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

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

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

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

VALIDITY OF THE WETTED-PERIMETER METHOD FOR RECOMMENDING INSTREAM FLOWS FOR RAINBOW TROUT IN A SMALL STREAM

by

Christopher L Randolph

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in
Fish and Wildlife Management

MONTANA STATE UNIVERSITY
Bozeman, Montana

September 1984

APPROVAL

of a thesis submitted by

Christopher Lee Randolph

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

9/5/84 — Robert G. White

Date — Chairperson, Graduate Committee

Approved for the Major Department

5 September 1984 — Robert E. Moore

Date — Head, Major Department

Approved for the College of Graduate Studies

9-12-84 — M. P. Malone

Date — Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment to the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my permission.

Signature [signature]

Date 9-5-84

ACKNOWLEDGEMENTS

I would like to thank Dr. Robert White for his conscientious efforts in designing, directing and criticizing this study. I also wish to express my appreciation to the other members of my graduate committee, Drs. Calvin Kaya, Ray White, Lynn Irby, and William Hunt for their assistance in completing this thesis. Dr. Henry Lee, Dr. Charles (Andy) Dolloff and Georgia Ziemba provided guidance in statistical analysis and computer operation. Employees of the Montana Cooperative Fisheries research Unit, Montana Department of Fish, Wildlife and Parks, United States Fish and Wildlife Service, Montana State University, and cooperating landowners assisted in the completion of this project.

My most sincere thanks go to my wife, Debbie, who has provided support, and confidence during my college career.

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.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

ABSTRACT

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

INTRODUCTION

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

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

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

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

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

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

a: cfs = liters/sec x 0.0351

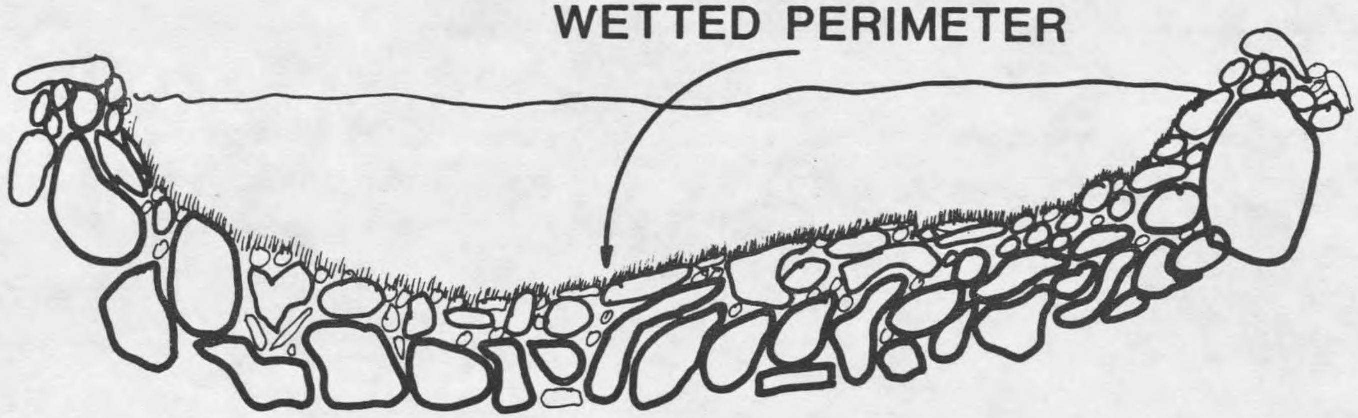

Figure 1. Diagrammatic representation of wetted perimeter in a typical stream cross section.

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

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

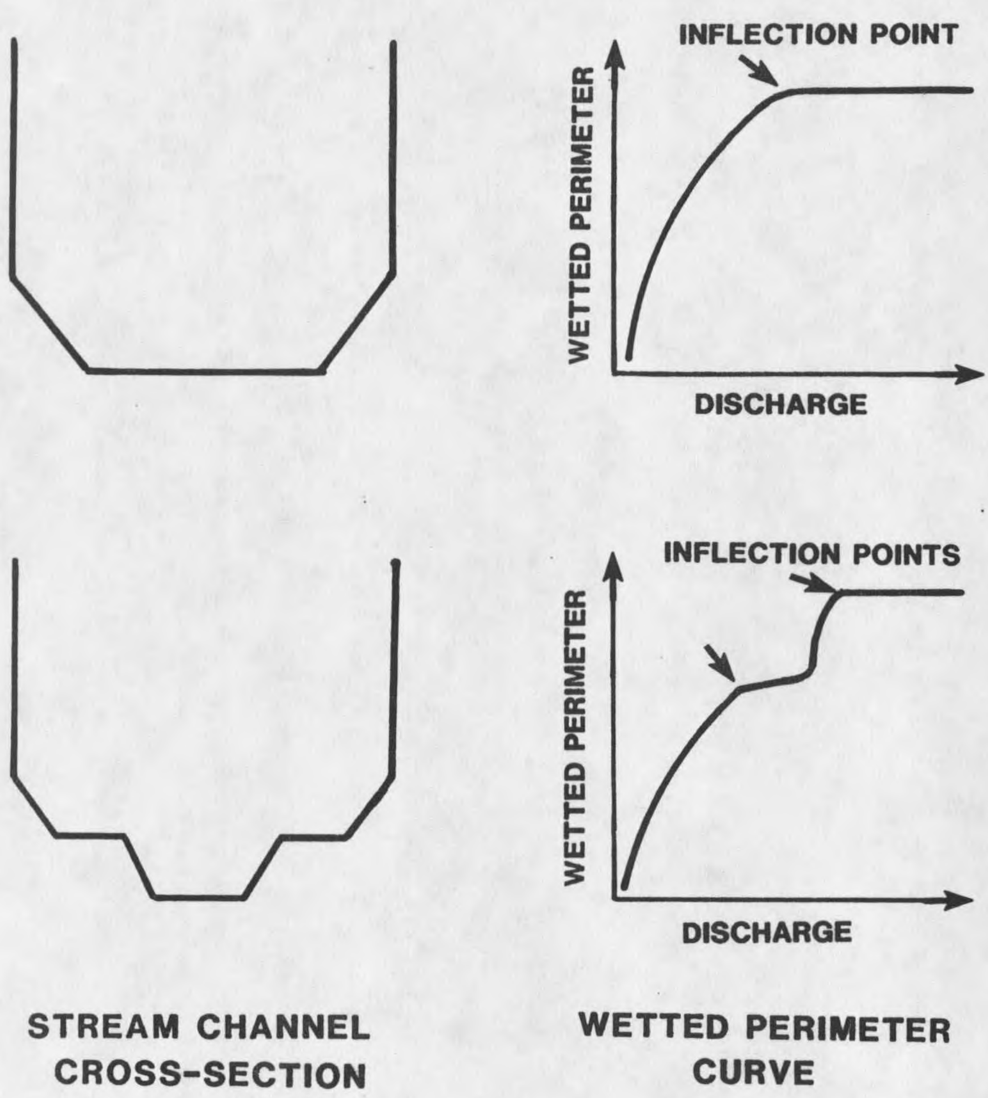

Figure 2. Diagrammatic representation of how stream channel cross section can influence the number of inflection points on corresponding wetted perimeter-discharge plots.

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

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

DESCRIPTION OF STUDY AREA

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

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

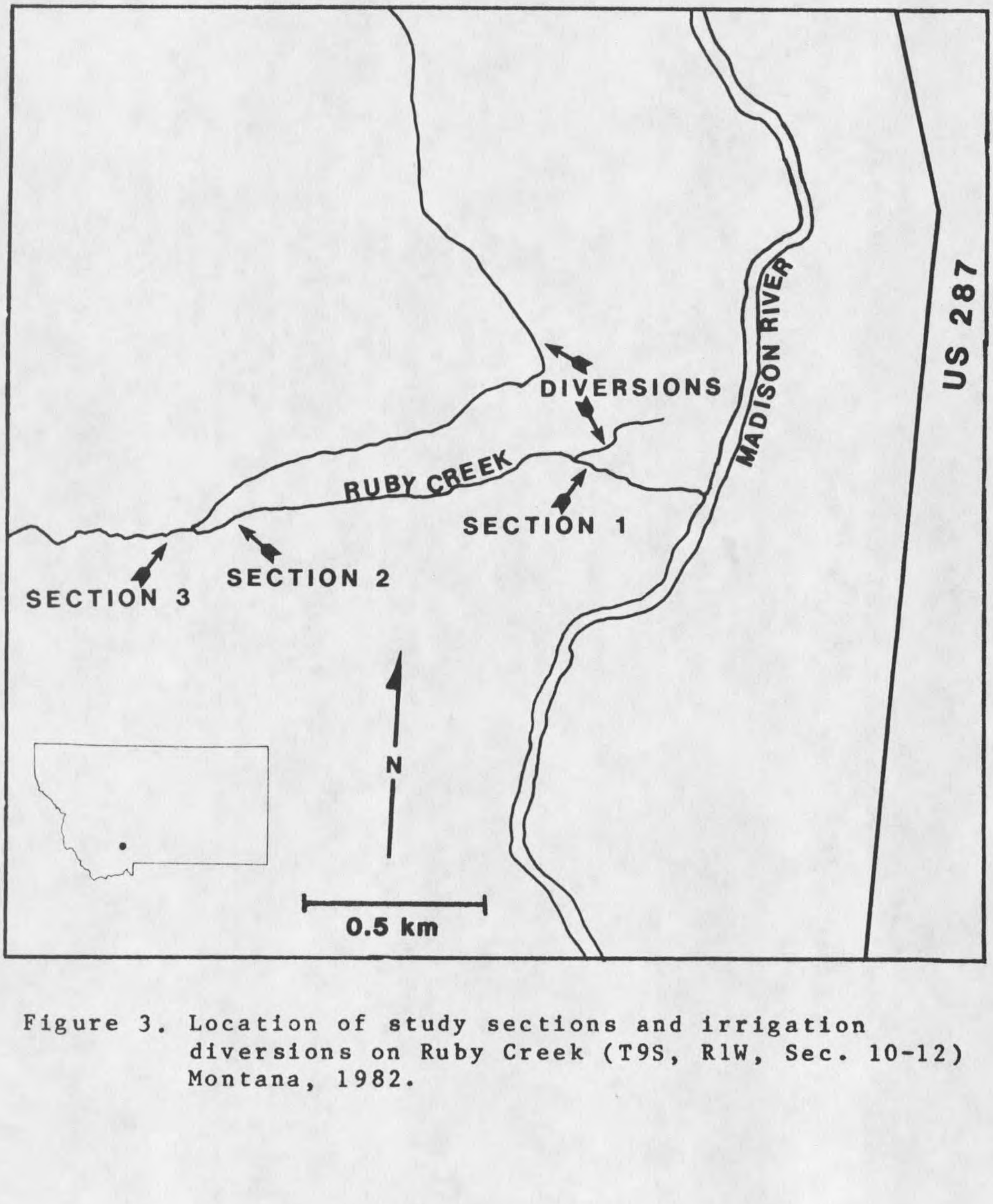

Figure 3. Location of study sections and irrigation diversions on Ruby Creek (T9S, R1W, Sec. 10-12) Montana, 1982.

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

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

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

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

METHODS

Fish Population Manipulation

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

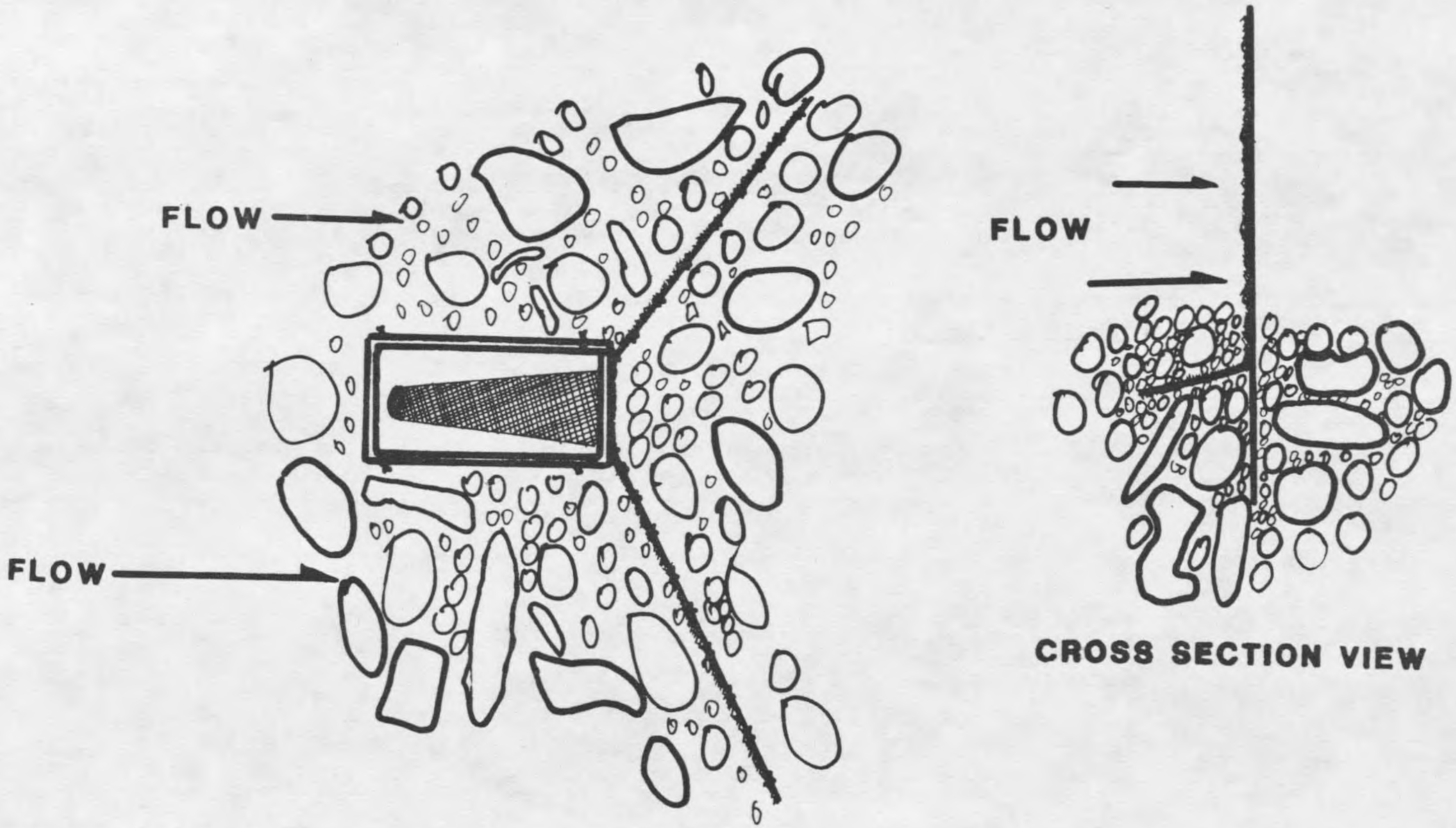

Figure 4. Diagrammatic representation of an upstream fish weir and trap used on Ruby Creek, Montana, 1982.

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

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

Habitat Evaluation

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

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

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

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

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