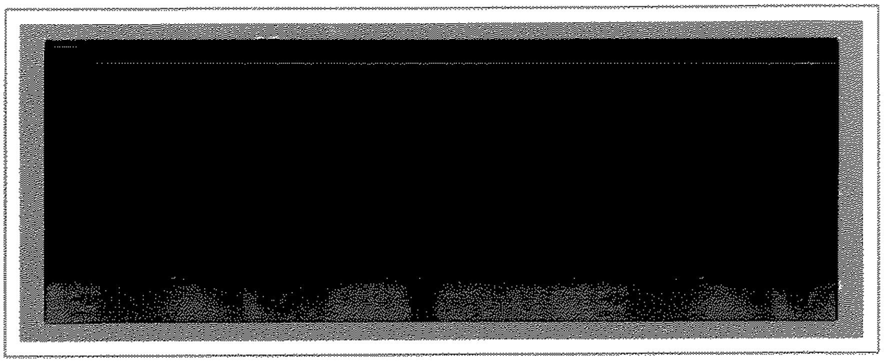

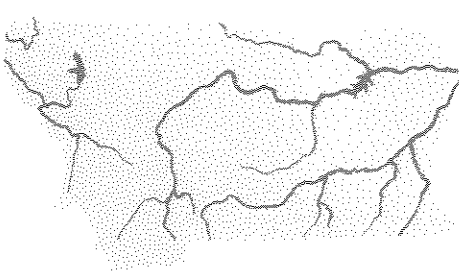

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VALIDITY OF THE WETTED PERIMETER METHOD FOR RECOMMENDING INSTREAM FLOWS FOR SALMONIDS IN SMALL STREAMS

by

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Research Project Technical Completion Report

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ABSTRACT

This study was conducted to evaluate the validity of the wetted perimeter/inflection point method of recommending instream discharge for salmonids in small streams. Specific objectives were to test the hypotheses that: 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, 3. average riffle wetted perimeter can be used as a general index of adult salmonid habitat suitability in small streams, and 4. reduction of flow during winter results in habitat related changes in trout distribution, behavior and abundance.

Field studies were conducted on three sections of a small stream. Discharge in two study sections was severely reduced by irrigation diversions while discharge in the third section was not artifically altered. Wild rainbow trout numbers and biomass were increased in each section during relatively high flow. Emigration response of trout was compared to reductions in discharge and flow related habitat parameters in each section via upstream and downstream traps. Behavioral response of rainbow trout to a decrease in winter discharge was observed in an artificial channel.

Comparisons of pre-study rainbow trout densities in altered and unaltered sections of Ruby Creek indicate that summer flow has a regulating influence on trout numbers and biomass in this stream. During our study, however, rainbow trout densities were

not reduced to pre-study levels in any study section. This may indicate that the populations are ultimately limited by factors other than low summer flow, that the experiment was not conducted over a long enough time period to observe a total response or that social tolerance was altered by initial stocking densities.

Rainbow trout abundance and biomass decreased as flow decreased in all study sections. Emigration from the two study sections influenced by irrigation diversion correlated better with average daily flow than emigration from the natural flow section. Response of experimental trout populations to reductions in flow was not immediate in two of the three stream sections. An 11 day lag increased correlations between fish number and flow from 0.185 to 0.99 in the pool-riffle reduced flow section, while a 15 day lag in the riffle-run unaltered flow section increased the correlation from 0.09 to 0.72. Emigration from all study sections was primarily in an upstream direction.

Wetted perimeter was not a consistent index of summer habitat suitability for rainbow trout in Ruby Creek. In the pool-riffle section, wetted perimeter was highly correlated with trout numbers and biomass and the inflection point on the wetted perimeter curve corresponded closely with the flow at which rate of trout emigration increased substantially. Correlation between riffle wetted perimeter and trout numbers in the two run-riffle sections was poor. In one run-riffle section the wetted perimeter inflection point corresponded to a flow which would substantially underestimate the flow we observed to be optimum.

In the other run-riffle section, which had two wetted perimeter inflection points, one would overestimate the optimum summer flow while the second would slightly underestimate that optimum.

Most habitat variables evaluated were highly correlated with one another as well as with flow. Rainbow trout emigration increased in each of the three study sections as initial discharge was reduced 30 to 40%. Empirical evaluation of plots of percentage change in each habitat and wetted perimeter variable with percentage change in flow indicated that only two variables changed in a pattern similar to percentage change in trout numbers and biomass. These variables were the longest continuous average riffle top width associated with depth $\geq$ 15 cm (WMAX) and total average riffle top width with this depth characteristic (WTOT).

Mean trout length decreased in the two reduced flow sections while mean weight and condition decreased in all study sections. Decrease in mean length was due to larger fish being more affected by reduced flow than smaller fish. Decrease in condition may have been due to suboptional food supply and/or to social interactions. Since emigrating trout of all size groups had only slightly lower condition factors than those remaining until the end of the study, there was no strong indication that food rather than flow related habitat changes had elicited the observed emigration response.

Reduced flow experiments in artifical channels during winter (temperature 2-4 C) indicated that rainbow trout preferred the deepest, slowest moving water in the channel. Pool habitat in the test channel provided adequate winter habitat for rainbow trout at test discharges.

ACKNOWLEDGMENTS

The United States Fish and Wildlife Service, Montana Department of Fish, Wildlife and Parks and The Foundation for Montana Trout supported this project through the Montana Cooperative Fisheries Research Unit. Artificial channel facilities were developed in cooperation with the Bozeman Fish Cultural Development Center, USFWS.

We would like to thank employees of the Montana Cooperative Fisheries Research Unit, Montana Department of Fish, Wildlife and Parks, United States Fish and Wildlife Service and cooperating landowners for their assistance and support in completing this project.

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INTRODUCTION

Water demand for agricultural, industrial, and domestic use has dramatically increased in the western United States. This has resulted in partial or total dewatering of many trout streams. To protect stream fisheries, biologists must be able to provide reliable instream flow recommendations. Methods of 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, White et al. 1981, and Nelson 1980). Wesche (1974) examined the relationship between discharge and trout cover by devising an equation to rate and compare cover on a stream section at different flow levels, and different stream sections at the same flow level. He found that available trout cover in pool-riffle type channels decreased at the greatest rate for discharge reductions between 25 and 12% average daily flow (Figure 1). Verification of Wesche's cover rating system as an indicator of standing crop of trout (brown, brook and rainbow) was made by comparing biomass estimates and cover

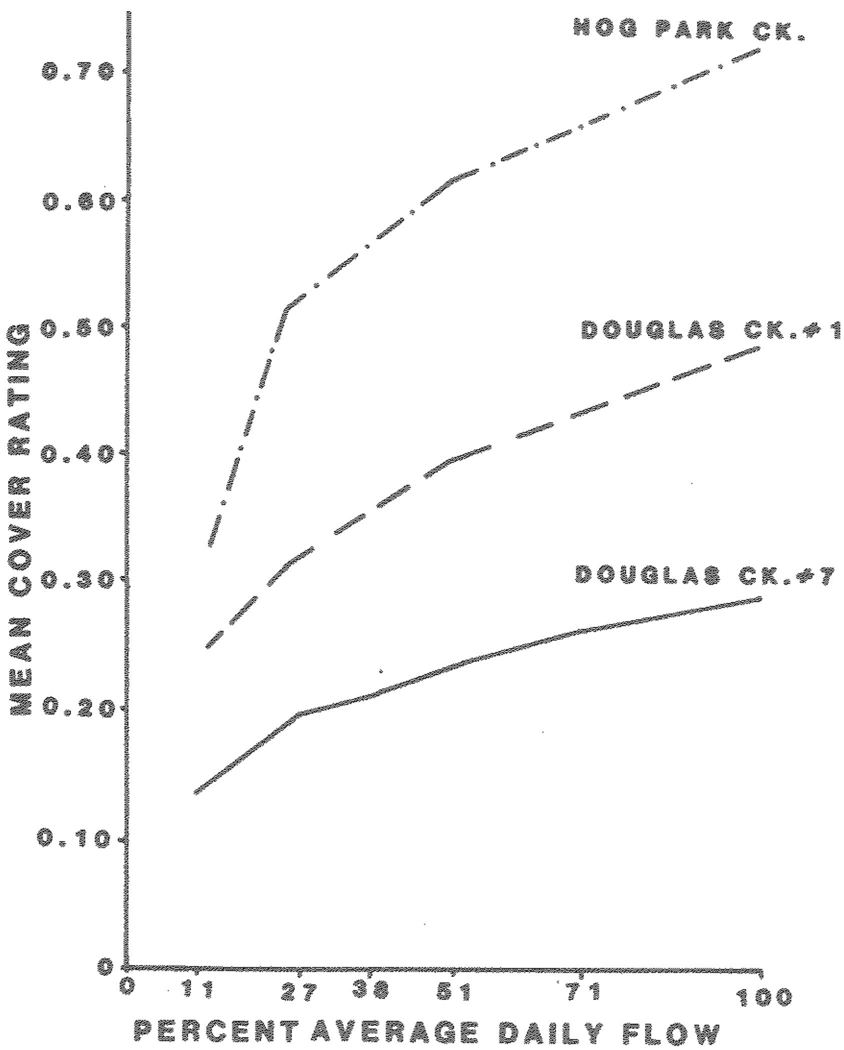

Figure 1. Changes observed in the mean trout cover rating as flow was reduced at the Douglas Creek No. 1, 7 and Hog Park Creek study areas (from Wesche, 1974).

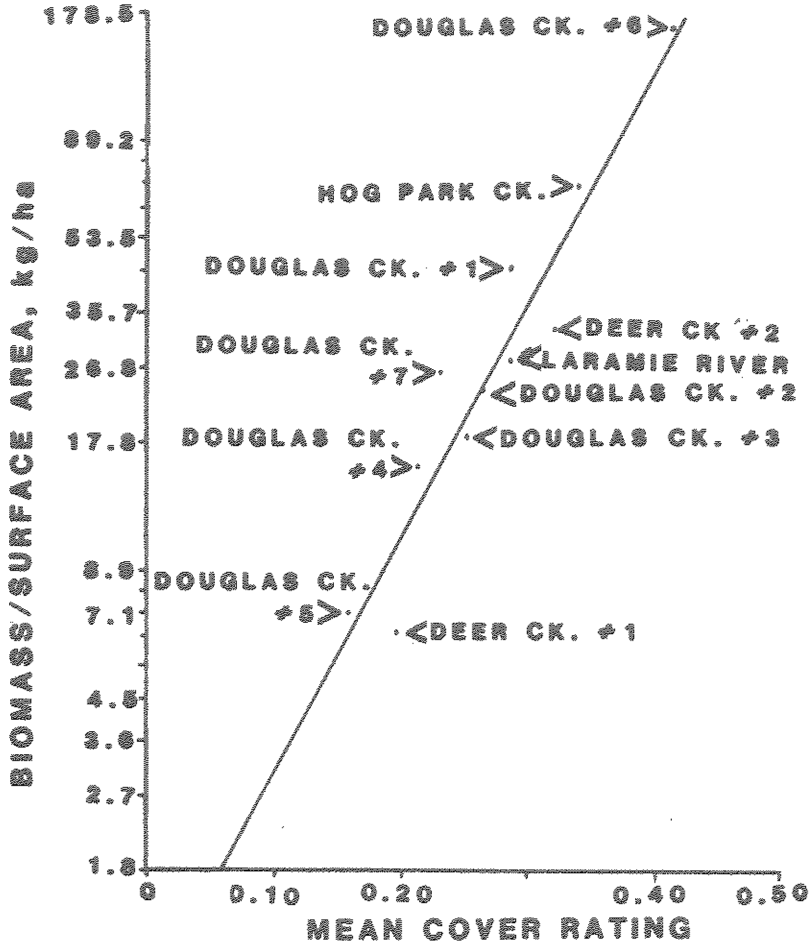

Figure 2. Relationship between mean trout cover rating and standing crop estimates of trout at 11 study areas in Wyoming (from Wesche, 1974).

ratings in 11 study areas (Figure 2). Based upon this relationship, it appears that Wesche's mean cover rating values do serve as a relatively good indicator of standing crop of trout present in various stream sections. However, Wesche did find some large discrepancies. He explained these inconsistencies by pointing out that the availablility of cover is only one factor limiting trout populations. Wesche's rating system does not take into consideration such factors as water chemistry, water temperature, the availability of spawning and food producing areas, the flow regime through the sections, and angler-caused mortality. Wesche did not relate changes in cover to changes in biomass over a range of flows in one stream.

Nickelson and Hafele (1978) approached the problem of estimating the effects of stream discharge on standing crop by developing models which predict salmonid standing crop from measurements of selected stream habitat parameters. For juvenile coho salmon, pool volume was found to explain 93% of the variation in biomass (Figure 3). Cutthroat and juvenile steelhead trout required other parameters to explain standing crop variation. For these species, models were developed which compute a habitat quality rating. This rating is the product of a cover value, a velocity preference factor and the wetted area of the study section. The developed models explain 91% and 79% of cutthroat and juvenile steelhead trout standing crops, respectively (Figures 4 and 5). These models were developed from data collected on streams in which fish populations were believed

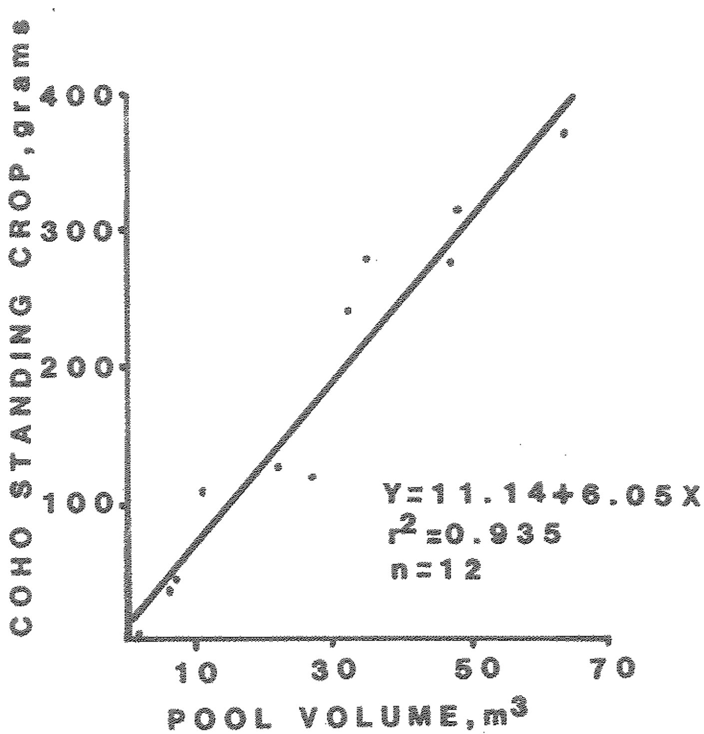

Figure 3. The relationship between pool volume and juvenile coho salmon (*Oncorhynchus kisutch*) standing crop (from Nickelson and Hafele, 1978).

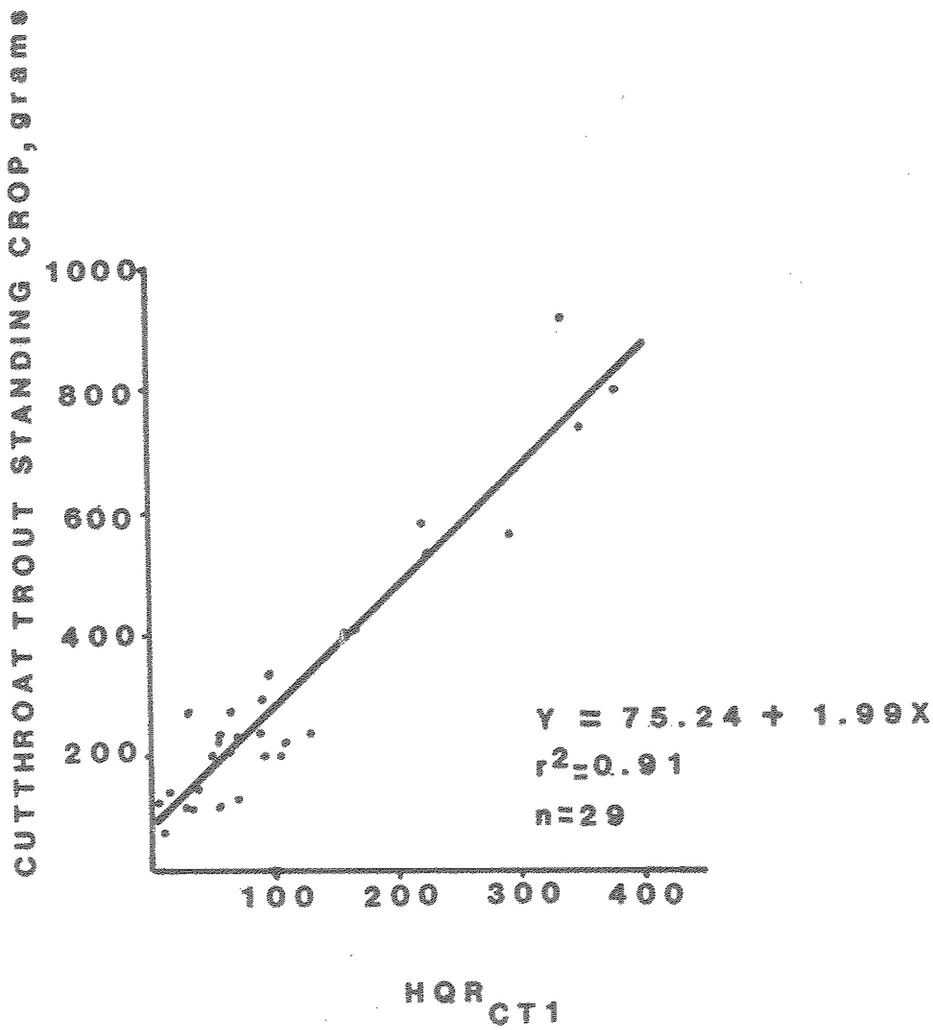

Figure 4. The relationship between habitat quality rating (HQR ct) and cutthroat trout (Salmo clarki) standing crop (from Nickelson and Hafele, 1978).

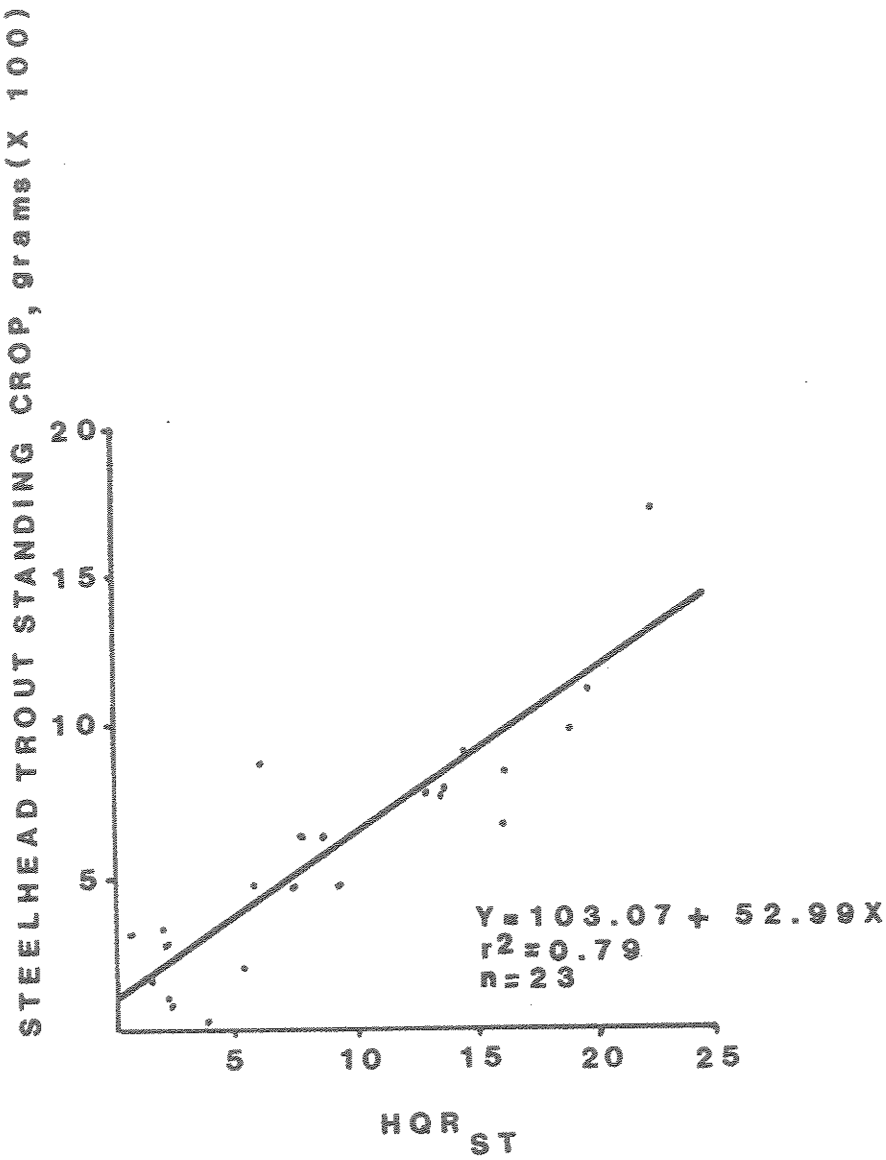

Figure 5. The relationship between habitat quality rating (HQR st) and juvenile steelhead trout (<u>Salmo gairdneri</u>) standing crop (from Nickelson and Hafele, 1978).

to be at or near maximum for the available habitat during the low flow period. As in Wesche's research, not all streams studied showed good correlation between computed habitat quality and observed standing crop. For these streams it was suggested that factors other than rearing habitat may have limited standing crop, or that rearing potential during the low flow period was determined by habitat factors not included in the models.

Nickelson (1976) examined the effects of altered discharge within a single experimental stream in 1975 and 1976. In 1975, he calculated habitat quality ratings for six study sections at three flow levels and his model explained 72% of the variation in coho salmon biomass of the sections. However, Nickelson obtained inconsistent results in a repeat of these studies in 1976. Where he observed a relativly good correlation between juvenile coho salmon biomass and habitat quality in 1975, such a relationship was nonexistant in 1976.

White et al. (1981) examined the response of juvenile rainbow-steelhead trout to flow related changes in habitat during spring, summer and fall. Tests were conducted in two large, near-natural artificial stream channels with run-riffle channel configurations. One channel was maintained at constant discharge, while flow in the second channel was incrementally reduced. All flow reduction tests resulted in decreased numbers and biomass of juvenile rainbow-steelhead trout. Since availability of food organisms in the drift was not decreased substantially, except at the lowest discharges tested, juvenile rainbow-steelhead trout apparently responded to changes in physical habitat parameters rather than decreased food availability. The relationship between hydraulic parameters and response of experimental fish was also examined. Velocity was found to be most affected by reduced flow followed by depth, surface area and wetted perimeter. No single hydraulic parameter could consistently be related to the response of test fish. Changes in cover with decreased flow appeared to have a dominant influence on juvenile rainbow-steelhead trout habitat utilization.

Nelson (1980) found a good correlation between annual variation in the standing crop of adult trout and annual flow variation in reaches of the Madison, Beaverhead, Gallatin and Bighole rivers. For example, higher estimates of trout numbers and biomass were associated with years of higher daily average flow (Table 1). Flows of the Madison River are primarily regulated by Hebgen Reservoir, which stores water for hydroelectric power generation. Prior to 1968, water storage policy created extremely low flows in the Madison River during the late winter and early spring. After 1968, water storage policy was changed such that flows were increased during this period. Although other factors, such as fishing mortality and elevated summer temperatures, could have limited the population, Nelson considered flow during the 12 months preceding the population estimate the overriding factor controlling the fish population. Trout population response to annual flow variation

Table 1. Distribution of daily flows during the approximate 12-month period preceding trout population estimates in a 6.4-km section of reach No. 1 of the Madison River in spring 1967 through spring 1971 (From Nelson 1980).

Spring to Spring	Average Daily Flows (liters/sec X 100)													Total Days measured	Age II+	
	197 to 198	198 to 226	227 to 255	255 to 283	283 to 311	312 to 339	339 to 368	368 to 396	397 to 425	425 to 453	453 to 481	481 to 510	>510		Number	Biomass (kg)
1966-67	1	16	10	8	36	37	37	36	42	26	17	9	90	392	6,779	2,473
1967-68	0	0	0	3	3	6	7	17	27	23	26	28	182	322	9,818	2,609
1968-69	0	0	0	2	9	10	19	18	26	55	37	31	171	378	9,625	3,099
1969-70	0	0	0	0	0	0	1	9	29	39	50	23	207	358	12,248	3,086
1970-71	0	0	0	1	2	6	8	16	15	93	13	15	192	361	11,613	3,065

Note: liters/sec X .03531 = cubic feet/sec was similar in other large rivers studied.

Nelson (1980) evaluated the adequacy of four methodologies for recommending instream flow. He found that the wetted perimeter/inflection point method provided acceptable absolute minimum flow recommendations when compared to long term standing crop flow relationships. Based on Nelson's study the Montana Department of Fish, Wildlife and Parks (MDFWP) chose riffle wetted perimeter as the preferred method for recommending minimum flows for Montana streams. The wetted perimeter/inflection point 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). A wetted perimeter-habitat relationship could also exist as wetted perimeter is a "bottom" measurement and adult trout are primarily oriented to the river bottom. Riffles are also the most affected by flow reductions. It was assumed that if a given flow provided adequate fish habitat and food production in riffles, more than adequate habitat and food would be available in the runs and pools.

The wetted perimeter/inflection point method uses the wetted perimeter-discharge relationship 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 6). As discharge decreases, wetted perimeter decreases, but not at a constant rate. Starting with zero flow, wetted perimeter increases rapidly up to the point

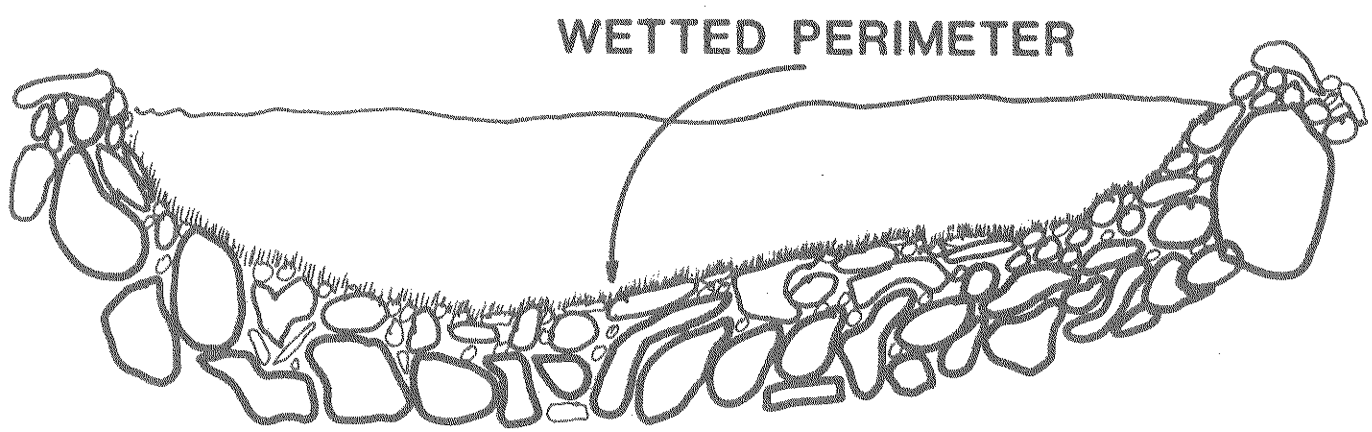

Figure 6. Diagramatic representation of wetted perimeter in a typical stream cross section.

where the stream channel nears its maximum width. Beyond this point, wetted perimeter increases less rapidly as discharge increases. 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 (Figure 7). There are generally one or two inflection points, depending on the channel cross section morphology. Instream flow recommendations are 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. According to Nelson (1983) "flows below the lower inflection point are judged undesirable based on their probable impacts on food production, bank cover and spawning and rearing habitat, while flows exceeding the upper inflection point are considered to provide a near optimal habitat for fish. The lower and upper inflection points are believed to bracket those flows needed to maintain the low and high levels of aquatic habitat potential."

The wetted perimeter-discharge curve for each riffle cross-section is derived using a wetted perimeter computer model (WETP) developed by the MDFWP (Nelson, 1983). The WETP model uses 2 to 10 sets of water surface elevations surveyed at different known discharges at each cross-section. Water surface elevations

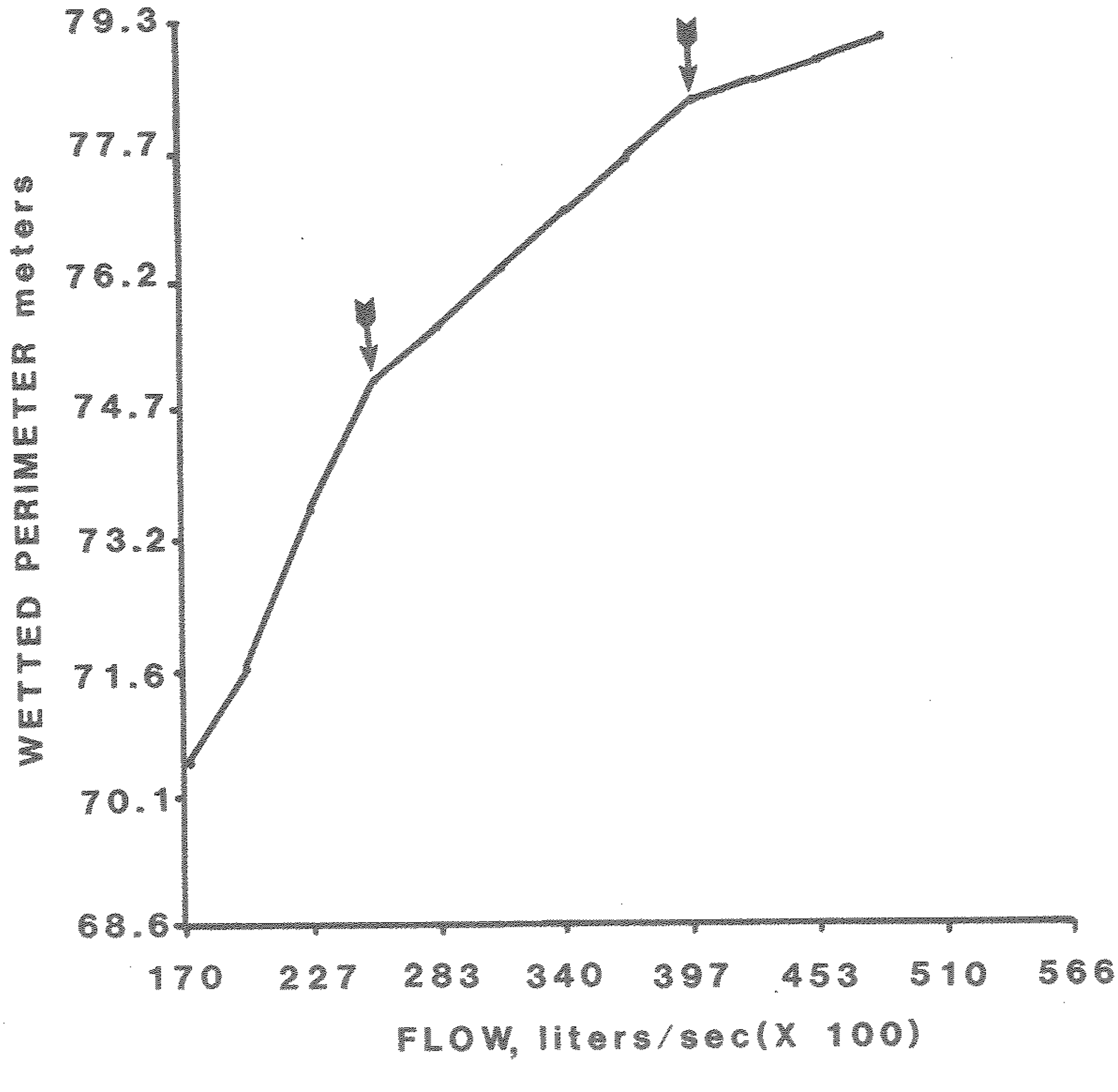

Figure 7. The relationship between wetted perimeter and flow for a typical riffle cross section.

(stages) are then used to establish a least-squared fit of log-stage versus log-discharge. This rating curve, coupled with a surveyed cross-sectional profile, is all that is needed to predict the wetted perimeter for each flow of interest.

The wetted perimeter/inflection point method is presently being applied to all Montana streams, although its reliability on small streams has not been demonstrated. The goal of this study was to examine the validity of the wetted perimeter/inflection point method of recommending minimum instream discharge for small streams. 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, 3. average riffle wetted perimeter can be used as a general index of adult salmonid habitat suitability in small streams, and 4. reduction of flow during winter results in habitat related changes in trout distribution, behavior and abundance.

DESCRIPTION OF STUDY AREA

Field studies were conducted on Ruby Creek, in Madison County Montana (T9S, R1W, Sec. 10-12, Figure 8). Ruby Creek, a tributary of the Madison River, flows down the east slope of the Gravelly Mountains. Elevation of the drainage ranges from 1682 m to 2682 m. The Ruby Creek drainage encompasses about 85 km^2 and has annual precipition of 53 cm.

Ruby Creek was chosen as the study area because: 1. the stream was of small size (less than 1400 liters/sec (50 cfs) average annual discharge) which allowed efficient electrofishing and permitted construction of semipermanent fish weirs, 2. the stream had adequate fish populations for experimental supplementation of the study sections, 3. rainbow trout (*Salmo gairdneri*) was the predominant fish species, 4. there was light fishing pressure, and 5. successive irrigation diversions provided different 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. Sections were located 0.64 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 artifical flow control. Study sections differed in length, gradient, average width, sinuosity, and substrate composition (Table 2).

Behavioral studies were conducted in artificial stream

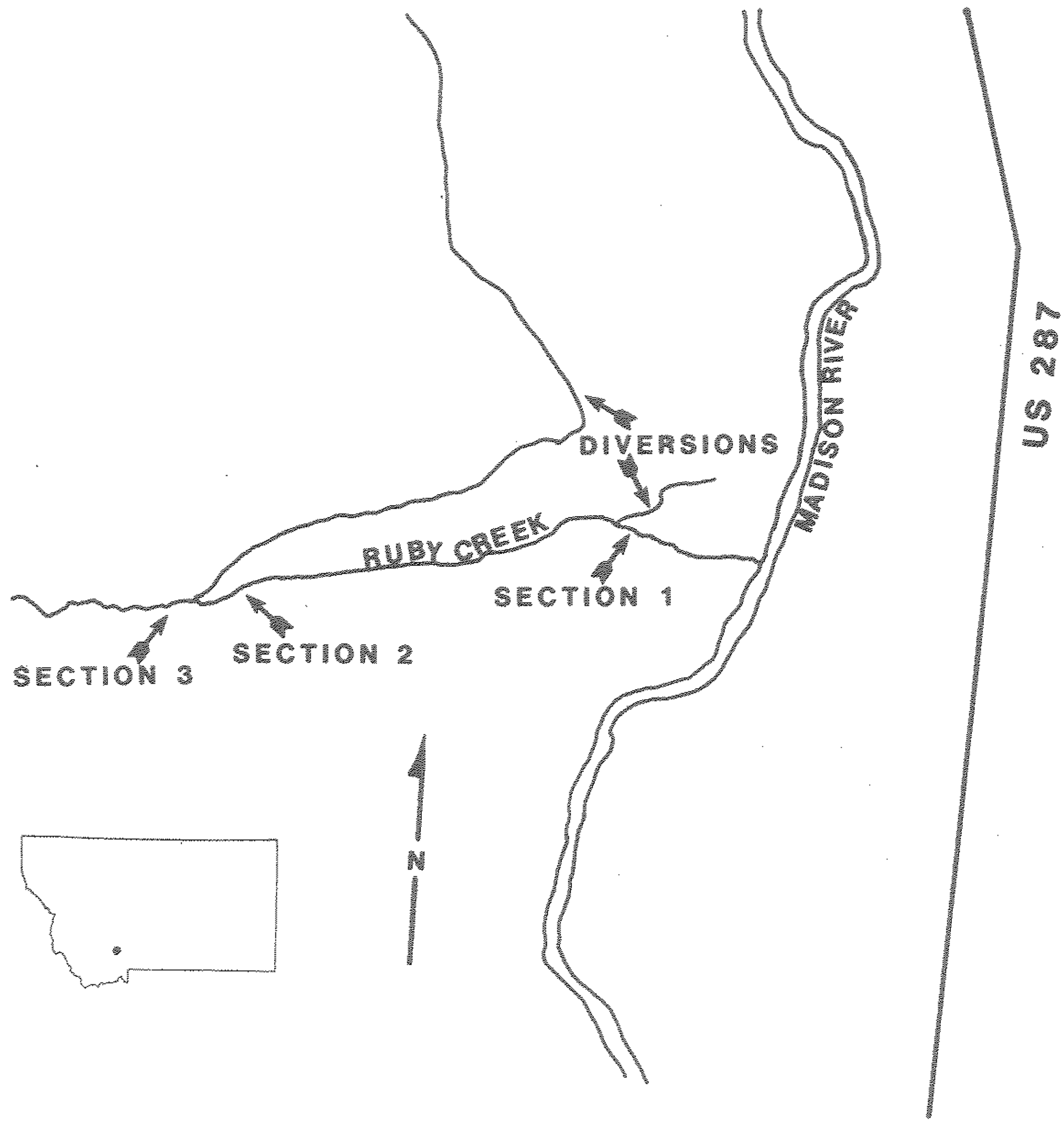

Figure 8. Location of study sections and irrigation diversions on Ruby Creek, Montana, 1982.

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

Section	Thalweg Distance (m)	Gradient (per/100m)	Average Width(m)	Sinuosity	Predominant Substrate Composition
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

channels constructed at the Bozeman Fish Cultural Development Center. The artificial stream channels allowed viewing response of test fish to reductions in flow in riffle, run and pool habitats.

METHODS

Fish Population Manipulation

Response of rainbow trout to flow related changes in habitat was evaluated by placing a weir and box trap at the upstream and downstream ends of three sections of Ruby Creek (Figure 9). The V-shaped weirs were constructed of 1.3 cm^2 mesh hardware cloth supported vertically by steel fence posts. After the weirs and traps were in place, resident fish were removed from each study section by electrofishing with a 110 V DC bankshocking unit. Resident rainbow trout >100 mm were then combined with resident rainbow trout electrofished from Ruby Creek above the study sections and stocked in experimental sections (177, 141, and 140 were stocked in sections 1 (123.7 m long), 2 (106.7 m long), and 3 (133.1 m long), respectively). Before stocking, fish total length, measured to the nearest millimeter, and weight, to the nearest gram, were recorded. Resident and supplemental fish were marked with different pelvic clips. Experimental fish were held in live buckets until they recovered from handling and were then released in the middle of study sections.

Fish were allowed to acclimate to test sections for 6 days, during which time all emigrants were returned to the study sections. During the acclimation period, the number of fish captured in the traps declined. Fish captured in the traps after the acclimation period were measured and checked for marks before

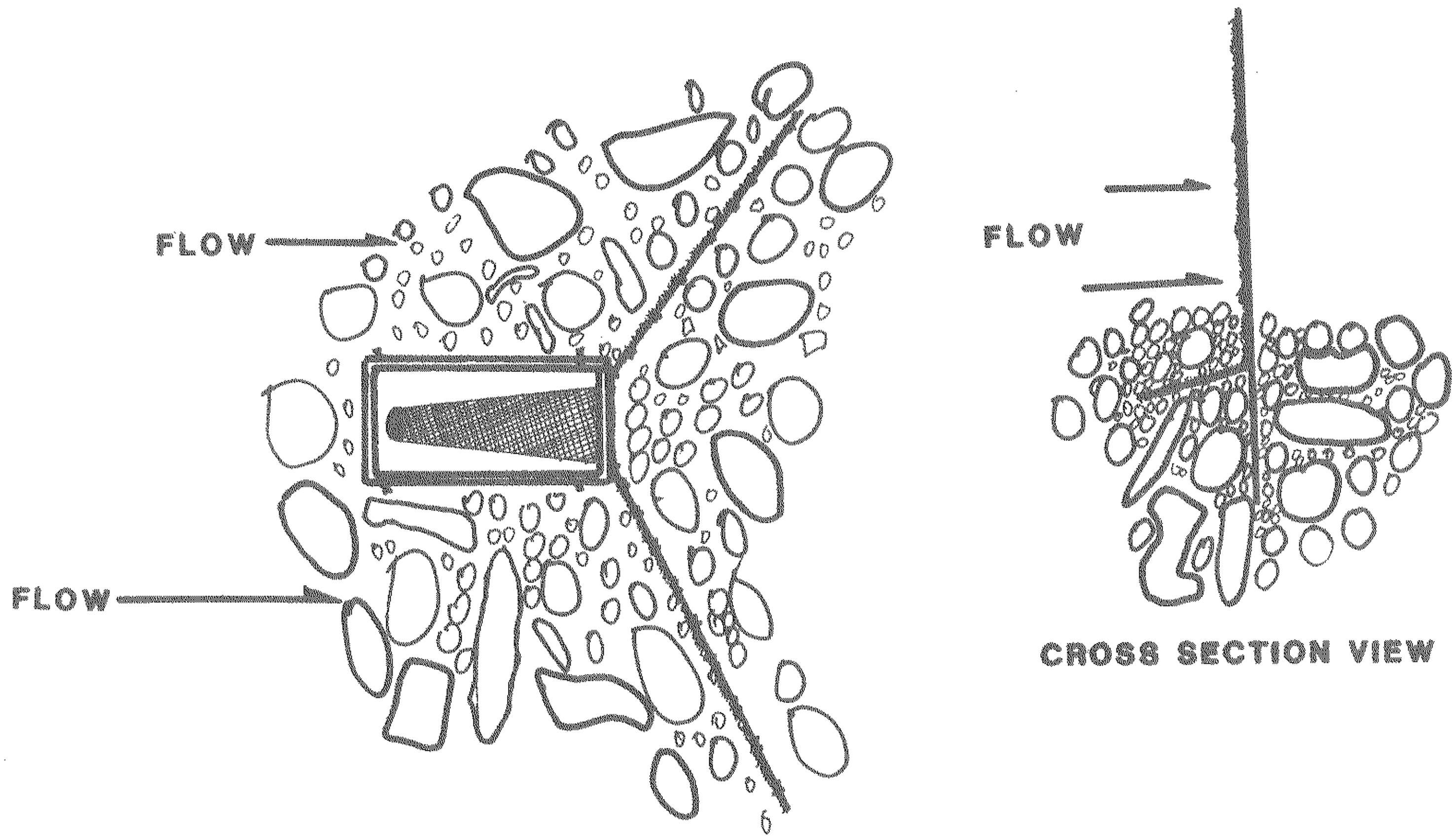

Figure 9. Diagramatic representation of an upstream fish weir and trap used on Ruby Creek, Montana, 1982.

being released below sections 1 and 2, and above section 3. Abundance of fish remaining in the study sections was determined as the difference between the total cumulative trap counts and the intial 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 multiple pass electrofishing on 2 consecutive days. Length and condition factors of fish emigrating from the study sections and flow grouped to the nearest 28 liters/sec (1 cfs) were regressed to determine if there was a differential size response in the experimental fish to decreases in flow. Distributions of condition factors, weights and lengths of the experimental fish before and after the study were statistically compared. Condition factors were 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 contained 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 mapping data were then scaled and transferred to paper. 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. Around each cross section linear length of streambed having overhanging plant material or overhanging bank was measured as well as the distance from this overhead material to the water surface and its perpendicular width over the water surface. Habitat areas measured were scaled and transferred to the respective section map. Alternate cross sections were used for depth and velocity mapping. Depth and velocity measurements were made along cross sections 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 depth, to the nearest 0.3 cm/s (0.1 f/s).

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 depths of 15 cm or more.
3. Velocity area (VA)-surface area with mean velocity of 0.3 cm/s (0.1 f/s) or less.
4. Overhanging vegetation area (OHV)-surface area of the study section having vegetation within 30 cm of the

waters surface, depth of 15 cm or more and 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 width of 10 cm.

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

Surface area habitat variables were measured from habitat maps by extrapolating between transects using a Tektronic digitizer pad and Geoscan computer program. Linear interpolation using known values of habitat variables was used to obtain estimates for values 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. Regression was used to predict average daily flows in each study section (Figures 10, 11, and 12). Daily water temperatures were measured with maximum-minimum thermometers in the upper and lower sections.

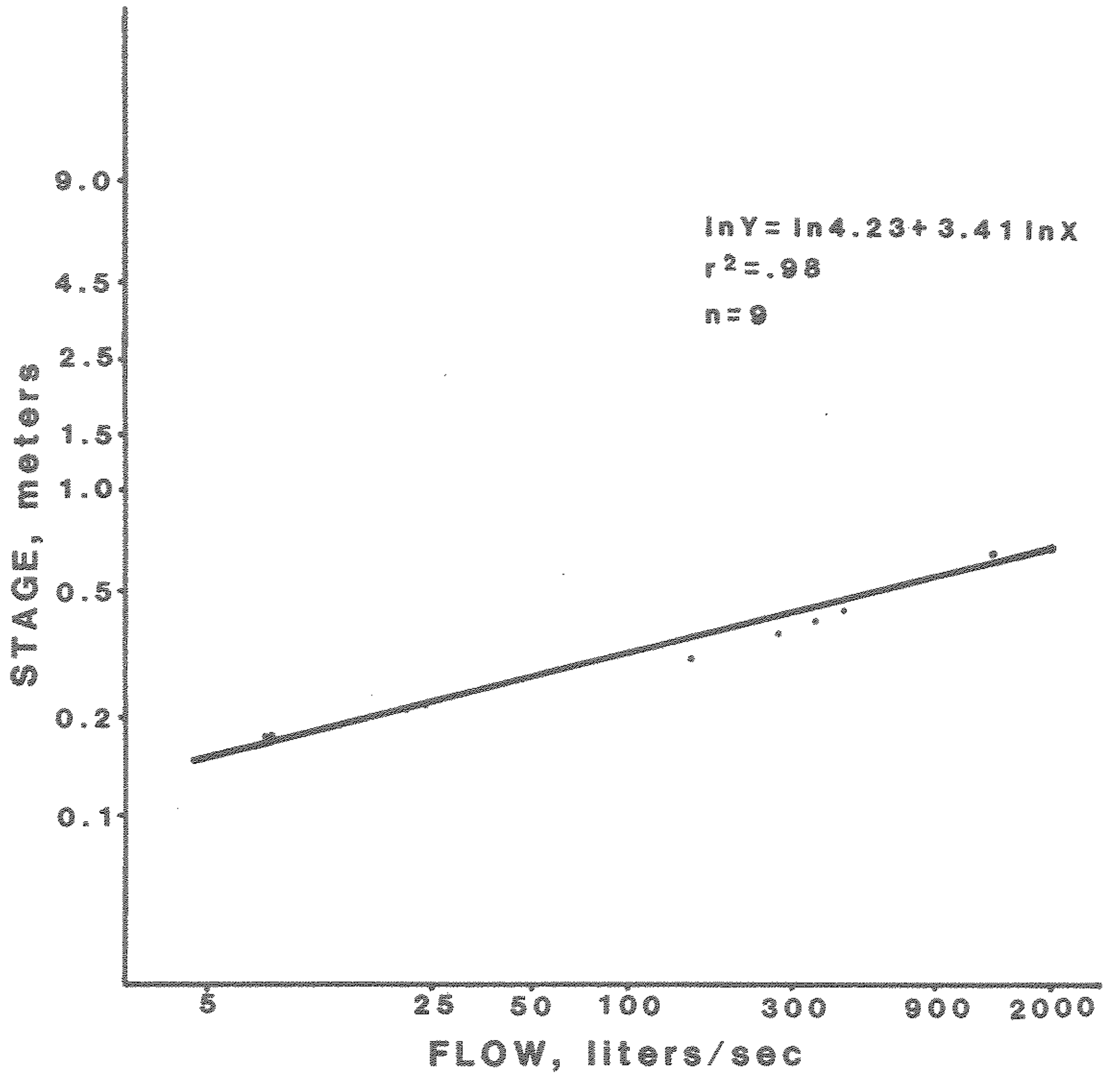

Figure 10. The relationship between log stage and log flow in section 1, Ruby Creek, Montana, 1982.

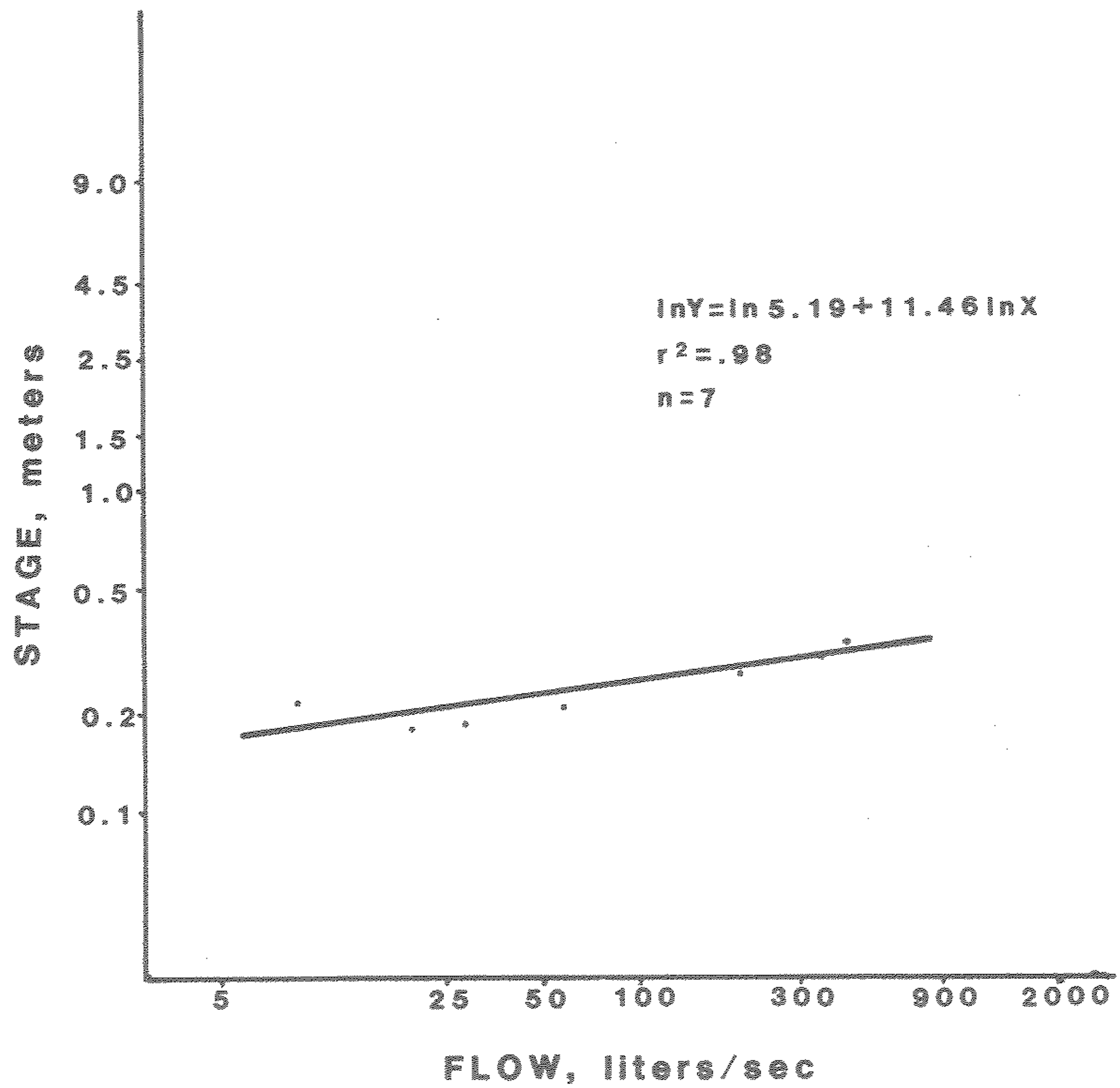

Figure 11. The relationship between log stage and log flow in section 2, Ruby Creek, Montana, 1982.

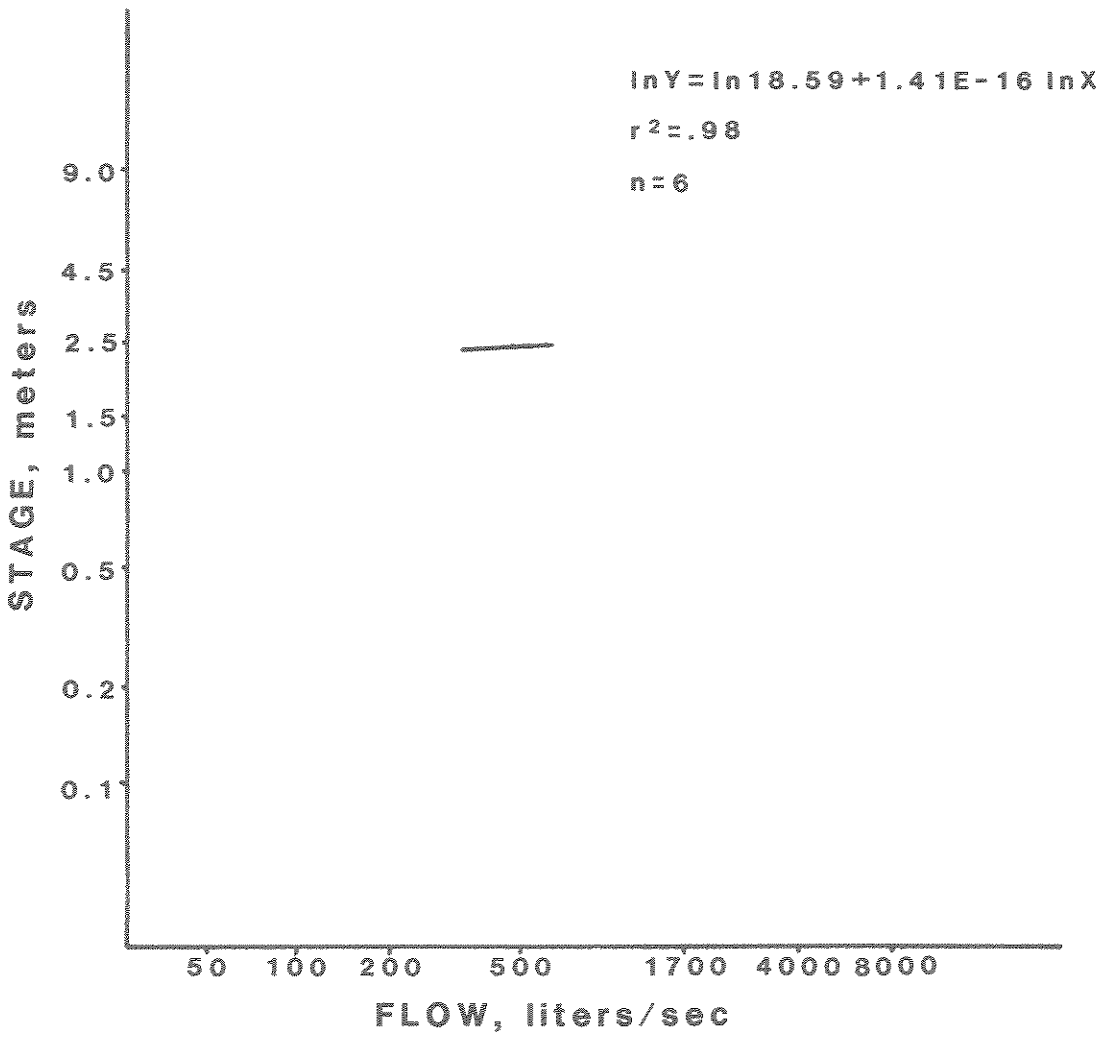

Figure 12. The relationship between log stage and log flow in section 3, Ruby Creek, Montana, 1982.

Wetted Perimetter Computer Modeling

Wetted perimeter transects (8 each in sections 1 and 2 and 9 in section 3) were established in typical riffles. Transect locations were related to habitat cross sections and drawn on study section habitat maps (Figures 13, 14, and 15). Each transect water surface elevation was surveyed at three to four flows (Nelson, 1983). Water 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 depth (DBAR)
3. Average velocity in the transect cross-section area (VBAR)
4. Top width of transect (WDTH)
5. Cross sectional area of transect (AREA)
6. Maximum depth (DMAX)
7. Total top width associated with depth of at least 15 cm (WTOT)
8. Longest continuous top width associated with depth of at least 15 cm (WMAX).

Within each section, physical characteristics of all wetted perimeter transects were computed by 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

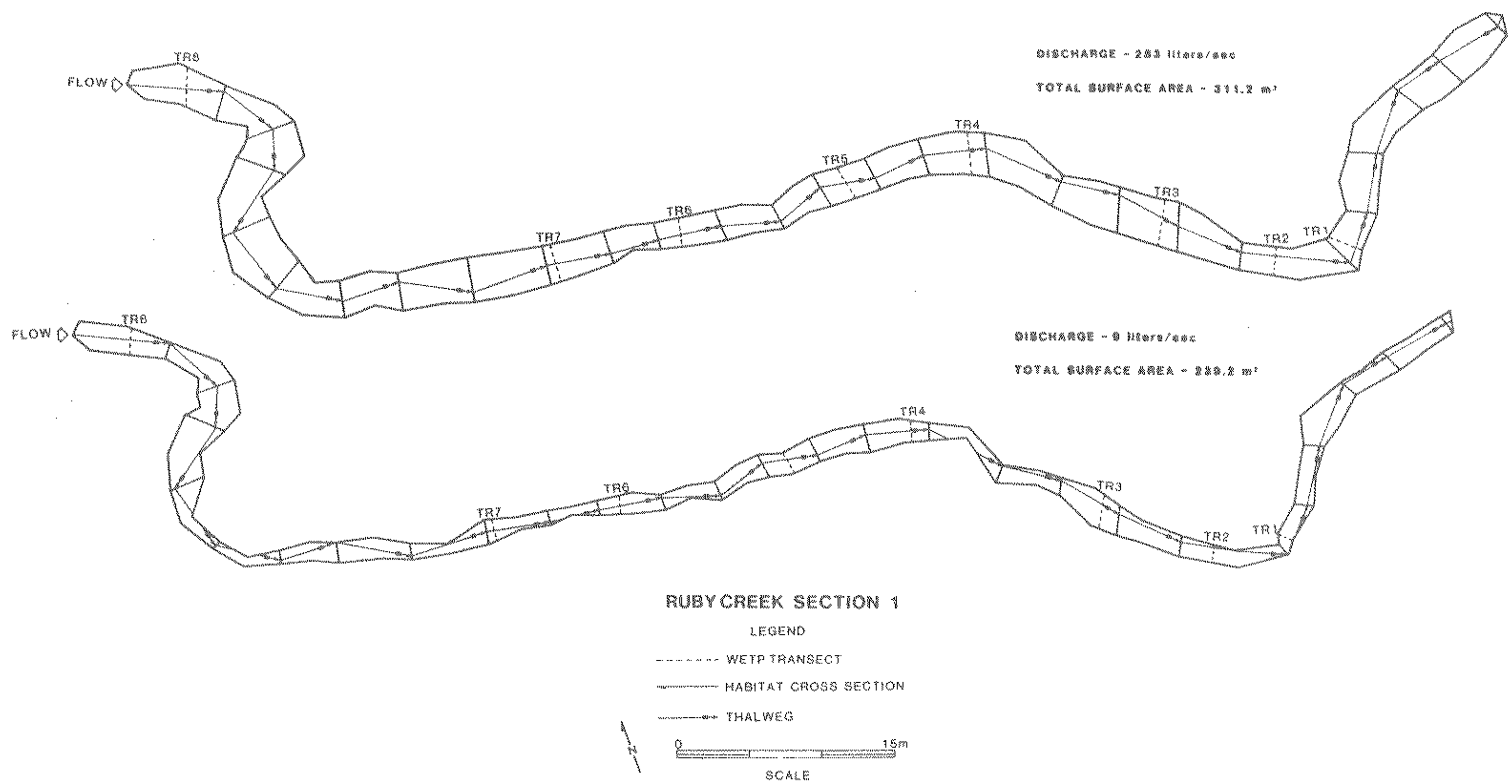

Figure 13. Surface area and thalweg of highest and lowest flows measured and location of wetted perimeter and habitat transects in section 1, Ruby Creek, Montana, 1982.

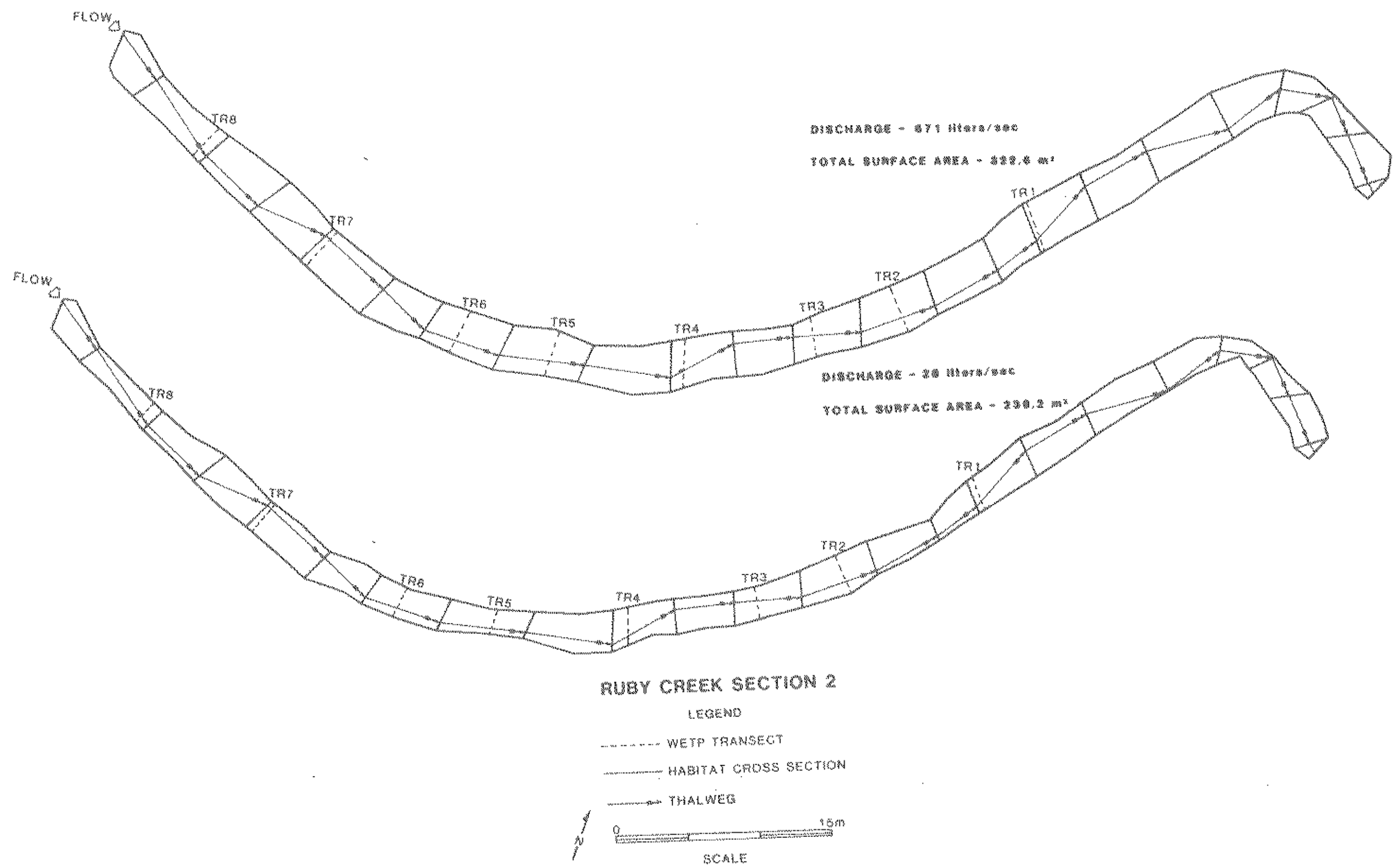

Figure 14. Surface area and thalweg of highest and lowest flows measured and location of wetted perimeter and habitat transects in section 2, Ruby Creek, Montana, 1982.

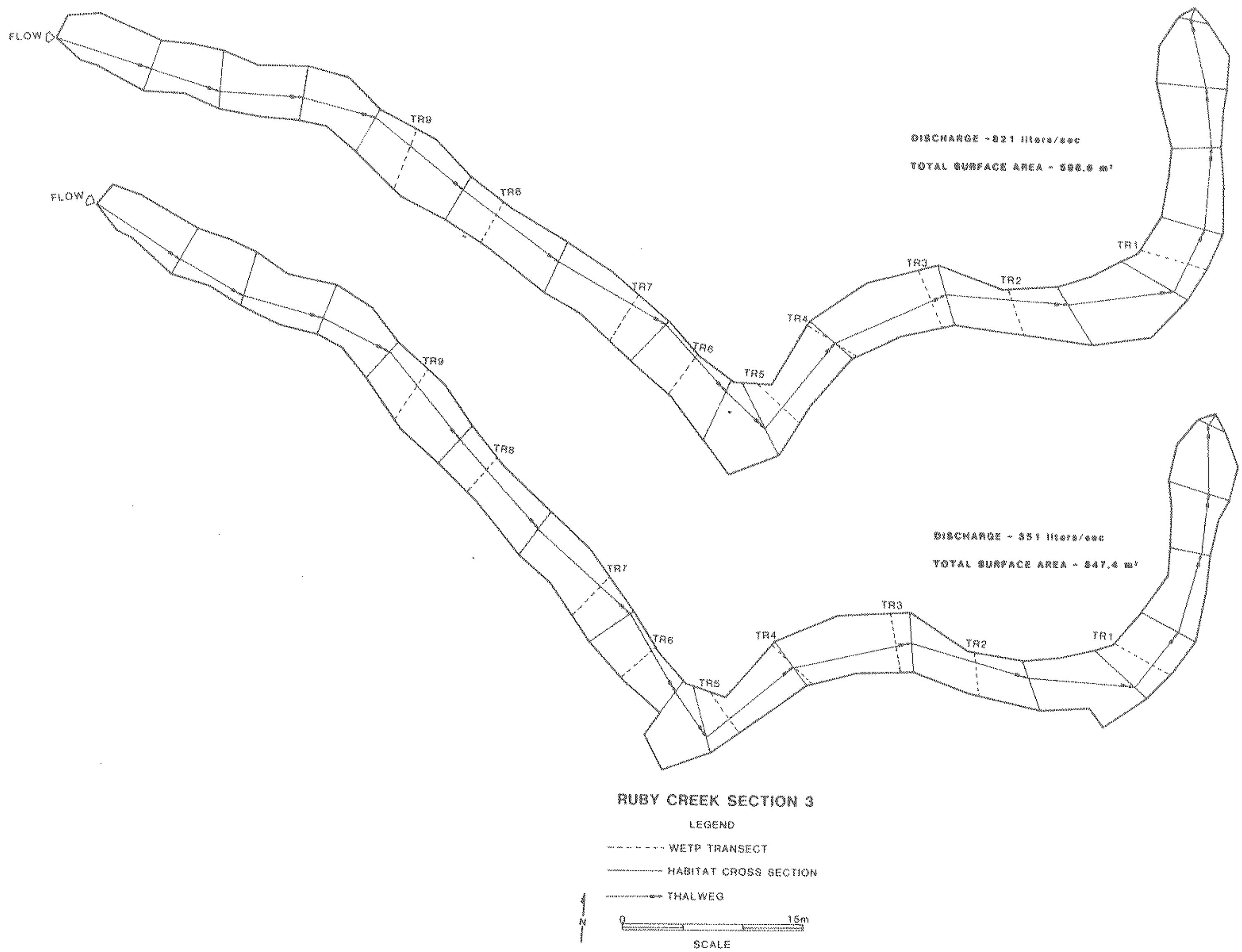

Figure 15. Surface area and thalweg of highest and lowest flows measured and location of wetted perimeter and habitat transects in section 3, Ruby Creek, Montana, 1982.

Table 3. Calibration data and stage discharge correlation coefficients (r) used in the wetted perimeter model (WETP) for three study section on Ruby Creek, Montana, 1982. Q = discharge in cfs; S = stage in feet.

	Riffle Cross Section											
	1		2		3		4		5		6	
Section	Q	S	Q	S	Q	S	Q	S	Q	S	Q	S
1	81.9	94.30	81.9	95.36	81.9	95.68	81.9	97.17	81.9	100.36		
	3.7	93.68	3.7	94.72	3.7	94.93	3.7	96.49	3.7	99.54		
	0.8	93.42	0.8	94.41	0.8	94.58	0.8	96.21	0.8	99.28		
	0.3	93.29	0.3	94.32	0.3	94.48	0.3	96.15	0.3	99.20		
r	0.995		0.991		0.990		0.980		0.972			
2	12.7	92.96	12.7	93.92	12.7	94.33	12.7	95.10	12.7	95.65		
	1.9	92.52	1.9	93.49	1.9	93.86	1.9	94.79	1.9	95.35		
	1.0	92.45	1.0	93.37	1.0	93.77	1.0	94.68	1.0	95.19		
r	0.983		0.998		0.989		1.000		0.992			
3	28.7	97.93	28.7	98.72	28.7	99.46	28.7	99.81	28.7	100.41	28.7	100.64
	12.7	97.73	12.7	98.53	12.7	99.24	12.7	99.64	12.7	100.13	12.7	100.46
	10.9	97.68	10.9	98.52	10.9	99.22	10.9	99.64	10.9	100.13	10.9	100.41
r	0.998		0.989		0.994		0.977		0.977		0.997	

various habitat variables to flow related changes in cross sectional wetted perimeters.

All statistical anaylses were done on a Honeywell CP6 (Level 66/DPS 8) computer with the Biomedical Computer Programs (BMDP 1983), Statistical Package for the Social Sciences (SPSS 1975) and MSUSTAT (Lund 1983) statistical analysis packages. Paired comparison statistical tests were done using the nonparametric Mann-Whitney test (Snedecor and Cochran 1980).

Fish Behavior and Locations

Artificial stream channels were used to quantify changes in habitat utilization and behavior of rainbow trout associated with a change in discharge of 76.1% (71 liters/sec (2.3 cfs) to 17 liters/sec (0.5 cfs). Stream channels were constructed at the Bozeman Fish Cultural Development Center. Raceway walls were cut so that two reaches could be made from the six (1.8 X 1.2 X 18 m) existing raceways. Four observation windows were cut in each of the two outside walls. Natural stream substrate, ranging in size from 4 to 8 cm, was contoured in the channels to form riffle, run, and pool habitats. River washed boulders (25 to 50 cm in diameter) were placed in a uniform pattern to provide instream cover (Figure 16). Cross sections were marked on the channel walls every 0.5 meters. Depth (nearest 1 cm) and mean column velocity (0.6 depth, nearest 3.0 cm/sec) were measured before and after the flow was reduced along 34 cross sections at the same

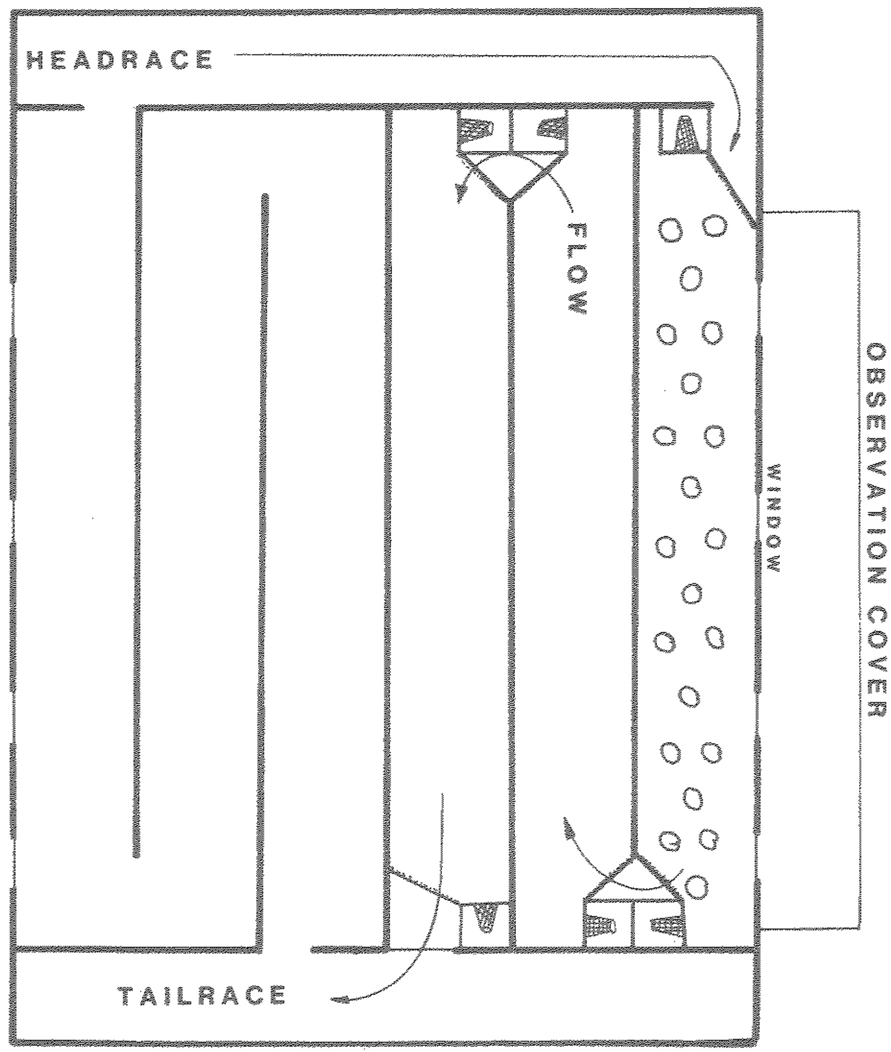

Figure 16. Diagramatic representation of artificial stream channels constructed at the Bozeman Fish Cultural Development Center, Montana.

equally spaced points. Depth and velocity data were evaluated by grouping in 5 cm and approximately 14 cm/sec groups, respectively. Isopleths were drawn on habitat maps using the depth and velocity data. Surface area of depth and velocity groups was then measured using gravimetric planimetery. Water temperatures during the experiment were measured continuously using a Taylor recording thermograph. Upstream and downstream traps were used to monitor fish emigration. Weirs were made using poultry wire in wooden frames buried 30 cm below the substrate surface.

Wild rainbow trout were collected on November 11, 1982 from the East Gallatin River using a 110v DC bank-shocking unit and transported to the experimental stream channels. Fish were measured for total length to the nearest millimeter, weighed to the nearest gram and marked using pelvic and adipose fin clips. Test fish were held in live buckets until they recovered from the handling and were then released into the stream channel. Thirty fish weighing 4737g were stocked in the test channel. Minimum length of test fish was 180 mm. During a 7 day acclimation period, the traps remained closed.

Observations of habitat utilized and interactions between trout began on December 2, 1982. Experimental trout were observed a total of 18 hours (Table 4) during the 2 week experiment. Discharge in the experimental channel was maintained at 71 liters/sec. (2.3 cfs) until December 8, 1983 when it was rapidly decreased (76.1%) to 17 liters/sec. (0.5 cfs).

Table 4. Trout observation schedule at the Bozeman Fish Cultural Development Center.

Observation Times	December 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Morning 07:45-08:45			X	X			X			X		X			X
Midday 12:30-13:30		X			X	X			X					X	X
Evening 16:25-17:25	X	X		X				X	X		X				

Note: The discharge was reduced 76.1% (71 liters/sec (2.3cfs) to 17 liters/sec (0.5cfs))at 09:00 on Decenber 8.

Trout location within the stream channel was recorded in relation to 11 painted rocks placed across each cross section. Trout location data before and after the flow reduction were compared to determine if fish responded to measured decreases in depth and velocity surface area.

RESULTS

Population Manipulation and Acclimation

To test the hypothesis that salmonid abundance is regulated by low summer flow, we increased existing rainbow trout densities 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, during mid-July when flows were relatively high (Table 5). Biomass densities were increased by a similar magnitude (Table 6). Length of experimental fish ranged from 104 to 315 mm (Table 7) and length frequency distribution was comparable between sections.

During a 6-day acclimation period, emigrants were returned to test sections; flow in all sections generally increased (Table 8). 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 corresponding 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 section 1, fewer fish attempted to emigrate during the acclimation period (Table 8). Similar numbers attempted to emigrate from sections 2 and 3. A larger number of emigrants moved in an upstream direction. Fish entering traps after the 6-day acclimation period were removed from experimental sections.

Table 5. Number and density (fish/meter) of trout in each section before and after the study on Ruby Creek, Montana.

		Numerical Abundance						
		Pre-study		Test		Post-study		% Density Increase
Section	Trout Species	Number	Density	Number	Density	Number	Density	Pre- to Post-study
1	Rainbow	6	0.05	177	1.43	42	0.34	180
	Brown	9	0.07	0	0.00	0	0.00	
2	Rainbow	8	0.07	141	1.32	37	0.35	400
3	Rainbow	29	0.22	140	1.05	67	0.50	127

Note: Brown trout were removed from section 1 before the study was started.

Table 6. 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		% Density Increase
Section	Trout Species	Weight	Density	Weight	Density	Weight	Density	Pre- to Post-study
1	Rainbow	826	6.68	14755	119.28	2389	19.31	8
	Brown	1390	11.24	0	0.00	0	0.00	
2	Rainbow	584	5.47	11829	110.86	2195	20.57	276
3	Rainbow	2857	21.47	16066	120.70	6857	51.52	140

Note: Brown trout were removed from section 1 before the study was started.

Table 7. 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	Start	Post-Study
1	Rainbow	102-182	104-315	113-248
	Brown	117-245	-----	-----
2	Rainbow	141-273	118-295	128-290
3	Rainbow	117-302	117-310	131-295

Table 8. Emigration of rainbow trout during the acclimation period in sections 1, 2 and 3, Ruby Creek, Montana, July, 1982.

Section	Date	Number Captured Upstream	Number Captured Downstream	Flow (liters/sec)
1	7/20	4	0	144
	7/21	8	10	71
	7/22	6	5	77
	7/23	3	2	109
	7/24	9	2	274
	7/25	6	2	232
2	7/19	19	0	249
	7/20	19	6	277
	7/21	6	0	167
	7/22	16	5	140
	7/23	14	0	308
	7/24	8	1	524
3	7/19	31	5	---
	7/20	26	6	---
	7/21	11	3	462
	7/22	8	3	---
	7/23	6	0	674
	7/24	3	0	614

a: cfs= liters/sec x 0.0351

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 emigration from the natural flow section. Empirical evaluation of the plots of numbers and biomass remaining, and flow in sections 1, 2 and 3, indicated that the trout population in sections 1 and 3 did not respond immediately to flow reductions (Figures 17, 18 and 19). Lagging flow 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 (section 3) (Table 9). These lags were used in all subsequent analyses. Lagging flow and number 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 17, 18 and 19).

Trout emigration rate increased in all sections as discharge was decreased 30 to 40 % below acclimation flow (Figures 20, 21 and 22) 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

Table 9. 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[a]		Section 3[b]	
Flow Days Lagged	n=40 Correlation	Flow Days Lagged	n=39 Correlation	Flow Days Lagged	n=37 Correlation
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 Evaluated with 15 data pairs deleted.
b Evaluated with 16 data pairs deleted.

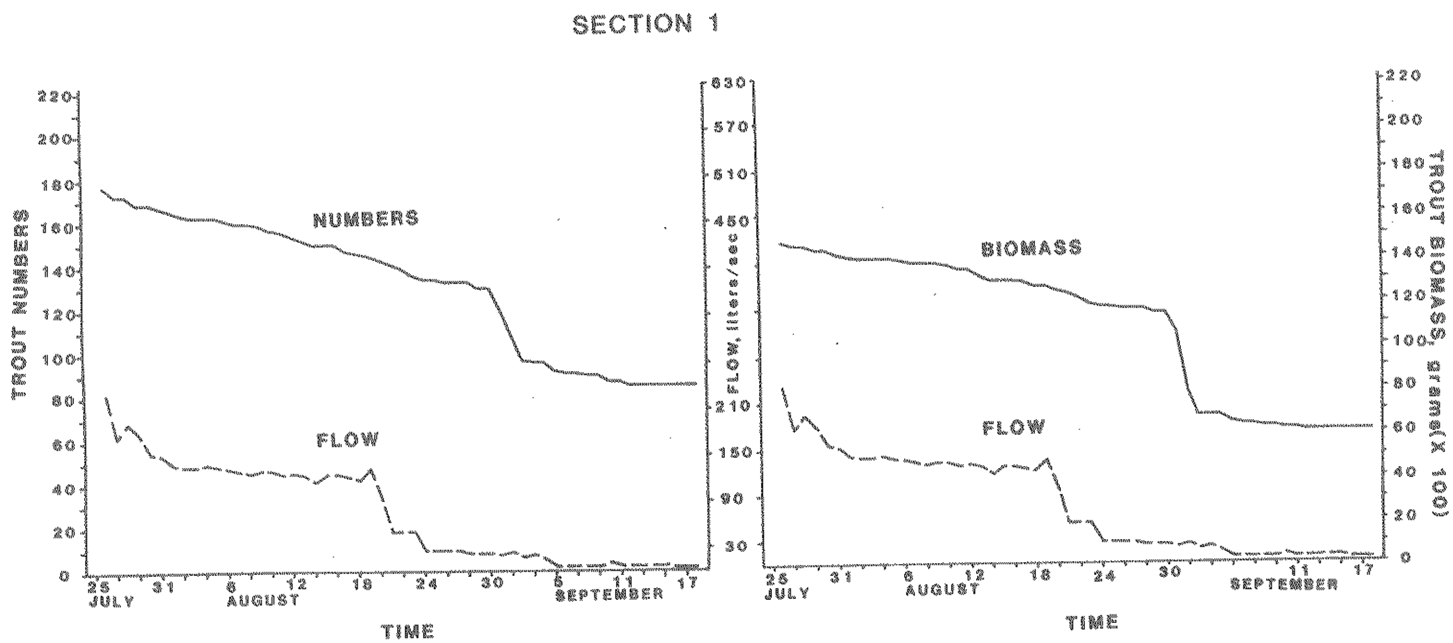

Figure 17. Response of rainbow trout (numbers and biomass) to decreases in discharge in section 1, Ruby Creek, Montana, 1982.

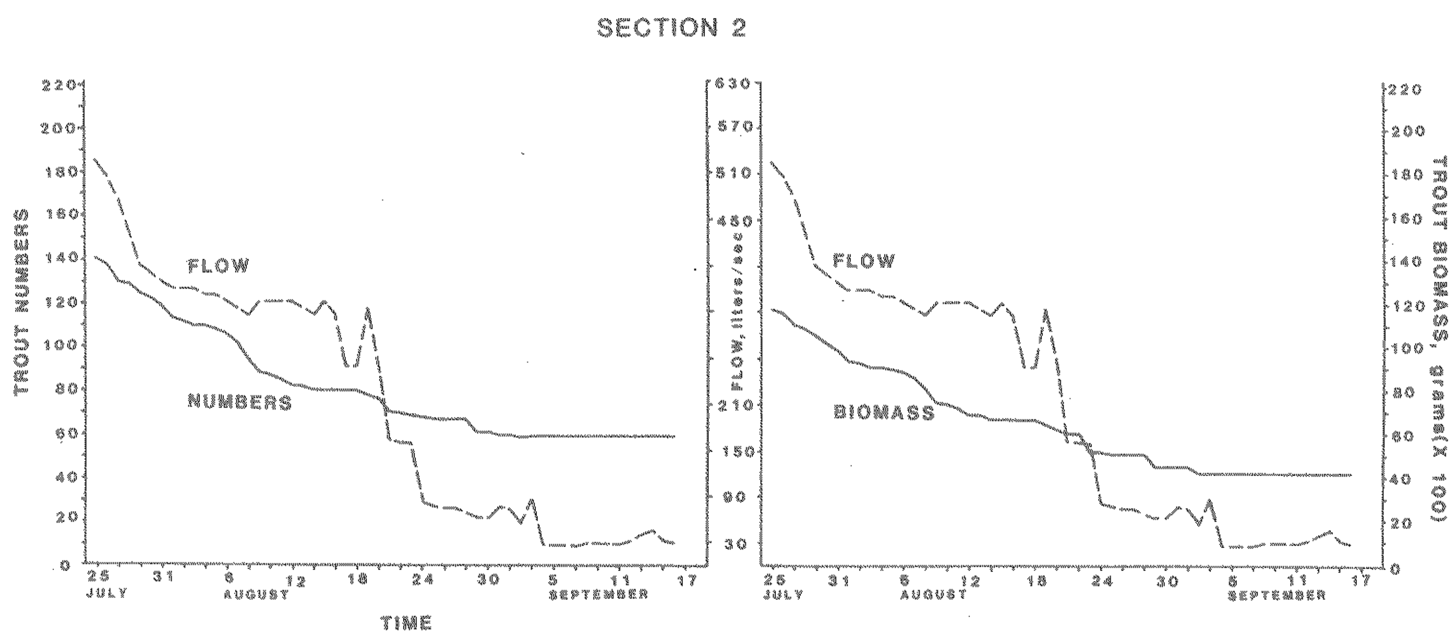

Figure 18. Response of rainbow trout (numbers and biomass) to decreases in discharge in section 2, Ruby Creek, Montana, 1982.

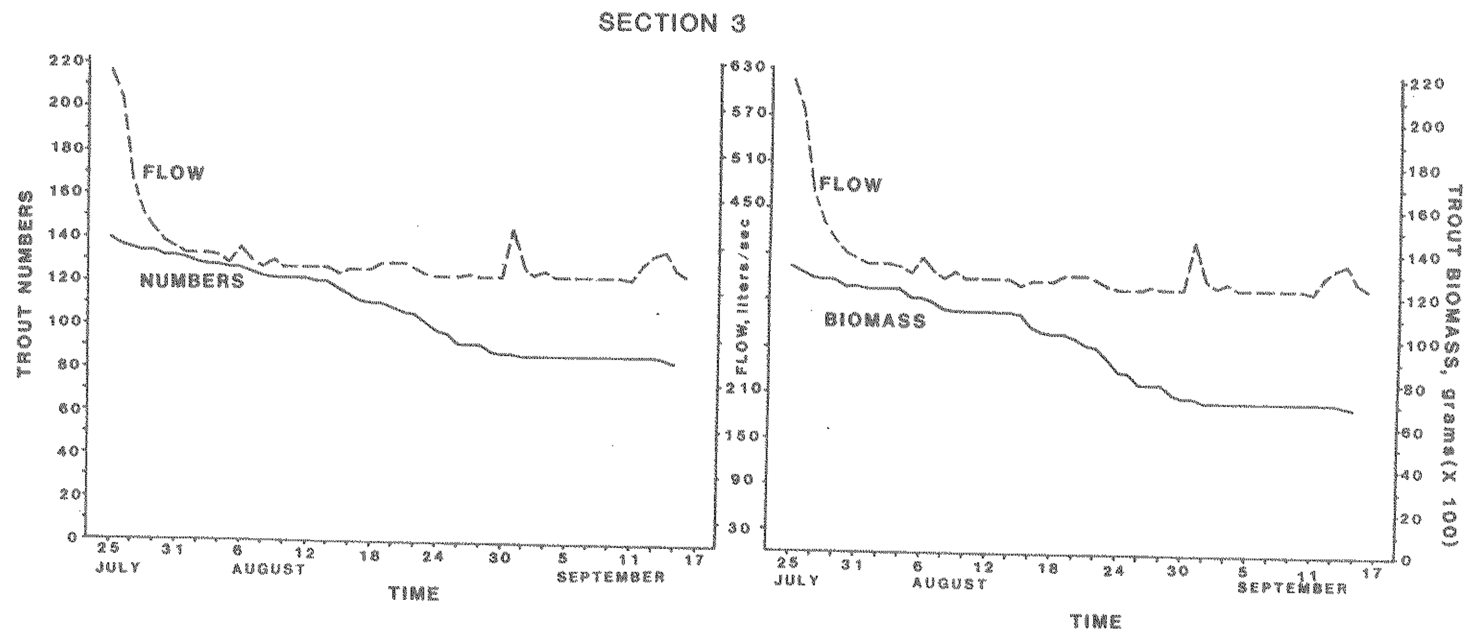

Figure 19. Response of rainbow trout (numbers and biomass) to decreases in discharge in section 3, Ruby Creek, Montana, 1982.

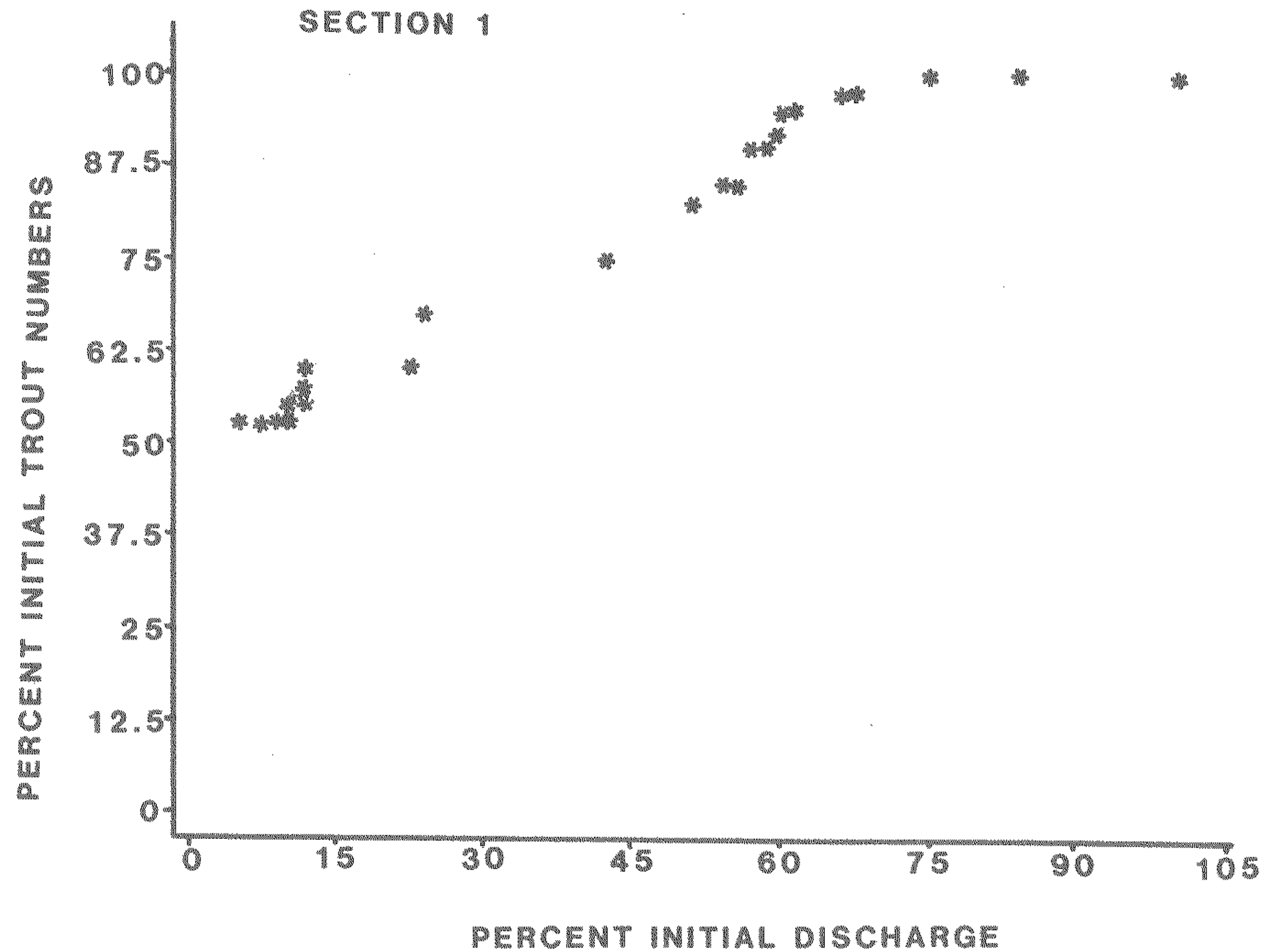

Figure 20. The relationship between percent intial trout numbers and percent initial discharge in section 1, Ruby Creek, Montana, 1982.

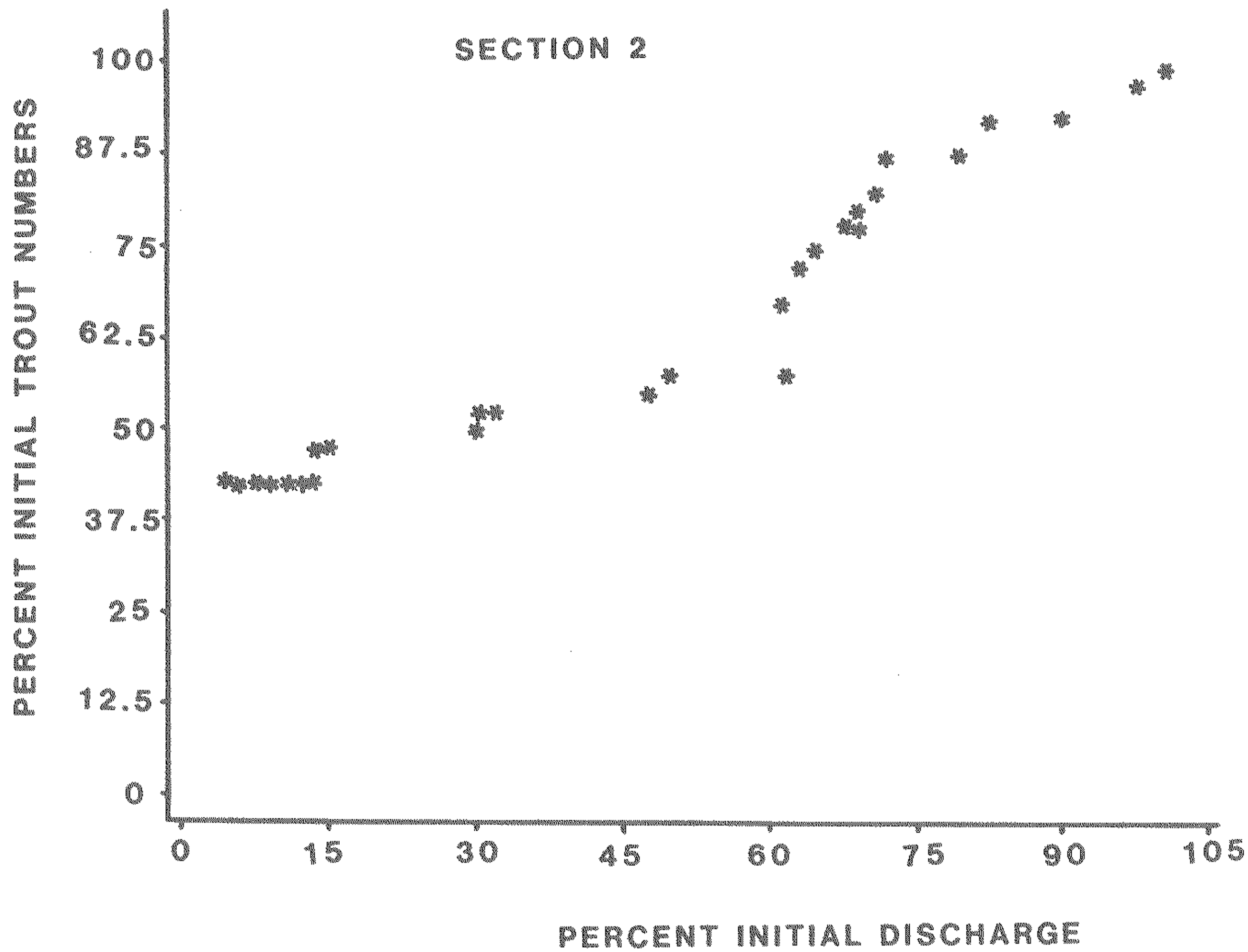

Figure 21. The relationship between percent initial trout numbers and percent initial discharge in section 2, Ruby Creek, Montana, 1982.

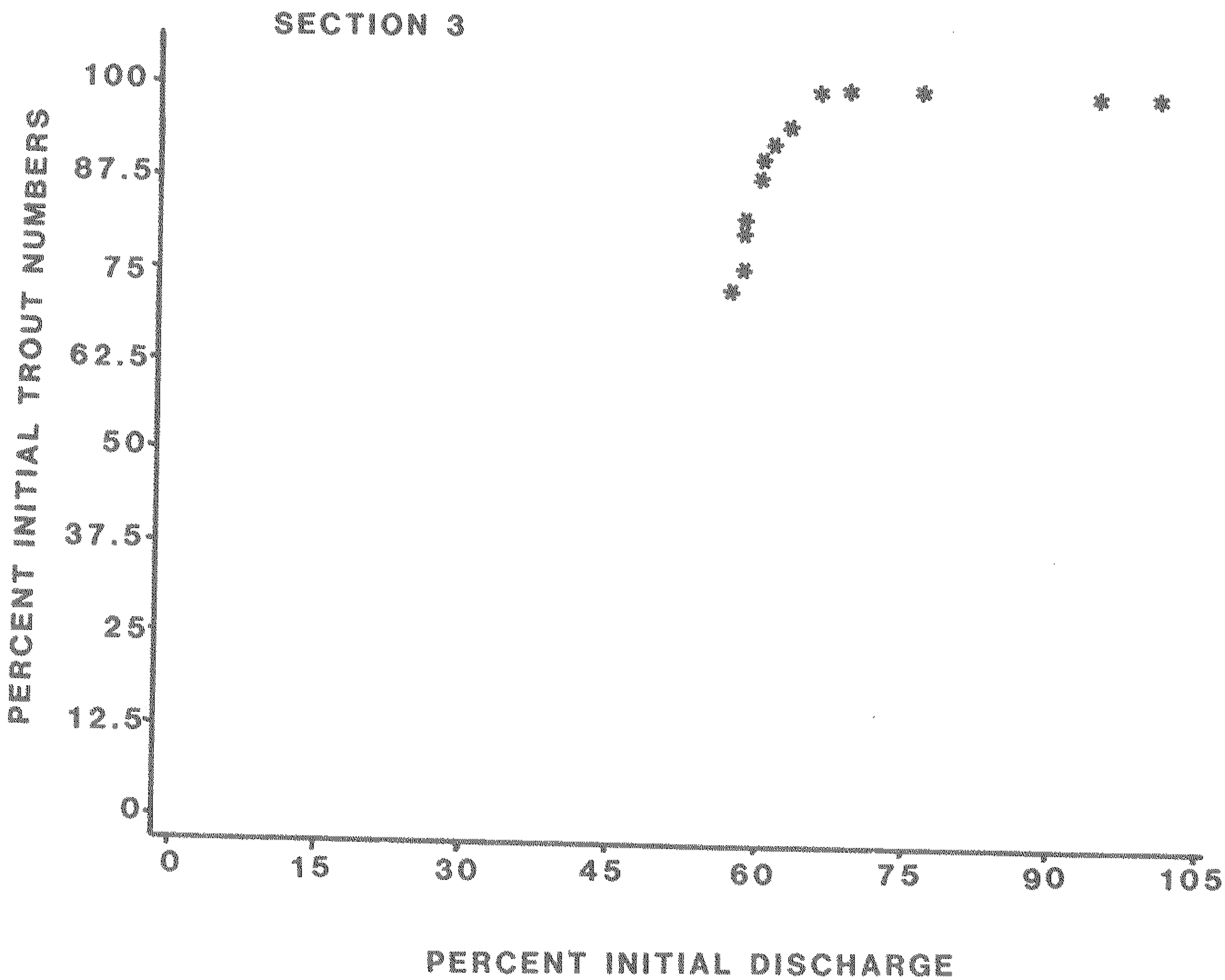

Figure 22. The relationship between percent initial trout numbers and percent initial discharge in section 3, Ruby Creek, Montana, 1982.

decreases in numerical density were 76 and 73% (Table 5). 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. A parallel magnitude of decrease in total biomass and biomass density was observed in all sections (Table 6).

Emigration response of resident trout was less (12.5-17.2%) than non-resident trout (44.4-59.4%) in each study section (Table 10). Chi-square statistical test however, failed to support the empirical 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 23).

Size Related Response

Mean trout length decreased in the two study sections having large flow reductions (Table 11). Although no significant differences were found between pre- and post-study rainbow trout length distributions in reduced flow sections (Mann-Whitney nonparametric test, Dixon, et al., 1983), inspection of empirical data indicates that larger fish were more influenced by flow reductions than were smaller fish (Figures 24 and 25). In the control section, length distribution remained relatively unchanged (Figure 26).

Mean weight of fish in all study sections decreased during

Table 10. Comparison of emigration of resident (R) and nonresident (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	

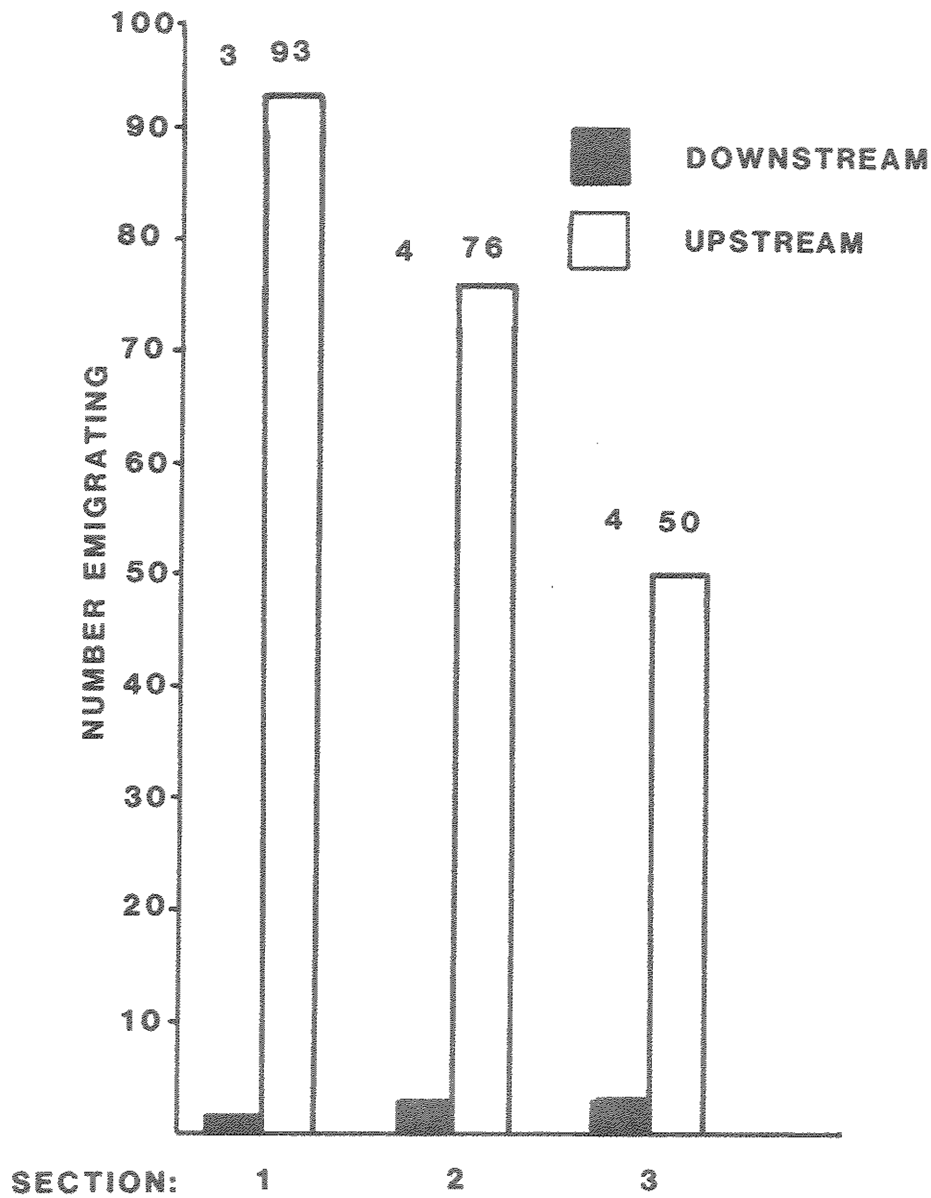

Figure 23. Number of rainbow trout trapped in each study section according to direction of emigration following flow reduction in Ruby Creek, Montana, 1982.

Table 11. Comparison between length and weight distributions before and after the experiment, Ruby Creek, Montana, 1982.

Section	Variable	Time	Number	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 at ALPHA=0.05

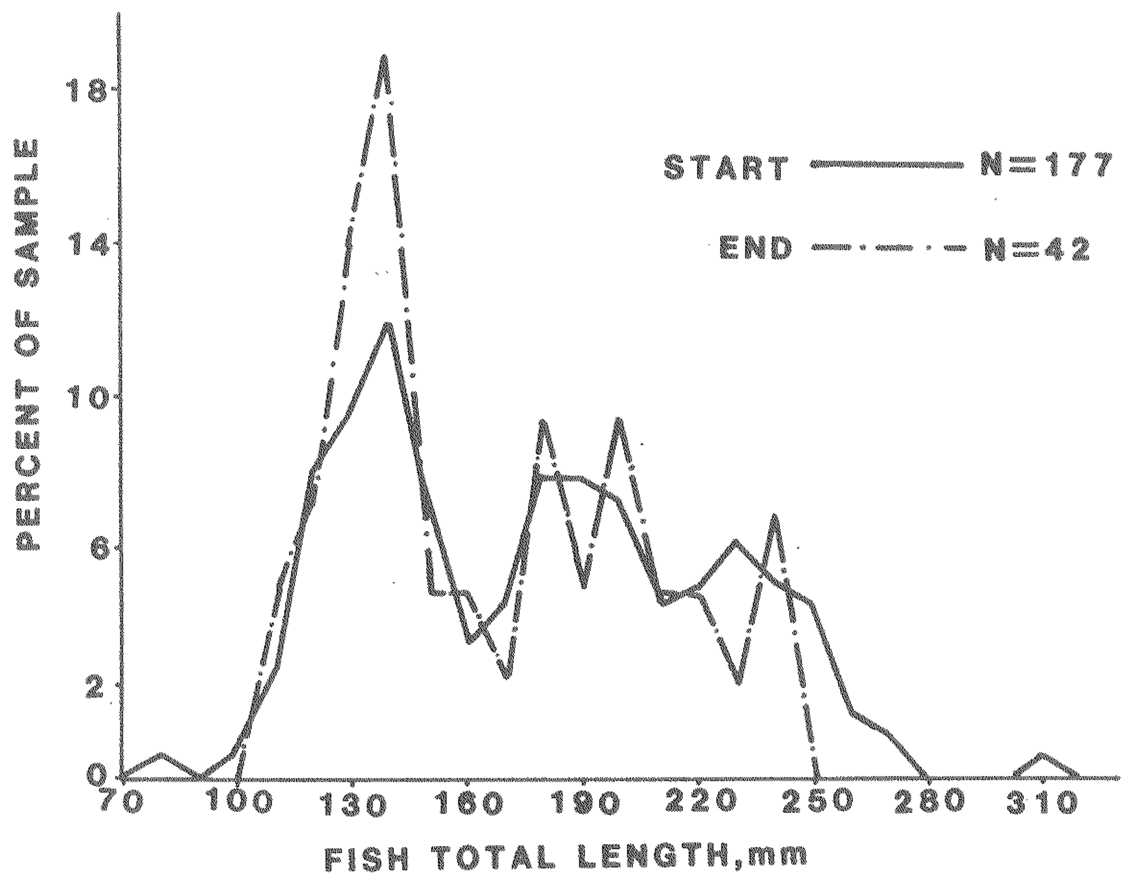

Figure 24. Comparison of the length distributions of trout (by 10mm groups) in section 1 at the start and end of the study on Ruby Creek, Montana, 1982.

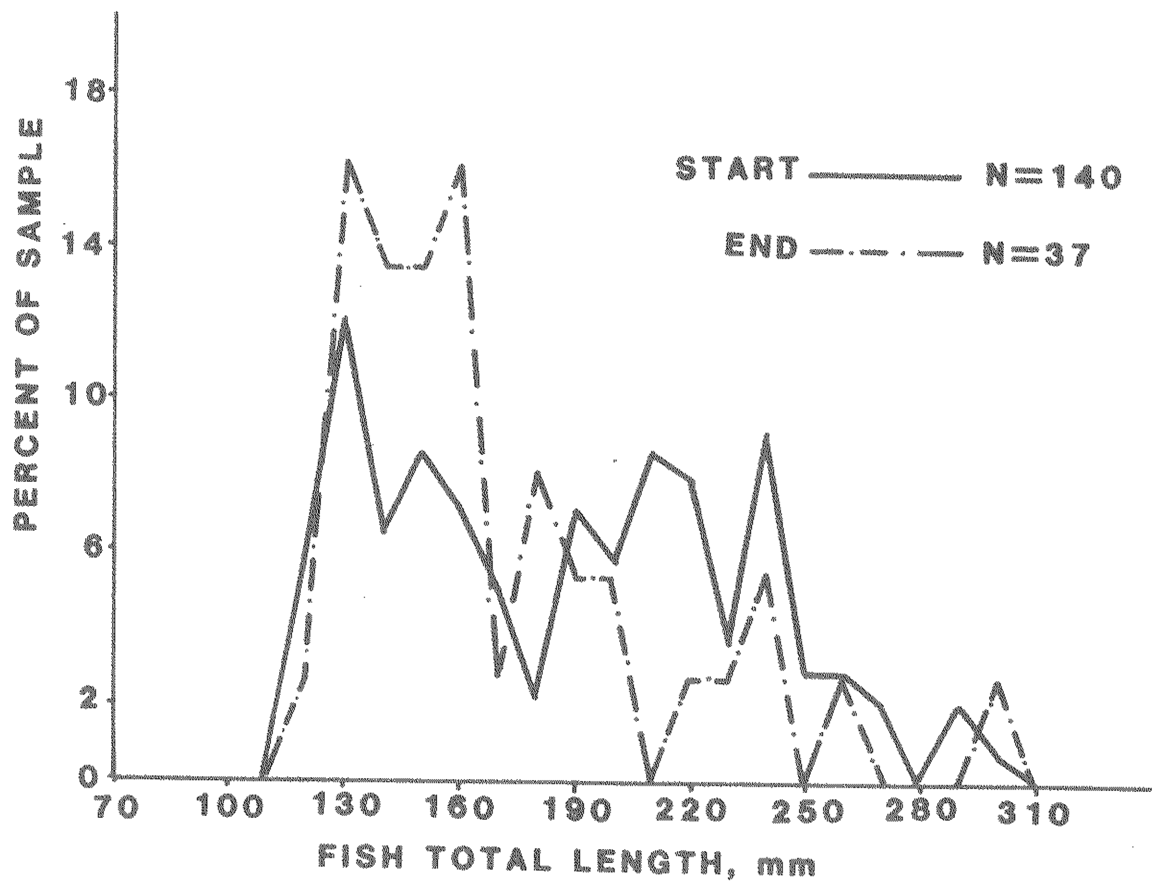

Figure 25. Comparison of the length distributions of trout (by 10mm groups) in section 2 at the start and end of the study on Ruby Creek, Montana, 1982.

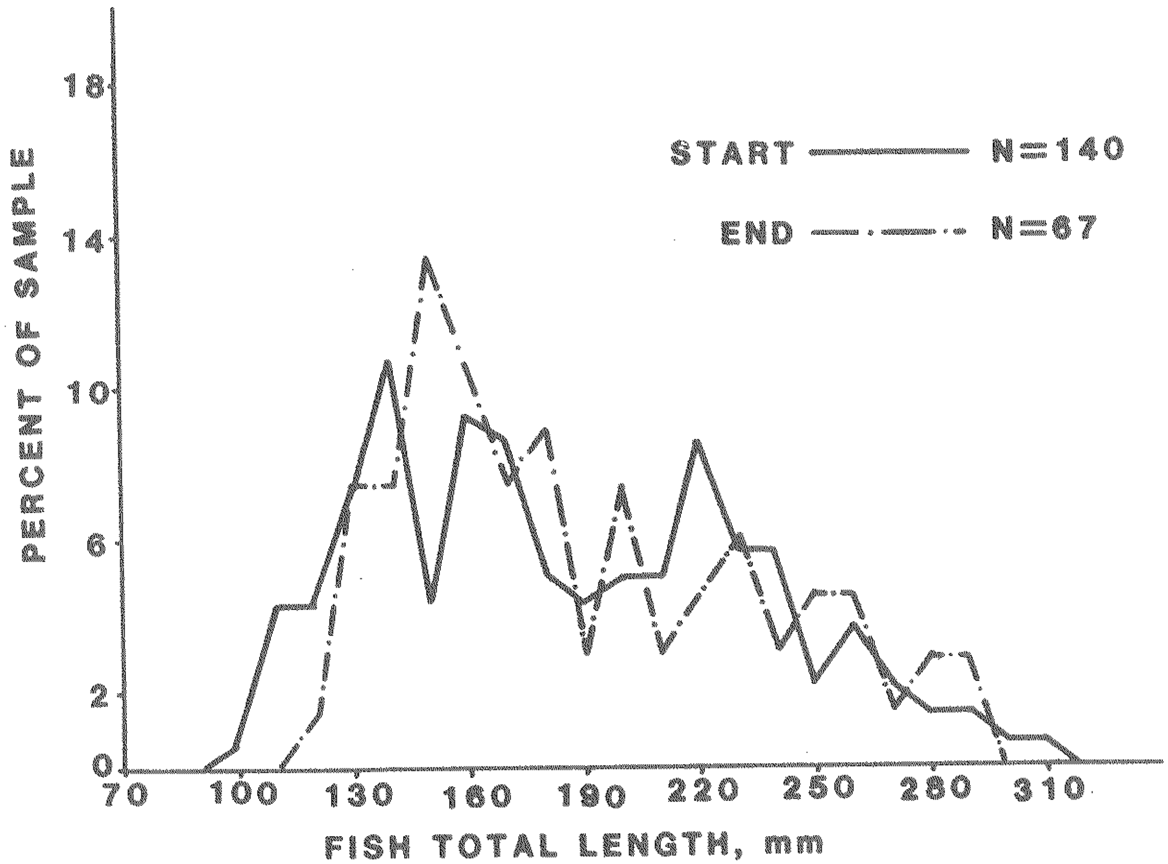

Figure 26. Comparison of the length distributions of trout (by 10mm groups) in section 3 at the start and end of the study on Ruby Creek, Montana.

the study period. Mean weight of fish in 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 11). Percetnage 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 12, 13 and 14). Mean condition factors of trout in section 1 were statistically different (ALPHA = .05) for all 20 mm length groups between 120-239 mm, but not for the smallest (100-119) or the largest length group (240-259 mm). In section 2, which was also subjected to large discharge reduction, 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. 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) in

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 1 Ruby Creek, Montana, 1982.

SECTION	SIZE RANGE OF FISH(mm)	TIME OF EXPERIMENT	NUMBER OF FISH	K-VALUE MIN.	K-VALUE MEAN	K-VALUE MAX.	MEAN K START-END P-VALUE
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**
		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**
		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**
		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**
		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**
		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**
		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
		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*
		END	42	0.565	0.929	2.204	
		NO.(%)MISSING	39(22)				

* SIGNIFICANTLY DIFFERENT AT ALPHA=0.05
** SIGNIFICANTLY DIFFERENT AT ALPHA=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 2 on Ruby Creek, Montana, 1982.

SECTION	SIZE RANGE OF FISH(mm)	TIME OF EXPERIMENT	NUMBER OF FISH	K-VALUE MIN.	K-VALUE MEAN	K-VALUE MAX.	MEAN K START-END P-VALUE
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	
		EMIGRATING	7	0.667	0.934	1.205	0.101
		END	7	0.890	0.985	1.097	
		NO.(%)MISSING	11(44)				
	140-159	START	24	0.739	0.970	1.172	
		EMIGRATING	10	0.684	0.871	1.039	0.496
		END	10	0.871	0.946	1.014	
		NO.(%)MISSING	4(17)				
	160-179	START	17	0.884	1.019	1.160	
		EMIGRATING	8	0.880	0.967	1.082	0.070
		END	7	0.868	0.951	1.088	
		NO.(%)MISSING	2(12)				
	180-199	START	13	0.876	0.999	1.092	
		EMIGRATING	6	0.850	0.942	1.005	0.460
		END	5	0.869	0.974	1.044	
		NO.(%)MISSING	2(15)				
	200-219	START	20	0.911	1.060	1.313	
		EMIGRATING	15	0.825	0.962	1.084	0.170
		END	2	0.978	0.983	0.988	
		NO.(%)MISSING	3(15)				
	220-239	START	16	0.694	1.096	1.787	
		EMIGRATING	16	0.898	0.964	1.130	0.325
		END	2	0.871	0.971	1.071	
		NO.(%)MISSING	+2(+13)				
	240-259	START	14	0.960	1.056	1.249	
		EMIGRATING	10	0.812	0.986	1.108	0.751
		END	2	0.993	1.022	1.051	
		NO.(%)MISSING	2(14)				
	260-279	START	7	0.983	1.090	1.232	
		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	
		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	
		EMIGRATING	80	0.667	0.948	1.205	0.302
		END	37	0.868	0.965	1.097	
		NO.(%)MISSING	24(17)				

* SIGNIFICANTLY DIFFERENT AT ALPHA=0.05
** SIGNIFICANTLY DIFFERENT AT ALPHA=0.01

Table 14. 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 MIN.	K-VALUE MEAN	K-VALUE MAX.	MEAN K START-END P-VALUE
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	
		EMIGRATING	2	1.057	1.196	1.335	0.021*
		END	5	0.931	1.010	1.172	
		NO.(%)MISSING	9(56)				
	140-159	START	21	0.838	1.168	2.198	
		EMIGRATING	3	0.919	0.963	0.998	0.000**
		END	15	0.864	0.962	1.039	
		NO.(%)MISSING	3(14)				
	160-179	START	25	0.963	1.093	1.432	
		EMIGRATING	5	0.830	0.950	1.031	0.008**
		END	12	0.880	0.966	1.200	
		NO.(%)MISSING	8(32)				
	180-199	START	12	1.003	1.138	1.281	
		EMIGRATING	7	0.903	1.002	1.077	0.001**
		END	8	0.781	0.797	0.823	
		NO.(%)MISSING	+3(+25)				
	200-219	START	14	0.847	1.112	1.219	
		EMIGRATING	5	0.943	1.028	1.097	0.073
		END	7	0.925	1.030	1.155	
		NO.(%)MISSING	2(14)				
	220-239	START	20	0.949	1.088	1.260	
		EMIGRATING	17	0.741	0.949	1.071	0.027*
		END	7	0.843	0.992	1.080	
		NO.(%)MISSING	+4(+20)				
	240-259	START	11	0.947	1.092	1.202	
		EMIGRATING	9	0.853	0.976	1.159	0.157
		END	5	0.932	1.028	1.092	
		NO.(%)MISSING	+3(+27)				
	260-279	START	8	0.961	1.069	1.218	
		EMIGRATING	4	0.558	0.899	1.104	0.497
		END	4	0.935	1.026	1.137	
		NO.(%)MISSING	0(0)				
	280-299	START	4	0.979	1.086	1.147	
		EMIGRATING	0	-----	-----	-----	0.083
		END	4	0.889	0.989	1.091	
		NO.(%)MISSING	0(0)				
	300-319	START	2	0.897	1.008	1.118	
		EMIGRATING	2	0.835	0.926	1.017	-----
		END	0	-----	-----	-----	
		NO.(%)MISSING	0(0)				
	OVERALL SIZES	START	140	0.838	1.112	2.198	
		EMIGRATING	54	0.558	0.988	1.335	0.099
		END	67	0.843	0.992	1.200	
		NO.(%)MISSING	19(14)				

* SIGNIFICANTLY DIFFERENT AT ALPHA=0.05
** SIGNIFICANTLY DIFFERENT AT ALPHA=0.01

section 1. The largest overall percentage decrease in condition was also observed in section 1. The maximum decrease in condition of any size group was 11% and 30 % in sections 2 and 3, 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 12, 13 and 14).

Flow Related Changes in Habitat

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 illustration of channel structure differences between sections difficult (Figures 27, 28 and 29).

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, mean depth was essentially the same in all three sections (Table 15). Initial mean thalweg depth was equivalent in sections 2 and 3, but was 11% deeper in section 1. At the end of the study mean depth and mean thalweg depth were similar 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/s); section 3 had a slightly higher mean velocity (73 cm/s). Mean velocity had been reduced 80% in section 1, 71% in section 2 and 19% in section 3

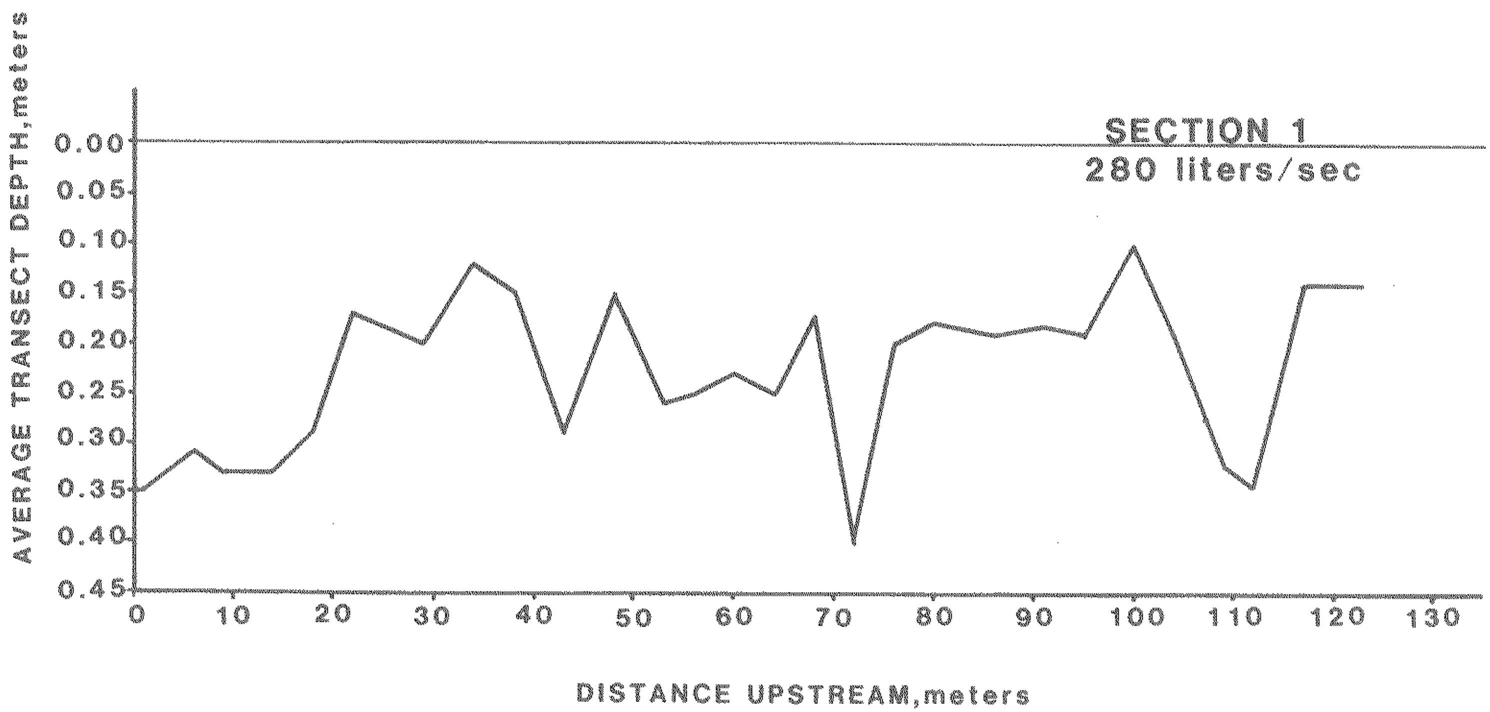

Figure 27. Average transect depth of section 1 at 280 liters/sec (10 cfs), Ruby Creek, Montana, 1982.

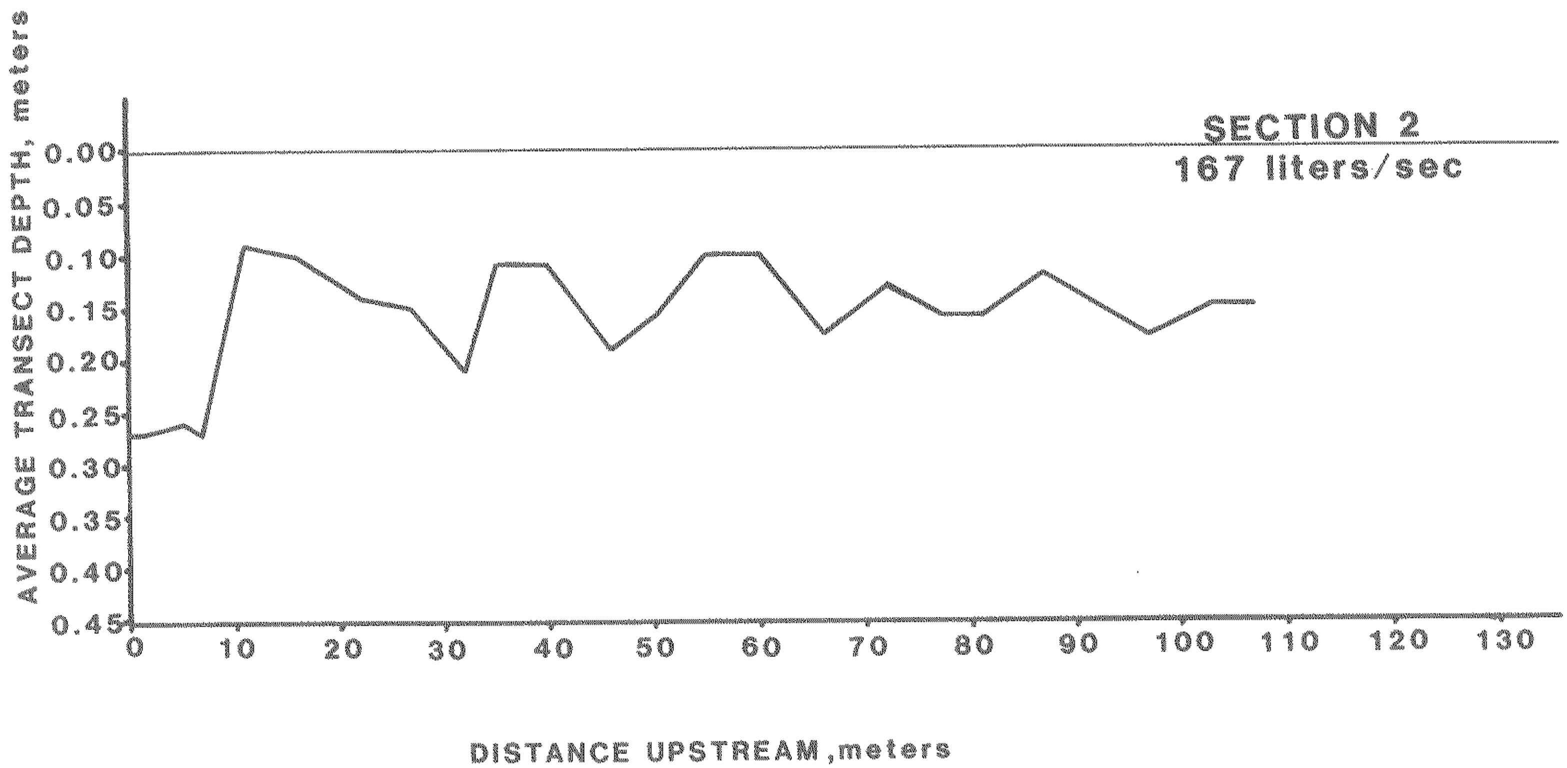

Figure 28. Average transect depth of section 2 at 167 liters/sec (5.9 cfs), Ruby Creek, Montana, 1982.

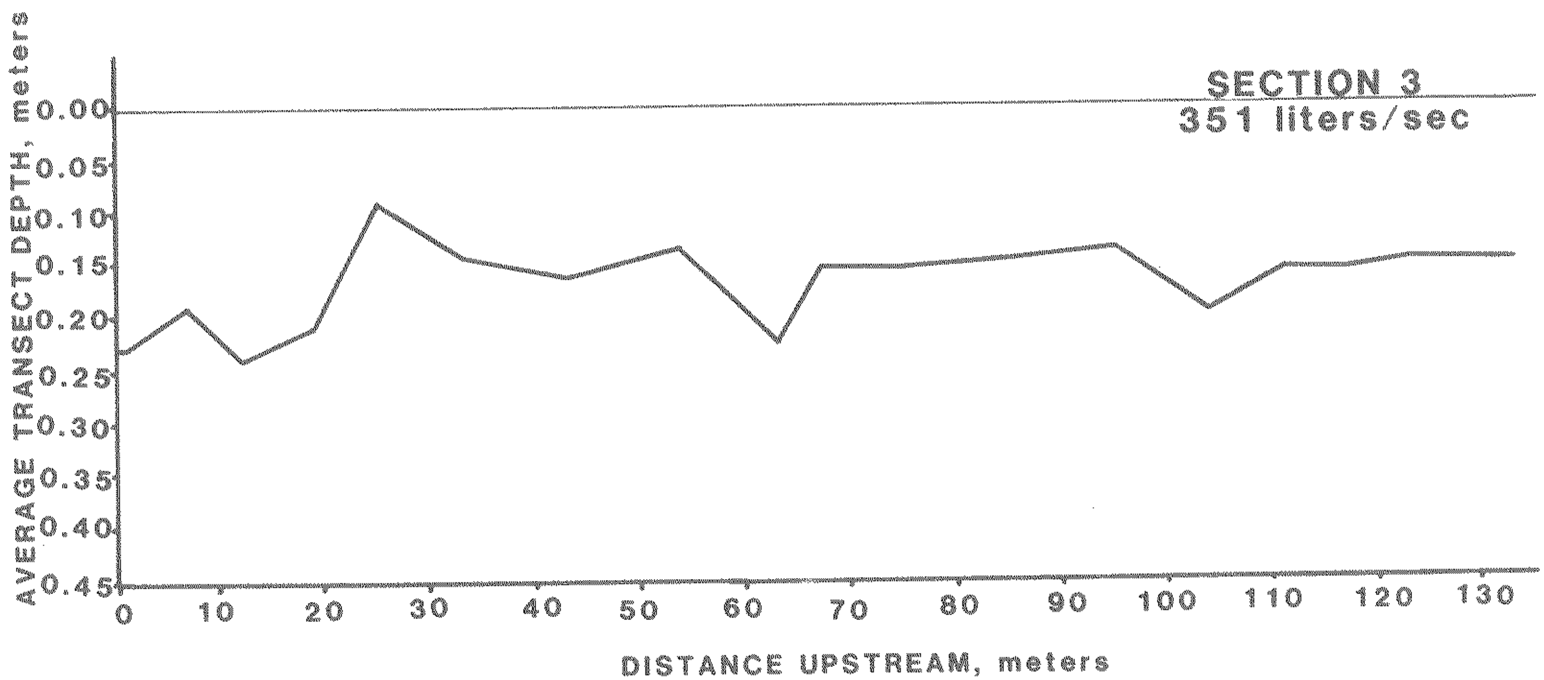

Figure 29. Average transect depth of section 3 at 351 liters/sec (12.4 cfs), Ruby Creek, Montana, 1982.

Table 15. Mean velocities, depths, and thalwag depths for measured flows in study sections 1, 2, and 3, Ruby Creek Montana, 1982.

SECTION	FLOW liters/sec (cfs)	MEAN DEPTH meters	MEAN VELOCITY cm/s	MEAN THALWAG DEPTH meters
1	283 (10.0)	0.23	61	0.37
	113 (4.0)	0.17	40	0.27
	23 (0.8)	0.11	21	0.18
	8 (0.3)	0.09	12	0.14
2	669 (23.7)	0.22	73	0.32
	167 (5.9)	0.16	49	0.24
	54 (1.9)	0.09	30	0.16
	28 (1.0)	0.07	21	0.13
3	821 (29.0)	0.21	64	0.33
	351 (12.4)	0.16	52	0.28

by the end of the study.

Due to flow and channel differences, the magnitude and order of percent change in quantity of the five habitat variables measured, differed between sections. All variables except velocity area (surface area with mean velocity ≤0.3 cm/sec (0.1 f/s)) decreased as flow decreased (Table 16).

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 ≥15 cm and a width ≥10 cm) was lost. In section 1, where total flow reduction was 97%, depth area (DA-surface area with associated depth of 15cm or more) was reduced 91.8%; overhead vegetation (OHV-surface area having vegetation within 30 cm of water surface with a depth of ≥15 cm and width of ≥10 cm) by 73.3% and total surface area (SA) by 45.2%. 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%.

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

All five habitat variables were highly intercorrelated with the exception of VA in section 1 which had almost no correlation with other habitat variables. Similarly, each habitat variable had a high positive correlation with flow except for VA which was negatively correlated in all sections and was poorly correlated

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

SECTION	DATE	FLOW		SA		DA		VA		OHV		OHB	
		liters/sec	%Change	m	%Change	m	%Change	m	%Change	m	%Change	m	%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)
Velocity Area-(VA)
Overhanging Vegetation Area-(OHV)
Depth Area-(DA)
Overhanging Bank-(OHB)

Note: cfs=liters/sec x 0.03531

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 Vegetation 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 15cm or more (WTOT)
Longest Continuous Top Width Associated with a Depth of 15cm or more (WMAX)

Table 18. Correlations between habitat variables, mean riffle transect 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 Vegetation 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 15cm or more (WTOT)
Longest Continuous Top Width Associated with a Depth of 15cm 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 Vegetation 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 15cm or more (WTOT)
Longest Continuous Top Width Associated with a Depth of 15cm or more (WMAX)

(r = -0.60) in section 1 (Tables 17, 18 and 19). With the exception of SA in section 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 form 0.75 to 0.83 . In section 3, no habitat variable correlated highly with numbers. Correlations ranged from 0.65 to 0.68.

Wetted Perimeter Modeling

To test the hypothesis that average riffle wetted perimeter can be used as a general index of salmonid habitat suitability in small streams we related wetted perimeter to habitat variables and to trout numbers remaining in three study sections. 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).

Changes in wetted perimeter were paralleled by changes in trout numbers and biomass in section 1 (Figure 30) 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. Trout number and wetted perimeter had a correlation of 0.766. 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 (4.6 cfs) (Figure 31).

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 (13.8cfs) (Figure 32). Calculated wetted perimeter decreased most rapidly as discharge was reduced below 460 liters/sec (16.4 cfs). Increased rate of trout emigration corresponds 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

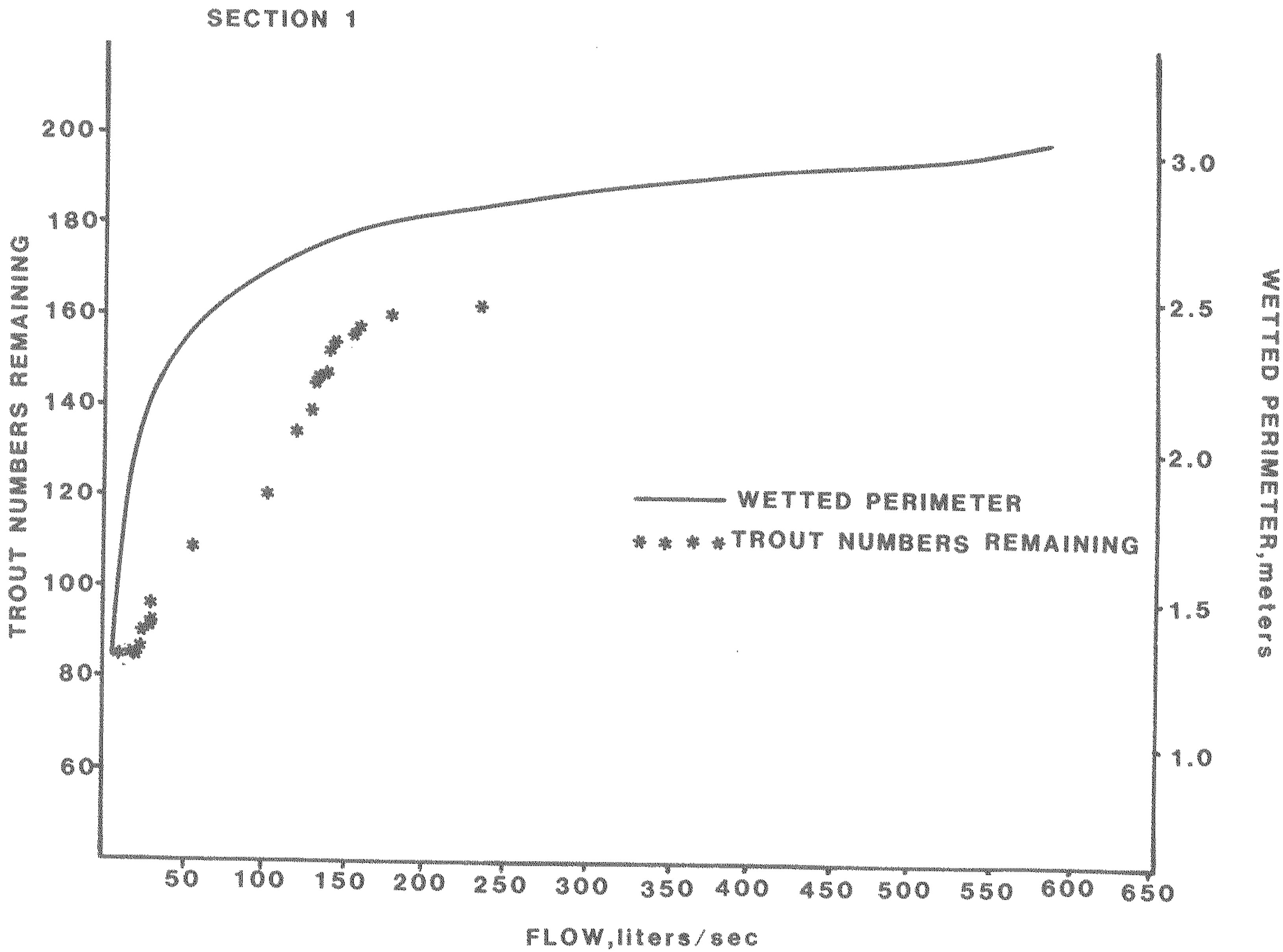

Figure 30. The relationship between wetted perimeter and trout numbers remaining in section 1, Ruby Creek, Montana, 1982.

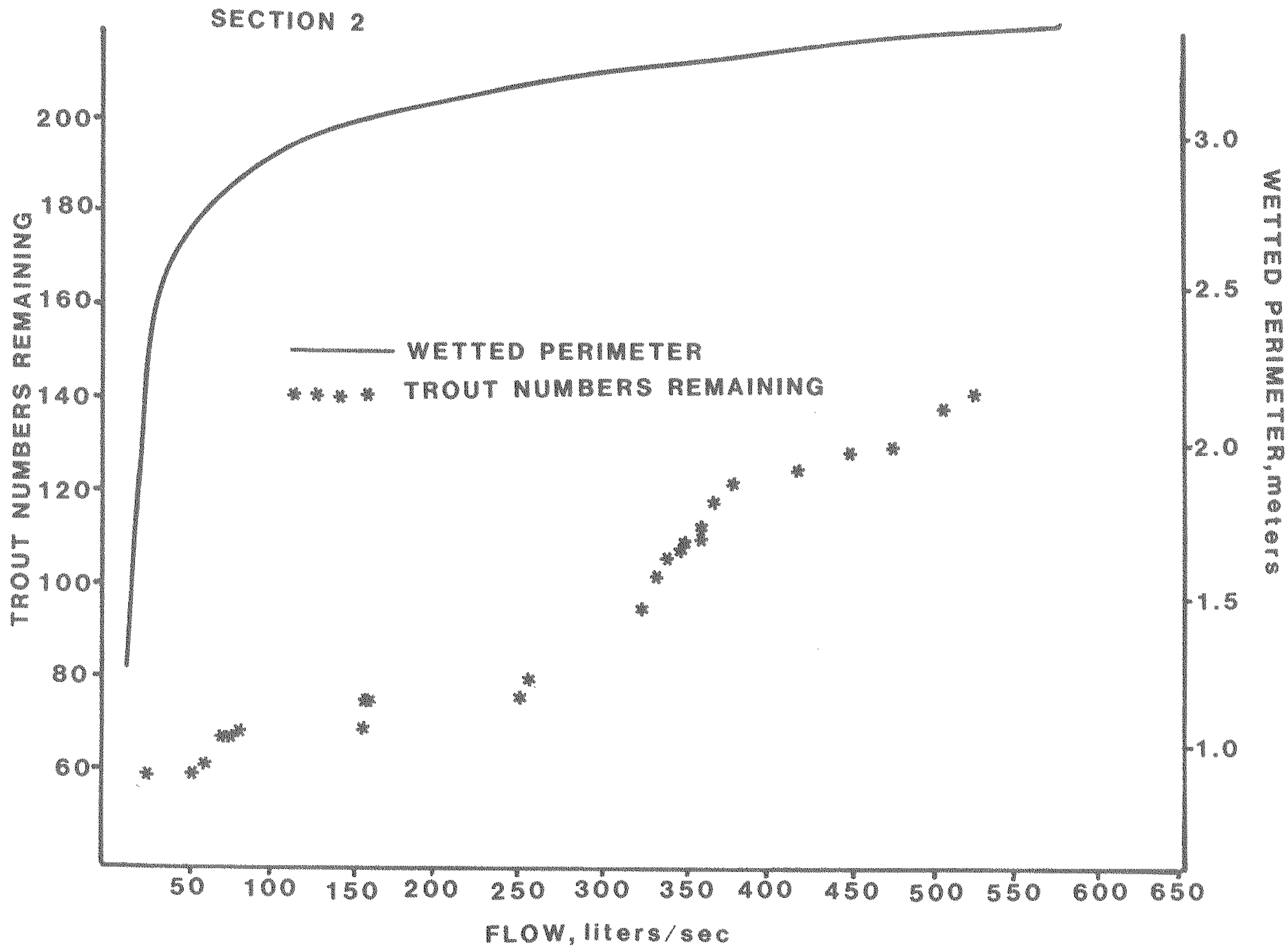

Figure 31. The relationship between wetted perimeter and trout numbers remaining in section 2, Ruby Creek, Montana, 1982.

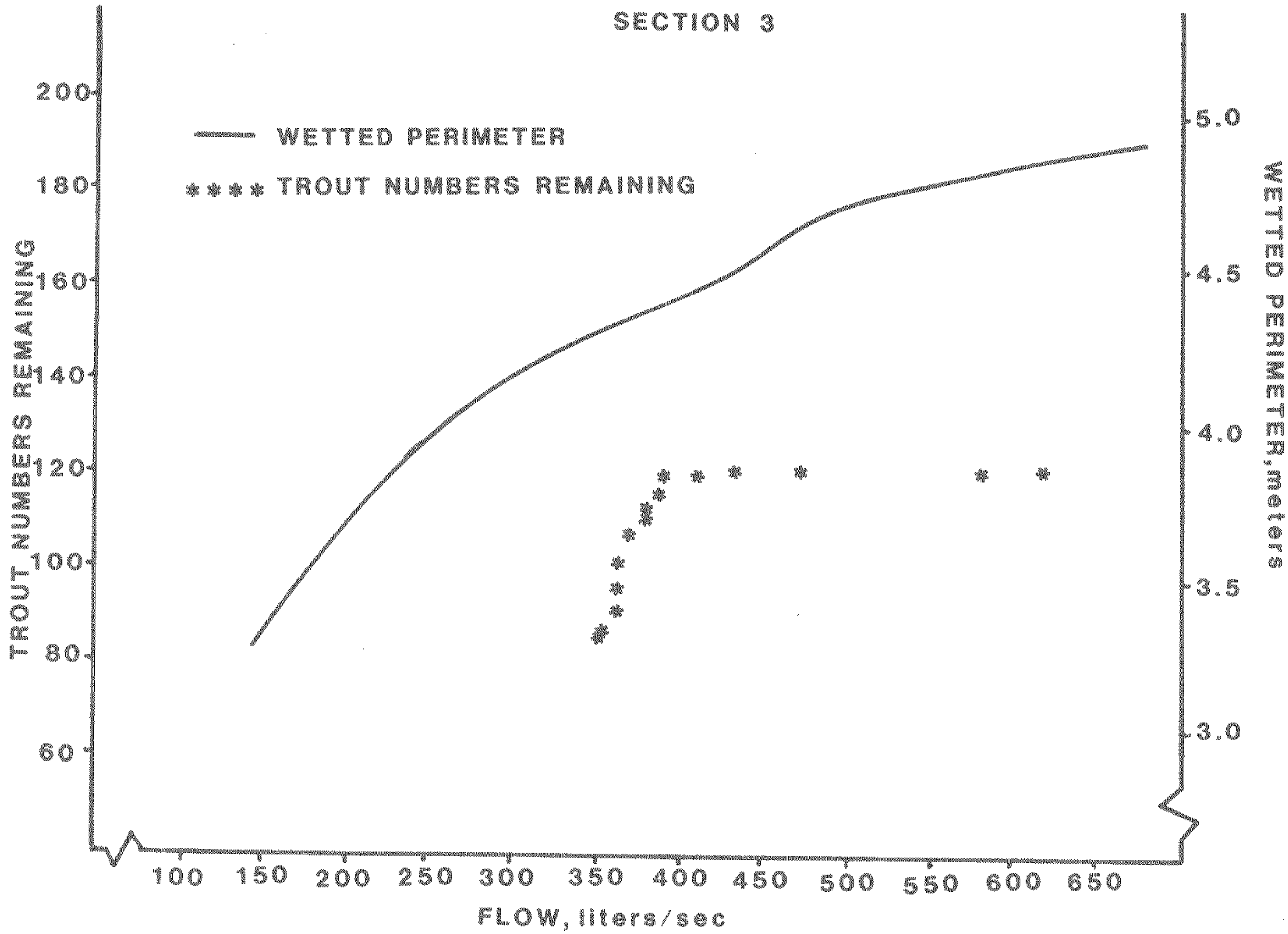

Figure 32. The relationship between wetted perimeter and trout numbers remaining in section 3, Ruby Creek, Montana, 1982.

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 consistant between study sections. In section 1 all variables except VBAR and WDTH had larger correlations with numbers than 0.93, indicating that they 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.

Habitat and Wetted Perimeter Variables *vs* Trout Numbers

Because of high intercorrelation of variables, standard multivariant 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, we plotted percent change in the five habitat variables and eight wetted perimeter variables with percent change in initial flow. Emperical evaluation of these plots indicated that no habitat variable decreased in parallel with 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 (Figures 33, 34 and 35). Each of these variables is a measure of the riffle habitat deeper than 15 cm.

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 5 and 6). Original numerical densities in sections 1, 2 and 3 were 0.12, 0.07, and 0.22 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, 362 and 131% larger than we observed in study sections before the experiment. Post study biomass densities had increased 8, 276 and 140% in sections 1,2 and 3, respectively (Table 6). 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 43%, had higher trout densities both before and after the study.

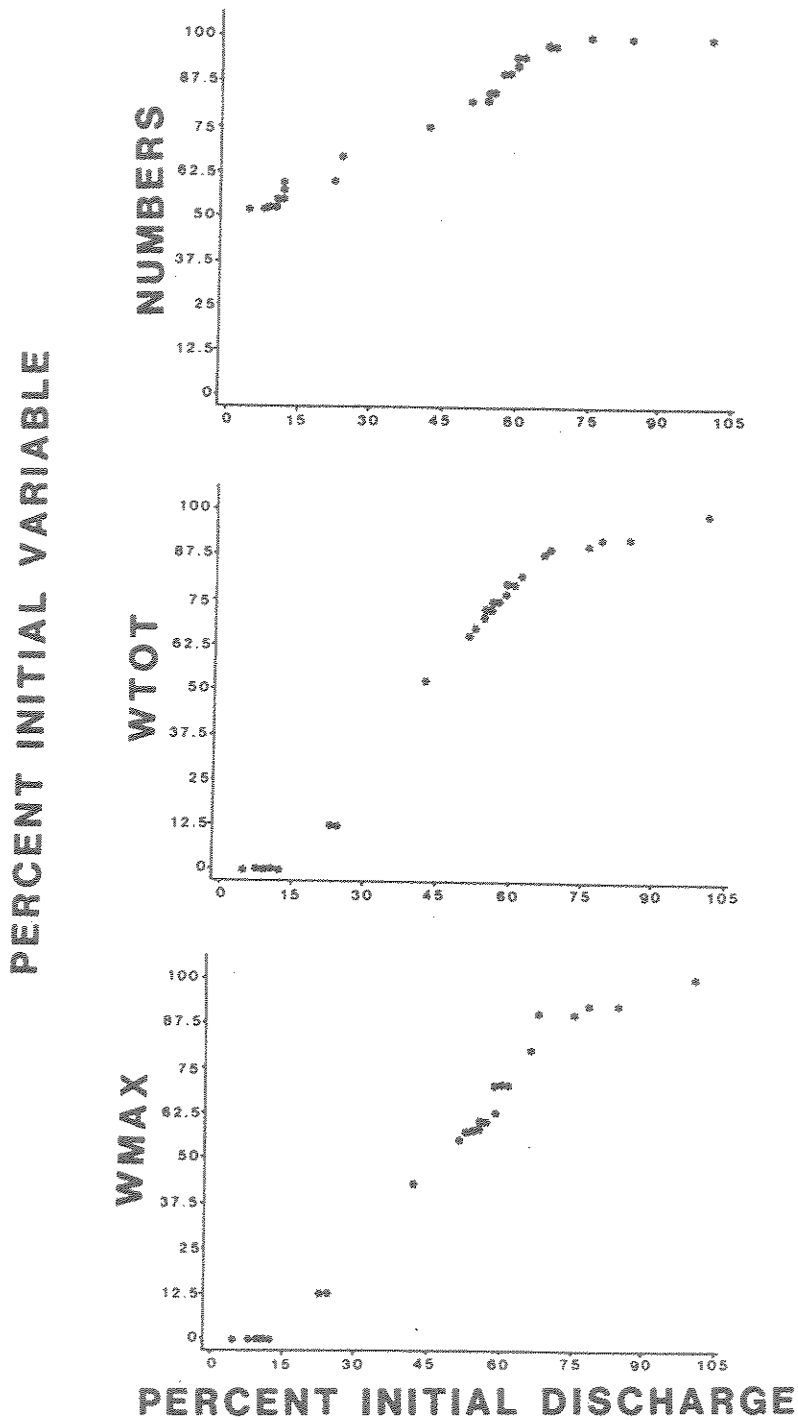

Figure 33. The relationship between percent initial discharge and trout numbers remaining, total top width with depth greater than 15 cm (WTOT) and longest continuous top width with depth greater than 15 cm (WMAX) for study section 1, Ruby Creek, Montana, 1982.

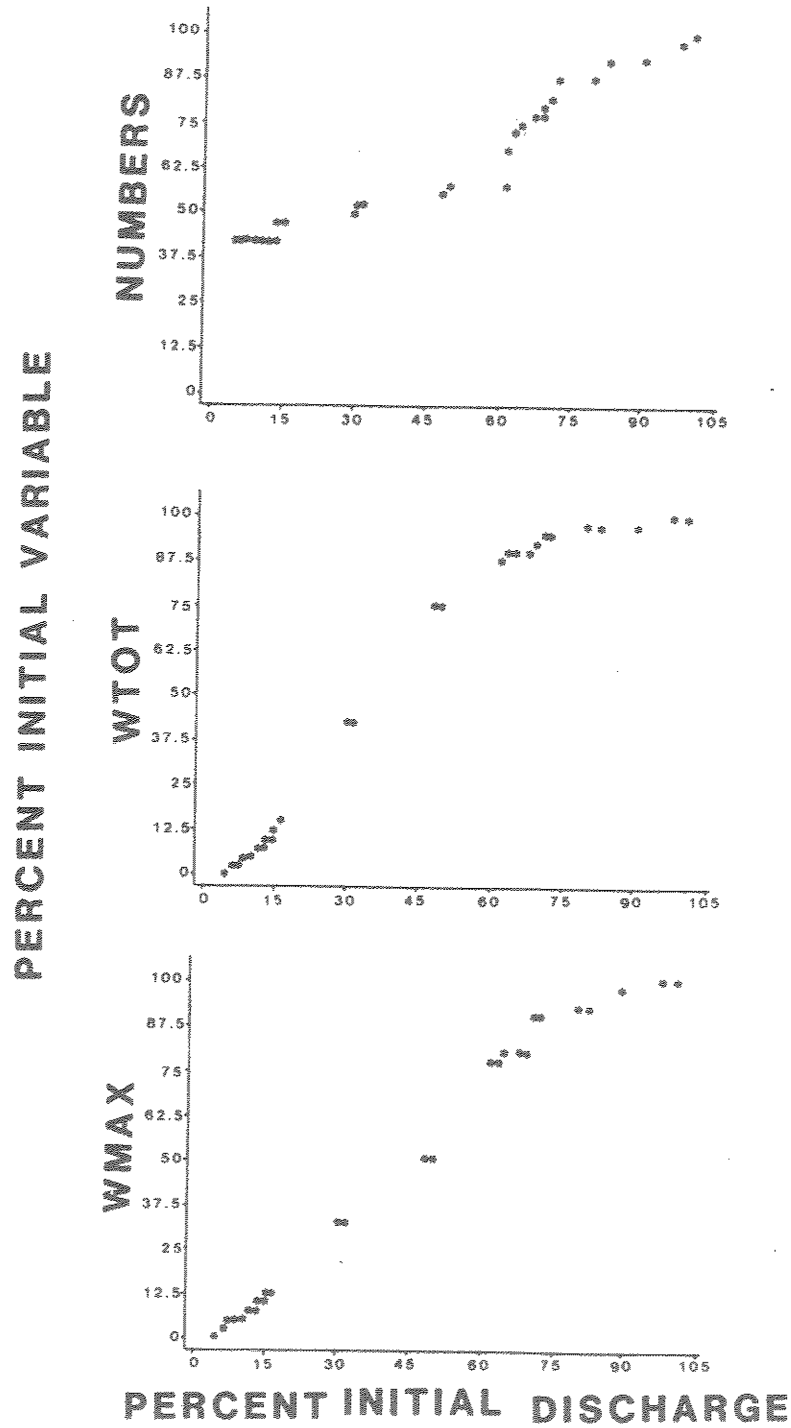

Figure 34. The relationship between percent initial discharge and trout numbers remaining, total top width with depth greater than 15 cm (WTOT) and longest continuous top width with depth greater than 15 cm (WMAX) for study section 2, Ruby Creek, Montana, 1982.

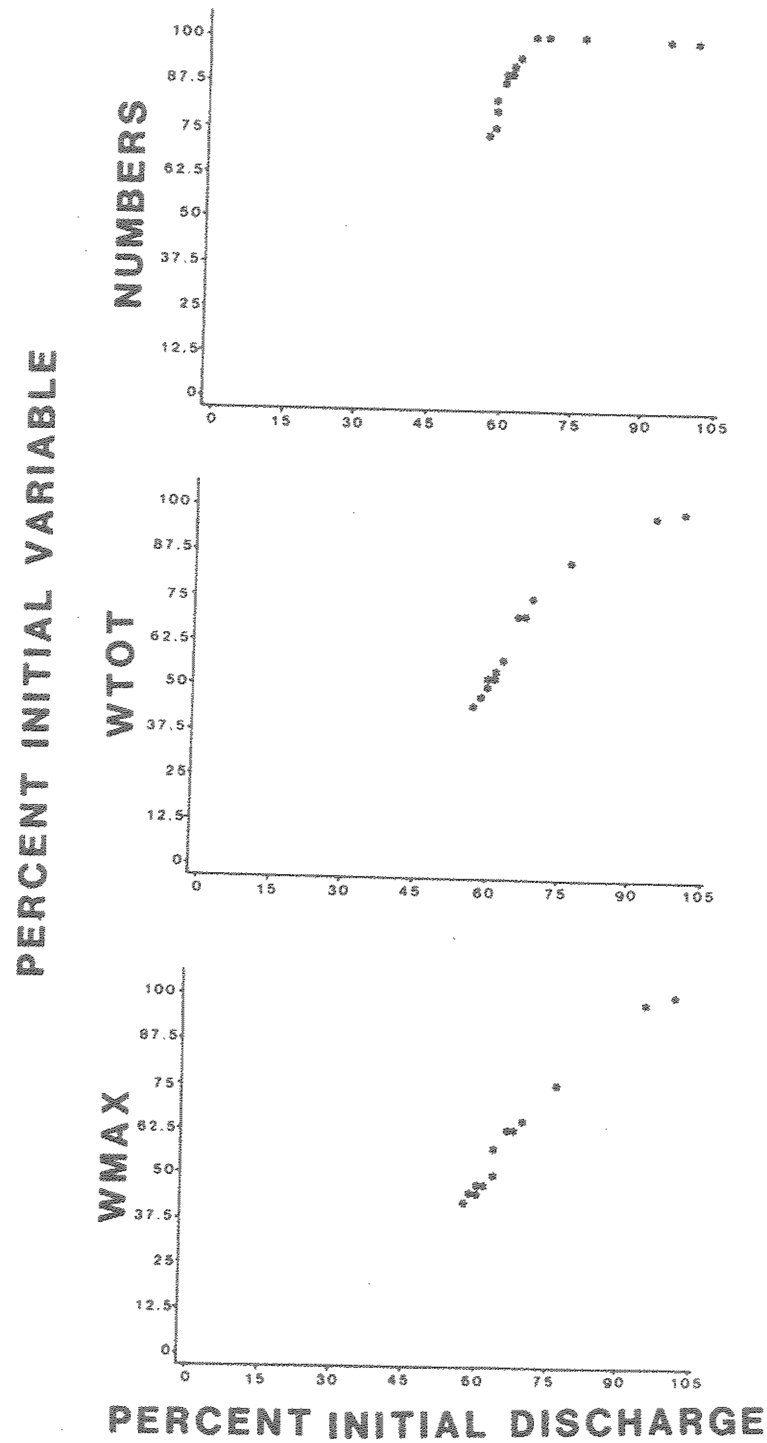

Figure 35. The relationship between percent initial discharge and trout numbers remaining, total top width with depth greater than 15 cm (WTOT) and longest continuous top width with depth greater than 15 cm (WMAX) for study section 3, Ruby Creek, Montana, 1982.

Fish Not Accounted For

A portion of fish in each study section could not be accounted for at the end of the study (Table 20). In section 1, 22 % of the trout numbers and 31.4 % of biomass were unaccounted for. 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. Trout numbers unaccounted for in sections 2 and 3 were 17 and 13.6%, respectively. 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 12, 13 and 14).

Temperature

Mean daily water temperature, measured in section 1 and 3, generally decreased during the study period. The decrease in water temperature occurred after most of the fish had emigrated from sections 1 and 3. Water temperature ranged from 3 to 15 C and 4 to 14 C, in sections 1 and 3, respectively (Figures 36 and 37). Average mean daily temperatures over the study period were 10.0 C in section 1 and 10.8 C in section 3.

Table 20. Fish numbers and biomass not accounted for by emigration from sections 1, 2 and 3 Ruby Creek, Montana, 1982.

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

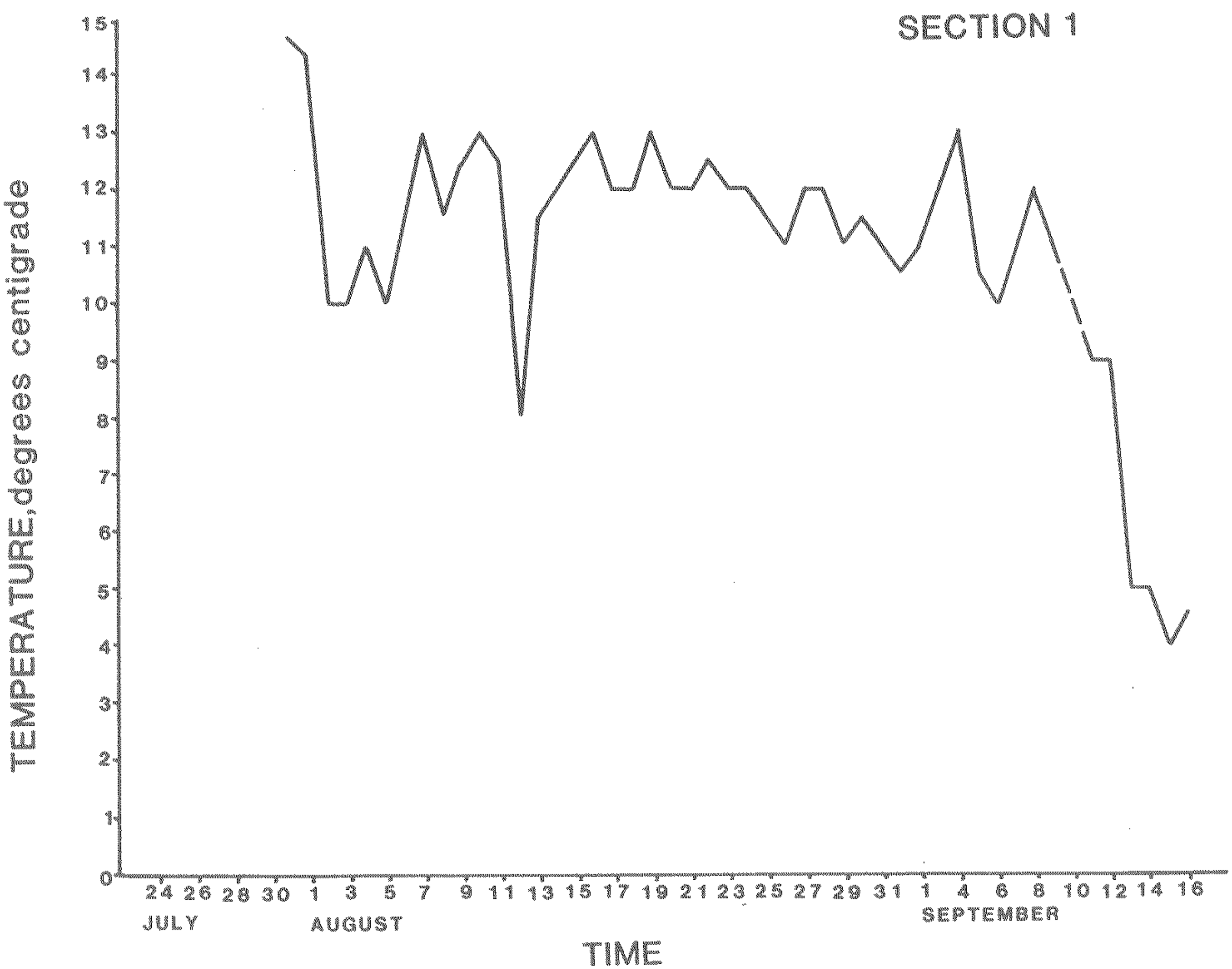

Figure 36. Average daily water temperatures (C) of section 1, Ruby Creek, Montana, 1982.

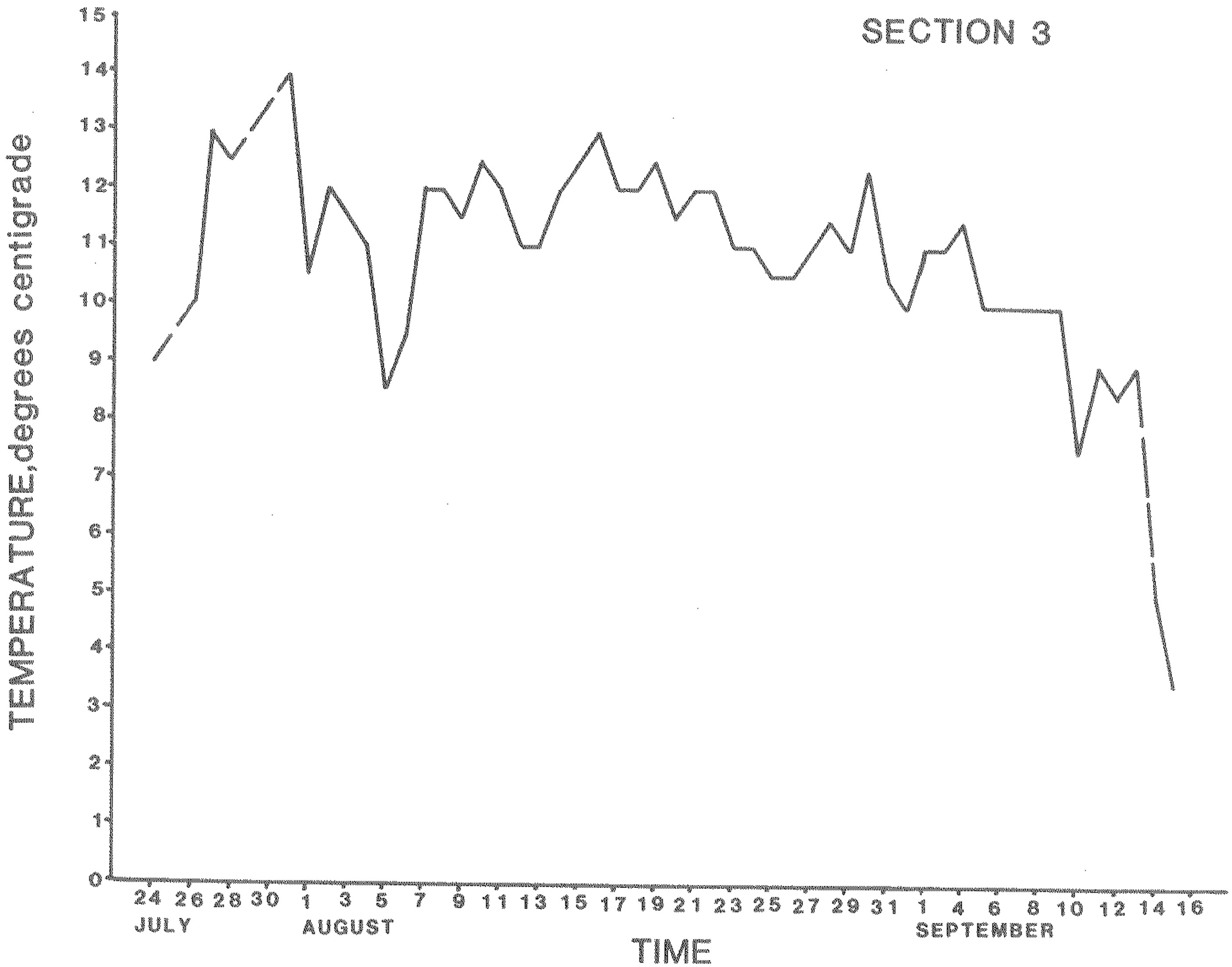

Figure 37. Average daily water temperatures (C) of study section 3, Ruby Creek, Montana, 1982.

Fish Behavior Observations

Evaluation of rainbow trout behavior before and after flow reduction in the artifical stream channels at the Bozeman Fish Cultural Development Center during winter revealed no detectable change in habitat utilization. Fish remained in the deepest portion of the pool habitat during both high and low flows (Figure 38 and 39). Immediately after the flow reduction, experimental fish moved from their focal points and swam randomly about the pool. Fish focal points in pool habitat were reestablished within 24 hours after flow reduction. Only one fish emigrated from the channel during the experiment. Because of lack of measurable response, analysis of habitat data was discontinued. Temperature during the experiment ranged from 2 to 4 C.

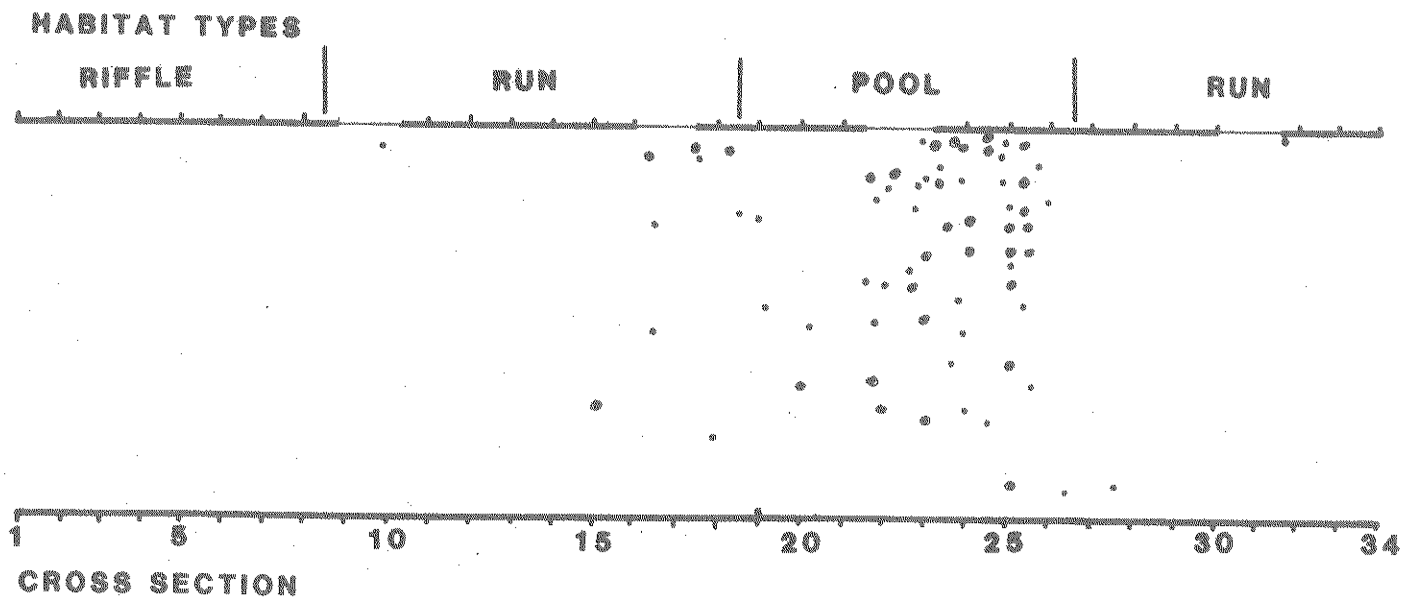

Figure 38. Composite of three hours of trout observations in artificial stream channels during high flow (71 liters/sec, 2.5 cfs) at the Bozeman Fish Cultural Development Center, December 1982.

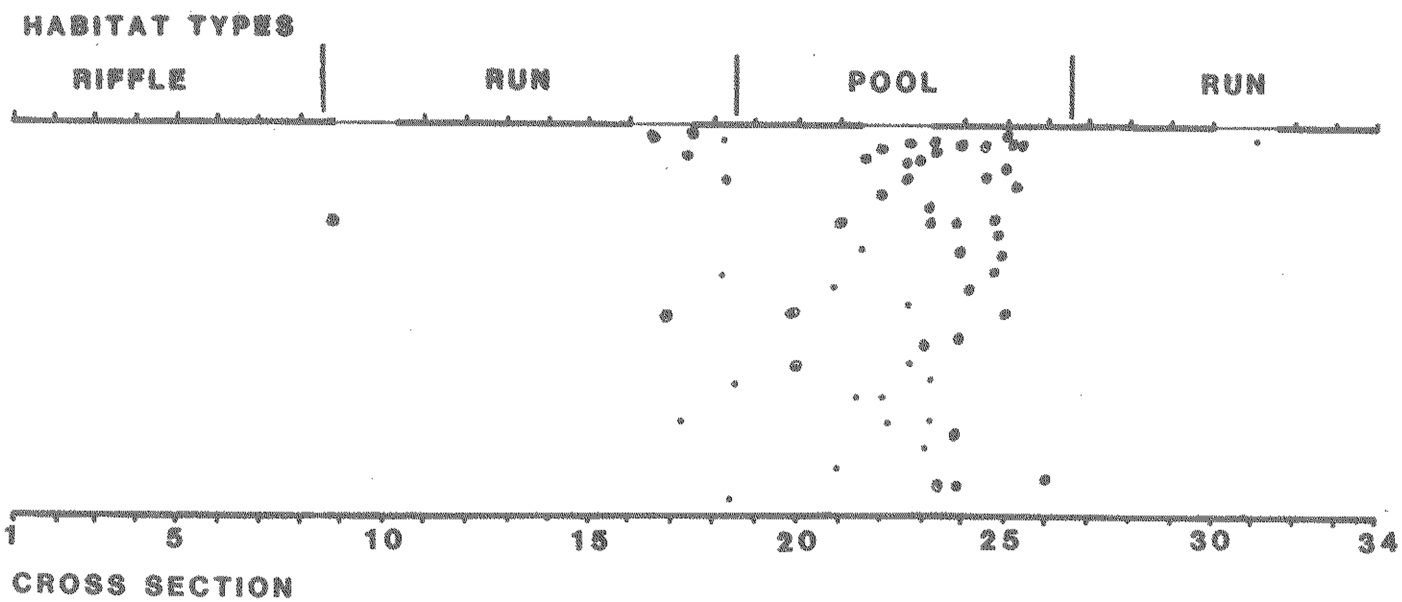

Figure 39. Composite of three hours trout observations in artificial stream channels during low flow (17 liters/sec, .6 cfs) at the Bozeman Fish Cultural Development Center, December, 1982.

DISCUSSION

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 is hypothesized to be due to social-habitat interactions.

Other researchers have reported reduction in trout numbers as well as lags in response to flow changes. Kraft (1968, 1972) examined the relationship between brook trout in Blacktail Creek, Montana and flow related changes in habitat. He found that a 75% reduction in discharge resulted in a 20% reduction in trout abundance in a run, with no fish leaving the study section. During a 3 month study with 90% reduction in flow, trout abundance 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. 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 as trout habitat in runs becomes less suitable as flow decreases, trout distribution first shifts from runs to pools and then density related social mechanisms result in emigration of a portion of the population. 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.

Most habitat variables evaluated were highly correlated with one another as well as with flow. Because of this we were unable to use multivariant statistics to distinguish which combination of variables best explained response of experimental fish populations or the order of importance of these variables.

Even though initial flow was quite different, trout emigration in each of the three study sections increased as discharge was reduced 30-40 % (Figures 20, 21 and 22). This similarity in response between sections suggests that similar flow related habitat changes may have been occurring among sections.

Although statistical evaluation was determined to be inappropriate, we empirically evaluated plots of percentage change in each habitat and wetted perimeter variable with percentage change in flow. The empirical 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, WMAX and WTOT, closely corresponded to change in numbers with flow (Figures 33, 34 and 35). Both of these variables were generated by the wetted perimeter model and are a measure of quantity of riffle depth greater than 15 cm. WMAX is the longest continuous top width associated with depth $\geq$ 15 cm, while WTOT is the total top width with this depth characteristic.

Other researchers have also reported that depth corresponds with 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 explained the importance of mean section depth as reflecting the availability 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 proposed that cover, in the form of sufficient depth, would become limiting as discharge declined in run-riffle channels. Easterbrooks (1981) reported 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 test fish from a more productive stream stabilized at a higher density.

Mean trout length decreased in the two study sections having large flow reductions. Although not statistically significant, our data indicate that larger fish were more influenced by flow reductions than were smaller fish (Figures 24 and 25). 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 the advantage and we 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. Unfortunately, food availability was not investigated during our study on Ruby Creek.

Although emigration response of rainbow trout in our study sections 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 12, 13 and 14). 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, we would suspect that they were 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.

Our data provided no explanation of these results. We suspect that the numbers remaining in study sections were within the social tolerance for rainbow trout during our 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.

In our three study sections, wetted perimeter was not a consistent index of salmonid habitat suitability. In section 1, which was characterized by pool-riffle habitat structure, wetted perimeter was a good index of rainbow trout habitat suitability. Decrease in trout abundance with decrease in discharge closely paralleled flow related changes in wetted perimeter (correlation 0.83) (Figure 30). In the study section below the first irrigation diversion (section 2), trout numbers decreased before large decreases in wetted perimeter, while in the natural flow section (section 3) wetted perimeter decreased gradually throughout the period of observation (Figures 31 and 32). Change in fish number occurred between the two poorly defined inflection points on the section 3 wetted perimeter curve (Figure 32).

Sections 2 and 3 were characterized by a run-riffle habitat structure. This habitat difference is best illustrated by comparing mean transect and thalweg depth between sections. Although flow 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. 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, similar habitat between sections is suggested by similar flow related response of the fish population (Figures 31 and 32). In both sections, as discharge was reduced below approximately 400 liters/sec (14 cfs) the rate of change in trout abundance increased. In section 3 (natural flow) lagged trout number stabilized as discharge stabilized at about 350 liters/sec (12 cfs) (Figure 19), while numbers in section 2 continued to decline with flow. This interpretation is based upon the assumption that the 15 day lag in response of the trout population to flow change in section 3 is correct. Since we detected essentially no lag in section 2, it is suggested that although both sections have a general run-riffle channel stucture, the mixture of habitat characteristics within sections must be substantially different. Otherwise, we would have expected more similar response regarding the amount of time elapsed between flow reduction and fish emigration.

If our results are representative of the habitat types studied and our interpretations are correct, 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. If the inflection point on the wetted perimeter curve for section 2 was used as the recommended flow (about 150 liters/sec (5 cfs)), this recommendation would substantially underestimate the approximate 375 liters/sec (13.2 cfs) which appeared optimum for our experimental fish population (Figure 31). In section 3 there were two inflection points (Figure 32); 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 30) corresponds well with the flow (150 liters/sec, 5 cfs) at which rate of trout emigration increased substantially. Since we only studied one pool-riffle section, we do not know if these findings are characteristic of small stream pool-riffle habitat in general.

Density of trout in supplemental stream sections was not reduced to pre-study levels during our 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 our study was not of long enough duration to elicit a total response.

Alteration of social tolerance by initial stocking density, to our knowledge, has not been reported in the literature. However, White (unpublished data) has observed in previous reduced flow experiments in articial channels 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, our tests 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 is 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 grossly 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 our experimental observations that trout populations respond negatively to changes in stream discharge. The larger magnitude of initial biomass difference between the sections also illustrates our 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 limiations such as winter habitat may reduce the population further.

Flow related rainbow trout fish emigration was primarily upstream from the study sections. Movement upstream when discharge is reduced has been found by Kraft (1972) and Easterbrooks (1981). Clothier (1953,1954) 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 explanatation would be that trout move upstream to seek preferred habitat above fish with social dominance.

The number of fish unaccounted for during this 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 (1981) reported 11 to 27% unaccounted fish during the 1978 and 1979 flow tests. A higher percentage of biomass, compared with numbers, remained unaccounted during the study in sections 1 and 2. This is probably a result of the fish losing weight during the study.

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.

Rainbow trout behavior changed only temporarily when flow was reduced 76% during winter in an artificial stream channel. Immediately after the flow reduction trout moved from their focal points and swam randomly around the pool. Within 24 hours trout had returned to positions similar to those occupied prior to flow reductions and no fish emigrated from the channels. Although pool habitat in the test channel appeared adequate at test discharges, these observations may not be applicable to winter habitat conditions in most small Montana streams since spring water was used in the experiments to prevent freezing.

In conclusion, the wetted perimeter/inflection point 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. In no case did the method provide an overly conservative estimate of instream flow needs.

Since our 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 our 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 intercorretated 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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