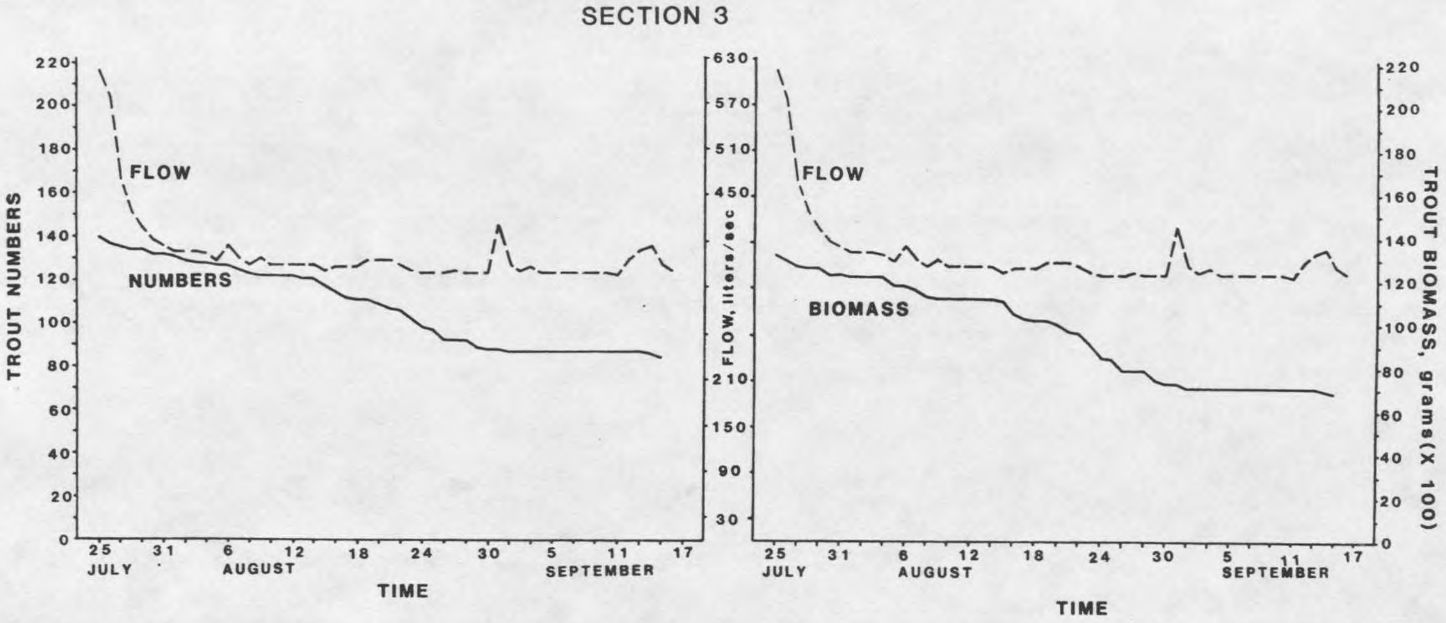

Figure 10. Response of rainbow trout (numbers and biomass) to decreases in discharge in section 3, Ruby Creek, Montana, 1982.

Table 8. Correlation coefficients (r) between fish abundance lagged by time and discharge in sections 1, 2 and 3, Ruby Creek, Montana, 1982.

Section 1[a]		Section 2[b]		Section 3[c]	
Flow days lagged	r	Flow days lagged	r	Flow days lagged	r
0	0.85	0	0.96	0	0.09
1	0.86	1	0.96	1	0.09
2	0.88	2	0.97	2	0.13
3	0.89	3	0.96	3	0.20
4	0.91	4	0.95	4	0.29
5	0.92	5	0.94	5	0.40
6	0.93	6	0.94	6	0.40
7	0.95	7	0.92	7	0.43
8	0.96	8	0.91	8	0.47
9	0.97	9	0.88	9	0.50
10	0.98	10	0.86	10	0.52
11	0.99	11	0.84	11	0.57
12	0.98	12	0.84	12	0.61
13	0.96	13	0.83	13	0.66
14	0.94	14	0.82	14	0.71
15	0.92	15	0.82	15	0.72
				16	0.67

a: Number of data points = 40.
b: Number of data points = 39.
c: Number of data points = 37.

Trout emigration rate increased in all sections as discharge was decreased 30 to 40% below acclimation flow (Figures 11, 12 and 13), even though initial discharge in sections 2 and 3 was more than double the discharge in section 1. Reductions in discharge of 96 and 95% resulted in decreases in trout numbers of 48 and 58% in sections 1 and 2, respectively. Corresponding decreases in numerical density were 76 and 73% (Table 4). In the natural-flow section, the total decrease in discharge of 43% was accompanied by a 31% decrease in trout numbers and a 52% decrease in numerical density. Total biomass and biomass density decreased as trout numbers decreased in each study section (Table 5).

Emigration response of resident trout was less (12.5-17.2%) than stocked trout (44.4-59.4%) in each study section (Table 9). A chi-square statistical test, however, failed to support the observed difference between the percentage of resident fish emigrating and their percentage in the population. Trout emigrated from the study sections in an upstream direction between 93 and 99% of the time (Figure 14).

Size Related Response

Mean body length of trout decreased in the two study sections having large flow reductions (Table 10).

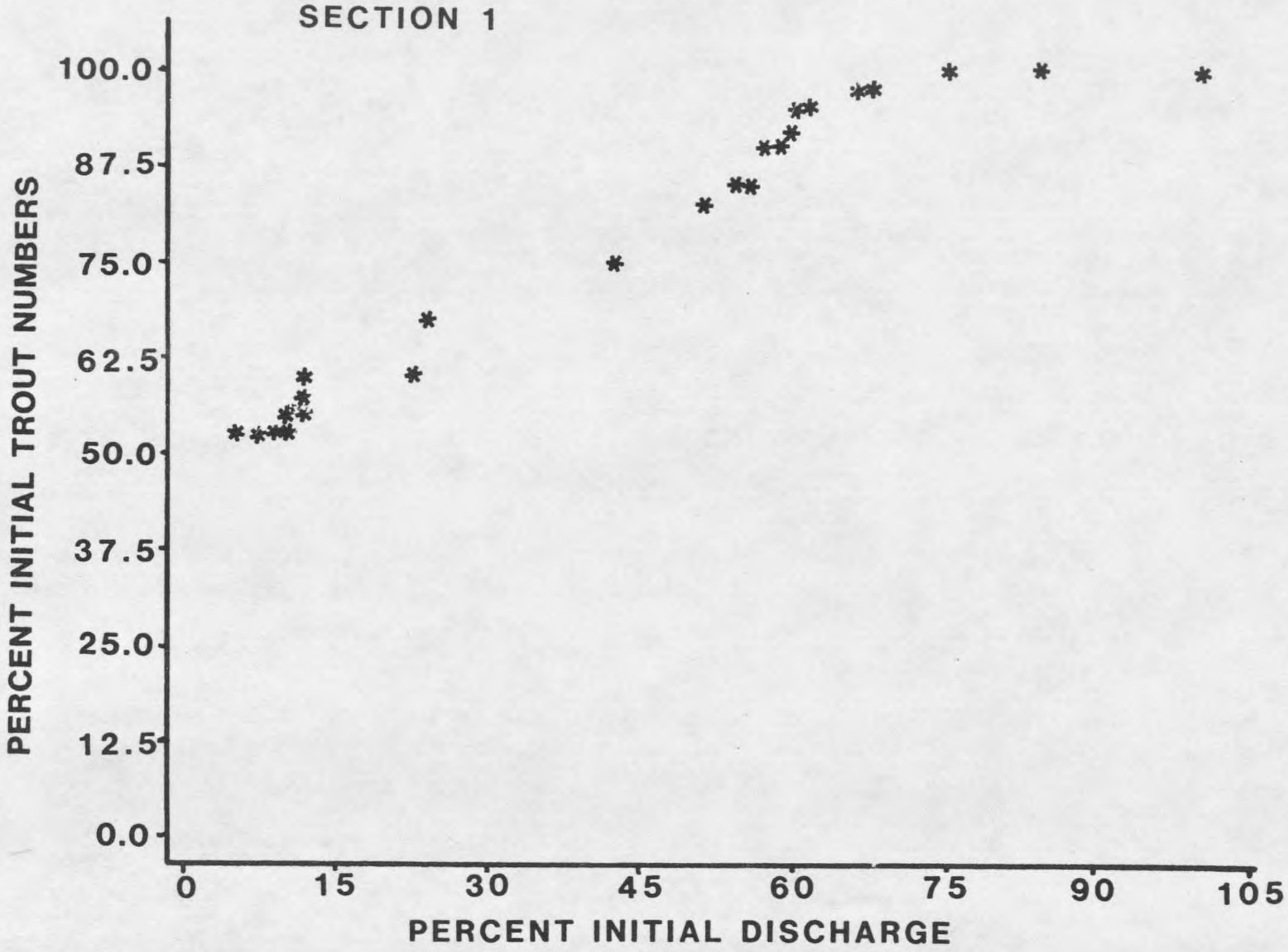

Figure 11. The relationship between percent intial trout numbers and percent initial discharge in section 1, Ruby Creek, Montana, 1982.

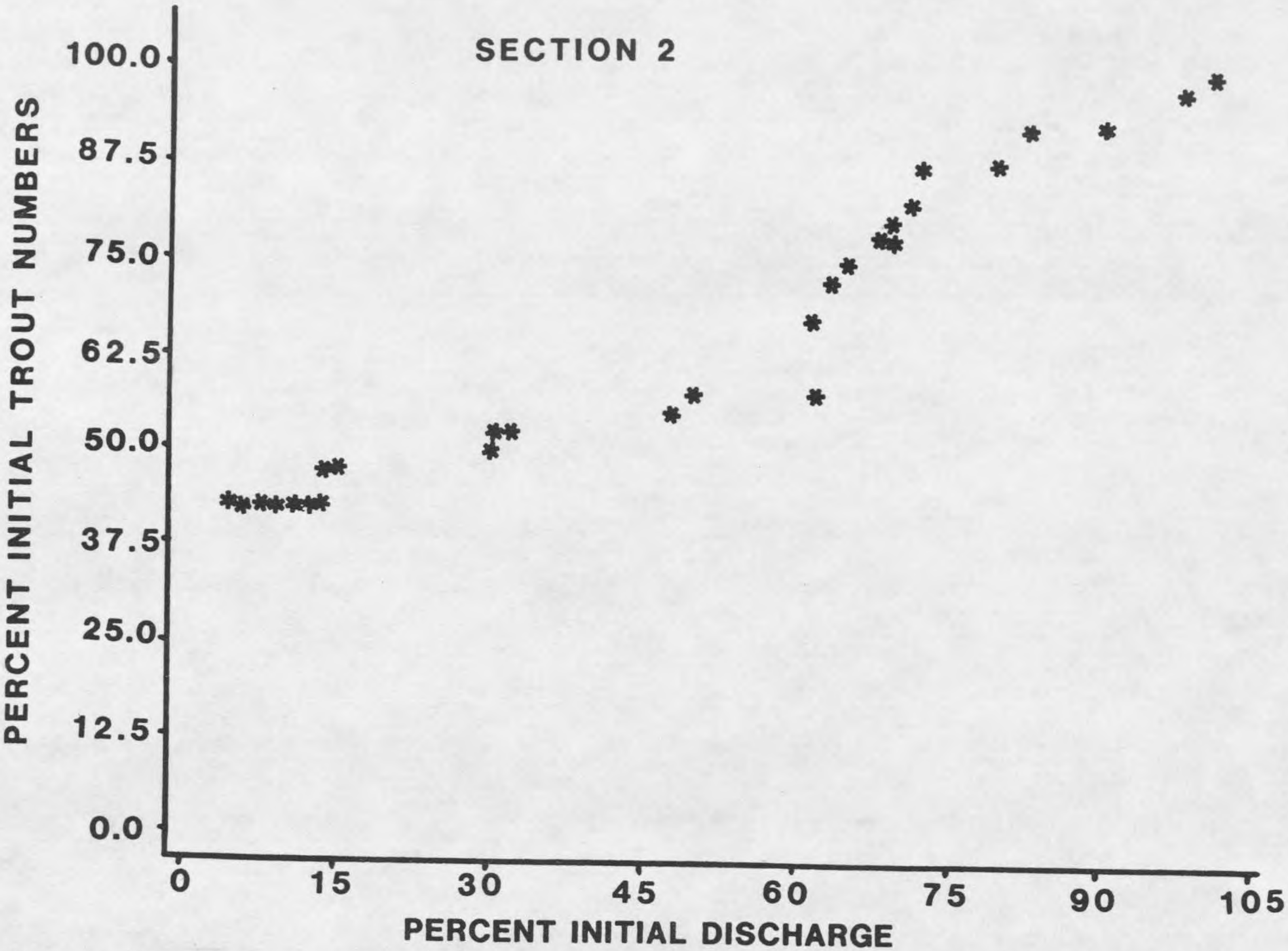

Figure 12. The relationship between percent initial trout numbers and percent initial discharge in section 2, Ruby Creek, Montana, 1982.

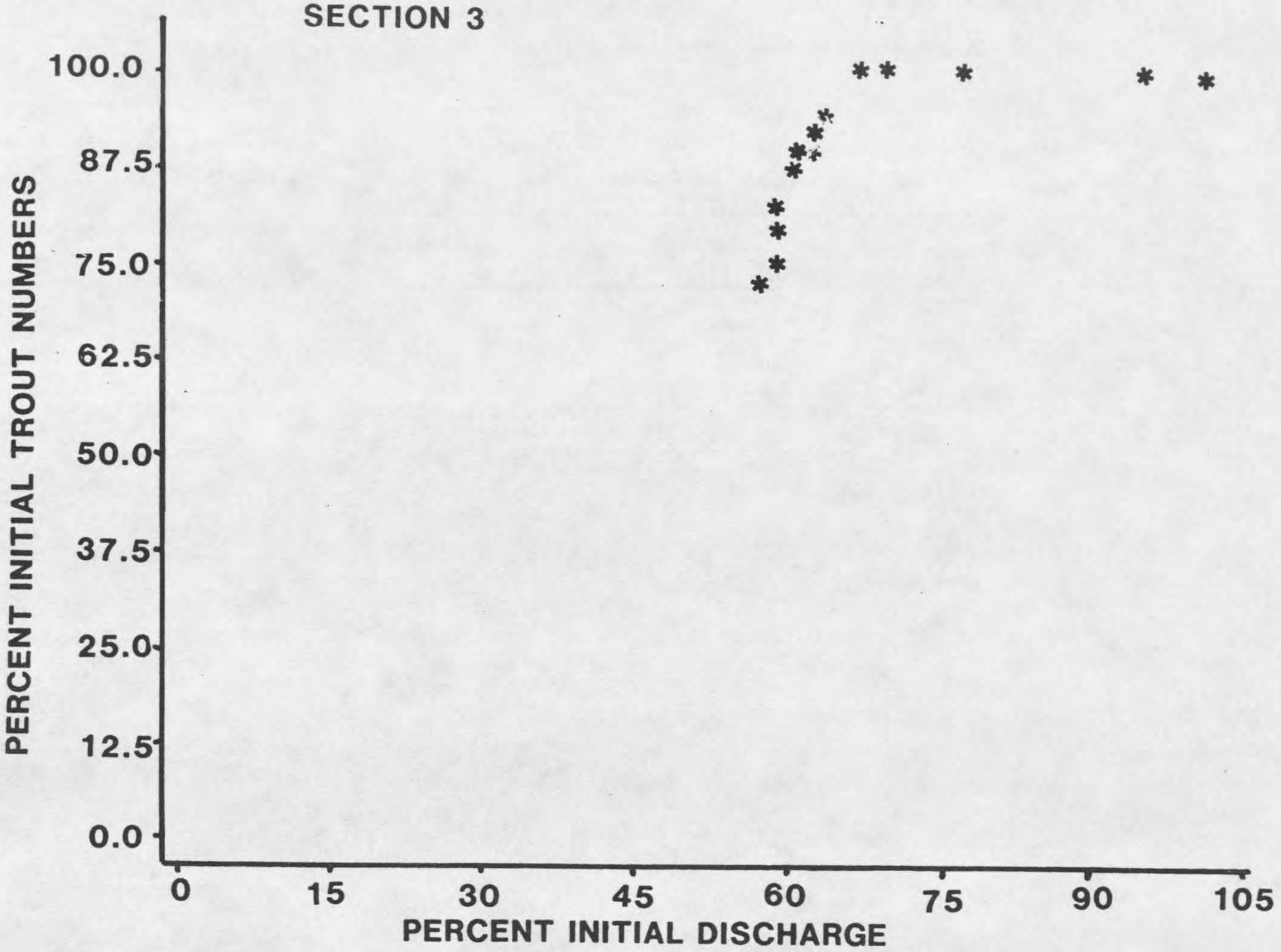

Figure 13. The relationship between percent initial trout numbers and percent initial discharge in section 3, Ruby Creek, Montana, 1982.

Table 9. Comparison of emigration of resident (R) and stocked (NR) rainbow trout from sections 1, 2 and 3, Ruby Creek, Montana, 1982.

Section	Origin	Number in population	% in population	Number emigrating	% of starting population emigrating	P-value
1	R	6	3.4	1	16.0	0.321
	NR	171	96.6	95	55.5	
2	R	8	5.7	1	12.5	0.140
	NR	133	94.3	79	59.4	
3	R	29	20.7	5	17.2	0.056
	NR	111	79.3	49	44.4	

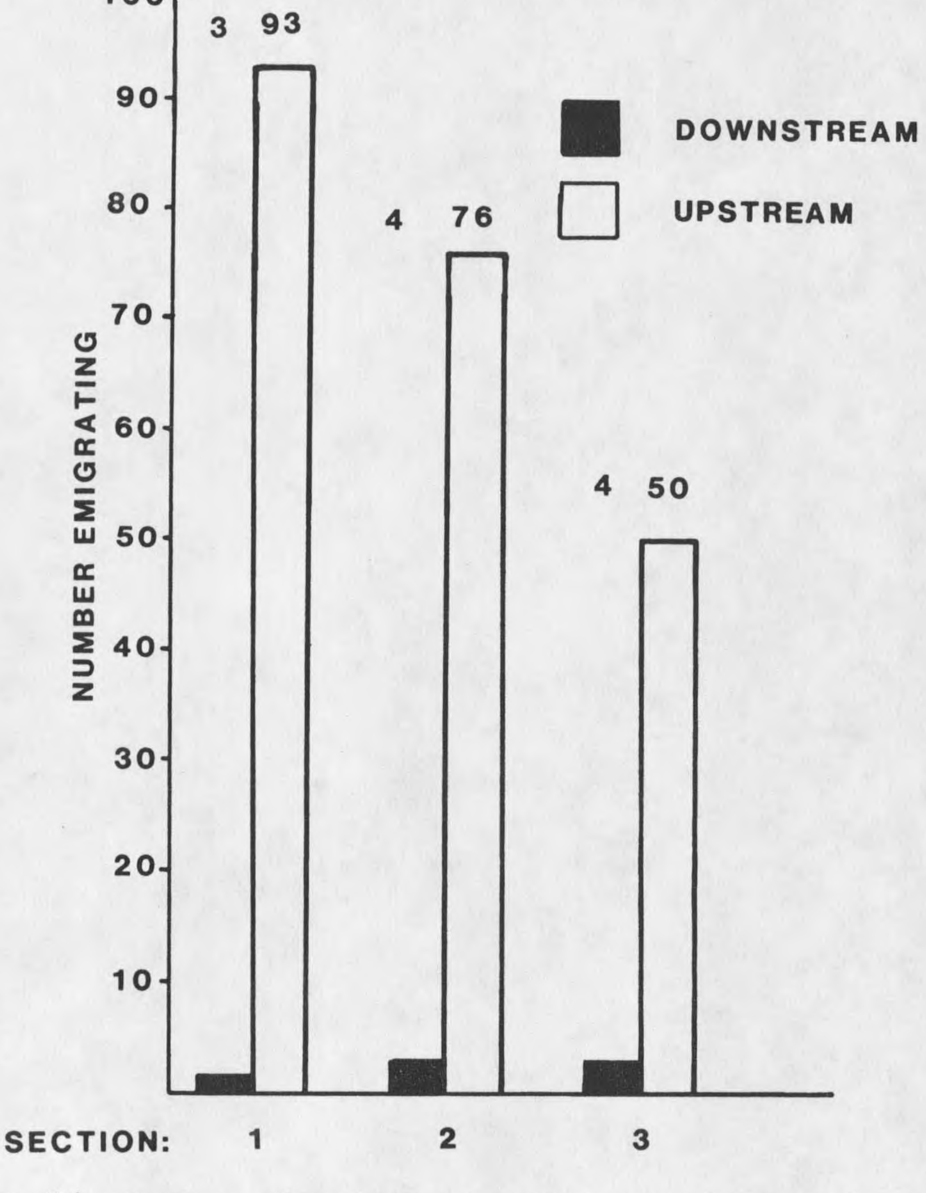

Figure 14. Number of rainbow trout trapped in each study section according to direction of emigration following flow reduction in Ruby Creek, Montana, 1982.

Table 10. Comparison of mean length and weight of rainbow trout in each study section before and after the experiment on Ruby Creek Montana, 1982.

Section	Body size variable	Time	Number of fish	Mean	P-value
1	Length(mm)	Before	177	182	0.174
		After	42	171	
	Weight(g)	Before	177	83	0.000*
		After	42	55	
2	Length(mm)	Before	140	190	0.103
		After	37	174	
	Weight(g)	Before	140	84	0.064
		After	37	59	
3	Length(mm)	Before	140	190	0.529
		After	67	194	
	Weight(g)	Before	140	91	0.738
		After	67	86	

* Significantly different $P < 0.01$

Although no significant differences were found between rainbow trout length distributions at the start and end of the experiment (Mann-Whitney nonparametric test, Dixon, et al. 1983), inspection of the data indicates that larger fish were more influenced by flow reductions than were smaller fish (Figures 15 and 16). In the control section, length distribution remained relatively unchanged (Figure 17).

Mean body weight of fish in all study sections decreased during the study period. Mean weight of fish in

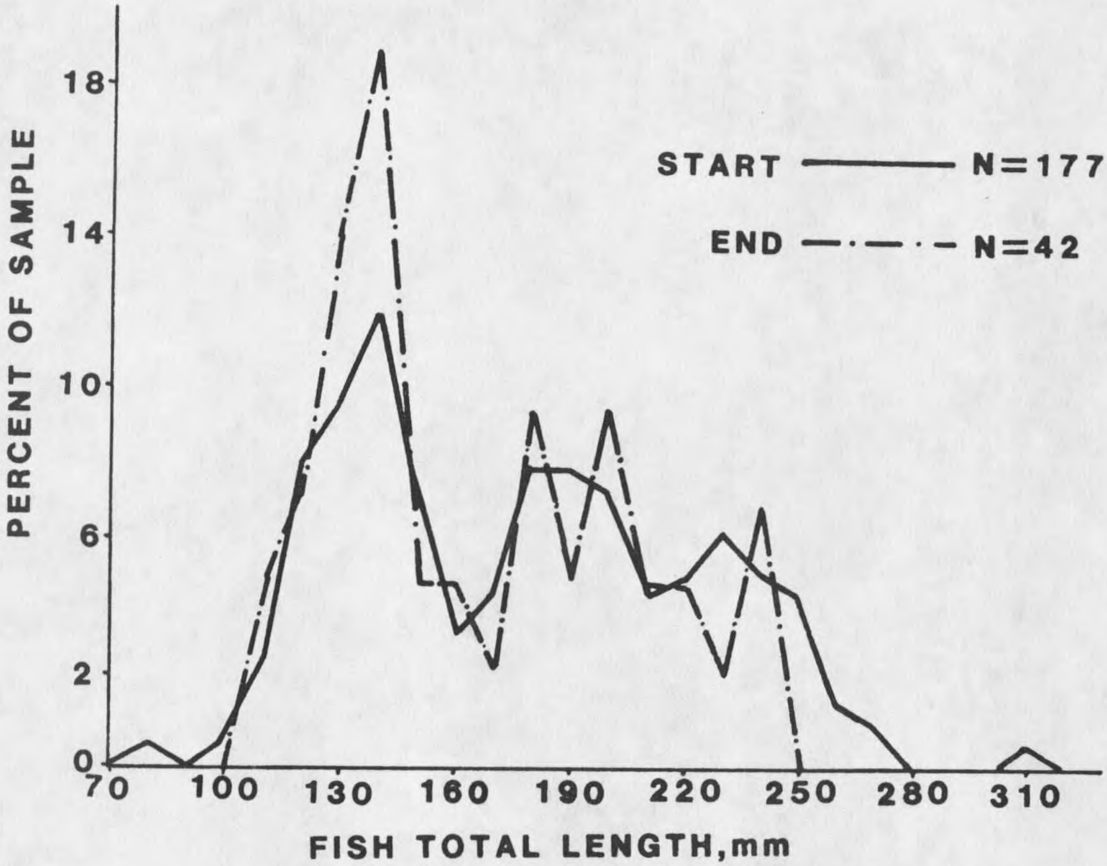

Figure 15. Comparison of the length distributions of trout (by 10 mm groups) in section 1 at the start and end of the study on Ruby Creek, Montana, 1982.

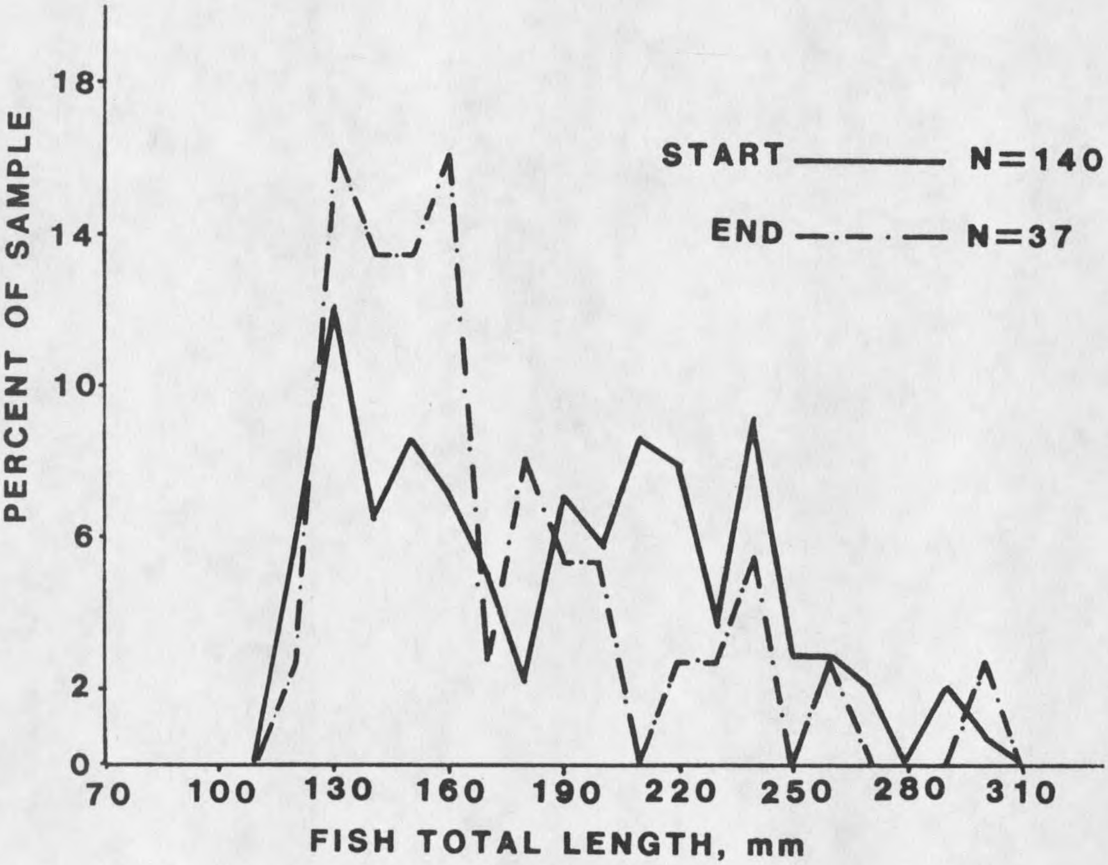

Figure 16. Comparison of the length distributions of trout (by 10 mm groups) in section 2 at the start and end of the study on Ruby Creek, Montana, 1982.

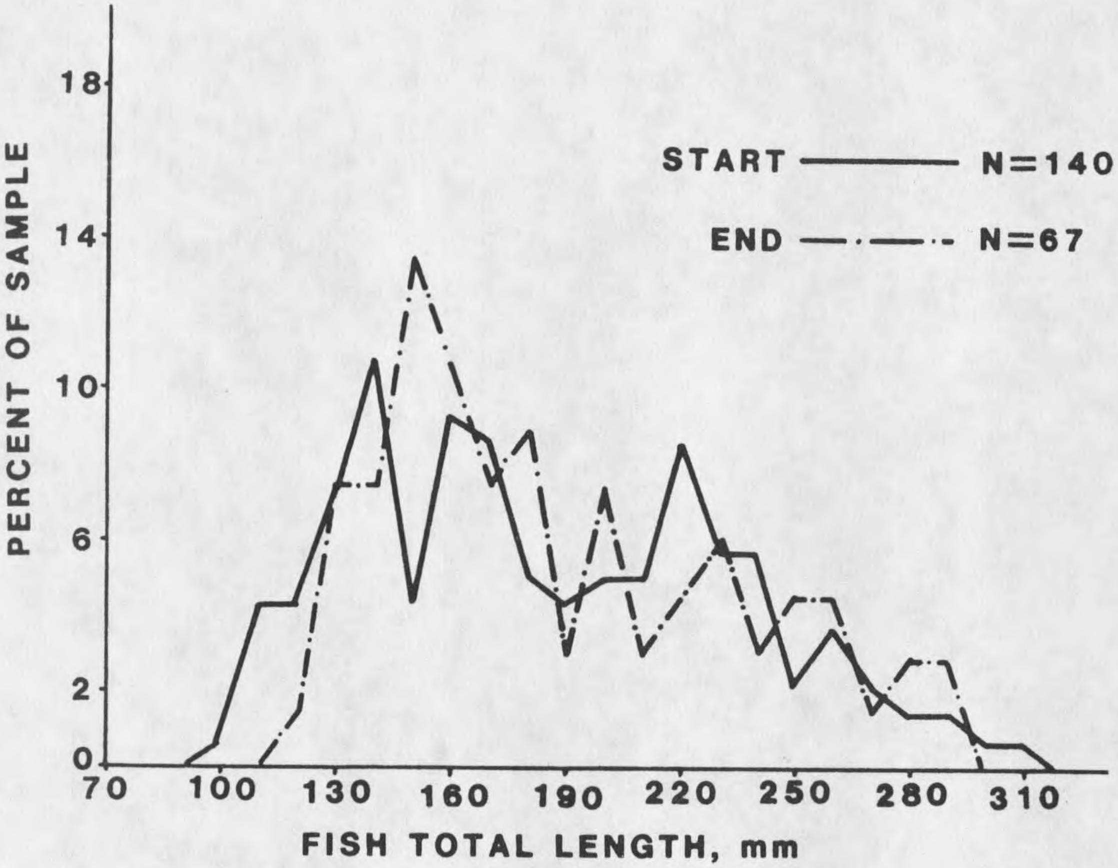

Figure 17. Comparison of the length distributions of trout (by 10 mm groups) in section 3 at the start and end of the study on Ruby Creek, Montana, 1982.

section 1 was significantly less at the end of the study, while there was no significant difference in weight between the beginning and end of the study in sections 2 and 3 (Table 10). Percentage weight decrease in sections 1, 2 and 3 was 34, 30 and 5%, respectively.

Changes in Condition Factors

Condition factors of rainbow trout, grouped by 20 mm intervals, generally decreased during the experiment in all study sections (Tables 11, 12 and 13). Decreases in section 1 were statistically different ($P < 0.05$) for all 20 mm length groups between 120-239 mm, but not for the smallest (100-119 mm) or the largest length group (240-259 mm). In section 2, which was also subjected to large discharge reductions, there was no statistically significant difference in mean condition factor between the start and end of the study for any size group. Trout in section 3, which were subjected to natural flow conditions, had significantly lower condition factors for all size groups between 120 and 239 mm except for the 200-219 mm group. At the beginning of the study, mean condition factors ranged from 1.017 to 1.598 in section 1, 0.609 to 1.096 in section 2, and 1.008 to 1.168 in section 3. In section 1 the largest decreases in condition between the beginning and end of the tests were 42 and 41% in the two smallest size groups (100-119 mm; 120-139mm).

Table 11. Comparison of condition factors of rainbow trout stocked, those emigrating, and those remaining at the end of reduced flow experiments in study section 1, Ruby Creek, Montana, 1982.

Section	Size range of fish(mm)	Time of experiment	Number of fish	K-value			Mean K start-end P-value	Mean K start-emigrating P-value	Mean K emigraring-end P-value
				Min.	Mean	Max.			
1	100-119	Start	6	1.246	1.598	1.803			
		Emigrating	0	-----	-----	-----	0.056	------	------
		End	2	0.832	0.933	1.035			
		No.(%)missing	4(66)						
	120-139	Start	31	0.954	1.390	1.637			
		Emigrating	10	0.652	0.902	1.451	0.000**	0.000**	0.880
		End	10	0.565	0.822	0.922			
		No.(%)missing	11(35)						
	140-159	Start	33	0.943	1.221	1.482			
		Emigrating	16	0.754	0.909	1.090	0.001**	0.000**	0.412
		End	9	0.811	1.013	2.204			
		No.(%)missing	8(24)						
	160-179	Start	14	1.076	1.218	1.482			
		Emigrating	7	0.653	0.881	1.001	0.008**	0.000**	0.909
		End	3	0.823	0.897	0.974			
		No.(%)missing	4(29)						
	180-199	Start	28	0.884	1.240	2.932			
		Emigrating	14	0.742	0.929	1.181	0.001**	0.000**	0.742
		End	6	0.830	0.944	1.061			
		No.(%)missing	8(29)						
	200-219	Start	22	0.899	1.126	1.358			
		Emigrating	17	0.750	0.950	1.184	0.002**	0.000**	0.624
		End	6	0.825	0.931	1.025			
		No.(%)missing	1(4)						
	220-239	Start	20	1.022	1.155	1.367			
		Emigrating	15	0.751	0.964	1.157	0.008**	0.000**	0.767
		End	3	0.857	0.944	1.023			
		No.(%)missing	2(10)						
	240-259	Start	17	0.744	1.070	1.432			
		Emigrating	13	0.867	0.932	1.100	0.368	0.001**	0.253
		End	3	0.911	1.008	1.129			
		No.(%)missing	1(16)						
	260-279	Start	5	1.018	1.070	1.127			
		Emigrating	4	0.918	0.953	1.018	-----	-----	-----
		End	0	-----	-----	-----			
		No.(%)missing	1(20)						
	280-299	Start	0	-----	-----	-----			
		Emigrating	0	-----	-----	-----	-----	-----	-----
		End	0	-----	-----	-----			
		No.(%)missing	0(0)						
	300-319	Start	1	-----	1.017	-----			
		Emigrating	0	-----	-----	-----	-----	-----	-----
		End	0	-----	-----	-----			
		No.(%)missing	1(100)						
	Overall sizes	Start	177	0.744	1.233	2.932			
		Emigrating	96	0.652	0.930	1.451	0.024*	0.000**	0.233
		End	42	0.565	0.929	2.204			
		No.(%)missing	39(22)						

* Significantly different $P < 0.05$

** Significantly different $P < 0.01$

Table 12. Comparison of condition factors of rainbow trout stocked, those emigrating, and those remaining at the end of reduced flow experiments in study section 2, Ruby Creek, Montana, 1982.

Section	Size range of fish(mm)	Time of experiment	Number of fish	K-value			Mean K start-end P-value	Mean K start-emigrating P-value	Mean K emigrating-end P-value
				Min.	Mean	Max.			
2	100-119	Start	1	-----	0.609	-----	-----	-----	-----
		Emigrating	1	-----	0.890	-----			
		End	0	-----	-----	-----			
		No.(%)missing	0(0)						
	120-139	Start	25	0.650	0.927	1.379	0.101	0.698	0.338
		Emigrating	7	0.667	0.934	1.205			
		End	7	0.890	0.985	1.097			
		No.(%)missing	11(44)						
	140-159	Start	24	0.739	0.970	1.172	0.496	0.073	0.199
		Emigrating	10	0.684	0.871	1.039			
		End	10	0.871	0.946	1.014			
		No.(%)missing	4(17)						
	160-179	Start	17	0.884	1.019	1.160	0.070	0.091	0.418
		Emigrating	8	0.880	0.967	1.082			
		End	7	0.868	0.951	1.088			
		No.(%)missing	2(12)						
	180-199	Start	13	0.876	0.999	1.092	0.460	0.035*	0.201
		Emigrating	6	0.850	0.942	1.005			
		End	5	0.869	0.974	1.044			
		No.(%)missing	2(15)						
	200-219	Start	20	0.911	1.060	1.313	0.170	0.009**	0.766
		Emigrating	15	0.825	0.962	1.084			
		End	2	0.978	0.983	0.988			
		No.(%)missing	3(15)						
	220-239	Start	16	0.694	1.096	1.787	0.325	0.005**	0.888
		Emigrating	16	0.898	0.964	1.130			
		End	2	0.871	0.971	1.071			
		No.(%)missing	+2(+13)						
	240-259	Start	14	0.960	1.056	1.249	0.751	0.084	0.480
		Emigrating	10	0.812	0.986	1.108			
		End	2	0.993	1.022	1.051			
		No.(%)missing	2(14)						
	260-279	Start	7	0.983	1.090	1.232	-----	0.850	-----
		Emigrating	4	1.006	1.070	1.130			
		End	1	-----	1.026	-----			
		No.(%)missing	2(29)						
	280-299	Start	3	0.951	1.011	1.054	-----	1.000	0.221
		Emigrating	2	0.912	0.989	1.065			
		End	1	-----	0.942	-----			
		No.(%)missing	0(0)						
	300-319	Start	1	-----	0.960	-----	-----	-----	-----
		Emigrating	1	-----	0.935	-----			
		End	0	-----	-----	-----			
		No.(%)missing	0(0)						
	Overall sizes	Start	141	0.609	1.011	1.787	0.302	0.001**	0.815
		Emigrating	80	0.667	0.948	1.205			
		End	37	0.868	0.965	1.097			
		No.(%)missing	24(17)						

* Significantly different $P < 0.05$
** Significantly different $P < 0.01$

Table 13. Comparison of condition factors of rainbow trout stocked, those emigrating, and those remaining at the end of reduced flow experiments in study section 3, Ruby Creek, Montana, 1982.

Section	Size range of fish(mm)	Time of experiment	Number of fish	K-value			Mean K start-end P-value	Mean K start-emigrating P-value	Mean K emigrating-end P-value
				Min.	Mean	Max.			
3	100-119	Start	7	1.061	1.167	1.317	-----	-----	-----
		Emigrating	0	-----	-----	-----			
		End	0	-----	-----	-----			
		No.(%)missing	7(100)						
	120-139	Start	16	1.000	1.114	1.205	0.021*	0.779	0.121
		Emigrating	2	1.057	1.196	1.335			
		End	5	0.931	1.010	1.172			
		No.(%)missing	9(56)						
	140-159	Start	21	0.838	1.168	2.198	0.000**	0.036*	0.953
		Emigrating	3	0.919	0.963	0.998			
		End	15	0.864	0.962	1.039			
		No.(%)missing	3(14)						
	160-179	Start	25	0.963	1.093	1.432	0.008**	0.007**	0.916
		Emigrating	5	0.830	0.950	1.031			
		End	12	0.880	0.966	1.200			
		No.(%)missing	8(32)						
	180-199	Start	12	1.003	1.138	1.281	0.001**	0.002**	0.862
		Emigrating	7	0.903	1.002	1.077			
		End	8	0.781	0.797	0.823			
		No.(%)missing	+3(+25)						
	200-219	Start	14	0.847	1.112	1.219	0.073	0.037	0.935
		Emigrating	5	0.943	1.028	1.097			
		End	7	0.925	1.030	1.155			
		No.(%)missing	2(14)						
	220-239	Start	20	0.949	1.088	1.260	0.027*	0.000**	0.216
		Emigrating	17	0.741	0.949	1.071			
		End	7	0.843	0.992	1.080			
		No.(%)missing	+4(+20)						
	240-259	Start	11	0.947	1.092	1.202	0.157	0.012*	0.221
		Emigrating	9	0.853	0.976	1.159			
		End	5	0.932	1.028	1.092			
		No.(%)missing	+3(+27)						
	260-279	Start	8	0.961	1.069	1.218	0.497	0.235	0.387
		Emigrating	4	0.558	0.899	1.104			
		End	4	0.935	1.026	1.137			
		No.(%)missing	0(0)						
	280-299	Start	4	0.979	1.086	1.147	0.083	-----	-----
		Emigrating	0	-----	-----	-----			
		End	4	0.889	0.989	1.091			
		No.(%)missing	0(0)						
	300-319	Start	2	0.897	1.008	1.118	-----	0.439	-----
		Emigrating	2	0.835	0.926	1.017			
		End	0	-----	-----	-----			
		No.(%)missing	0(0)						
	Overall sizes	Start	140	0.838	1.112	2.198	0.099	0.000**	0.475
		Emigrating	54	0.558	0.988	1.335			
		End	67	0.843	0.992	1.200			
		No.(%)missing	19(14)						

* Significantly different $P < 0.05$

** Significantly different $P < 0.01$

In sections 2 and 3 the largest decrease in condition of any size group was 11% and 30%, respectively. In general, emigrating trout in all size groups and sections were in slightly poorer condition than those remaining until the end of the study (Tables 11, 12 and 13).

Post-Study Densities

Supplemented trout populations in the study sections were not reduced to pre-study levels by flow reduction experienced during the 63-day study period (Table 4 and 5). Original numerical densities (fish/meter) in sections 1, 2 and 3 were 0.12, 0.07, and 0.22 rainbow trout/meter, respectively. These were increased to 1.43, 1.30 and 1.05 rainbow trout/meter at the beginning of the study. When the study was completed in September, numerical densities had decreased to 0.34, 0.35 and 0.50 in sections 1, 2 and 3, respectively. These densities were 180, 400 and 127% larger than we observed in study sections before the experiment (Table 4). Post study biomass densities had increased 8, 276 and 140% in sections 1,2 and 3, respectively (Table 5). Sections 1 and 2, subjected to similar large flow reductions (96 and 95%, respectively), had similar rainbow trout densities during all phases of the study. The control section, with natural flow reduction of 57.2%, had higher trout densities both before and after the study than in the sections subjected to large flow reductions.

Fish Not Accounted For

A portion of fish in each study section could not be accounted for at the end of the study (Table 14).

Table 14. Fish numbers and biomass not accounted for by emigration from sections 1, 2, and 3, Ruby Creek, Montana, 1982.

	Trout unaccounted for		%Loss	
Section	Numbers	Biomass(g)	Numbers	Biomass(g)
1	39	4692	22	32
2	24	2009	17	17
3	19	2110	14	16

Electrofishing upstream from section 1 to a natural fish barrier produced four marked rainbow trout. These fish may have escaped before the study started, when the upper fish weir failed. Electrofishing immediately above section 2 in a large pool produced no marked fish. No attempt was made to recover lost fish above section 3. The largest percentage of missing fish in all three study sections were from length groups less than 140 mm total length (Tables 11, 12 and 13).

Flow Related Decreases in Habitat Availability

Habitat Differences

Section 1 was characterized by a pool-riffle channel structure while sections 2 and 3 had a predominance of riffle-run habitat. Because of flow differences between sections, habitat data were collected at different discharges. This makes comparison of channel structure differences between sections difficult (Figures 18, 19 and 20).

Mean depth was essentially the same in all three sections, although discharge in sections 2 and 3 was 2.6 and 2.9 times larger, respectively, than in section 1 at the initiation of the study (Table 15). Initial mean thalweg depths were similar in sections 2 and 3, but was 11% deeper in section 1. At the end of the study, mean depth and mean thalweg depth in sections 1 and 2 but were about 50% shallower than in section 3. Mean velocity at the beginning of the study was similar in sections 1 (61 cm/sec) and 2 (64 cm/sec); section 3 had a slightly higher mean velocity (73 cm/sec). Mean velocity had been reduced 80% in section 1, 71% in section 2 and 19% in section 3 by the end of the study.

Due to flow and channel differences, the order of percent change in the five habitat variables measured differed between sections. All variables except velocity

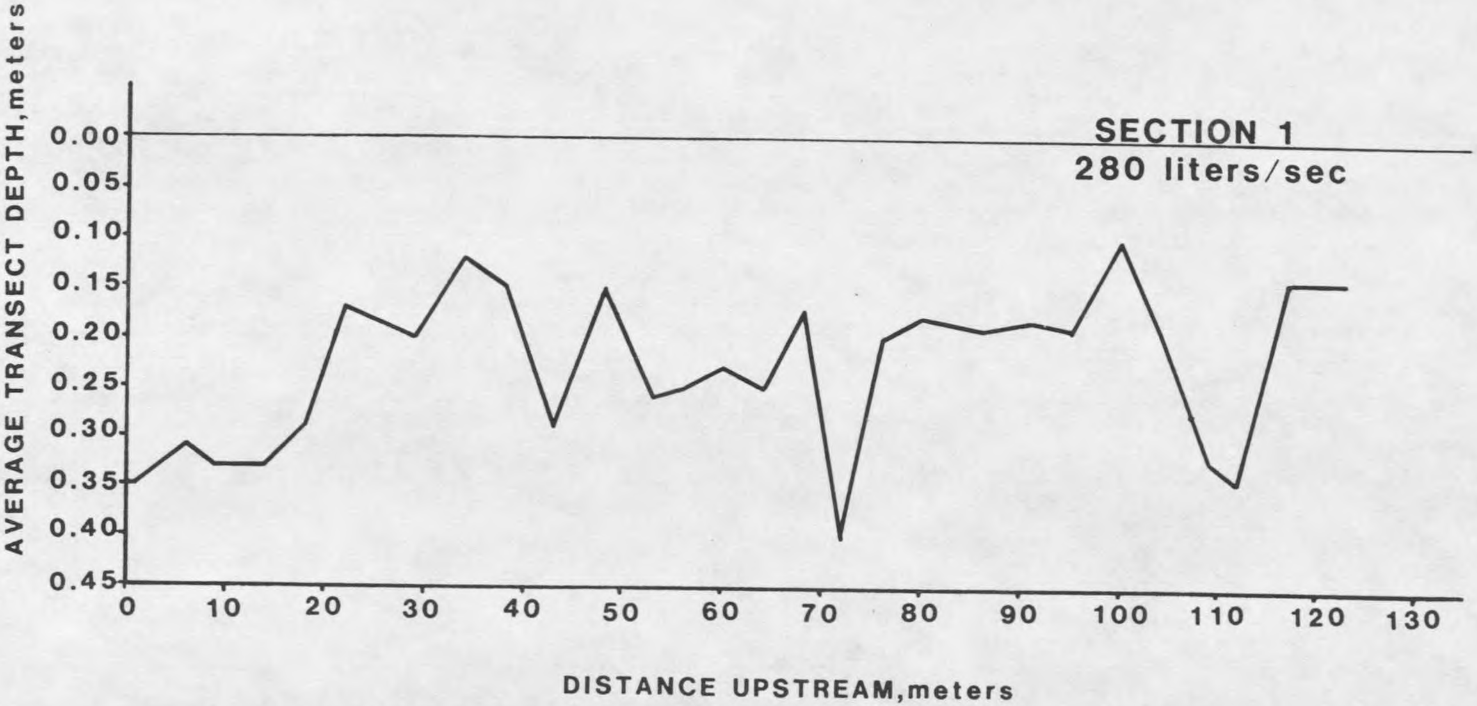

Figure 18. Average transect depth of section 1 at 280 liters/sec (10 cfs), Ruby Creek, Montana, 1982.

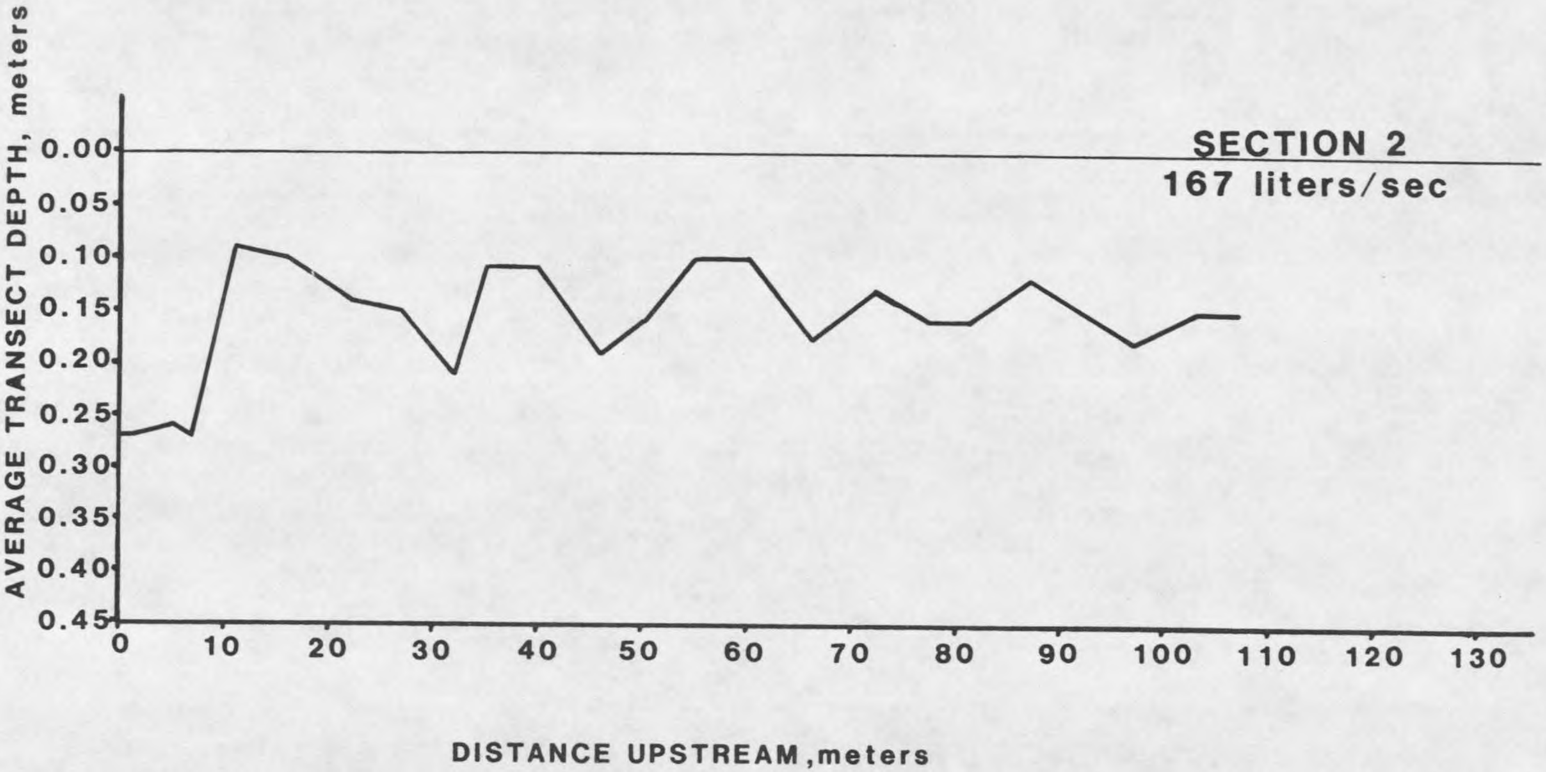

Figure 19. Average transect depth of section 2 at 167 liters/sec (5.9 cfs), Ruby Creek, Montana, 1982.

Figure 20. Average transect depth of section 3 at 351 liters/sec (12.4 cfs), Ruby Creek, Montana, 1982.

Table 15. Mean depth (m), depth standard deviation and mean velocity (cm/sec) in study sections 1, 2 and 3, Ruby Creek, Montana, 1982.

Section	Flow (liters/sec, cfs)	Number of observations	Mean depth (meters)	Depth standard deviation (meters)	Mean velocity (cm/sec)
1	283 (10.0)	285	0.23	0.14	61
	113 (4.0)	239	0.17	0.12	40
	23 (0.8)	191	0.11	0.10	21
	8 (0.3)	163	0.09	0.09	12
2	669 (23.7)	225	0.22	0.10	73
	167 (5.9)	194	0.16	0.08	49
	54 (1.9)	186	0.09	0.06	30
	28 (1.0)	171	0.07	0.05	21
3	821 (29.0)	149	0.21	0.12	64
	351 (12.4)	144	0.16	0.10	52

area (surface area with mean velocity $\leq$ 0.3 cm/sec (0.1 ft/sec) decreased as flow decreased (Table 16).

Decreases in Habitat

In both reduced flow sections, 100% of usable overhanging bank cover (OHB-surface area associated with overhanging bank within 30 cm of the waters surface with a depth of $\geq$ 15 cm and a overhang width $\geq$ 10 cm) was lost. In section 1, where total flow reduction was 97%, depth area (DA-surface area with associated depth of 15 cm or more) was reduced 91.8%; overhead vegetation (OHV-surface area having vegetation within 30 cm of water surface with a depth of $\geq$ 15 cm and overhang width of $\geq$ 10 cm) by 73.3% and total surface area (SA) by 45.2% (Figure 21). The 96% decrease in flow in section 2 was accompanied by a 100% reduction in OHV followed by a reduction in DA of 98%, VA of 97%, and SA of 25.8% (Figure 22).

In the natural flow section, discharge decreased only 57.2%. Accompanying decrease in OHV was 38.3% followed by a 28.1% decrease in DA and an 8.2% decrease in SA (Figure 23). There was no OHB cover in section 3.

Habitat Correlations

All five habitat variables were highly intercorrelated with the exception of VA in section 1 which had lower correlation with other habitat variables. Similarly each

Table 16. Calculated surface area and percent change of five habitat variables (per 100 m stream length), Ruby Creek, Montana, 1982.

Section	Date	Flow[a]		SA		DA		VA		OHV		OHB	
		(liters/sec)	%Change	(m^2)	%Change	(m^2)	%Change	(m^2)	%Change	(m^2)	%Change	(m^2)	%Change
1	7/24	283	0.0	251.6	0.0	85.0	0.0	135.1	0.0	7.5	0.0	0.6	0.0
	7/20	113	-60.0	213.3	-15.2	69.8	-17.9	148.8	-10.1	6.5	-13.1	0.6	0.0
	9/1	23	-92.0	171.0	-32.0	14.6	-82.8	166.9	-23.5	2.6	-65.3	0.0	-100.0
	9/8	9	-97.0	137.9	-45.2	7.0	-91.8	137.8	2.0	2.0	-73.3	0.0	-100.0
2	7/24	671	0.0	302.3	0.0	192.9	0.0	106.9	0.0	9.2	0.0	0.1	0.0
	7/21	167	-75.1	275.1	-9.0	105.3	-45.4	112.6	5.3	2.6	-71.7	0.1	0.0
	9/2	54	-92.0	255.0	-15.6	62.9	-67.4	193.3	80.0	0.0	-100.0	0.0	-100.0
	9/9	28	-95.8	224.2	-25.8	3.2	-98.3	219.4	105.2	0.0	-100.0	0.0	-100.0
3	7/22	822	0.0	448.2	0.0	231.3	0.0	228.1	0.0	6.0	0.0	0.0	0.0
	8/11	351	-57.2	411.3	-8.2	166.3	-28.1	233.8	2.5	3.7	-38.3	0.0	0.0

Surface Area-(SA)
Depth Area-(DA)
Velocity Area-(VA)
Overhanging Bank-(OHB)
Overhanging Vegatation Area-(OHV)

[a] cfs = liters/sec x 0.03531

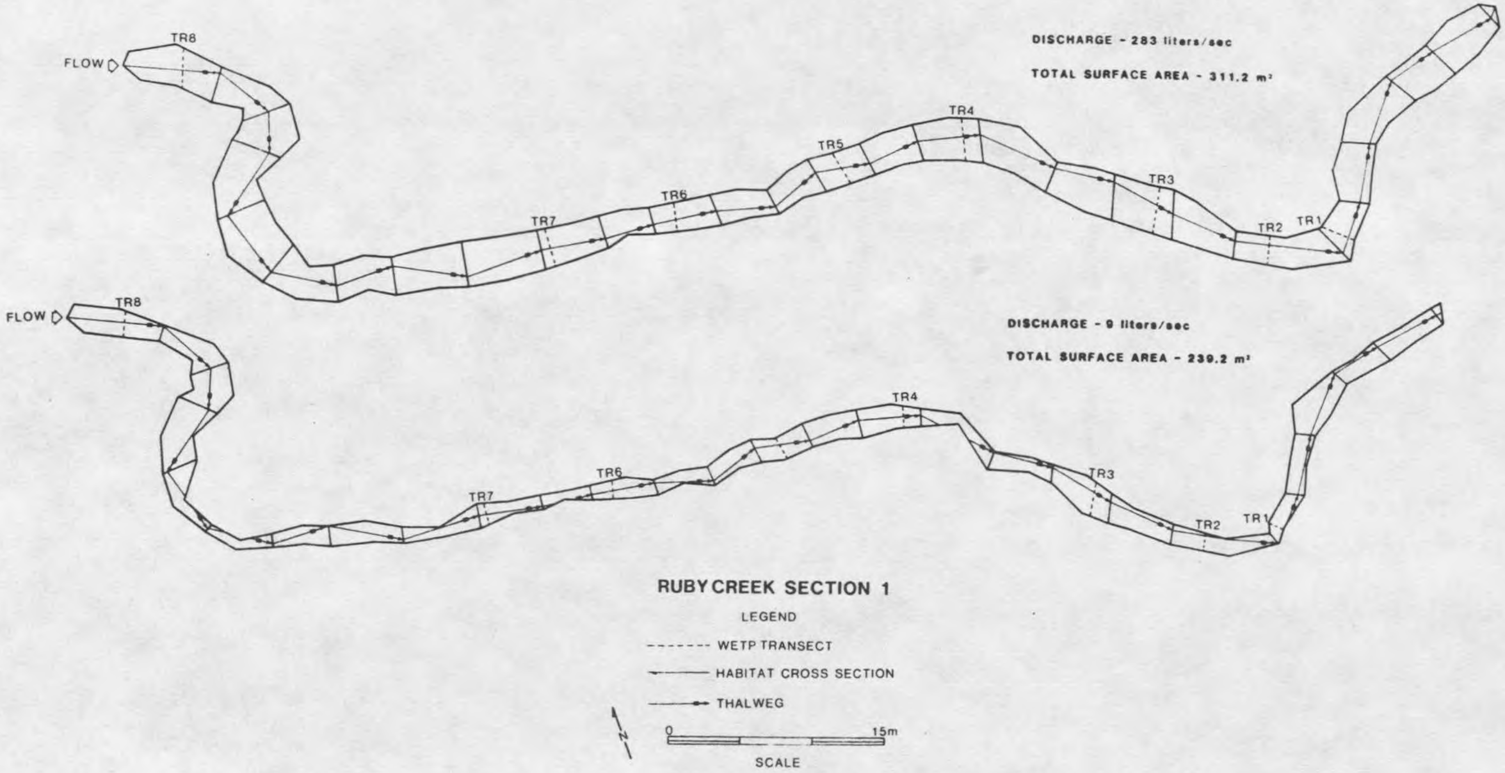

Figure 21. Surface area and thalweg of highest and lowest flows measured and location of wetted perimeter and habitat transects in section 1, Ruby Creek, Montana, 1982.

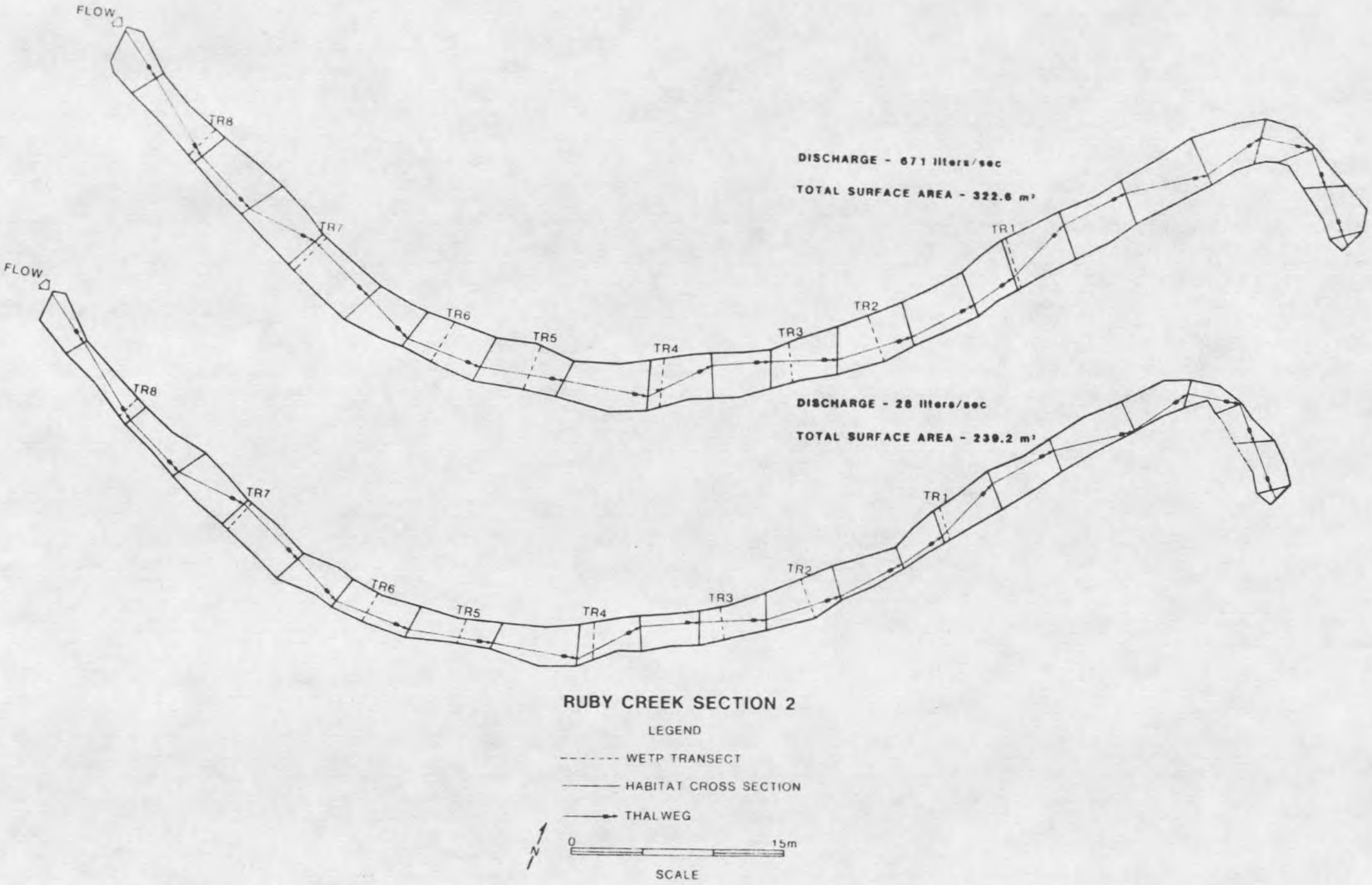

Figure 22. Surface area and thalweg of highest and lowest flows measured and location of wetted perimeter and habitat transects in section 2, Ruby Creek, Montana, 1982.

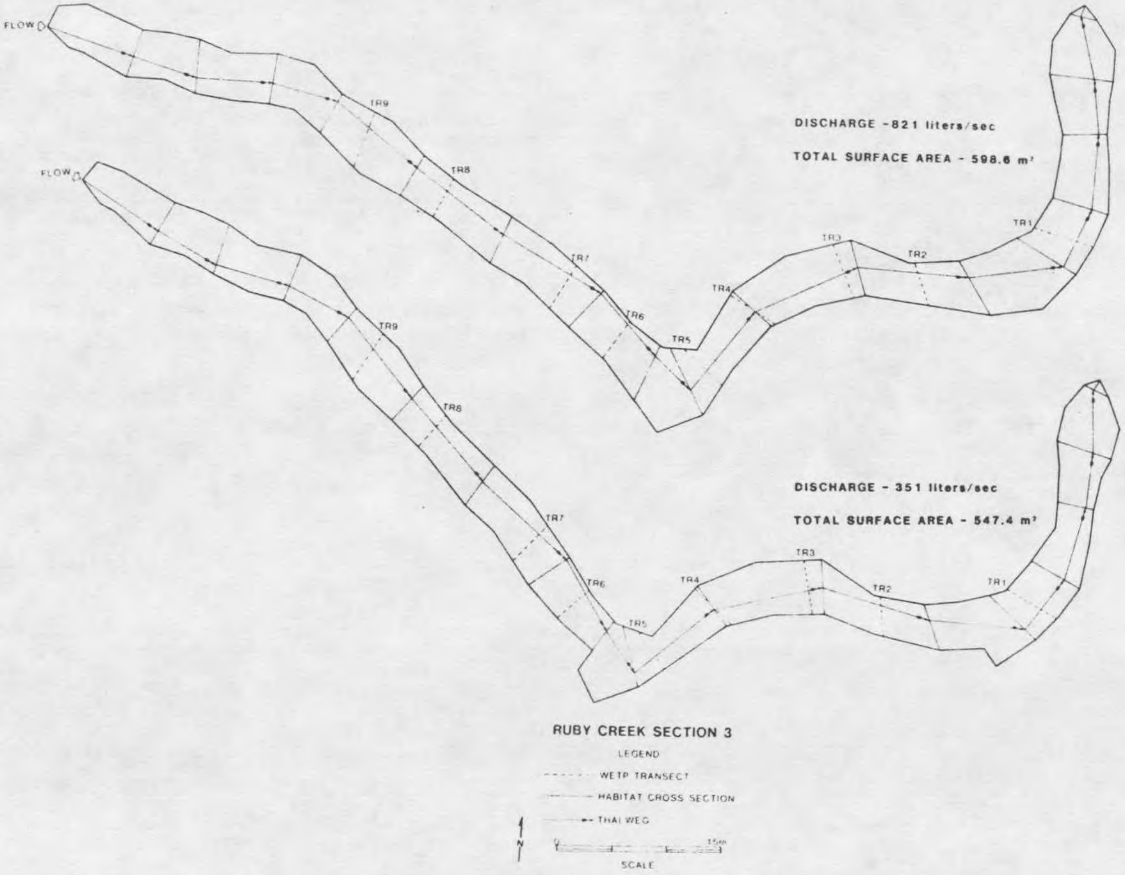

Figure 23. Surface area and thalweg of highest and lowest flows measured and location of wetted perimeter and habitat transects in section 3, Ruby Creek, Montana, 1982.

habitat variable had a high positive correlation with flow except for VA which was negatively correlated in all sections and was poorly correlated (r= -0.60) in section 1 (Tables 17, 18 and 19). With the exception of SA in sections 2 and 3, all other correlations were above 0.93.

In general, trout numbers and biomass were not as highly correlated with habitat variables as was flow. The exception was section 1 where all habitat-flow correlations were above 0.95, except for velocity. In section 2, the correlation between OHV and numbers was 0.90. Other variables had correlations with numbers ranging from 0.75 to 0.83. In section 3, no habitat variable correlated highly with numbers. Correlations ranged from 0.65 to 0.68.

Temperature

Mean daily water temperature, measured in sections 1 and 3, generally decreased during the study period. The decrease in water temperature occurred after most of the fish had emigrated from study sections. Water temperature ranged from 1 to 17 C and 1 to 18 C, in sections 1 and 3, respectively (Figures 24 and 25). Average mean daily temperatures, over the study period, were 11.1 C in section 1 and 10.8 C in section 3 (Table 20).

Table 17. Correlations between habitat variables, mean riffle transect variables and trout numbers remaining in section 1, Ruby Creek, Montana, 1982. Habitat variables were measured at flows ranging from 232 to 6 liters/sec (8.2 to 0.3 cfs).

	Flow	Numbers	SA	DA	VA	OHV	OHB	WETP	DBAR	VBAR	WDTH	AREA	WMAX	WTOT	WMAX
Flow	1.000														
Numbers	0.978	1.000													
SA	0.963	0.947	1.000												
DA	0.963	0.965	0.971	1.000											
VA	-0.598	-0.610	-0.394	-0.567	1.000										
OHV	0.965	0.966	0.973	0.999	-0.566	1.000									
OHB	0.958	0.963	0.952	0.995	-0.622	0.997	1.000								
WETP	0.843	0.892	0.955	0.979	-0.122	0.881	0.843	1.000							
DBAR	0.952	0.941	0.996	0.974	-0.398	0.975	0.956	0.956	1.000						
VBAR	0.684	0.683	0.482	0.626	-0.965	0.620	0.665	0.203	0.476	1.000					
WDTH	0.830	0.816	0.948	0.865	-0.098	0.869	0.830	1.000	0.948	0.179	1.000				
AREA	0.963	0.952	0.997	0.980	-0.432	0.982	0.965	0.945	0.999	0.510	0.936	1.000			
DMAX	0.949	0.939	0.997	0.972	-0.388	0.974	0.954	0.959	1.000	0.467	0.952	0.999	1.000		
WTOT	0.980	0.985	0.949	0.983	-0.652	0.985	0.987	0.823	0.943	0.708	0.809	0.956	0.941	1.000	
WMAX	0.990	0.986	0.940	0.962	-0.653	0.965	0.964	0.808	0.933	0.724	0.794	0.946	0.930	0.991	1.000

Surface Area (SA)
Depth Area (DA)
Veloctiy Area (VA)
Overhanging Vegitation Area (OHV)
Overhanging Bank Area (OHB)
Wetted Perimeter (WETP)
Average Depth (DBAR)

Average Velocity (VBAR)
Top Width of Transect (WDTH)
Transect Area (AREA)
Maximum Depth (DMAX)
Total Top Width with Depth of 15 cm or more (WTOT)
Longest Continuous Top Width Associated with a Depth of 15 cm or more (WMAX)

Table 18. Correlations between habitat variables, mean riffle variables and trout numbers remaining in section 2, Ruby Creek, Montana, 1982. Habitat variables were measured at flows ranging from 524 to 28 liters/sec (18.5 to 1.0 cfs).

	Flow	Numbers	SA	DA	VA	OHV	OHB	WETP	DBAR	VBAR	WDTH	AREA	DMAX	WTOT	WMAX
Flow	1.000														
Numbers	0.918	1.000													
SA	0.896	0.766	1.000												
DA	0.934	0.815	0.995	1.000											
VA	-0.900	-0.751	-0.983	-0.979	1.000										
OHV	0.997	0.904	0.895	0.931	-0.911	1.000									
OHB	0.964	0.833	0.970	0.984	-0.979	0.969	1.000								
WETP	0.899	0.766	0.996	0.991	-0.982	0.897	0.969	1.000							
DBAR	0.962	0.834	0.977	0.990	-0.982	0.965	0.998	0.978	1.000						
VBAR	0.995	0.914	0.856	0.900	-0.872	0.996	0.946	0.858	0.940	1.000					
WDTH	0.879	0.746	0.995	0.986	-0.977	0.877	0.957	0.999	0.968	0.835	1.000				
AREA	0.967	0.842	0.974	0.988	-0.979	0.970	0.998	0.975	1.000	0.947	0.964	1.000			
DMAX	0.958	0.832	0.982	0.993	-0.983	0.961	0.967	0.983	1.000	0.934	0.973	0.999	1.000		
WTOT	0.980	0.850	0.910	0.937	-0.934	0.988	0.979	0.915	0.976	0.978	0.896	0.979	0.971	1.000	
WMAX	0.992	0.892	0.896	0.931	-0.907	0.993	0.967	0.901	0.965	0.990	0.881	0.970	0.961	0.990	1.000

Surface Area (SA)
Depth Area (DA)
Velocity Area (VA)
Overhanging Vegitation Area (AREA)
Overhanging Bank Area (OHB)
Wetted Perimeter (WETP)
Average Depth (DBAR)
Average Velocity (VBAR)
Top Width of Transect (WDTH)
Transect Area (AREA)
Maximum Depth (DMAX)
Total Top Width with Depth of 15 cm or more (WTOT)
Longest Continuous Top Width Associated with a Depth of 15 cm or more (WMAX)

Table 19. Correlations between habitat variables, mean riffle transect variables and trout numbers remaining in section 3, Ruby Creek, Montana, 1982. Habitat variables were measured at flows ranging from 615 to 351 liters/sec (21.7 to 12.4 cfs).

	Flow	Numbers	SA	DA	VA	OHV	WETP	DBAR	VBAR	WDTH	AREA	DMAX	WTOT	WMAX
Flow	1.000													
Numbers	0.647	1.000												
SA	0.785	0.650	1.000											
DA	0.997	0.683	0.804	1.000										
VA	-0.997	0.684	0.804	-1.000	1.000									
OHV	0.997	0.682	0.803	1.000	-1.000	1.000								
WETP	0.987	0.717	0.814	0.997	-0.997	0.997	1.000							
DBAR	0.990	0.650	0.811	0.992	-0.992	0.992	0.987	1.000						
VBAR	0.999	0.648	0.788	0.997	-0.997	0.997	0.989	0.990	1.000					
WDTH	0.986	0.720	0.815	0.996	-0.996	0.996	1.000	0.987	0.988	1.000				
AREA	0.998	0.677	0.800	1.000	-1.000	1.000	0.995	0.992	0.998	0.995	1.000			
DMAX	0.992	0.695	0.793	0.997	-0.997	0.997	0.994	0.992	0.992	0.994	0.996	1.000		
WTOT	0.964	0.724	0.845	0.981	-0.981	0.980	0.991	0.972	0.966	0.991	0.978	0.978	1.000	
WMAX	0.986	0.666	0.812	0.992	-0.992	0.992	0.990	0.985	0.987	0.990	0.992	0.987	0.984	1.000

Surface Area (SA)
Depth Area (DA)
Velocity Area (VA)
Overhanging Vegitation Area (AREA)
Wetted Perimeter (WETP)
Average Depth (DBAR)

Average Velocity (VBAR)
Top Width of Transect (WDTH)
Transect Area (AREA)
Maximum Depth (DMAX)
Total Top Width with Depth of 15 cm or more (WTOT)
Longest Continuous Top Width Associated with a Depth of 15 cm or more (WMAX)

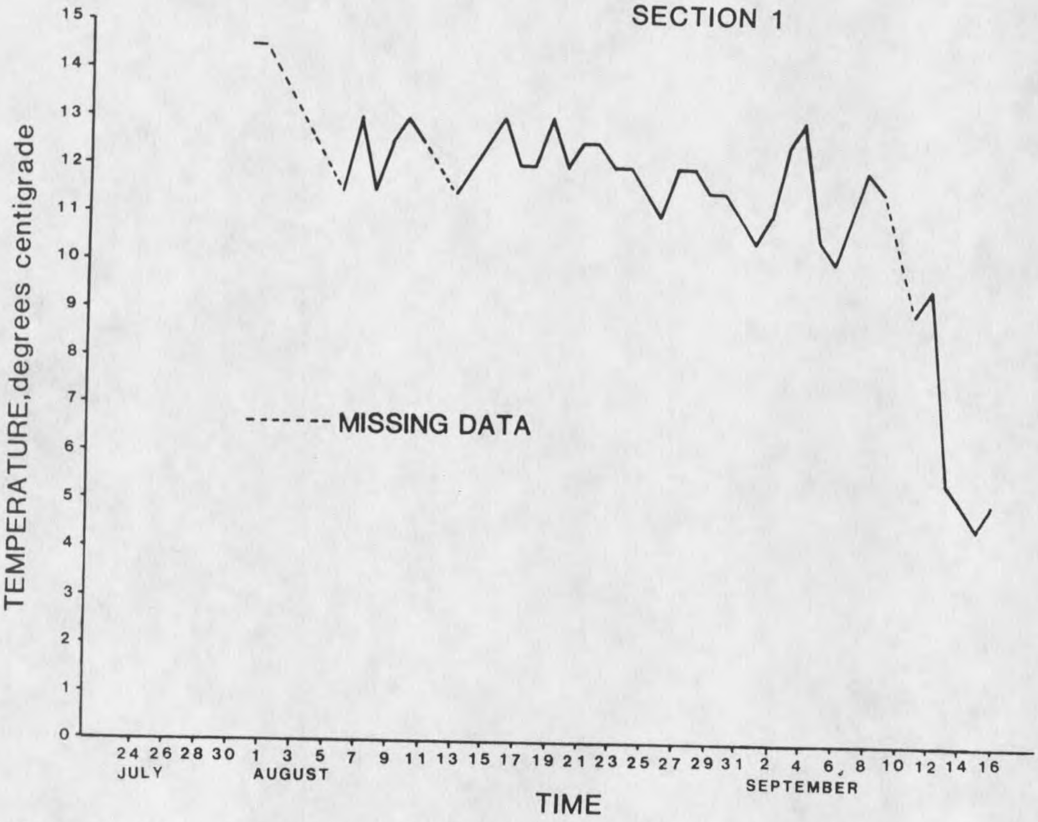

Figure 24. Average daily water temperatures (C) of section 1, Ruby Creek, Montana, 1982.

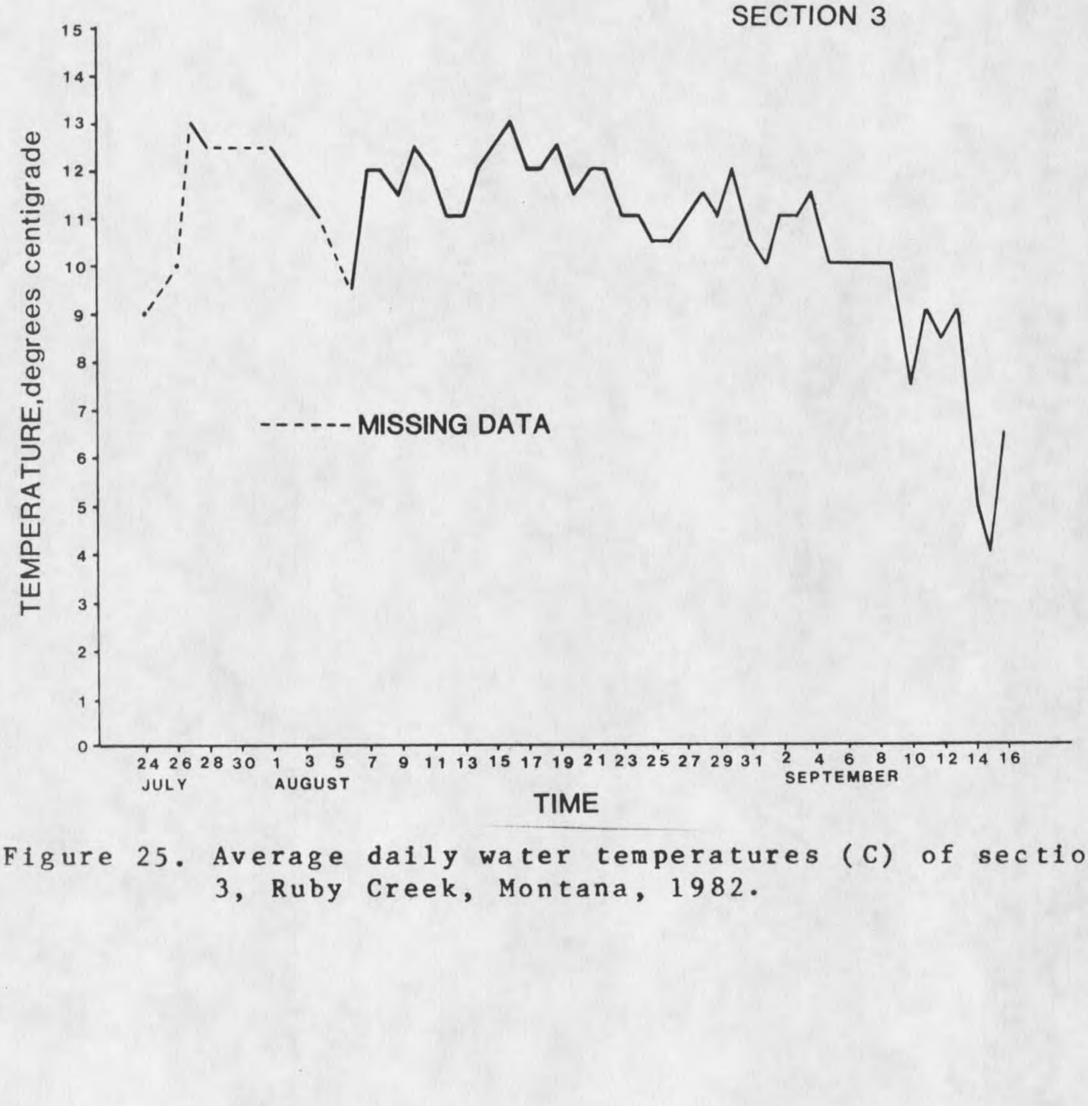

Figure 25. Average daily water temperatures (C) of section 3, Ruby Creek, Montana, 1982.

Wetted Perimeter as a Habitat Index

Wetted Perimeter and Habitat Correlations

Wetted perimeter correlated highly with the five habitat variables in all sections, except for velocity area in section 1. Correlation of wetted perimeter with habitat variables in section 1 ranged from a low of -0.122 for velocity area (VA) to a high of 0.979 for depth area (DA, Table 17). In section, 2 wetted perimeter correlation with habitat variables ranged from 0.897 OHV to 0.996 for SA (Table 18). In section 3, the correlation coefficients between wetted perimeter and habitat variables depth area (DA), velocity area (VA), and overhanging vegetation (OHV) were 0.997. The lowest correlation in section 3 was with SA (r= 0.814, Table 19).

Trout Abundance and Wetted Perimeter

Changes in wetted perimeter were paralleled by changes in trout numbers in section 1 (Figure 26) with a correlation of 0.892 (Table 17). Wetted perimeter and trout numbers decreased rapidly as flow slowly decreased below 140 liters/sec (4.9 cfs).

Trout numbers decreased in section 2 before large decreases in wetted perimeter occurred (Figure 27). Trout number and wetted perimeter had a correlation of 0.766.

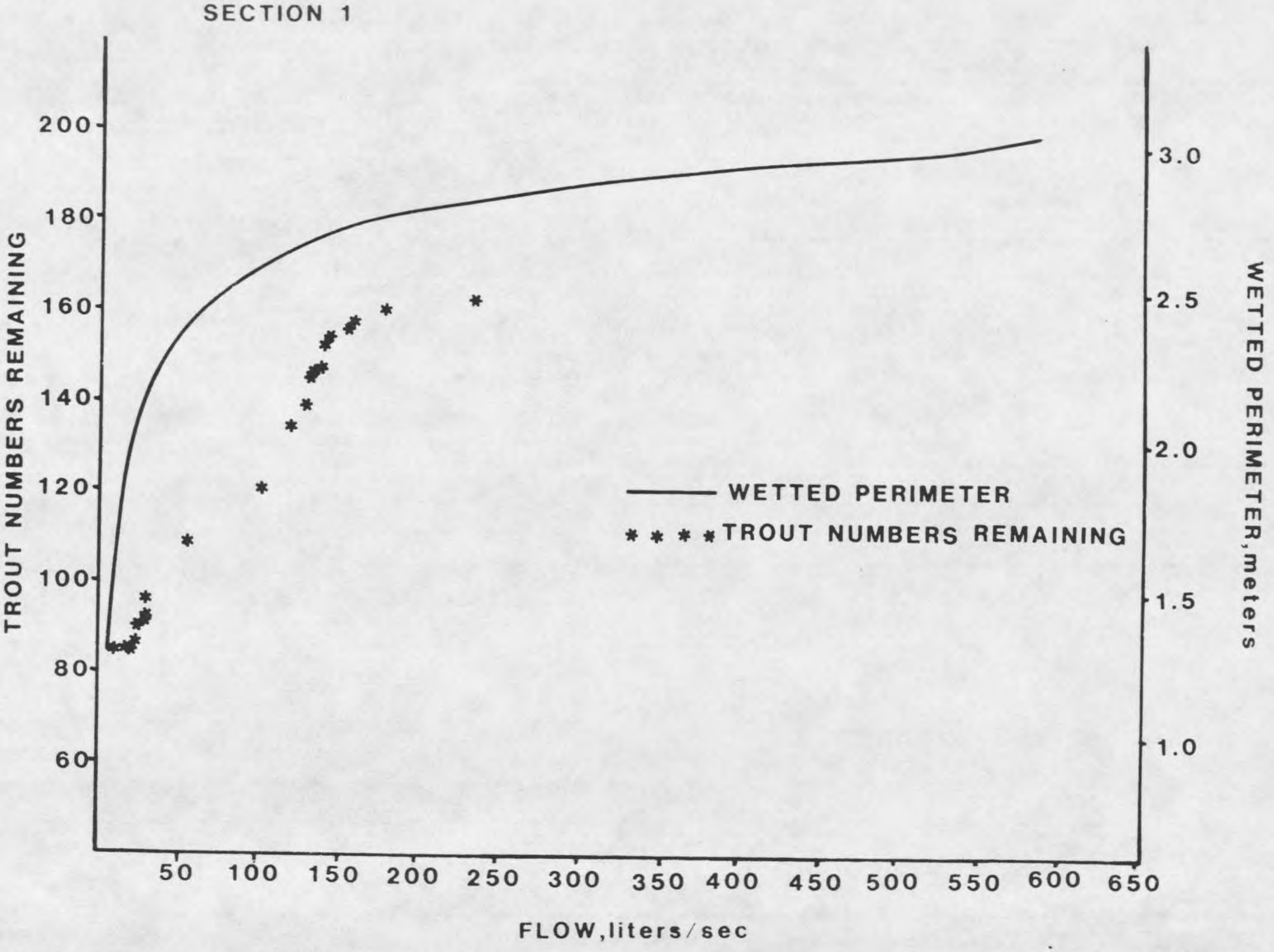

Figure 26. The relationship between wetted perimeter and trout numbers remaining in section 1, Ruby Creek, Montana, 1982.

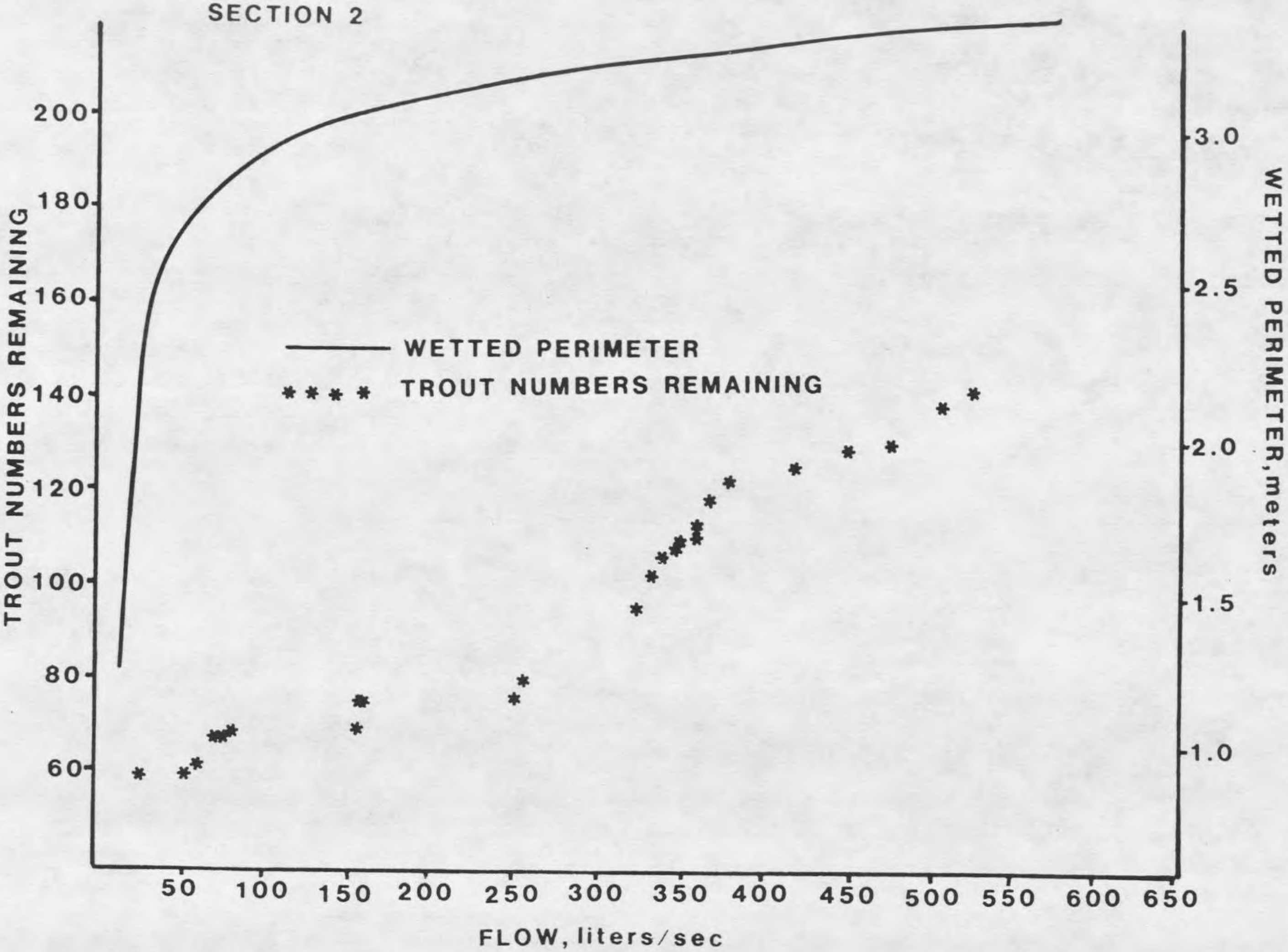

Figure 27. The relationship between wetted perimeter and trout numbers remaining in section 2, Ruby Creek, Montana, 1982.

Trout number in section 2 decreased rapidly with small decreases in discharge below 360 liters/sec (12.7 cfs). Wetted perimeter did not decrease rapidly until flow was reduced below 130 liters/sec or 4.6 cfs.

In the natural flow section (section 3) the correlation between trout numbers and wetted perimeter was 0.717. With a 15-day lag between flow change and trout emigration response, trout numbers stabilized as flow stabilized at about 390 liters/sec or 13.8 cfs. Calculated wetted perimeter decreased most rapidly as discharge was reduced below 460 liters/sec (16.4 cfs, Figure 28). Increased rate of trout emigration corresponded reasonably well to this inflection point in the wetted perimeter curve.

The wetted-perimeter computer model predicted the following associated parameters: average cross section depth (DBAR), average cross section velocity (VBAR), cross section width (WDTH), cross section water area (AREA), maximum cross section depth (DMAX), total top width having a depth of 15 cm or more (WTOT), and the longest continuous top width with depth of 15 cm or more (WMAX).

Order of importance of wetted perimeter habitat variables, based upon correlation with trout numbers, was not consistent between study sections. In section 1 all variables except VBAR and WDTH had correlations with numbers of trout larger than 0.93, indicating that they

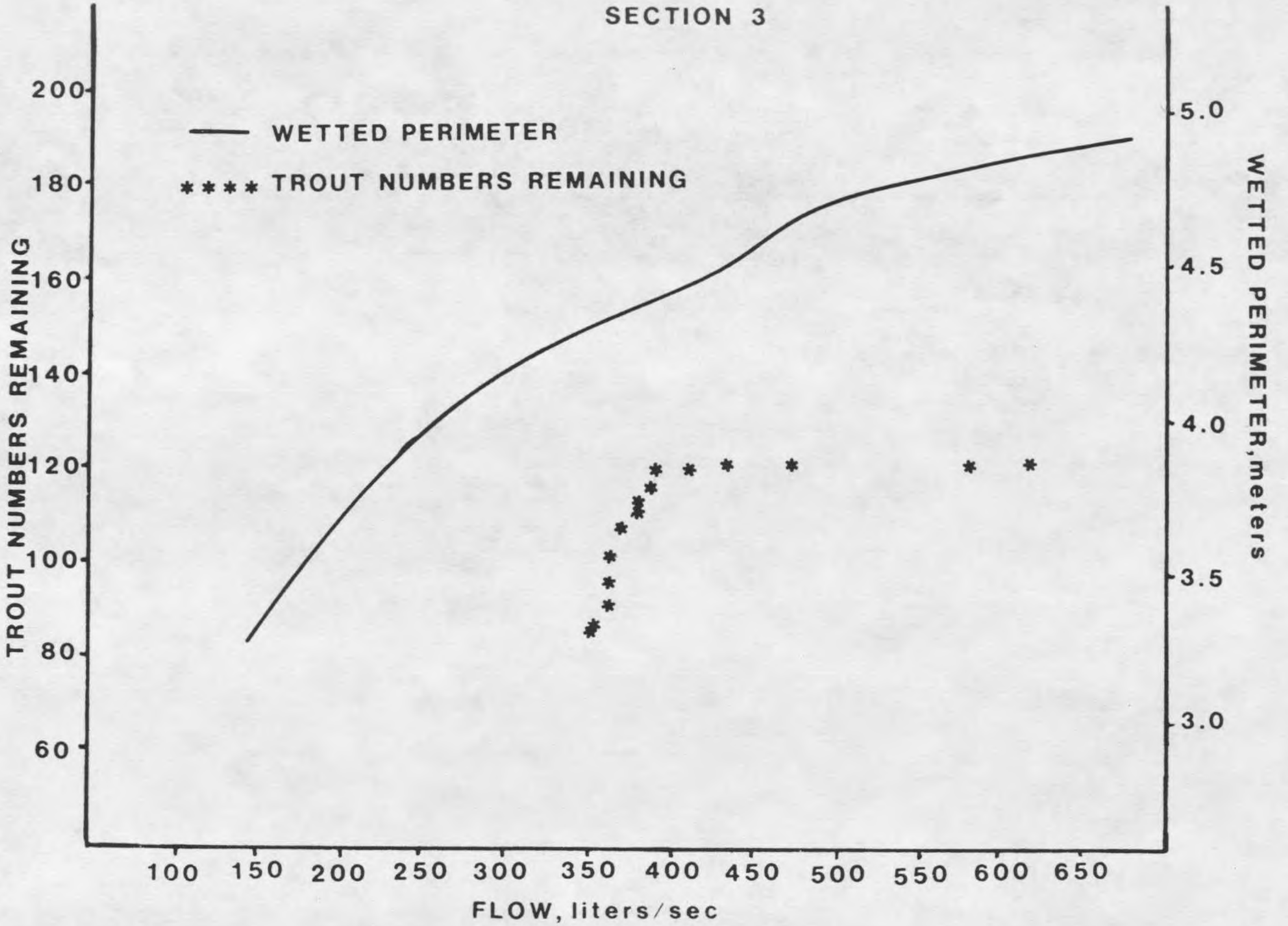

Figure 28. The relationship between wetted perimeter and trout numbers remaining in section 3, Ruby Creek, Montana, 1982.

are all highly important. In section 2 VBAR was the only variable with a correlation exceeding 0.90. WDTH had a correlation of 0.75 and each of the remaining five variables had correlations ranging from 0.83 to 0.89. No variable was highly correlated with numbers in section 3. Both WDTH and WTOT had a correlation of 0.72, while other wetted perimeter variables had correlations of 0.64-0.70.

Variables Versus Trout Numbers

Because of high intercorrelation of variables, standard multivariate tests were unsuitable for statistically evaluating the order of importance of habitat components. In an attempt to explain the observed increase in emigration in all study sections when flow was reduced 30-40% of inital discharge (Figures 29, 30 and 31), percent change in the five habitat variables and eight wetted perimeter variables were plotted with percent change in initial flow. Visual evaluation of these plots indicated that no habitat variable decreased in parallel with trout numbers. The pattern of decrease of wetted perimeter variables WTOT and WMAX, however, was similar to the decrease in numbers and most closely explained the response of the fish population. Each of these variables is a measure of the riffle habitat deeper than 15 cm.

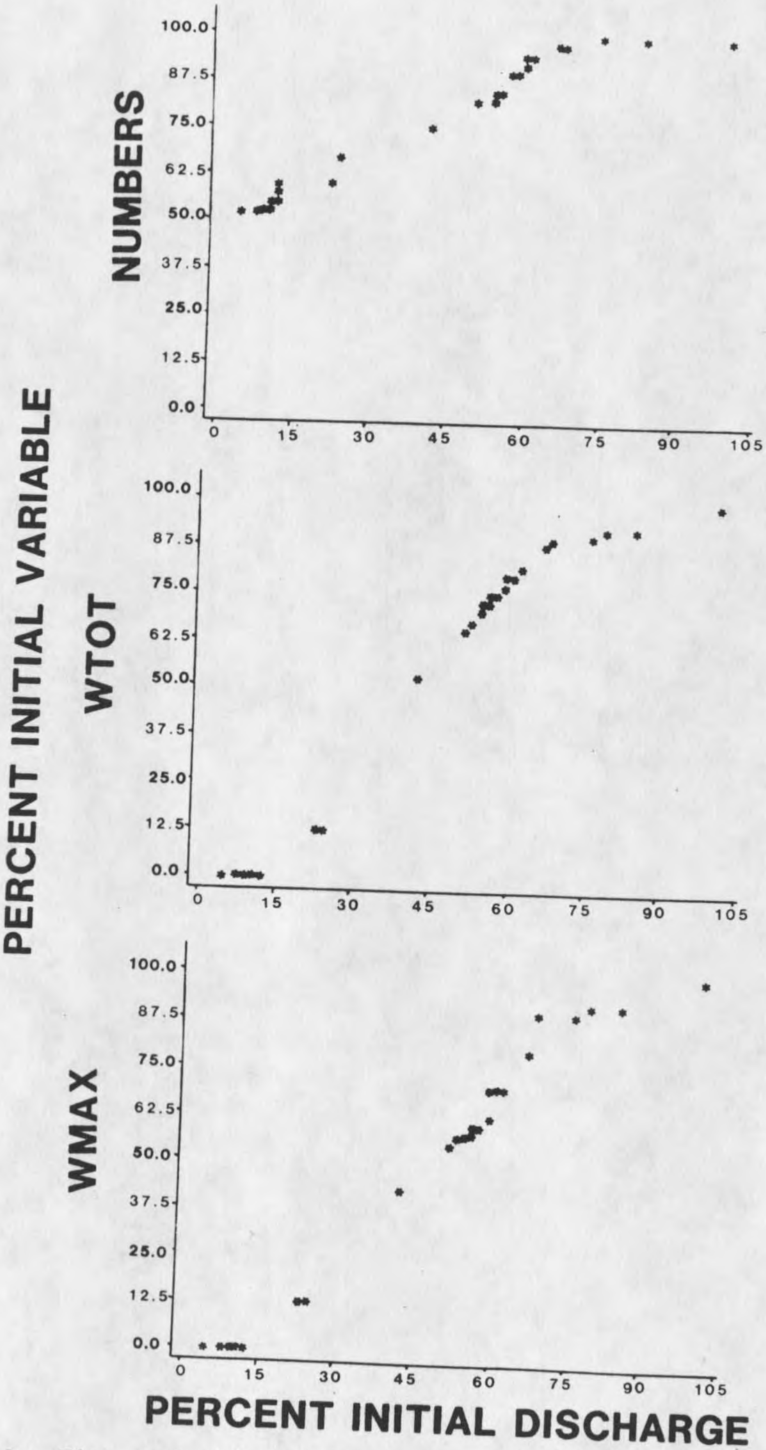

Figure 29. The relationship between percent initial discharge and trout numbers remaining, total top width with depth greater than 15 cm (WTOT) and longest continuous top width with depth greater than 15 cm (WMAX) for study section 1, Ruby Creek, Montana, 1982.

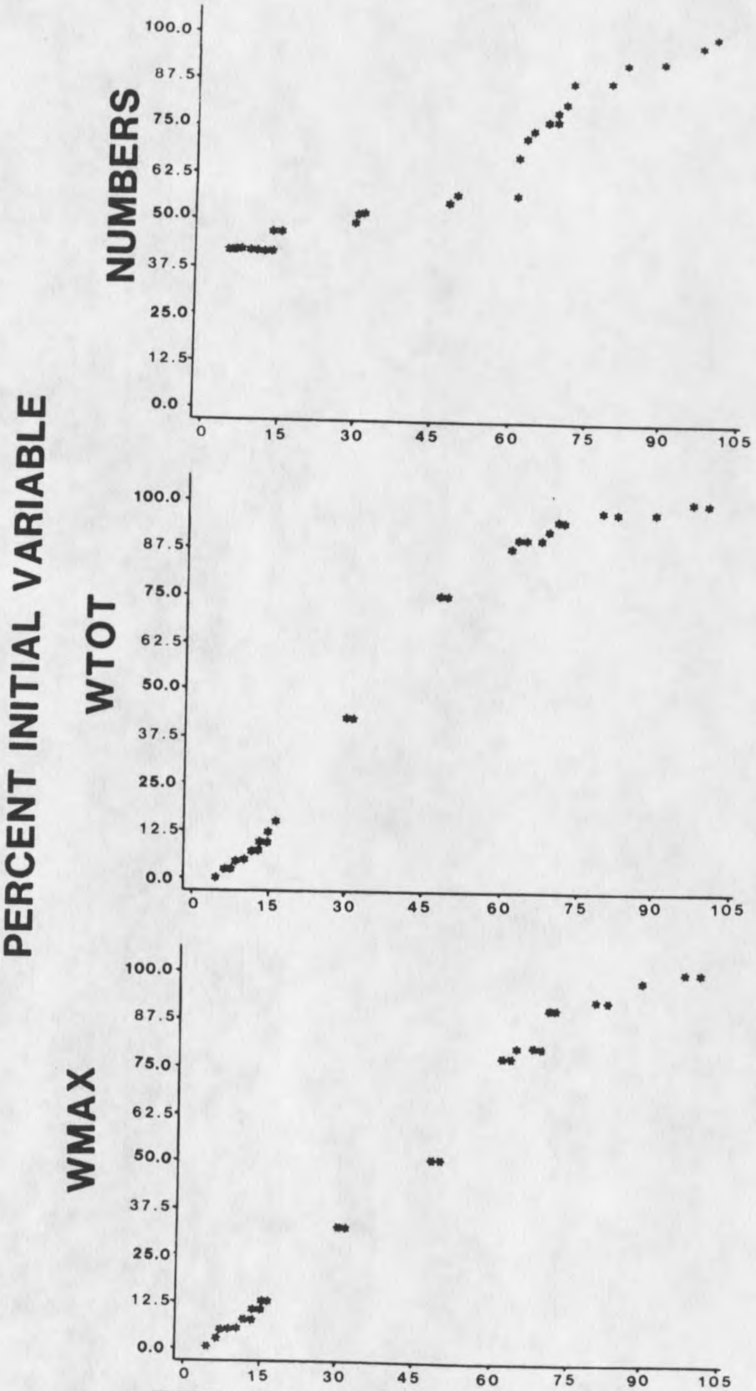

Figure 30. The relationship between percent initial discharge and trout numbers remaining, total top width with depth greater than 15 cm (WTOT) and longest continuous top width with depth greater than 15 cm (WMAX) for study section 2, Ruby Creek, Montana, 1982.

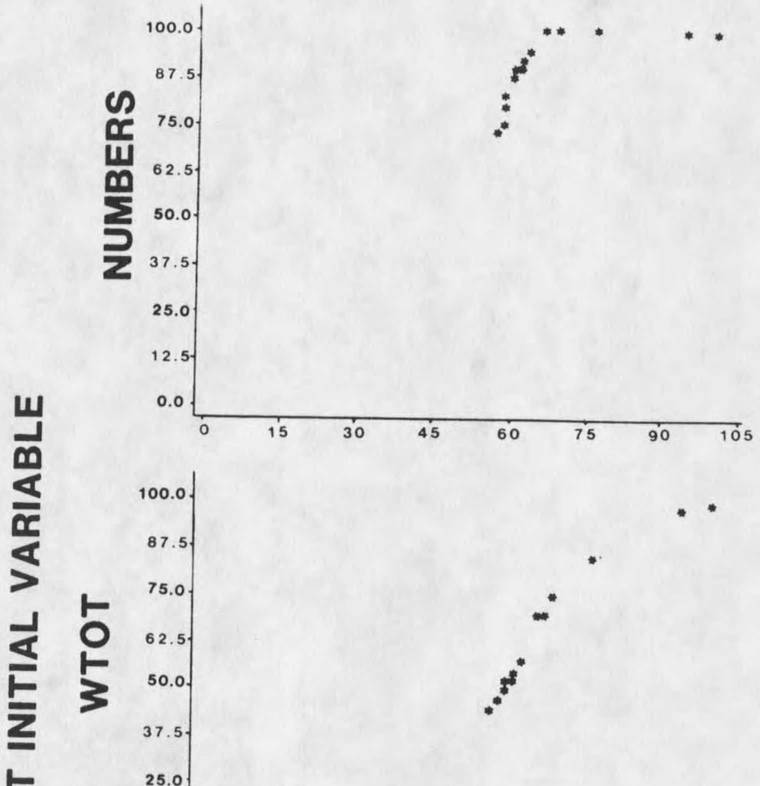

Figure 31. The relationship between percent initial discharge and trout numbers remaining, total top width with depth greater than 15 cm (WTOT) and longest continuous top width with depth greater than 15 cm (WMAX) for study section 3, Ruby Creek, Montana, 1982.

DISCUSSION

Abundance Regulation by Low Summer Flow

Density of trout in supplemented stream sections of Ruby Creek was not reduced to pre-study levels during the 63-day experiment. Numerical density in sections 1, 2 and 3 was 180, 400 and 127% larger, respectively, at the end of the study while biomass density had corresponding increases of 8, 276 and 140%. The smaller increase in biomass, compared to numbers, in all sections was due to emigration of larger fish and to loss in weight of experimental trout.

The reason for the increase in biomass and numerical densities of rainbow trout at the end of the summer low flow period in all sections, compared to initial densities, is not clear. Possible explanations include alteration in social tolerance by forced initial density increases, the possibility that summer low flow is not the limiting factor on Ruby Creek, or that the study was not of a long enough duration to elicit a total response.

Alteration of social tolerance by initial stocking density is not known to have been reported in the literature. However, Robert G. White (unpublished data, Montana State University) has observed in previous reduced-flow experiments in an artificial channel that under identical flow and habitat conditions, the larger the initial stocking density of juvenile rainbow-steelhead trout, the larger the stabilization number (at constant flow) and the larger the ending density following severe flow reduction. If these observations apply to natural streams, the large number of rainbow trout introduced into experimental sections could have influenced final density.

Another consideration is that factors other than low summer flows regulate rainbow trout abundance in Ruby Creek. Abnormally high spring scouring flows have been shown to have a negative influence on trout populations (Nehring 1983). In Ruby Creek, however, there is no evidence that spring scouring is a common event. Winter mortality is also known to be large in many streams (Hunt 1969, Vincent 1984). Because of the relatively small size of Ruby Creek and the harsh winter conditions in the drainage, winter habitat conditions could influence population abundance.

Lastly, tests during the present study may not have been of long enough duration for a total response to be seen. This, however, seems unlikely since flow and number in all sections had stabilized 12 or more days prior to the end of the study.

The effects of long term summer dewatering on trout populations in riffle-run habitat maybe illustrated by comparing initial rainbow trout densities from sections 2 and 3. Section 2 has historically been dewatered from August to mid-September (MDFWP 1981) while section 3 has not been influenced by artificial flow reductions. Although habitat in the two sections is very similar, initial numerical density of rainbow trout in the unaltered flow section was three times that in the section influenced by irrigation diversion, while biomass density was four times larger. These comparisons support the experimental observations that trout populations respond negatively to changes in stream discharge. The larger magnitude of initial biomass difference between the sections also illustrates the finding that larger trout are more influenced by flow reductions than are smaller trout. From these comparisons it appears clear that low summer flow has a regulating influence on rainbow trout populations, even though other factors such as winter habitat may reduce the population further.

Rainbow trout abundance and biomass decreased as flow decreased in all study sections. In sections 1 and 3, flow related emigration of rainbow trout was not observed until 11 and 15 days after major flow reductions. The mechanism for this delayed response is not known, but I hypothesize it to be due to social interactions caused by increased trout densities.

Other researchers have reported reduction in trout numbers as well as lags in response to flow changes.

Kraft (1968 and 1972) examined the relationship between brook trout in Blacktail Creek, Montana and flow-related changes in habitat. During a 3-month study with 90% reduction in flow, trout abundance in the reduced flow section decreased an average of 62% in runs, compared to 20% in control-section runs, and movement out of the stream section peaked 10 days following flow reduction (Kraft 1972). Trout numbers in pools of the test sections generally increased, while trout numbers in pools of a control section decreased more than 14%. Kraft's (1972) data suggest that trout habitat in runs becomes less suitable with decreasing flow. Trout distribution first shifted from runs to pools and then density-related social mechanisms resulted in emigration of a portion of the population.

Bachman (1984) described a density-related social mechanism of an undisturbed population of wild brown trout. He found that at high population density, energy saving foraging sites that allowed drift feeding with a minimum of energy expenditure were a limiting factor. This was indicated by agonistic encounters associated with foraging sites and not with refuge sites. Krueger (1979) examined the response of juvenile chinook salmon to decreased discharge in a straight, narrow, riffle-run artificial channel. When discharge was reduced 94% over a 48-hour period, fish emigrated from the channel until 53 and 46% of wild and hatchery-reared fish remained, respectively. Krueger found that substantial numbers of emigrants were captured in traps the day following discharge reduction from 17 to 3 liters/sec.

Flow related rainbow trout emigration was primarily upstream from the study sections. Movement upstream when discharge is reduced has been found by Kraft (1972) and Easterbrooks (1981). Clothier (1953 and 1954) reported that rainbow trout in irrigation canals consistently moved upstream following gradual decline in flows. White et al. (1981) also found that most juvenile rainbow-steelhead trout emigrated upstream in response to flow reductions. Easterbrooks (1981) observed similar upstream movement in flow reduction tests with wild rainbow and cutthroat trout. He speculated that upstream emigration may be triggered by an instinct which stimulated trout to move upstream in search of cool tributaries or springs, thereby increasing the chance of survival during periods of low flow and high water temperature in downstream, mainstem stream reaches. Another possible explanation would be that trout move upstream to seek preferred habitat above fish with social dominance.

Mean trout length decreased in the two study sections having large flow reductions. Although not statistically significant, the data may indicate that larger fish were more influenced by flow reductions than were smaller fish (Figures 15 and 16). This suggests that larger fish emigrated from the reduced flow sections due to reduction in habitat rather than food. If food were limited, larger dominant fish would have advantage over smaller fish, and one would expect a larger relative percentage decrease in numbers of small trout. White et al. (1981) reported similar response of juvenile steelhead-rainbow trout in reduced flow tests conducted in artificial channels. They also documented that trout left experimental channels in response to reduced flow before aquatic invertebrate abundance was reduced. Food availability was not investigated during my study.

Although emigration response of rainbow trout in the present study provided no indication that food was limiting, mean weight of fish in all study sections decreased during the study. Likewise, condition factors of nearly all size groups of trout decreased. In general, emigrating trout had only slightly poorer condition than those remaining until the end of the study (Tables 11, 12 and 13). Decrease in overall mean weight in reduced flow sections was, in part, due to a disproportionate number of large fish emigrating from test sections. Decrease in mean condition, however, was not a result of size related emigration.

The observation that mean weight and condition decreased even in the control section, where flow related food limitation would not be expected, makes interpretation difficult. If emigrating fish had much lower condition than those remaining to the end of the study, the fish may have been food limited and were leaving the area because of social interaction. A similar conclusion could be reached if the largest size groups in each section had not lost condition. Although not statistically significant, fish in these size groups in all sections lost condition during the summer study period, when condition should have remained the same or increased (Carlander 1969).

It is thought that the numbers remaining in study sections were within the social tolerance for rainbow trout during the present short-term study. Although quantity of food may have been less than optimum, it apparently was not in short enough supply to elicit further density adjustments.

The number of fish unaccounted for during the present study was comparable to losses reported during studies with similar designs. Krueger (1979) reported loss of juvenile chinook salmon between 5 and 21% of the stocked fish. White et al. (1981) reported 11 to 27% unaccounted fish during the 1978 and 1979 flow tests. A higher percentage of biomass, compared with numbers, remained unaccounted for during the study in sections 1 and 2. This is probably a result of the fish losing weight during my study. The loss of trout numbers during this study is likely due to the reduction in cover with decreased streamflow which I hypothesize increased the chance of predation by kingfisher, great blue heron and river otter.

Flow Related Decreases in Habitat Availability

Sections 2 and 3 were characterized by a run-riffle habitat structure. Study section 1 was characterized by a riffle-pool habitat sturcture. This habitat difference is best illustrated by comparing mean transect and thalweg depth between sections. Although streamflow at the initiation of the study was more than 50% less in the pool-riffle section, mean depth was essentially the same and mean thalweg depth was 11% greater than in the run-riffle channels.

In section 3 (natural flow) lagged trout number stabilized as discharge stabilized at about 350 liters/sec or 12 cfs (Figure 10), while numbers in section 2 continued to decline as flow declined (Figure 9). This interpretation is based on the assumption that the 15-day lag in response of the trout population to flow change in section 3 is correct. Since essentially no lag was seen in section 2 the mixture of habitat characteristics within sections must be substantially different because of the observed difference in trout response to decreases in flow. If the habitats were the same between sections 2 and 3 a similar response regarding the amount of time elapsed between flow reduction and fish emigration would have been expected.

Temperatures during the study were well within the tolerance range of rainbow trout and would not be expected to increase mortality or negatively influence growth (Carlander 1969). Relatively similar temperatures in sections 1 and 3 during extreme differences in flow and the lower variation of water temperatures in section 1, suggest that ground water influenced water temperatures in section 1.

Wetted Perimeter as a Habitat Index

Most habitat variables evaluated were highly correlated with one another as well as with flow. Because of this, multivariant statistics were unsuitable for distinguishing which combination of variables best explained the response of experimental fish populations or the order of importance of these variables. Although statistical evaluation was determined to be inappropriate, plots of percentage change in each habitat and wetted perimeter variable with percentage change in flow were visually evaluated. The observed rate of change in these variables was then related to observed percent decrease in rainbow trout abundance with percent decrease in flow. Of the 13 variables examined, change in only two, total top width associated with depth of at least 15 cm (WTOT) and longest continuous top width associated with a depth of 15 cm or more (WMAX), closely corresponded to change in numbers with flow (Figures 29, 30 and 31). Both of these variables were generated by the wetted perimeter model and are a measure of quantity of riffle depth greater than 15 cm.

Other researchers have also reported that depth is important in explaining fish abundance in streams. Stewart (1970) found that of 15 variables evaluated, mean depth was the single most significant factor affecting abundance of wild brook and rainbow trout. He speculated mean section depth was an index of deep water suitable for fright cover. Everest (1969) correlated density of juvenile steelhead trout and chinook salmon with substrate size, bottom velocity, surface velocity, depth, and density of other species. He found that depth was the only variable with significant correlation with density of age 0-chinook salmon. In one stream, depth also accounted for the largest variation in age I steelhead trout density.

White (1976) attempted to predict effects of flow reductions on rainbow trout populations in the Teton River, Idaho. He predicted that cover, in the form of sufficient depth, would be limiting as discharge declined in run-riffle channels. Easterbrooks (1981) reported that wild rainbow and cutthroat trout exhibited a linear decrease in abundance with reductions in depth. This study was conducted in laboratory channels in which variables other than depth remained constant. He also found that wild rainbow trout from streams with different levels of productivity responded to depth reductions differently. Given equal flow and depth conditions, abundance of experimental fish from a more biologically productive stream stabilized at a higher density in laboratory channels.

If the results are representative of the habitat types studied it appears that riffle wetted perimeter may not be a good index of summer habitat suitability for rainbow trout in riffle-run habitats in small streams similar to Ruby Creek. Although the wetted perimeter curves were considerably different between the two run-riffle sections (sections 2 and 3), and the lowest flow was 92% less in section 2 than in section 3, similarity between sections is illustrated by similar flow-related response of the fish population (Figures 12, 13, 27 and 28). In both sections, as discharge was reduced below approximately 400 liters/sec (14 cfs), the rate of change in trout abundance increased. If the inflection point on the wetted perimeter curve for section 2 were used as the recommended flow (about 150 liters/sec or 5 cfs), this recommendation would substantially underestimate the approximate 375 liters/sec (13.2 cfs) which appeared optimum for my experimental fish population (Figure 27). In section 3 there were two inflection points (Figure 28); one at about 475 liters/sec (17 cfs) and one at about 300 liter/sec (11 cfs). The first would overestimate the amount of water needed while the second would be slightly less than optimum.

In contrast, the inflection point on the wetted perimeter curve for the pool-riffle habitat in section 1 (Figure 26) corresponded well with the flow (150 liters/sec, 5 cfs) at which rate of trout emigration increased substantially. Since only one pool-riffle section was studied (section 1), it is not known if these findings are characteristic of small stream pool-riffle habitat in general.

Annear and Conder (1983) found that subjectively chosen inflection points on average-riffle-wetted perimeter curves overestimated minimum flow 77% of the time, when compared to a validated habitat quality index (HQI Model II, Binns 1979). These results are in contrast to findings of the present study where average riffle wetted perimeter inflection points either predicted flow needs accurately or underestimated flow needs as determined from trout emigration response in three study sections. The inconsistency in results between studies may be explained by the questionable appropriateness of the HQI method for Montana streams. The HQI method of estimating trout standing crop was evaluated during a study of the effects of urbanization on the physical habitat for trout in streams. White et al. (1983) found that trout standing crops predicted by the HQI method were poorly correlated (r= 0.228) with actual standing crops found in studied stream reaches. Subjective habitat parameter measurements required in the HQI model may explain the poor correlation between predicted and actual standing crops of trout. The subjectiveness of choosing wetted perimeter inflection points may also be responsible for inconsistencies between Annear and Conder (1983) and the present study.

In conclusion, the wetted-perimeter method of determining minimum stream discharge on small streams does not appear to be a consistent index of rainbow trout habitat suitability. In pool-riffle habitat of Ruby Creek the method worked well. In run-riffle habitats, however, this approach may underestimate the amount of water necessary to maintain rainbow trout populations at a reasonable level.

Since my study was conducted on habitat types in only one small stream and for only one summer season, results should be applied with caution. Long term research should be initiated to validate findings and to gain a better understanding of the trout abundance-habitat relationship, particularly related to the quantity of riffle habitat with depths greater than 15 cm. Researchers should examine the effects of stocking densities and the influence of flow reductions on the invertebrate food base. Additional habitat variables which are not highly intercorrelated should be examined. Also the validity of using the inflection point on the curves of longest continuous riffle top width with depths $\geq$ 15 cm and total quantity of riffle top width with this depth characteristic for recommending instream flows in small streams should be examined.

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APPENDIX

Table 20. List of ranges and means of daily water temperatures in section 1 and 3 Ruby Creek Montana 1982.

	Section 1 (C)		Section 3 (C)	
Date	Range	Mean	Range	Mean
7-24			8.0-10.0	9.0
25				
26			8.5-11.0	9.8
27			8.5-17.5	13.0
28			9.0-16.0	12.5
29				
30				
31	13.0-16.0	14.5		
8-1	12.0-16.5	14.3	7.0-18.0	12.5
2			7.0-17.0	12.0
3			7.0-16.0	11.5
4			7.0-15.0	11.0
5				
6	9.0-14.0	11.5	7.0-12.0	9.5
7	11.0-15.0	13.0	7.0-17.0	12.0
8	11.0-12.0	11.5	8.0-16.0	12.0
9	11.0-14.0	12.5	8.0-15.0	11.5
10	11.0-15.0	13.0	8.0-17.0	12.5
11	11.0-14.0	12.5	7.0-17.0	12.0
12			7.0-15.0	11.0
13	9.0-14.0	11.5	6.0-16.0	11.0
14	11.0-13.0	12.0	8.0-16.0	12.0
15	11.0-14.0	12.5	8.0-17.0	12.5
16	9.0-17.0	13.0	9.0-17.0	13.0
17	8.0-16.0	12.0	8.0-16.0	12.0
18	8.0-16.0	12.0	8.0-16.0	12.0
19	9.0-17.0	13.0	8.0-17.0	12.5
20	9.0-15.0	12.0	8.0-15.0	11.5
21	9.0-15.5	12.3	8.0-16.0	12.0
22	9.0-16.0	12.5	7.5-16.0	11.8
23	8.0-16.0	12.0	6.5-16.0	11.3
24	8.0-15.5	11.8	6.5-15.5	11.0
25	8.0-15.0	11.5	6.0-15.0	10.5
26	8.0-14.0	11.0	6.5-14.5	10.5
27	8.0-15.5	11.8	6.5-16.0	11.3
28	9.5-14.0	11.8	7.5-15.5	11.5
29	8.0-14.5	11.3	7.5-14.5	11.0
30	10.0-13.0	11.5	10.0-14.0	12.0
31	8.5-13.5	11.0	6.5-14.5	10.5
9-1	7.0-14.0	10.5	6.0-14.0	10.0
2	8.0-14.0	11.0	7.0-15.0	11.0
3	8.5-16.0	12.3	7.5-15.0	11.3

Table 20 (continued)

4	10.5-15.5	13.0	8.0-15.3	11.5
5	6.5-14.5	10.5	5.5-14.0	9.8
6	6.5-13.5	10.0	5.0-14.0	9.8
7	7.0-14.5	10.8	5.0-14.5	9.8
8	8.0-16.0	12.0	5.5-14.5	10.0
9	7.5-15.0	11.3	6.0-14.5	10.3
10			5.0-10.0	7.5
11	5.0-12.5	8.8	5.0-12.5	8.8
12	7.0-11.5	9.3	6.0-11.0	8.5
13	3.0-7.5	5.3	4.5-13.5	9.0
14	2.0-8.0	5.0	1.0-8.5	4.8
15	1.0-8.0	4.5	1.0-7.0	4.0
16	3.0-7.0	5.0	5.0-8.0	6.5

N=84 Overall mean=11.1
Standard deviation=3.8(C)

N=100 Overall mean=10.8
Standard deviation=4.5(C)

Randolph, C. L.
Validity of the wetted-perimeter method for recommending instream flows for rainbow trout in a small stream.

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