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EFFECTS OF REDUCED STREAM DISCHARGE ON FISH AND AQUATIC MACROINVERTEBRATE POPULATIONS

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ABSTRACT

We examined the response of aquatic insects and juvenile rainbow-steelhead trout to flow related changes in habitat and assessed the predictive reliability of three hydraulic simulation models currently used in making instream flow recommendations. We conducted spring, summer and fall tests 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 increased behavioral drift and catastrophic drift of aquatic insects, with peak drifting at night. Magnitude and duration of increased drift abundance varied with season, amount of flow reduction, taxa and developmental stage of aquatic insects affects. In all tests, drift rate was reduced during the lowest flow tested. Benthic insect density was not significantly reduced following any discharge reduction tested. However, several insect taxa were significantly affected by low flow conditions. Increased drift appeared to be a mechanism by which aquatic insects redistributed themselves into suitable habitat.

All flow reduction tests resulted in decreased numbers and biomass of juvenile rainbow-steelhead trout. We found that large test fish were affected more by reduced flow than small fish. Since availability of food organisms in the drift was not decreased substantially, except at the lowest discharges tested, larger juvenile rainbow-steelhead trout apparently responded primarily to changes in physical habitat parameters rather than decrease in food availability.

Of the hydraulic parameters we examined in relation to response of experimental fish, velocity was most affected by reduced flow followed by depth, surface area and wetted perimeter. No single hydraulic parameter, however, could consistently be related to the response of test fish. In examining changes in weighted useable area (based on depth and velocity) using the IFG Incremental Methodology and habitat preference curves for juvenile steelhead trout, we found that test fish did not respond entirely as predicted; it appeared that depth and velocity preferences alone were not adequate for predicting the response of juvenile steelhead. Although our data on cover were limited, flow related changes in cover appeared to have a dominant influence on juvenile rainbow-steelhead habitat utilization.

Hydraulic simulation models tested generally predicted accurately the parameters they were designed for. Models varied in ease of calibration, application and useful range of extrapolation. Placement of transects for collecting data for hydraulic simulation in our run-riffle channel was more important than the number of transects used.

CHAPTER 1
INTRODUCTION

Increased demand for water development in the western United States has resulted in a rapid decline in the quality and extent of stream ecosystems. Use of water for domestic, agricultural, and industrial purposes often conflicts with in-stream uses of water by fish and wildlife. Water resource developers are interested in how much of a stream's discharge is available for off-stream use. Consequently, biologists must be able to determine how much water is needed to meet ecological requirements of aquatic biota and what will be lost in terms of fish production, numbers or biomass at various increments of reduced discharge.

Fish, a primary management target of instream flow reservations, depend upon adequate physical habitat, suitable water quality, and food for survival. Each of these requirements is related to discharge. We know that as discharge changes the quantity and quality of physical habitat in terms of cover, depth, velocity, temperature, and wetted perimeter also changes. Food availability and quantity may also change, thus limiting the population. In predicting the impact of reductions in discharge, the biologist needs to know what factor or factors become limiting to the fish population at increments of reduced flow and how these factors relate to standing crop at any particular discharge. If this habitat-standing crop relationship were known, fishery biologists would be able to better predict the impact of alterations in discharge.

Numerous papers appear in the literature which make some reference to relationships between stream flow and aquatic organisms. Many of these, however, are general in content and of little value in clarifying relationships for establishing water needs for aquatic life (Giger 1973).

Reduced stream flow appears to negatively affect abundance and biomass of salmonids (Smoker 1953; Kraft 1968; Burton and Wesche 1974) but little information documenting this relationship is available (Giger 1973), particularly for the rearing portion of the life history. Similarly, little is known about the discharge-habitat requirements of aquatic macroinvertebrates, the food base of the fish. Habitat selection of fish and benthic insects depends upon a complex interaction of physcial and biological factors. Giger (1973) presented an extensive review of research dealing with the relationship between stream flow and aquatic life.

Most research on effects of reduced flow has been related to the influence of decreased cover on fish populations. Kraft (1968, 1972) related changes in stream flow to cover and to fish populations in run and pool type habitats. He found that at 75% reduction in discharge (from a base flow level), abundance of brook trout in a run was reduced by 20%. No fish left the study area during the 75% reduced flow tests, indicating a shift from inhabiting runs to inhabiting pools. At 90% reduction in discharge, abundance of brook trout in two runs decreased 76 and 71%. Although Kraft did not specifically relate changes in trout abundance to changes in fish cover in the runs, his data indicate a fairly close relationship between the two.

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. Wesche found that available trout cover in pool-riffle type channels decreased at the greatest rate for discharge reduction between

25 and 12% average daily flow (Figure 1). Verification of Wesche's cover rating systems as an indicator of standing crop of trout [brown (*Salmo trutta*), brook (*Salvelinus fontinalis*), and rainbow (*Salmo gairdneri*)] was made by comparing biomass estimates and cover 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. Wesche found some large discrepancies, however. He explained these by pointing out that the availability of cover is only one factor limiting trout populations and that this 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 effect of stream discharge on biomass by developing models which predict salmonid standing crop from measurements of select stream habitat parameters. For juvenile coho salmon (*Oncorhynchus kisutch*), pool volume was found to explain 93% of the observed variation in biomass (Figure 3). For cutthroat (*Salmo clarki*) and juvenile steelhead trout (*Salmo gairdneri*), other parameters were necessary to explain variation in standing crop. For these species, models were developed which compute a habitat quality rating, which is the product of a cover value, a velocity preference factor, and the wetted area of the study section. Models developed explained 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 to be

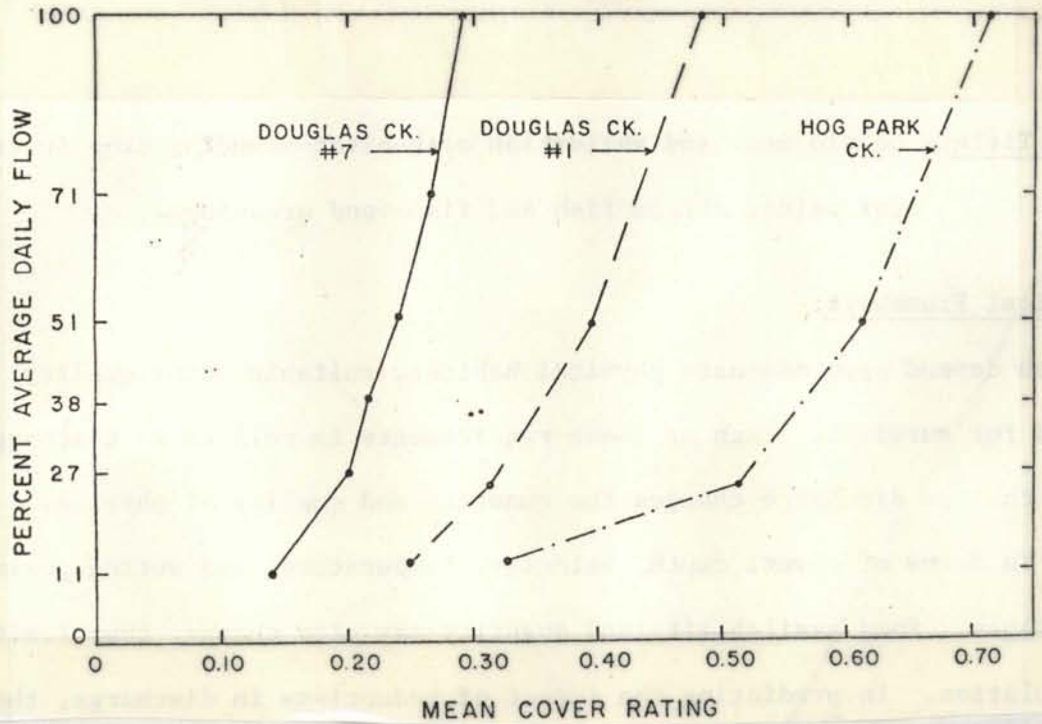


Figure 1. Changes observed in the mean trout cover rating as flow was reduced at the Douglas Creek No. 1, 7 and Hog Park Creek study areas (from Wesche 1974).

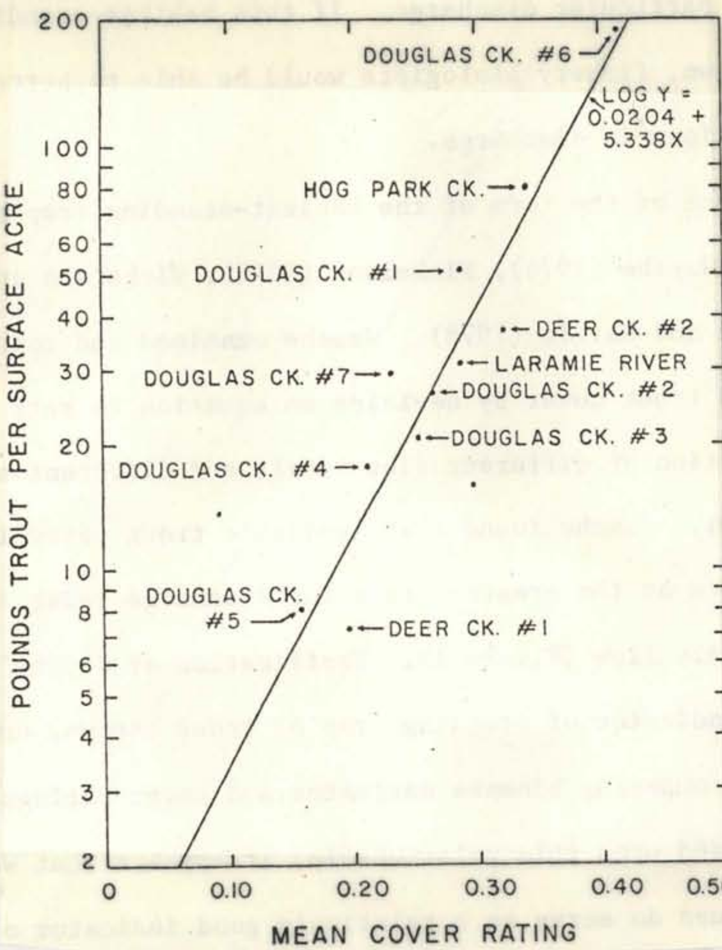


Figure 2. Relationship between mean trout cover rating and the standing crop estimates of trout at the eleven primary and secondary study areas (from Wesche 1974).

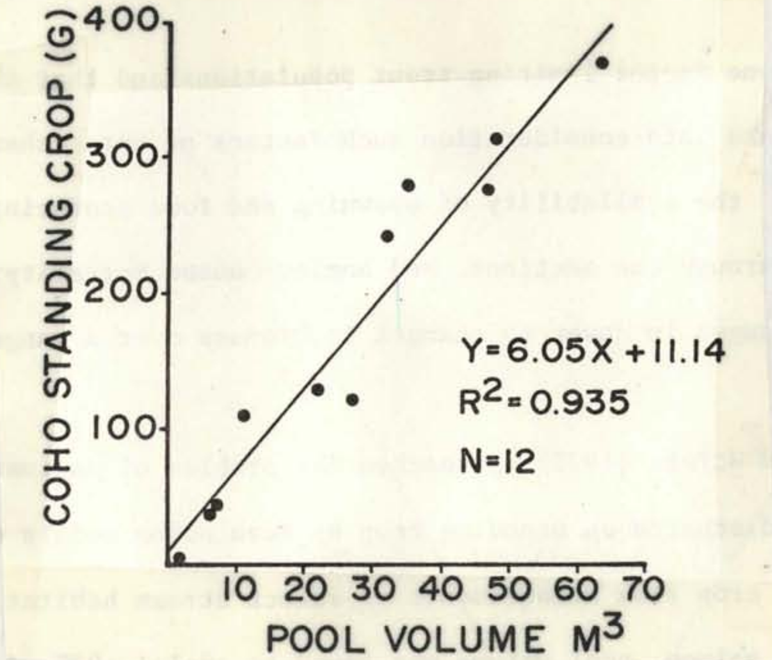


Figure 3. The relationship betwen pool volume and juvenile coho salmon (*Oncorhynchus kisutch*) standing crop (from Nickelson and Hafele 1978).

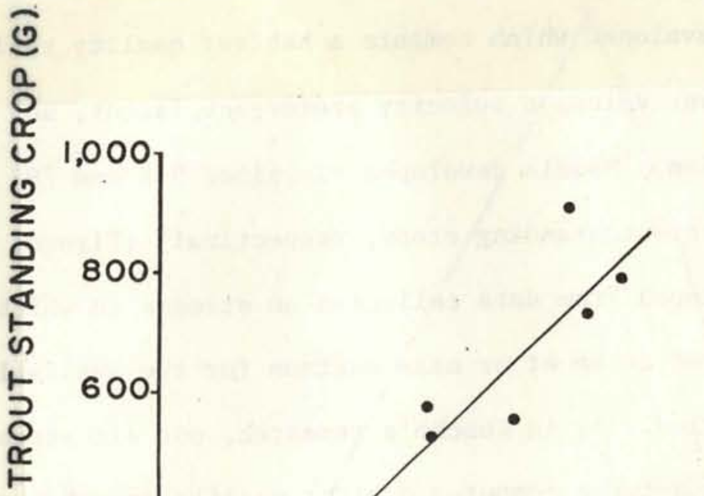


Figure 4. The relationship between HQR_{ct1} and cutthroat trout (*Salmo clarki*) standing crop (from Nickelson and Hafele 1978).

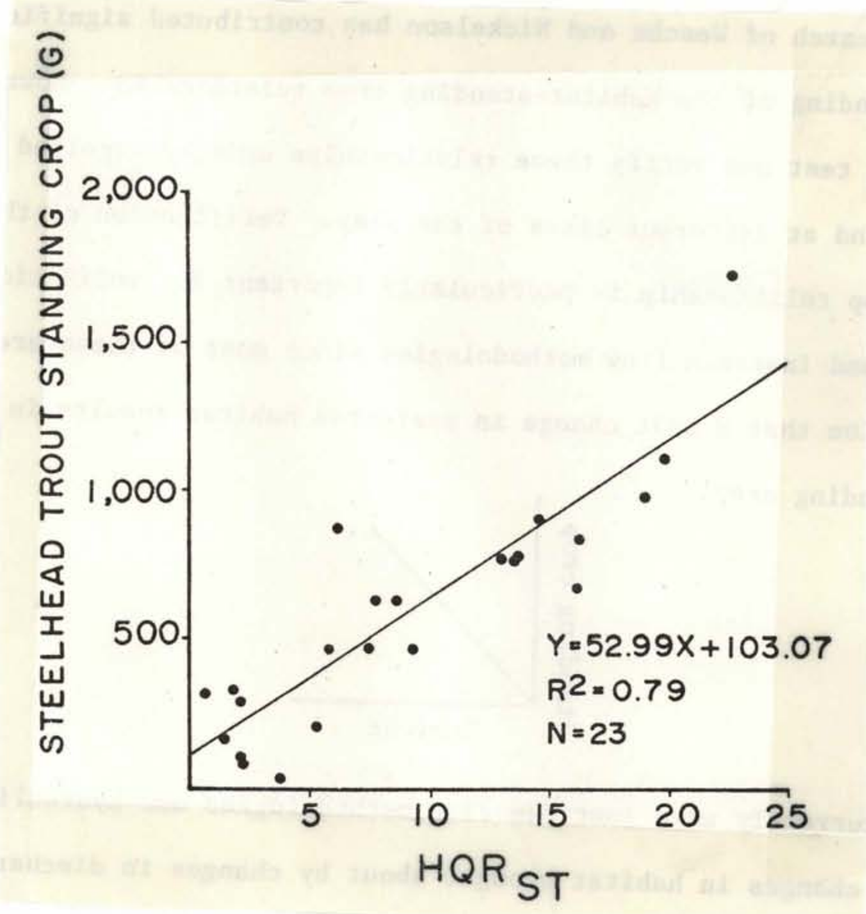


Figure 5. The relationship between HQR_{st} and juvenile steelhead trout (*Salmo gairdneri*) standing crop (from Nickelson and Hafele 1978).

at or near maximum density 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) also 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 observed variation in coho salmon biomass. Nickelson obtained inconsistent results, however, in a repeat of these studies in 1976. Where he observed a relatively good correlation between juvenile coho salmon biomass and habitat quality in 1975, such a relationship was nonexistent in 1976.

Verification of the habitat-standing crop relationship is particularly important for validation of currently used instream flow methodologies. Our study was a first step toward this end.

Discharge alterations may also affect the abundance and/or availability of fish-food organisms. The reported response of the benthic community to low flow conditions is varied. McClay (1968) found significantly larger numbers of invertebrates on a riffle after a 75% flow reduction. Following a series of incremental discharge reductions in an Oregon coastal stream, however, Hafele (1978) concluded that the benthos were unaffected by low flow conditions. Community composition of the Tongue River, Montana, was radically altered by reduced discharge following the closure of a dam (Gore 1977). Geographic location, time of year, channel configuration, hydraulic regime, and species composition are some of the factors that may influence the response of benthic biota to discharge alterations. Because of the importance of aquatic insects as food for fish, a better understanding of how these populations respond to reductions in stream flow is needed.

Most currently used instream flow methodologies use hydraulic simulation to predict changes in habitat brought about by changes in discharge. Empirical equations, most notably the Manning equation, are commonly used in these simulation models. Certain assumptions about such parameters as type of flow (i.e., uniform steady flow), slopes, roughness, velocity distributions and discharge are included in the development and use of the models. As long as the various assumptions used are reasonably consistent with actual observations and experience, they are amenable to the analytical treatment of theoretical hydraulics (Chow 1959). If hydraulic simulation models are to be used in methodologies for making instream flow recommendations, we must be confident that the models are producing reasonably accurate predictions of hydraulic conditions as they would actually exist at a given flow. The best biological criteria when interfaced with erroneous hydraulic parameters could result in stream flow recommendations that are wholly inadequate both in amount and in timing.

Before methodologies for recommending suitable instream flows can be confidently applied, a better understanding of the discharge-ecosystem relationship must be developed. The first phase of a long-term research effort by the Idaho Cooperative Fishery Research Unit to study the effects of reduced flows on fish and macroinvertebrate populations started in 1977.

The objectives of our study were:

1. to measure the drift response of aquatic invertebrates to increments of reduced stream discharge.

2. to relate benthic invertebrate abundance and biomass to stream discharge.

3. to determine the relationship between juvenile rainbow-steelhead trout (*Salmo gairdneri*) abundance, in numbers and biomass, and increments of reduced stream discharge.

4. to determine order of importance of depth, velocity, cover and food in limiting abundance of juvenile rainbow-steelhead trout at increments of reduced stream discharge.

5. to assess changes in primary hydraulic characteristics associated with incremental reductions in streamflow.

6. to evaluate the validity and utility of selected hydraulic simulation models currently being used in methodologies for recommending instream flows, especially with respect to predictions of stage-discharge relationships, depths and velocities.

CHAPTER 2
STUDY SITE AND FACILITIES

Reduced stream flow tests were conducted in two large flumes at the Troy Experimental Facility on the Grande Ronde River near Troy, Oregon (Figures 6 and 7). The Grande Ronde River originates in the Blue Mountains of northeastern Oregon and flows into the Snake River. Surface rock formations are mostly of Tertiary to Quaternary volcanic origin, and most of the basin is underlain by Columbia River Basalt (Laird 1964). The climate is semi-arid at the study site with most precipitation occurring in the winter and spring. Summer air temperatures often exceed 38 C (100 F), and, while winter air temperatures are usually above -6.5 C (20 F), surface and anchor ice formation in the river occurs frequently. Water chemistry (Table 1) is typical of soft water streams in areas of volcanic origin. Such waters are normally less productive, and support lower standing crops of aquatic organisms than hard water streams (Armitage 1958; Egglishaw and Morgan 1965; Egglishaw 1968). Average annual discharge for the 34 years of record was 88.67 m^3/s (3,131 ft^3/s) (U.S. Geological Survey 1979).

The two identical concrete and wood flumes, 62.3 m (204.4 ft) in length and 6 m (19.7 ft) in width, were partially filled with 1223.3 m^3 (43200 ft^3) of river gravel and shaped into simulated natural streams with near-identical run-riffle configurations and trapezoidal cross-sections (Figure 8). Each channel contained two 9.14 m (30 ft) riffles and two 12.2 m (40 ft) runs. The bottom width of the riffles was 3.0 m (10 ft), and the runs 2.4 m (8 ft). The channel configuration was nearly rectangular in cross-section. Cobbles 2.5 to 7.6 cm (1-3 inch) formed the substrate of the riffles. Similar cobble substrate was in the

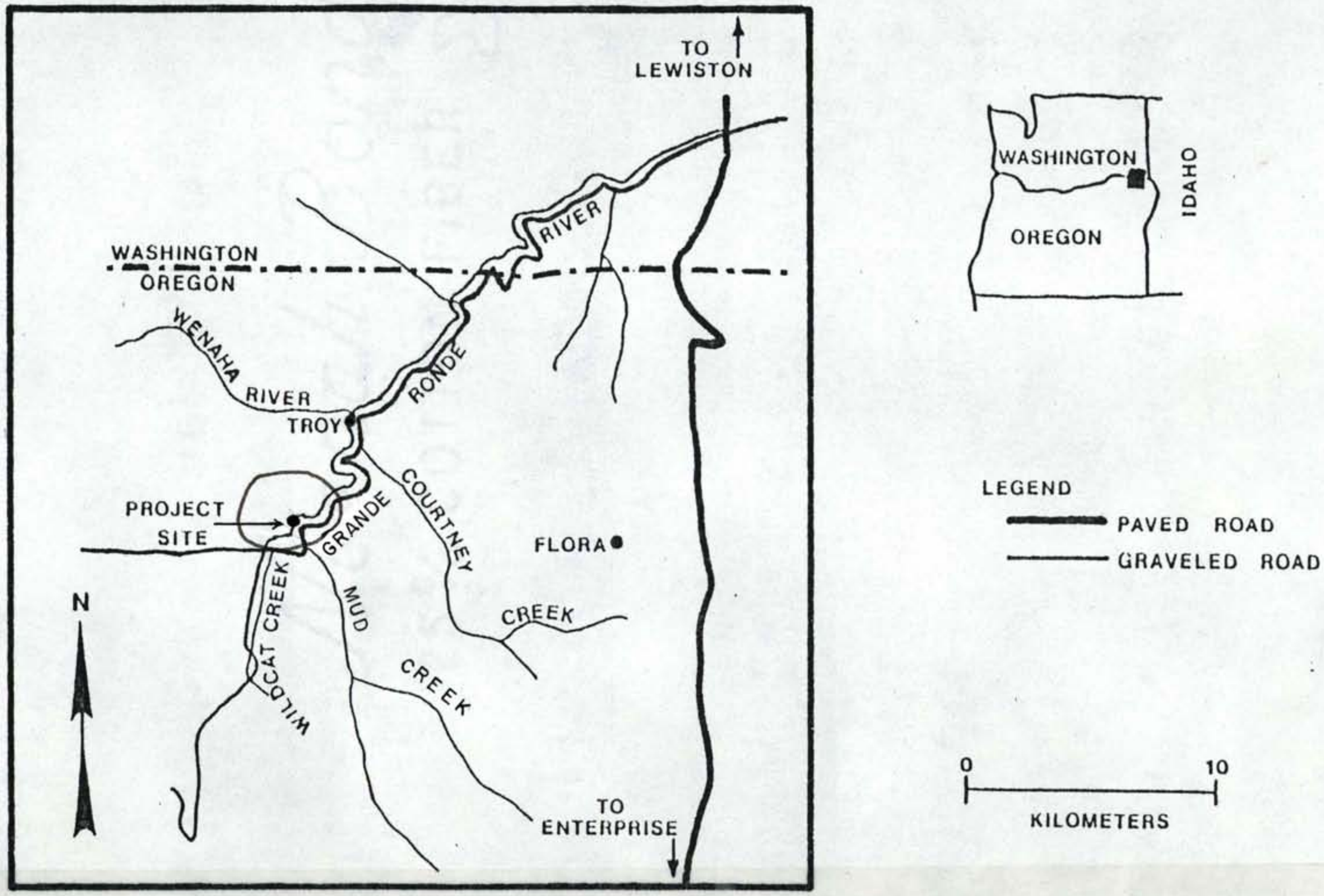
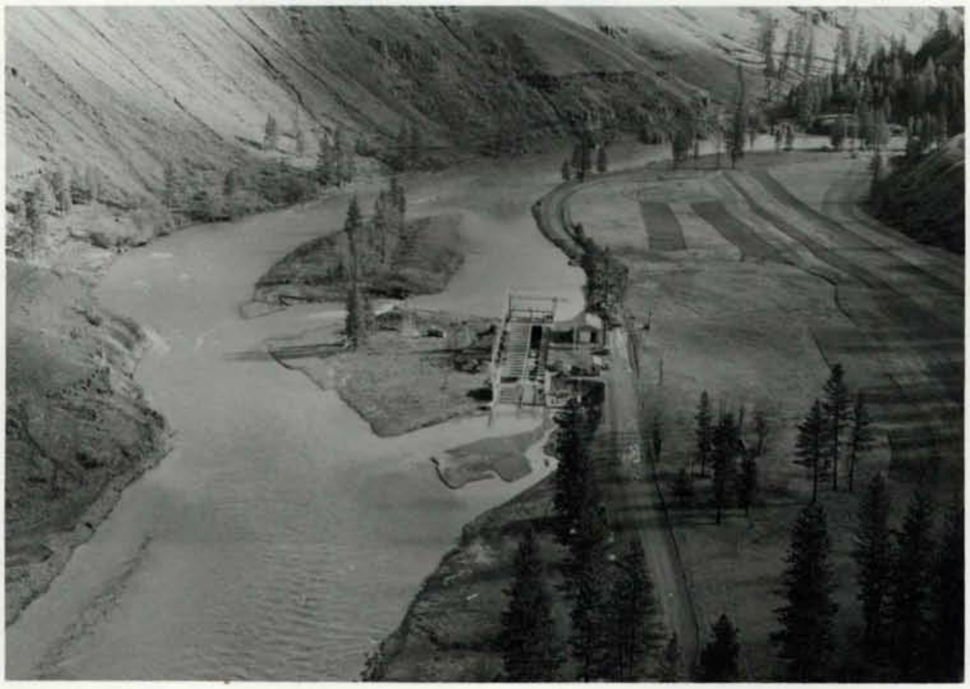


Figure 6. Location of the Troy Instream Flow Research Facilities on the Grande Ronde River, Wallowa County, Oregon.



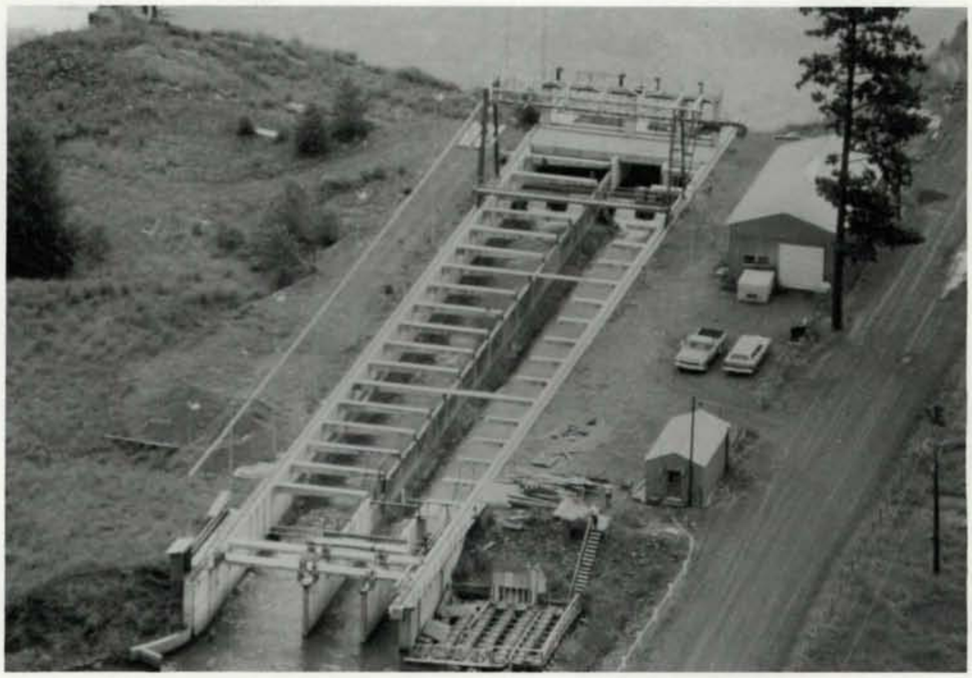


Figure 7. Troy Instream Flow Research Facilities located on the Grande Ronde River, Wallowa County, Oregon.

Table 1. Mean values from monthly water quality analysis, Grande Ronde River, Asotin County, Washington, 1976-1977[a].

Measurement	Mean value [b]
Calcium	15
Magnesium	3.3
Sodium	6
Potassium	2.2
Sulfate	4.2
Chloride	1.3
Nitrate-Nitrite N	.04
Total NH_3N	.05
Ortho P	.02
Total P	.05
Hardness	51
Carbonate	9.0
Bicarbonate	71
Alkalinity	58
Conductivity	116.5
pH	7.3-7.6[c]

[a] Data from U.S. Geological Survey 1978.

[b] All values in mg/l except conductivity (micromhos cm^{-1} @ 25 C).

[c] Laird 1964.

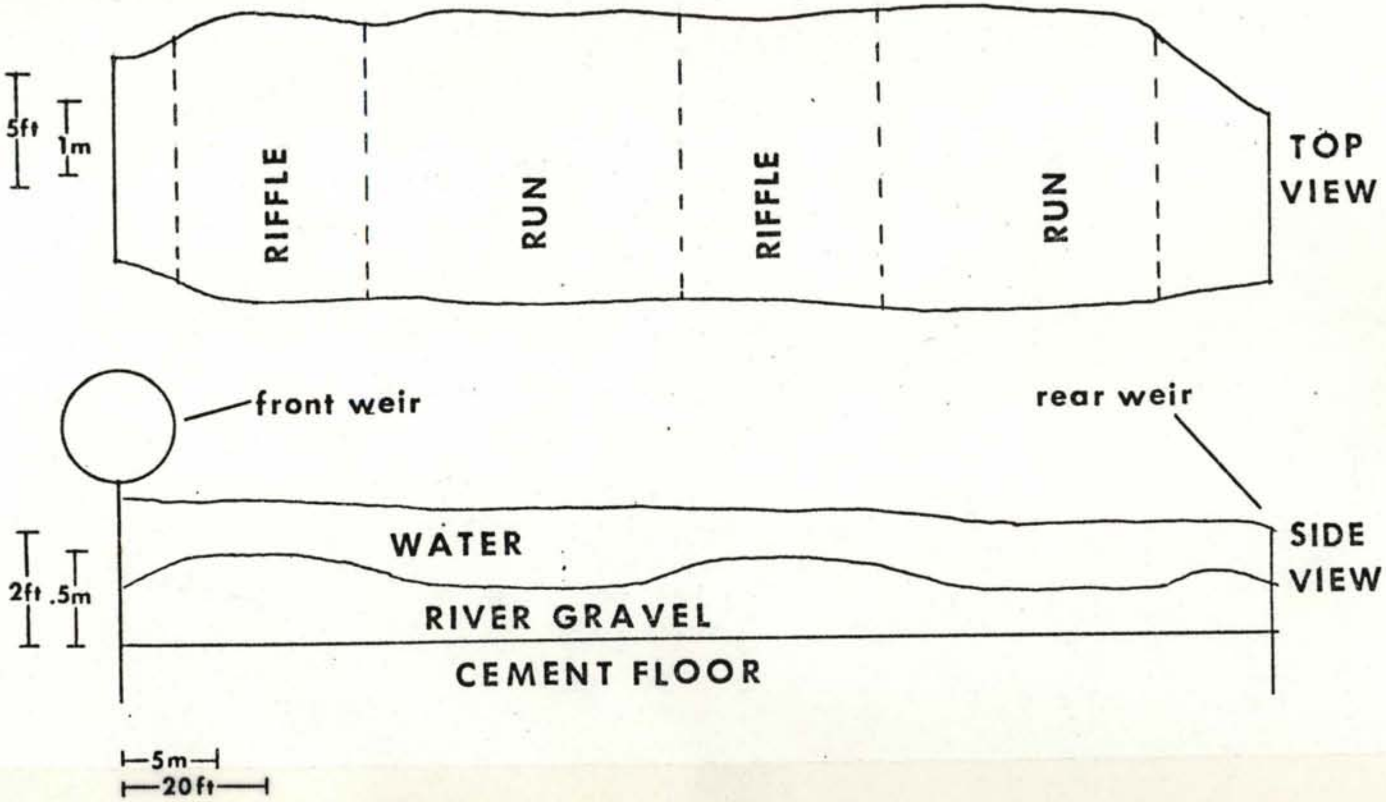
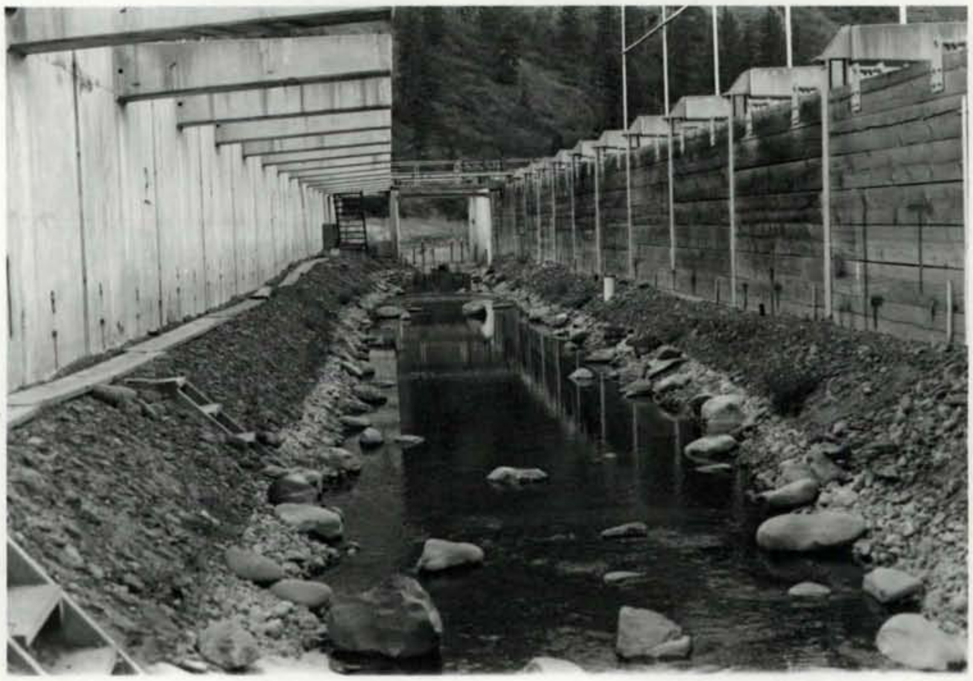


Figure 8. Schematic diagram of simulated stream channel of the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Water depths and widths represent a discharge of 0.57 m^3/s (20 ft^3/s).

runs during the fall 1978 tests, however, during the winter of 1978-79 large amounts of organics and fine inorganics accumulated in the runs. These accumulations, deeper than 15 cm in places, remained for the spring and summer 1979 experiments. Boulders (>0.3 m) were placed in runs to provide cover and resting areas for fish (Figure 9). Weirs and fish traps were located at the upstream and downstream ends of the channels to monitor fish emigration (Figures 10 and 11).

Grande Ronde River water, diverted through a diked side channel, provided for up to 0.57 m^3/s (20 ft^3/s) flow in each test channel (Figure 12). Flow into the flumes was controlled by head gates which were manipulated to provide a range of test discharges. Discharge in the channels was monitored using stage recorders and flows were adjusted as necessary to maintain constant known discharges based upon a stage-discharge relationship. Temperature was monitored during all tests by recording thermographs (Figure 13).

During fall 1978 water flowed into each channel through self-cleaning rotating screened drums (Figure 10). These drums reduced immigration of non-stocked fish into each channel from the upstream end. The downstream traps prevented immigration from below the channels. Because of problems of maintaining adequate head of water during low flow periods, the rotating screens were replaced in 1979 by self-cleaning inclined screens which did not prevent fish immigration from the upstream direction (Figure 14).



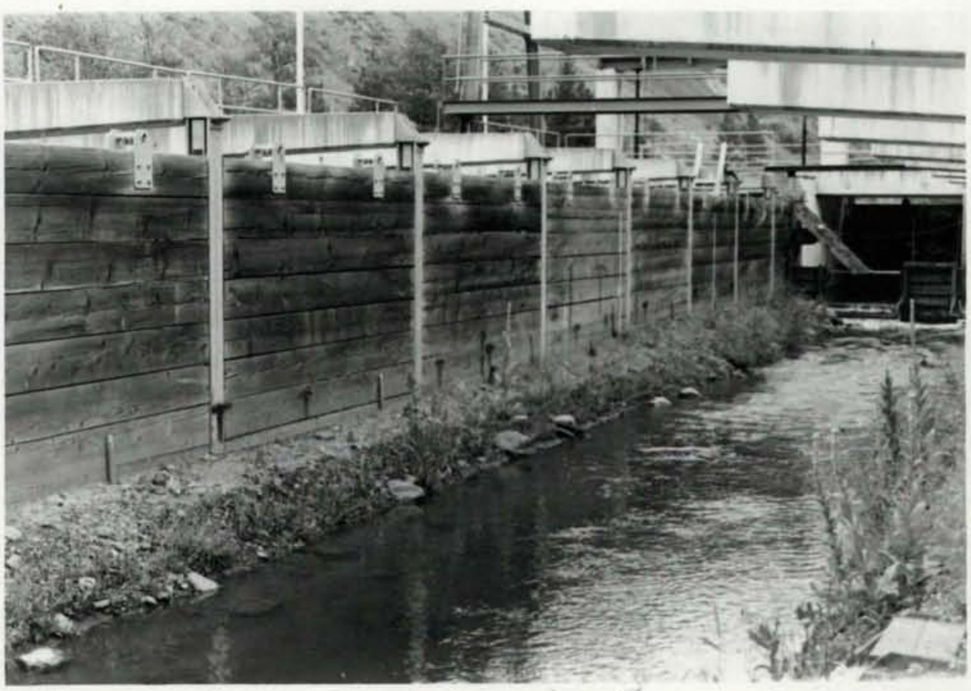
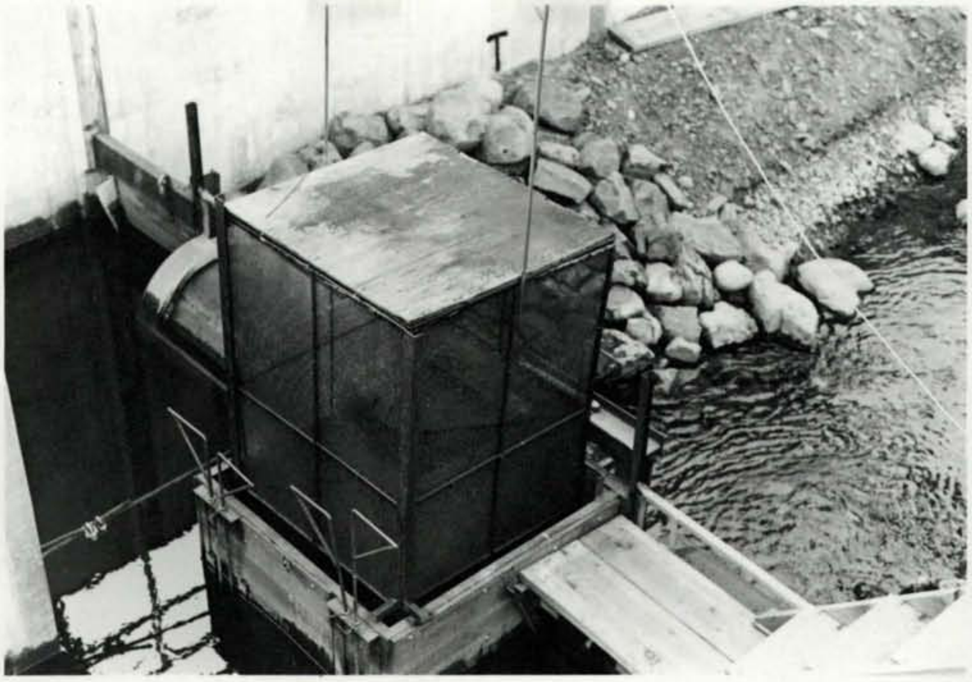


Figure 9. Simulated stream channel of the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Upper photo depicts the west channel at approximately 0.03 m^3/s (1 ft^3/s) prior to vegetative growth. Lower photo depicts the west channel at approximately 0.28 m^3/s (10 ft^3/s) after vegetative growth.



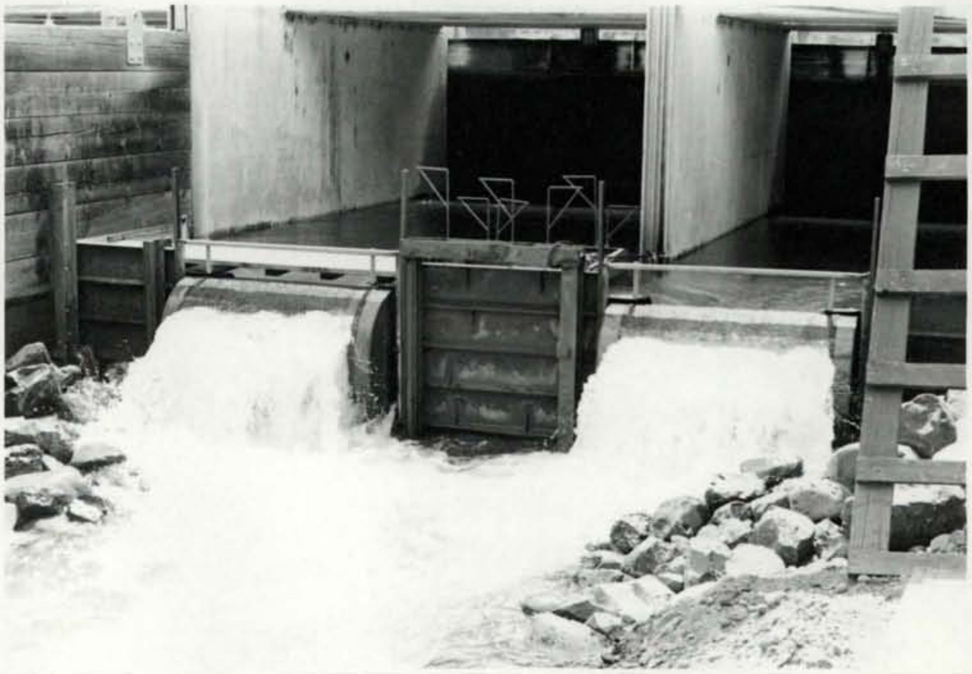


Figure 10. Upstream weir and trapping structures used during the fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

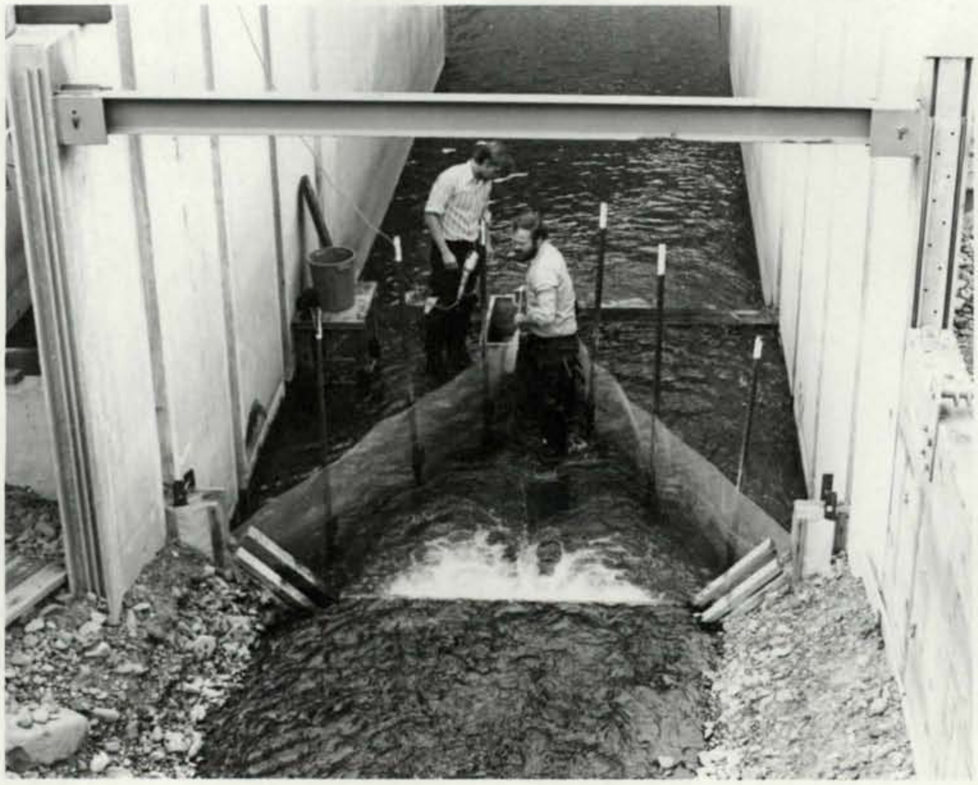


Figure 11. Downstream weir and trapping structures of the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

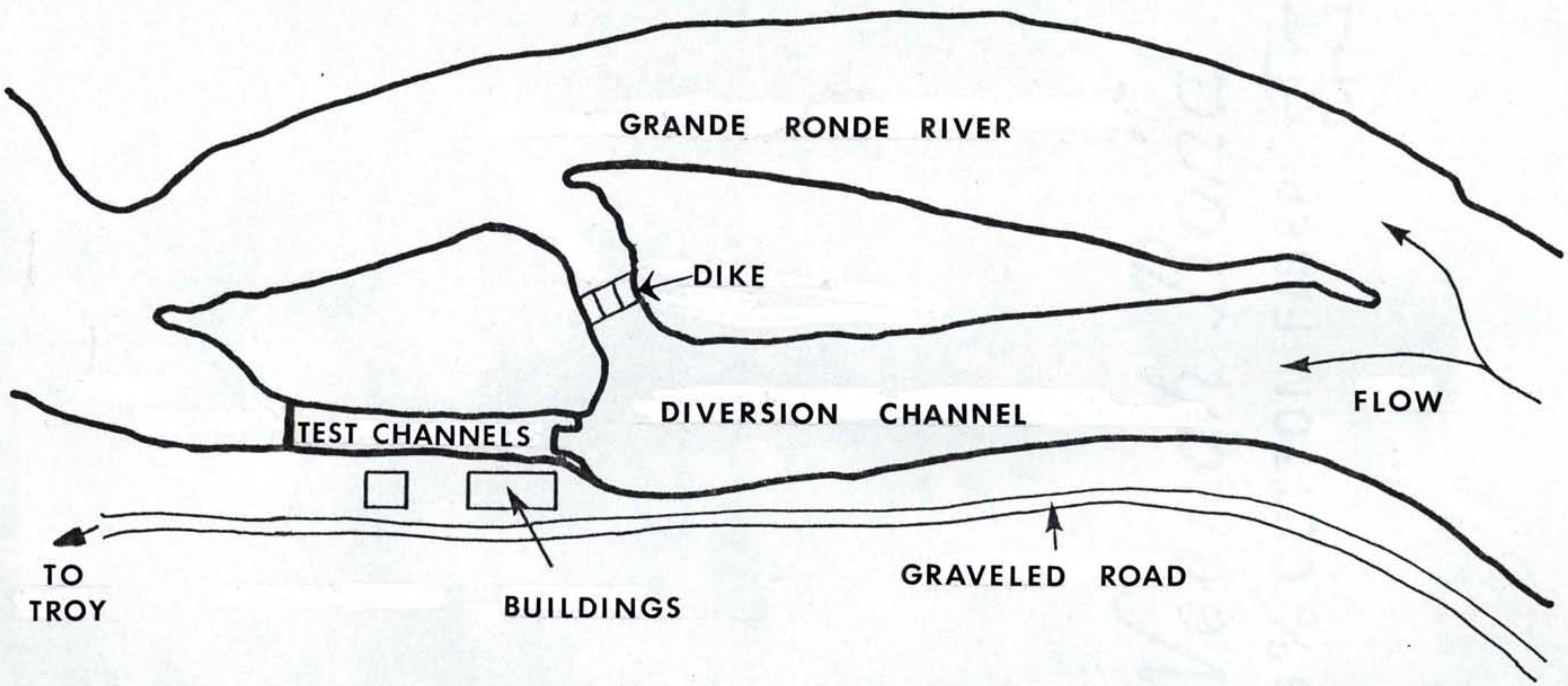


Figure 12. Location of the experimental stream channels in relation to the Grande Ronde River, Wallowa County, Oregon.

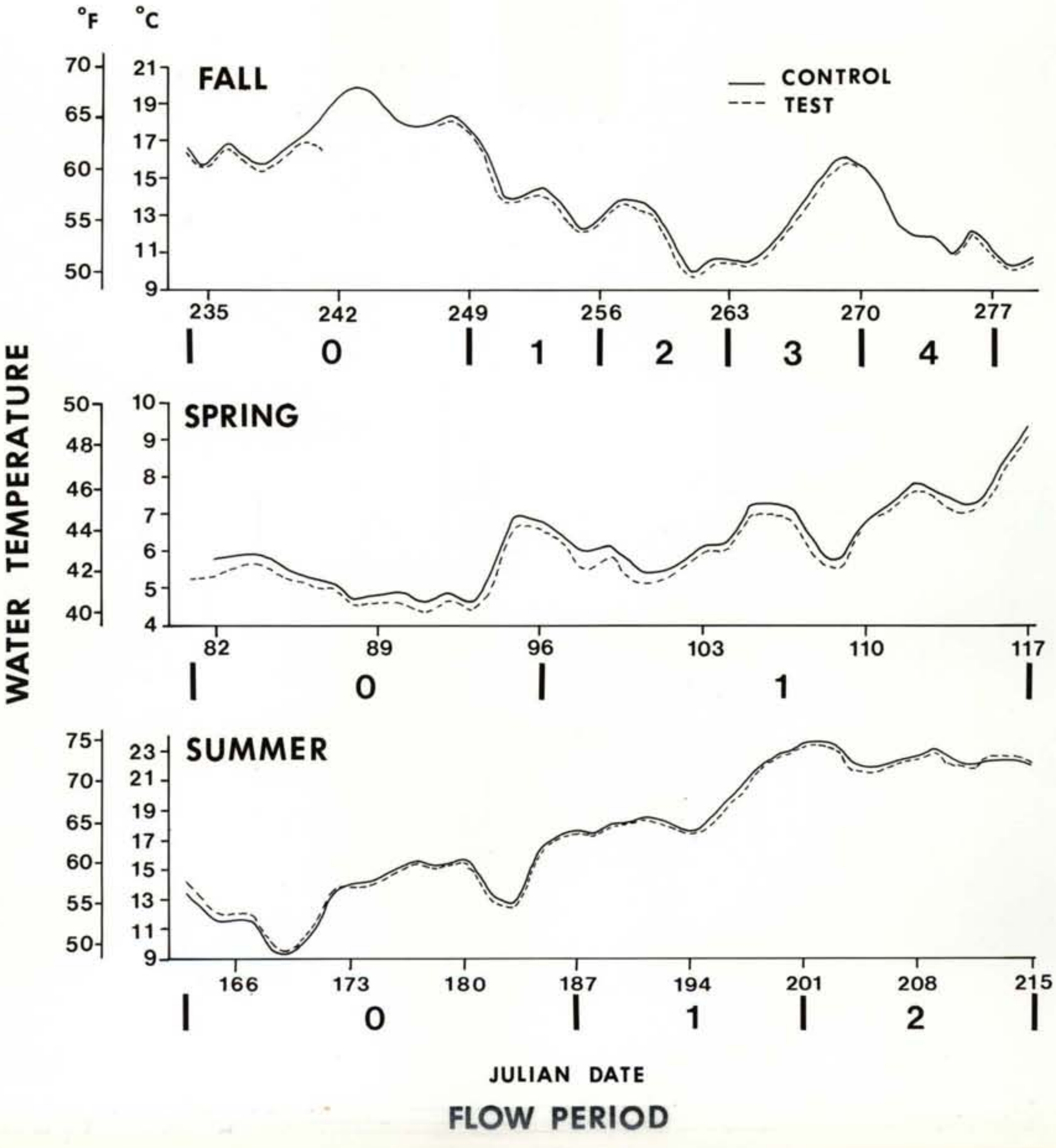


Figure 13. Mean daily water temperatures for the fall 1978, spring, and summer 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. The fall 1978 experiment has missing record for days 242-247 and 271-274 for the test channel.

Figure 14. Upstream weir and trapping structures used during the spring and summer 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

CHAPTER 3
FLOW REGIMES

Three reduced flow experiments were completed during our study: fall 1978 (22 August-4 October), spring 1979 (22 March - 27 April), and summer 1979 (12 June-4 August) (Table 2). One channel was used as a control (discharge unchanged) while discharge in the test channel was reduced incrementally from a base flow (100%). In the fall experiment, reductions of 50, 70, 85, and 95% were made. One reduction of 90% was made in the spring. One controlled reduction of 50% was tested in the summer; a second reduction of 80% was terminated after 4 days because of declining flows in the Grande Ronde River; a flow 95% below base flow was used for the remainder of the experiment. A base flow of 0.57 m^3/s (20 ft^3/s) was used during the fall experiment while 0.28 m^3/s (10 ft^3/s) was used for the spring and summer experiments. Flows were reduced gradually in the the test channel over a 3 hour period from 0800 to 1100 h. Reduced flow tests had a duration of 1 to 3 weeks.

Table 2. Dates, flows and percent decrease from base flow studied in controlled flow reduction tests at the Troy, Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, 1978 and 1979.

Season, Year	Flow period	Date	Days	Control flow[a] m^3/s (ft^3s)	Test flow[a] m^3/s (ft^3/s)	%decrease
Fall, 1978	0	22 August-6 September	15	.57 (20)	.57 (20)	0
	1	6 September-13 September	7	.57	.28 (10)	50
	2	13 September-20 September	7	.57	.17 (6)	70
	3	20 September-27 September	7	.57	.08 (3)	85
	4	27 September-4 October	8	.57	.03 (1)	95
Spring, 1979	0	22 March-6 April	15	.28 (10)	.28 (10)	0
	1	6 April-27 April	22	.28	.03 (1)	90
Summer, 1979	0	12 June-6 July	24	.28 (10)	.28 (10)	0
	1	6 July-20 July	14	.28	.17 (6)	50
	2	20 July-4 August	16	.01 (.5)[b]	.01 (.5)[c]	95

[a] Actual measured discharge during tests varied somewhat from these intended discharges and are reported in the hydraulic assessment section of this report.

[b] Unable to maintain control flow at .28 m^3/s after second day of flow period.

[c] Unable to maintain scheduled discharge of .06 m^3/s after fourth day of flow period.

CHAPTER 4
RESPONSE OF FISH-FOOD ORGANISMS TO REDUCTIONS IN STREAM DISCHARGE

Habitat selection by benthic invertebrates depends upon a complex interaction of physical and biological factors. Microdistribution patterns are influenced by water velocity, depth, substrate particle size, and food (Needham and Usinger 1956; Kennedy 1967; Egglishaw 1969; Barber and Kevern 1973; Minshall and Minshall 1977). Many benthic invertebrates have an intrinsic need for water current, either for feeding purposes or because of respiratory requirements (Philipson 1954; Hynes 1970; Wallace 1975). Current is considered a major factor in the occurrence and abundance of benthic fauna (Hynes 1970), however, with the exception of filter feeders such as netspinning caddisflies and the black fly dipteran larvae, the effects of current are generally indirect. Current interacts with most factors determining invertebrate distribution; it influences the type of substratum, transports oxygen, and transports and sorts the detrital food base (Rabeni and Minshall 1977). Water depths of 0.03 m or less tend to be the most productive (Hooper 1973), but the influence of depth is poorly understood. Physical characteristics such as water velocity and depth interact during flow reductions and may produce conditions unfavorable for benthic invertebrates.

A positive correlation exists between water velocity (or stream discharge) and the quantity of drifting organisms (Elliot 1967). However, short-term increases in invertebrate drift may result from reductions in stream flow (Pearson and Franklin 1968; Minshall and Winger 1968; Radford and Hartland-Rowe 1971b; Brusven and MacPhee 1976; Gore 1977). Minshall and Winger (1968) concluded that increased behavioral drift following a rapid flow reduction was an active response to changes in depth and velocity. Elliot (1967) found that a decrease in velocity caused a reversal of the normal positive thigmotaxis and initiated swimming activity. In laboratory studies, Ciborowski et al. (1977) found that a disproportionately large number of mayfly nymphs drifted during a period of flow change. They suggested that the change in water velocity is more important in determining drift magnitude than is the actual velocity.

This portion of our study was designed to document the response of the invertebrate community to decreases in stream discharge. These objectives were:

1. to measure the drift response of aquatic invertebrates to increments of reduced stream discharge; and

2. to relate benthic invertebrate abundance and biomass to stream discharge.

Methods

To evaluate the response of the aquatic macroinvertebrates to reductions of stream discharge, we monitored the composition and abundance of the invertebrate drift and benthic communitites within each channel. Drifting invertebrates were sampled with 30 cm^2 (1 ft^2) nets having a mesh size of 750 micrometers. Inadequate sampling of small and early instar organisms was likely because of the large mesh size of the nets. Drift nets were placed at the upper and lower portions of each channel to monitor immigration and emigration. In the fall 1978 experiment, drift was collected for 2 days prior to the initial flow reduction and then on the first 2 days and last 2 days of each successive 1 week flow period.

For the spring and summer experiments when flow tests were of 2 weeks duration, drift was sampled 1 week and 1 day prior to reduction from base flow and on day 1, 4, 7, and 15 of each flow reduction period. On each sample day, drifting insects were collected at midday, dusk, midnight, and dawn. Due to time constraints, midday samples from the fall experiment were not analyzed. Drift nets were set one-half hour before the prescribed time and left for 1 hour. To remove insects and debris from the drift nets, the nets were held in a bucket and sprayed with water. To consolidate the drift sample material, we poured the contents of the bucket through a 0.5 mm sieve. Each sample was then preserved in 10% formalin.

Benthic organisms were collected with a 30 m^2 (1.0 ft^2) cylindrical Hess sampler with a 750 micrometer mesh net. The substrate within the sample area was stirred thoroughly to a depth of approximately 10 cm; all rocks larger than 7.6 cm were scrubbed with a brush. The sample was placed into a plastic tub then washed through a 0.5 mm mesh sieve. If a large amount of substrate material was present, the sample was sugar-floated three times to separate the invertebrates and organic matter from the gravel and sand (Anderson 1959). During the sugar-floating procedure the samples were washed through a 0.18 mm mesh sieve to insure that most organisms were retained. Samples were preserved in 10% formalin. In each channel, benthic samples were collected from run and riffle habitat types. During the fall 1978 experiment and the base flow period of the spring 1979 experiment, two benthic samples were taken from each habitat type. During the reduced flow period of the spring 1979 experiment and throughout the summer 1979 experiment, three samples were taken from each habitat type. All samples were collected on the last day of each flow period.

The vertical distribution of invertebrates in the hyporheic zone was sampled with 10.5 by 17.5 cm perforated cans (Radford and Hartland-Rowe 1971a) imbedded in a riffle. Each can had approximately 50 2.0 cm holes cut into it. The cans were divided into two depth zones of 0-7.5 cm and 7.5-17.5 cm. The cans were allowed to colonize with insects for 28 days prior to the first flow reduction of the fall experiment; canisters used in the summer experiment had been in place for 9 months (273 days) prior to removal at the start of the test. Three cans were collected at the end of the base flow period and at the end of the final reduced flow period. All samples were washed through a 0.5 mm mesh sieve and were sugar-floated if a large amount of sand was present.

Water velocity and depth were measured at each drift and benthic sample location. Velocity for drift samples, measured with a Marsh-McBirney (Model 201) direct readout current meter, was taken at 0.6 depth for stream depths under 0.3 m and at 18 cm for depths over 0.3 m. Velocities for benthic sample locations were measured at the water surface, 0.6 depth, and at 2-3 cm above the substrate.

In the laboratory, invertebrates were hand sorted from detritus with the aid of a dissecting microscope (8-40X). When large amounts of detritus were present, samples were mechanically sub-sampled (Reger 1980). The taxonomic keys used for invertebrate identification were: Merritt and Cummins (1978), Baumann et al. (1977), Wiggins (1977), Edmunds et al. (1976), and Jensen (1966).

Biomass estimates (dry weight) for selected insect genera were based on aggregates of organisms taken from the test and control riffles. All samples were placed on pre-dried and weighed filters and oven-dried for 24 hours at 105 C (Weber 1973). The resultant dry weight was divided by the number of organisms in the aggregate to get estimates of individual biomass. Separate estimates for each genera, by flow period, were calculated.

The Brillouin diversity index was used to calculate generic diversity. Generic diversity provides similar information about the community as species diversity (Kaesler et al. 1978). Diversity and evenness values calculations were aided by use of a computer. Statistical analyses were performed with Statistical Analysis System (SAS Institute 1979) procedures). The Kruskel-Wallis non-parametric, one-way analysis of variance procedure was used when sample size was three and the Wilcoxon Rank Sum procedure was used when sample size was two. Statistical comparisons for total insect and generic abundance between each flow period were valid only if there was an overall significant difference ($p < .15$) during the experiment.

Results

Thirty-six families representing 55 genera of aquatic insects, and five families not keyed to genera were collected during the study period. Five noninsect aquatic taxa were also collected (Appendix A).

Fall 1978 Experiment

Drift

Invertebrate drift was largest during the base flow period (0.57 m^3/s, 20 ft^3/s) and early part of the first reduction period (0.28 m^3/s, 10 $ft^3/3$); for the remainder of the experiment behavioral drift in the control channel decreased to generally less than one-half of the initial values (Appendix B) indicating either seasonal effects or response to lower water temperatures (Figure 13). Changes in water temperature during the experiment were similar in both channels.

Drift densities during the base flow period were similar in the test and control channels (Figure 15 and Appendix B). Flow reductions in the test channel altered behavioral drift patterns from those observed in the control. Behavioral drift was least affected by the 50% flow reduction (0.28 m^3/s, 10 ft^3/s). While total drift increased slightly at dusk (Appendix B), densities returned to control levels by the end of the flow period indicating a return to normal behavioral drift patterns. Midnight and dawn drift patterns were unaffected by the reduction. The second flow reduction (0.17 m^3/s, 6 ft^3/s) resulted in increased numbers of organisms in the drift throughout the night, with the largest increase at dusk of the first night. This response was short-term and drift densities and rates in the test channel had returned to near control levels by the end of the week.

A flow reduction of 85% (.08 m^3/s, 3 ft^3/s) caused an average six-fold increase in insect drift densities compared to control levels. The greatest response occurred at dusk of the first night when twice as many insects drifted and the resulting drift density was nearly eight

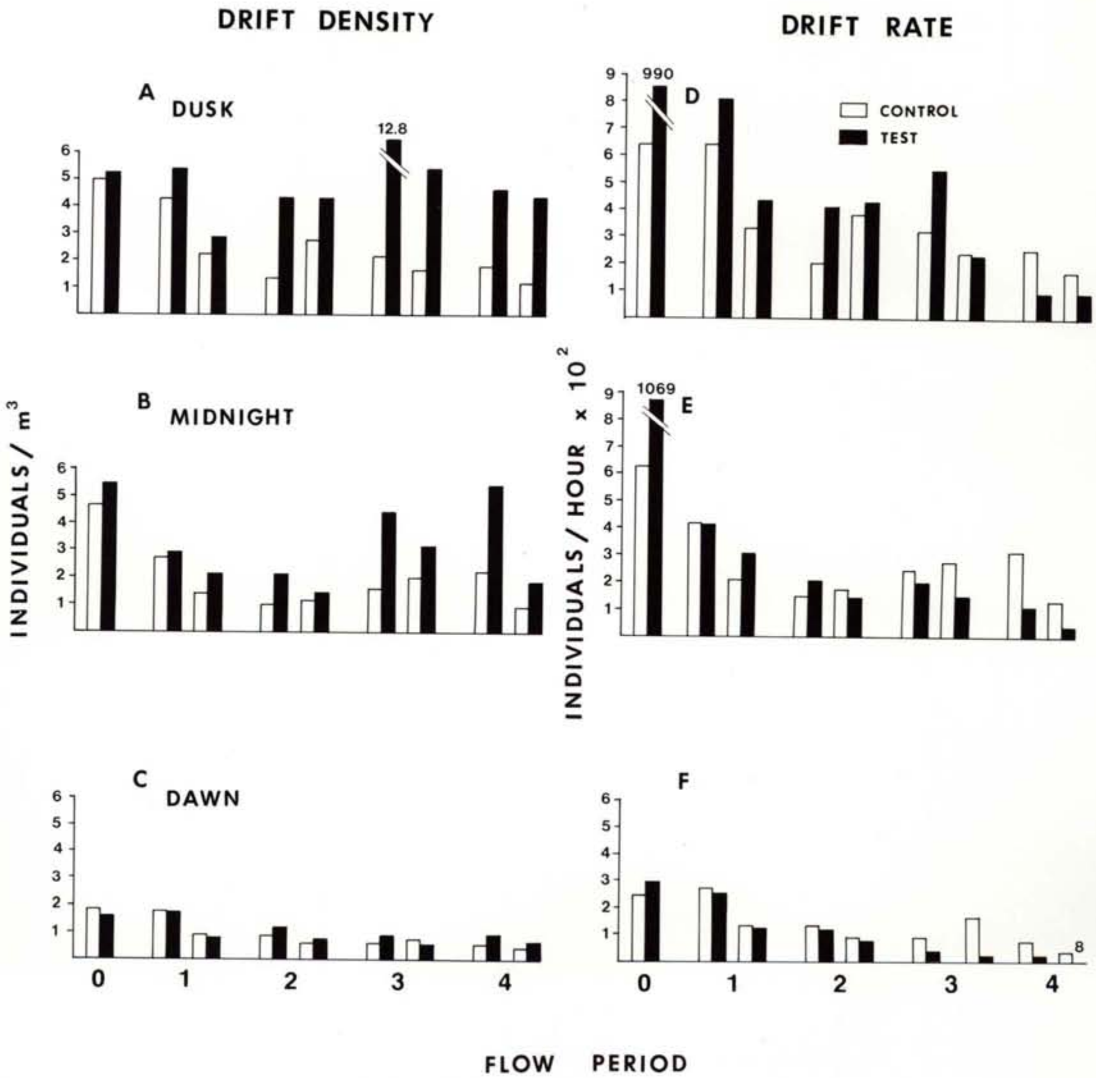


Figure 15. Total insect drift density and rate at dusk (A, D), midnight (B, E) and dawn (C, F), respectively, fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Bars represent mean drift of the first two and last two days of each flow period, except base flow period (0), in which only the last two days are presented. Test flow periods: 0 = 0.57 m^3/s; 1 = 0.28 m^3/s; 2 = 0.17 m^3/s; 3 = 0.08 m^3/s; 4 = 0.03 m^3/s. Control flow = 0.57 m^3/s.

times the control drift level. While drift density remained high throughout the night, drift rates at midnight and dawn were generally below those observed in the control (Figure 15). Increased behavioral drift continued throughout the 1 week flow period. Drift densities remained high during the final flow reduction test (95%; 0.03 m^3/s, 1 ft^3/s) but drift rates were reduced 50% or more as compared to drift rates in the control channel. During the 70, 84, and 95% flow reduction tests, drift patterns in the control channel remained nearly constant.

We found that insect genera responded differently to reduced discharges. The most abundant caddisflies in the drift were the hydropshychids *Cheumatopsyche* and *Hydropsyche* and the leptocerid *Oecetis* (Appendix B). The drift of *Cheumatopsyche* and *Hydropsyche* was similar and is represented by *Cheumotopsyche* in Figure 16. Hydropsychid drift in the control channel was intermittent with no individuals taken in most samples. Short-term increases in hydropsychid drift occurred at dusk following the first two reductions (50 and 70%), however, the 85 and 95% reductions (0.08 m^3/s, 3 ft^3/s and 0.03 m^3/s, 1 ft^3/s) resulted in longer-term increases in behavioral drift with drift at the end of the flow period often larger than at the beginning. *Oecetis* was seldom present in drift from the control channel, however, a dramatic response to flow reductions in the test channel was observed (Figure 16). Drift of *Oecetis* in the test channel was low until the end of the 0.08 m^3/s (3 ft^3/s) flow period when drift density increased 10-fold. Nearly all subsequent test samples contained large numbers of *Oecetis*. Many of these individuals were captured while still enclosed in their stone case.

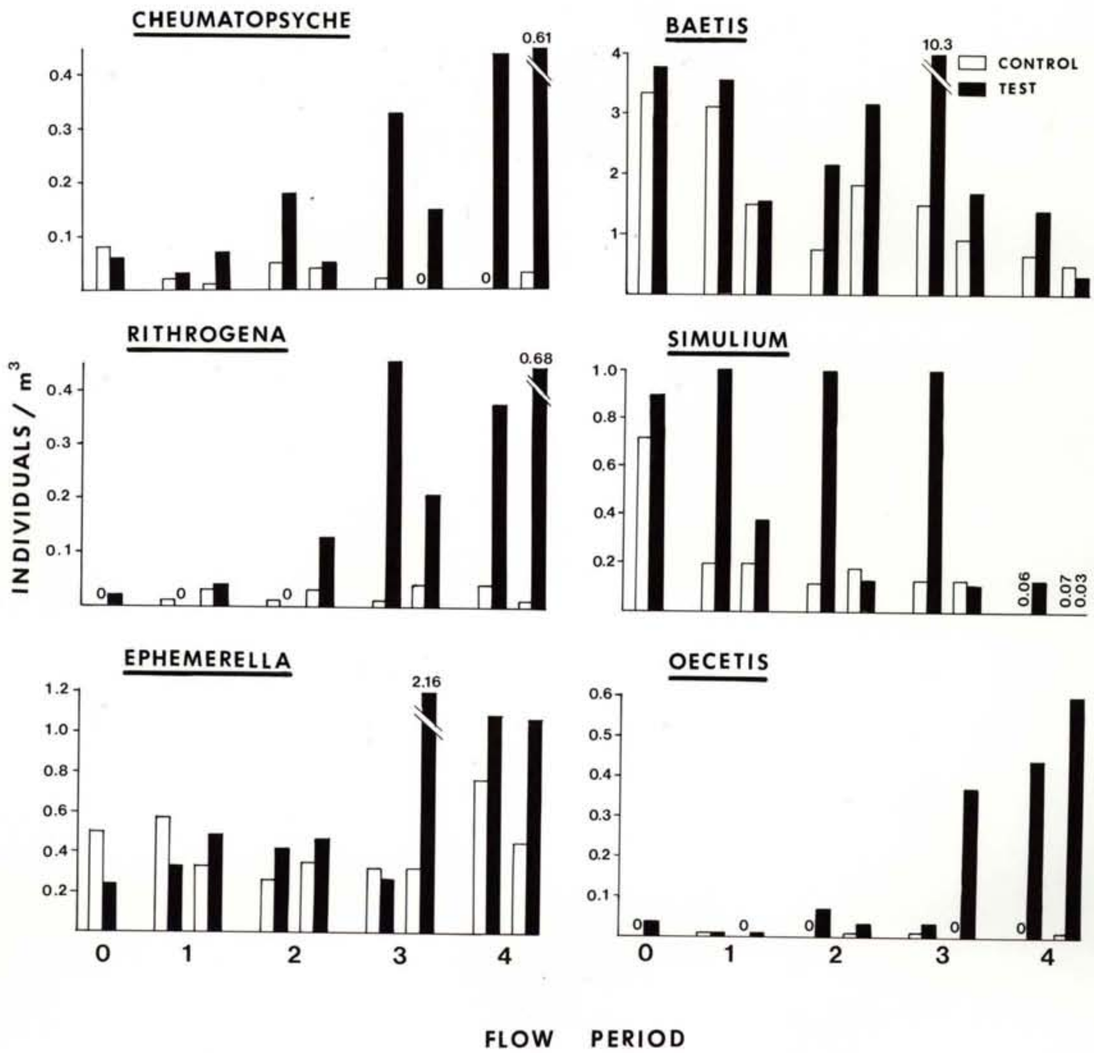


Figure 16. Drift density at dusk for genera dominating aquatic insect drift, fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Bars represent mean drift of the first two and last two days of each flow period, except base flow period (0), in which only the last two days are presented. Test flow periods; 0 = 0.57 m^3/s; 1 = 0.28 m^3/s; 2 = 0.17 m^3/s; 3 = 0.08 m^3/s; 4 = 0.03 m^3/s. Control flow = 0.57 m^3/s.

The mayflies *Rhithrogena, Ephemerella* and *Baetis* made up most of the drift, with *Baetis* being the single most numerous taxon represented. *Rhithrogena* were present in the drift at dusk and midnight, but were a minor component of the drift throughout the experiment in the control channel and in the first half of the experiment in the test channel. Eighty-five and 95% discharge reductions to 0.08 m^3/s (3 ft^3/s) and 0.03 m^3/s (1 ft^3/s) produced high drift of *Rhithrogena* (Figure 16, Appendix B).

Drift of *Ephemerella*, the second most abundant drift organism (Appendix B), remained constant in the control channel during the experiment and was unaffected by the first three flow reductions in the test channel. During the last 2 days of the 85% flow reduction test (0.08 m^3/s, 3 ft^3/s), however, *Ephemerella* drift increased. Drift densities were as much as five times control levels. The final reduction period produced larger drift densities but smaller drift rates in the test channel than the control channel.

Drift of *Baetis* in the control channel gradually decreased throughout the period of our tests (Figure 16, Appendix B). In the test channel, the second flow reduction (0.17 m^3/s, 6 ft^3/s) produced a threefold increase in behavioral drift density of *Baetis* and increased drift continued throughout the flow period. The 85% reduction (0.08 m^3/s, 3 ft^3/s) resulted in an 11-fold increase in *Baetis* drift density at dusk following the flow change. The number of *Baetis* in the drift was nearly three times the control level. The final flow reduction caused an increase in drift density (mostly at midnight) the day of reduction, followed by a return to control levels (Appendix B). Drift rates of *Baetis* were substantially reduced during the final two flow periods.

While the behavioral drift of *Simulium* remained unchanged in the control channel, very dramatic drift responses resulted from flow reductions (Figure 16, Appendix B). Black fly larvae responded to the first three flow reductions with increased behavioral drift, with the highest drift activity occurring at dusk. Increased drift activity of *Simulium* was short-term, with drift densities returning to control level by the end of each flow period.

Benthic Insect Standing Crop

No statistical differences in total insect abundance in either the test or control run or riffle habitats resulted from four incremental reductions in stream discharge. Insect abundance was similar in the run habitat (Figure 17) of both channels during flow period 0 (0.57 m^3/s, 20 ft^3/s). At flow period 1 (0.28 m^3/s, 10 ft^3/s) there was a small increase in density in the test run while abundance in the control declined 33%. During flow period 2 (0.17 m^3/s, 6 ft^3/s) density in the test run declined 25%. Density increased in the control run, during flow period 2, to the level it was during flow period 0 and remained close to this level for the remainder of the experiment. During flow period 3 (0.08 m^3/s, 3 ft^3/m) density increased 59% in the test run to the highest level observed during the experiment. During the final flow period (0.03 $m^3/$ s, 1 ft^3/s) the insect abundance in the test run decreased slightly. Invertebrate density in the test run was 30% larger than in the control.

During the first three flow periods (0, 1, and 2), insect densities increased 54% in the test riffle and 40% in the control. Abundance at each flow period was similar in both channels (Figure 17, Table 3).

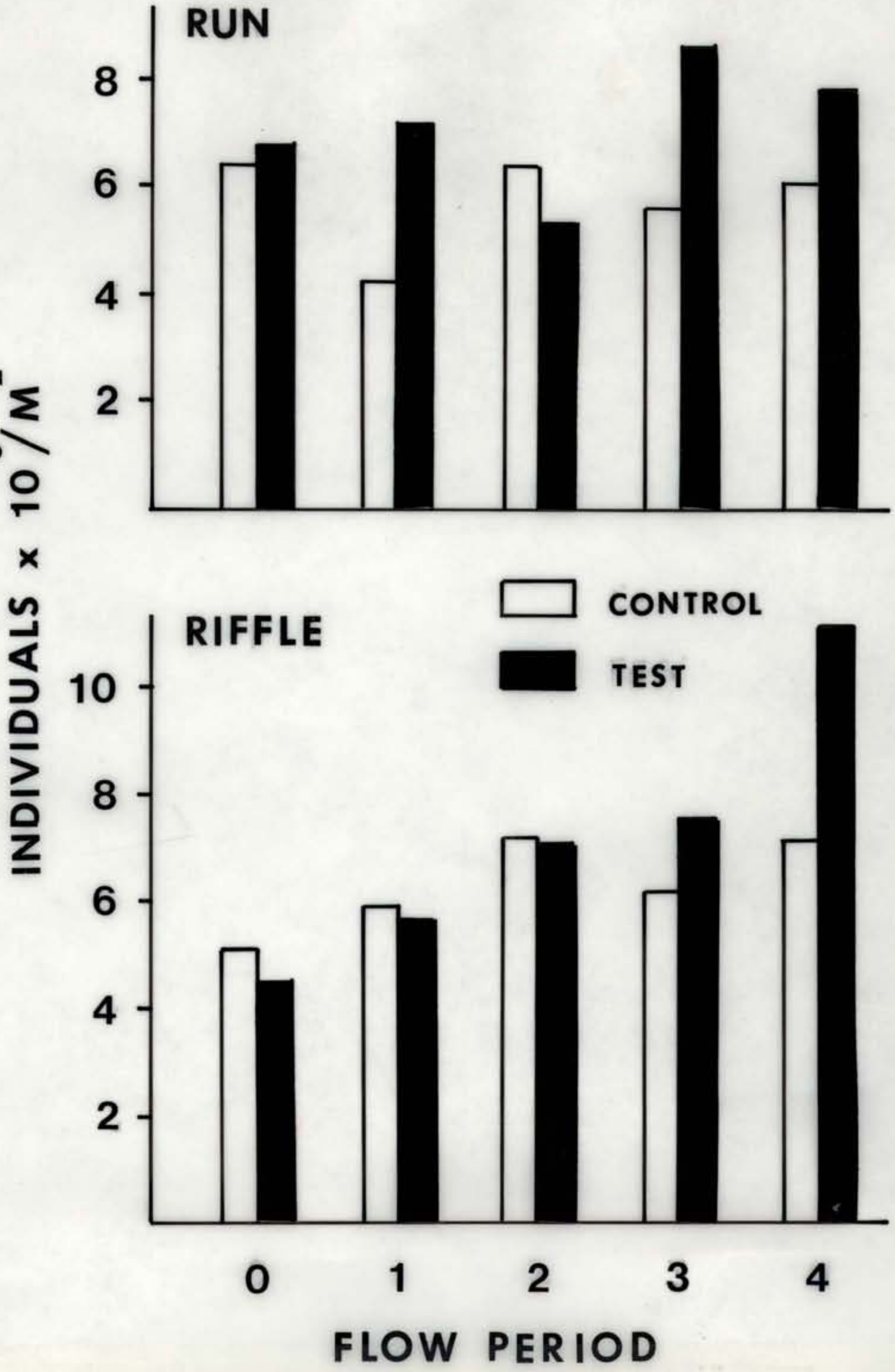


Figure 17. Mean insect densities (no/m^2) on run and riffle habitats, fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.57 m^3/s; 1 = 0.28 m^3/s; 2 = 0.17 m^3/s; 3 = 0.08 m^3/s; 4 = 0.03 m^3/s. Control flow = 0.57 m^3/s.

Table 3. Mean insect densities (no/m^2) and relative abundance (% total) in run and riffle habitats, during the fall 1978 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

Organisms	Test discharge (m^3/s)	Location: Control Run No.	Control Run %	Control Riffle No.	Control Riffle %	Test Run No.	Test Run %	Test Riffle No.	Test Riffle %
Cheumatopsyche	.57	210	3	1803	35	317	5	1265	27
	.28	162	4	2319	39	167	2	1663	29
	.17	495	8	2276	31	183	3	2179	30
	.08	1007	18	1749	28	404	5	1550	20
	.03	447	7	3202	46	97	1	2841	26
Oecetis	.57	345	5	97	2	528	8	11	< 1
	.28	210	5	189	3	1044	14	22	< 1
	.17	291	5	205	3	474	9	17	< 1
	.08	221	4	156	3	958	11	113	2
	.03	350	6	108	2	43	< 1	69	< 1
Rhithrogena	.57	103	2	1297	25	65	< 1	1114	24
	.28	76	2	980	16	70	1	1168	20
	.17	565	9	2115	30	538	10	2029	28
	.08	560	10	1319	21	302	4	2384	31
	.03	404	7	1119	16	140	2	3040	27
Heptagenia	.57	162	3	11	< 1	6	< 1	200	4
	.28	113	3	103	2	0	0	146	3
	.17	286	5	33	< 1	33	< 1	178	3
	.08	711	13	33	< 1	0	0	581	8
	.03	135	2	0	0	81	1	1173	11
Ephemerella	.57	458	7	377	7	312	5	76	2
	.28	108	3	501	8	495	7	495	9
	.17	845	13	754	10	393	7	474	7
	.08	711	13	694	11	2115	25	1119	15
	.03	996	17	1012	14	2368	30	1281	12

Table 3. Continued.

Organisms	Test discharge (m^3/s)	Location: Control Run No.	%	Control Riffle No.	%	Test Run No.	%	Test Riffle No.	%
Baetis	.57	92	1	533	10	323	5	533	11
	.28	146	3	495	8	156	2	1060	18
	.17	275	4	436	6	113	2	931	13
	.08	151	3	549	9	108	1	194	3
	.03	27	< 1	248	4	17	< 1	135	1
Paraleptophlebia	.57	54	< 1	43	< 1	38	< 1	382	8
	.28	146	3	43	< 1	49	< 1	232	4
	.17	65	1	60	< 1	108	2	528	7
	.08	135	2	0	0	43	< 1	436	6
	.03	296	5	17	< 1	205	3	1189	11
Chironomidae larvae	.57	4358	68	205	4	4315	63	356	8
	.28	2464	58	409	7	4267	59	135	2
	.17	3110	49	501	7	2873	53	232	3
	.08	1017	18	388	6	3890	45	356	5
	.03	2653	44	167	2	4428	57	216	2
Other	.57	603	9	797	15	958	14	721	15
	.28	829	19	920	15	980	14	818	14
	.17	431	7	867	12	705	13	635	9
	.08	1098	20	1335	21	791	9	850	11
	.03	732	12	1163	17	426	5	1200	11
Total	.57	6381	100	5160	100	6860	100	4654	100
	.28	4251	100	5956	100	7226	100	5736	100
	.17	6360	100	7242	100	5418	100	7199	100
	.08	5606	100	6220	100	8625	100	7581	100
	.03	6037	100	7032	100	7801	100	11142	100

During the remainder of the experiment (flow periods 3 and 4), density in the control riffle was nearly constant. Between flow periods 2 and 3, insect numbers in the test riffle increased slightly, but, during the low flow conditions of period 4 there was a 47% increase in density. At this time, benthic density in the riffle was 43% larger than in the control.

Significant changes in abundance occurred for two insect genera in the test channel and two different genera in the control (Table 4). *Baetis* abundance on the test riffle (Figure 18) was largest during flow periods 1 (0.28 m^3/s, 10 ft^3/s) and 2 (0.17 m^3/s, 6 ft^3/s). During the last two flow periods (0.08 m^3/s, 3 ft^3/s and 0.03 m^3/s, 1 ft^3/s), significantly smaller densities of *Baetis* were observed which corresponded to the observed increase in drift (Figure 16).

The caddisfly *Oecetis* significantly increased in density in the test riffle and declined significantly in density in the test run (Figure 18). These trends were not observed in the control channel where numbers of *Oecetis* in the run changed little and numbers in the riffle increased to a peak during flow period 2 then declined during the latter two flow periods.

Heptagenia numbers in the control riffle decreased significantly during the fall 1978 test. Numbers in the control riffle peaked during flow period 1 and declined to zero by flow period 4 (Table 4, Figure 18). More important, but not statistically significant, *Heptagenia* density in the test riffle dramatically increased (586%) by the end of decreased flow tests. Recruitment of early instar individuals occurred in the test riffle during the experiment, particularly during the past three flow periods, as evidenced by the reduced weight per individual (Table 5).

Table 4. Insect genera with significant ($P < 0.15$) within channel density differences during fall 1978, spring and summer 1979 reduced stream discharge experiments at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Numbers connected by underlines are not significantly different. During the fall 1978 experiment, test flow periods were 0 = 0.57 m^3/s; 1 = 0.28 m^3/s; 2 = 0.17 m^3/s; 3 = 0.08 m^3s; 4 = 0.03 m^3/s; control flow = 0.57 m^3s. During the spring 1979 experiment test flow periods were 0 = 0.28 m^3s; 1 = 0.03 m^3/s; control flow = 0.28 m^3/s. During the summer 1979 experiment test flow periods were 0 = 0.28 m^3s; 1 = 0.17 m^3/s; 2 = 0.01 m^3/s; control flow periods were 0 and 1 = 0.28 m^3/s; 2 = 0.01 m^3/s.

	Control Riffle		Test Riffle		Test Run	
Fall, 1978	*Heptagenia*	4 0 2 3 1[a]	*Baetis*	4 3 0 2 1	*Oecetis*	4 2 0 3 1
	Chironomidae larvae	4 0 3 1 2	*Oecetis*	0 2 1 4 3		
Spring, 1979	*Baetis*	0 1	*Cheumatopsyche*	1 0	*Baetis*	1 0
	Chironomidae larvae	0 1	*Lepidostoma*	1 0		
			Baetis	0 1		
Summer, 1979	*Cheumatopsyche*	0 1 2	*Cheumatopsyche*	2 0 1	Chironomidae larvae	2 0 1
	Hydropsyche	0 2 1	*Hydropsyche*	0 2 1		
	Heptagenia	0 1 2	*Heptagenia*	0 1 2		
	Ephemerella	1 0 2	*Baetis*	2 1 0		
	Baetis	2 1 0	*Paraleptophlebia*	0 1 2		
	Paraleptophlebia	0 1 2	Chironomidae larvae	2 0 1		
	Chironomidae larvae	2 0 1				

[a] Flow periods listed in order of increasing density.

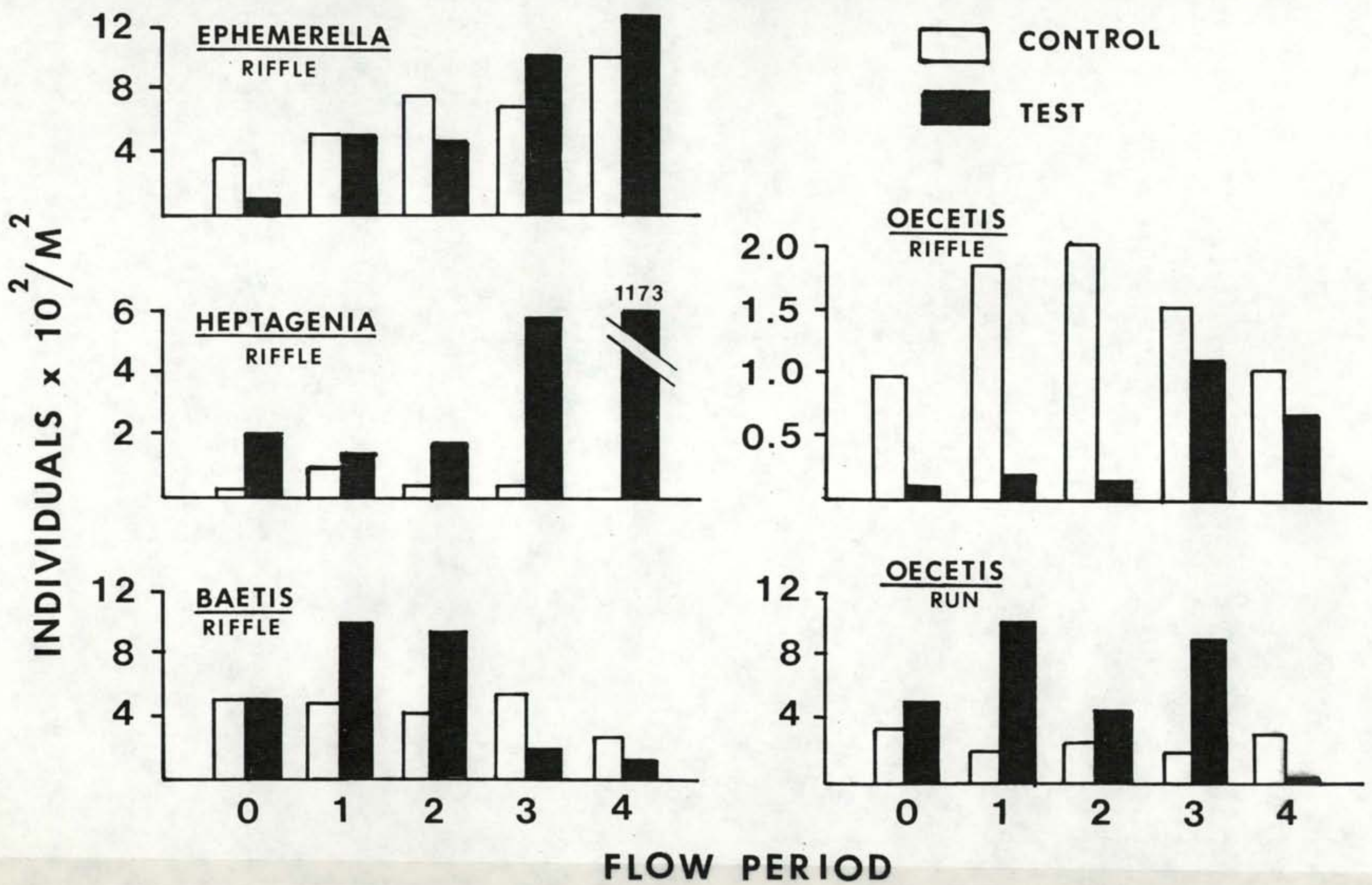


Figure 18. Density (no/m^2) of aquatic insect genera which were statistically changed in abundance (except *Ephemerella*), fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.57 m^3/s; 1 = 0.28 m^3/s; 2 = 0.17 m^3/s; 3 = 0.08 m^3/s; 4 = 0.03 m^3/s. Control flow = 0.57 m^3/s.

Table 5. Mean biomass per individual (mg dry weight) and density (no/m^2) of selected insect genera, fall 1978 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.57 m^3/s; 1 = 0.28 m^3/s; 2 = 0.17 m^3/s; 3 = 0.08 m^3/s; 4 = 0.03 m^3/s. Control flow = 0.57 m^3/s.

		Flow Period 0		Flow Period 1		Flow Period 2		Flow Period 3		Flow Period 4	
		mg	no/m^2	mg	no/m^2	mg	no/m^2	mg	no/m^2	mg	no/m^2
Cheumatopsyche	Control	.442	1803	.565	2319	.904	2276	.780	1749	.667	3202
	Test	.341	1265	.422	1663	.611	2179	.740	1550	.672	2841
Rhithrogena	Control	.221	1297	.275	980	.443	2115	.480	1319	.444	1119
	Test	.191	1114	.219	1168	.458	2029	.336	2384	.355	3040
Heptagenia	Control	--[a]	11	.500	103	--	33	.225	33	0	0
	Test	.257	200	.380	146	.175	178	.288	581	.246	1173
Ephemerella	Control	.087	377	.032	501	.052	754	.047	694	.093	1012
	Test	.015	76	.027	495	.043	474	.046	1119	.070	1281
Baetis	Control	.373	533	.358	495	.358	436	.466	549	.620	248
	Test	.208	533	.158	1060	.486	931	.217	194	.387	135
Parleptophlebia	Control	.014	43	.050	43	.125	60	0	0	--	17
	Test	.237	382	.115	232	.105	528	.658	436	.505	1189

[a] Not enough organisms for weight measurement.

Chironomid larvae densities on the control riffle were significantly higher during flow periods 1, 2, and 3 with peak abundance occurring in flow period 2 (Table 3). Chironomid numbers were significantly lower during flow period 4. No significant changes in chironomid larvae abundance occurred in the test channel.

Cheumatopsyche, *Rhithrogena*, *Ephemerella*, and *Paraleptophlebia* also increased in abundance on the test riffle with peak numbers observed during flow period 4. Similar trends for *Cheumatopsyche*, *Rhithrogena*, and *Ephemerella* occurred on the control riffle, however, *Paraleptophlebia* numbers declined (Table 3). None of these changes were statistically significant. These population increases correspond to increases in mean individual weight for the respective genera in both channels (Table 5).

We observed little change in diversity and evenness values at all sampling stations except the test run (Table 6). Low diversity and evenness values in the test run during the final flow period were a result of a high density of early instar *Ephemerella* nymphs.

Vertical Distribution of Streambed Benthos

Vertical distribution samples were collected to monitor invertebrate use of the hyporheic zone and to observe if this use was affected by reduced discharge. Between the two sampling periods there was a 137% and 57% increase in total insect numbers in the test and control samples, respectively (Figure 19). This was due to increased numbers of the caddisfly *Cheumatopsyche* and the mayflies *Rhithrogena*, *Ephemerella*, and *Paraleptophlebia*. The increases were probably a result of a longer

Table 6. Diversity, evenness, number of genera and density/m^2 of insects in run and riffle habitats during the fall 1978 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Chironomidae omitted from calculations of diversity, evenness and number of genera but included in density.

	Discharge (m^3/s)	Diversity	Evenness	Number of genera	Density (no/m^2)
Run					
Control	.57	3.01	.79	14	6381
	.57	3.47	.89	15	4251
	.57	3.02	.71	19	6360
	.57	3.11	.73	19	5606
	.57	3.05	.77	16	6037
Test	.57	3.12	.75	18	6860
	.28	2.87	.69	18	7226
	.17	3.29	.76	20	5418
	.08	2.44	.62	15	8625
	.03	1.78	.47	14	7801
Riffle					
Control	.57	2.68	.61	21	5160
	.57	2.77	.63	21	5956
	.57	2.64	.63	18	7242
	.57	2.90	.65	22	6220
	.57	2.44	.60	17	7032
Test	.57	2.74	.66	18	4654
	.28	2.81	.64	21	5736
	.17	2.63	.66	16	7199
	.08	2.76	.73	14	7581
	.03	2.80	.66	19	11142

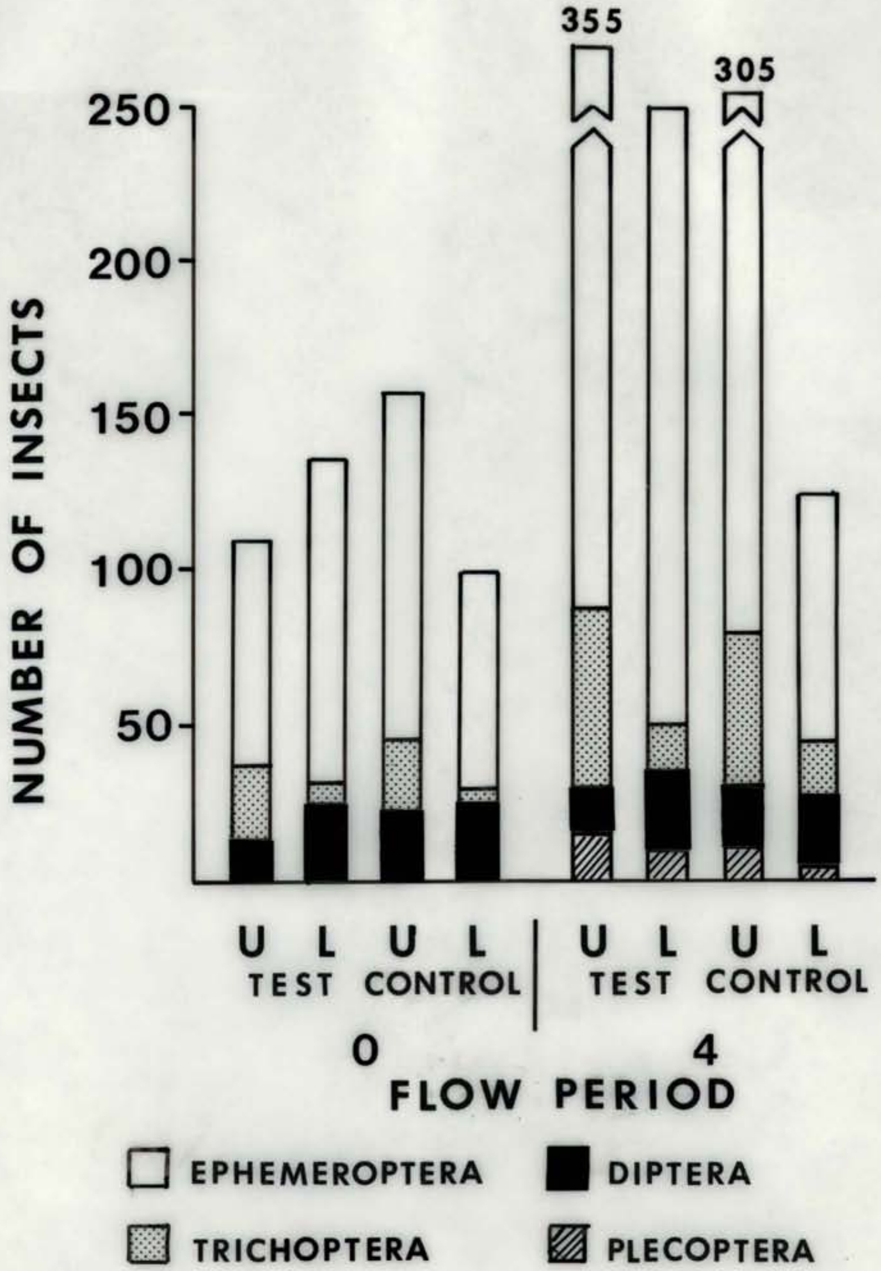


Figure 19. Vertical distribution of insects in canister samples from riffles at interstitial depth zones of 0.0-7.5 cm (U) and 7.5-17.5 cm (L), fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.57 m^3/s; 4 = 0.03 m^3/s. Control flow = 0.57 m^3/s.

colonization time (28 days at flow period 0 vs. 56 days at flow period 4) and recruitment of new generations.

In samples removed at the end of flow period 0, we found 55% and 39%, test and control, respectively, of the insects were in the lower chamber (7.5-17.5 cm) of the canisters. At the end of flow period 4, the number of organisms in the lower chamber of the test samples increased 79% while numbers increased only 18% in the control (Table 7). The disparity in the degree of population increase between the test and control channels was due to a large accumulation of silt and sand in the control samples and not to flow changes in the test channel. The percent of total insects found in the lower chamber declined slightly in both channels by the end of flow period 4.

Changes in depth distribution between sampling periods were similar in both channels for most taxa. However, the percentage of *Rhithrogena* in the upper level increased from 58 to 77% in the test riffle while there was no change in the control. *Heptagenia* nymphs also increased in the upper level in the test channel (27 to 51%) but there was a decrease in the control (81 to 67%).

All of the insect groups were found in both the upper and lower levels of the samplers. With the exception of *Paraleptophlebia* and the Diptera (mostly chironomid larvae), all groups were more numerous in the upper level.

Spring 1979 Experiment

Drift

Drift sampling during the base flow period (0.28 m^3/s, 10 ft^3/s) of the spring 1979 experiment indicated only minor differences in drift

Table 7. Percent and abundance of benthic insects in canister samples from riffles at depth zones of 0.0-7.5 cm (upper) and 7.5-17.5 cm (lower), fall 1978 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Start = September 5, end = October 3. Number of individuals in parentheses.

	Test				Control			
	Start		End		Start		End	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Plecoptera	29 (2)	71 (5)	54 (15)	46 (13)	50 (4)	50 (4)	72 (13)	28 (5)
Trichoptera	65 (15)	35 (8)	77 (57)	23 (17)	76 (22)	24 (7)	81 (51)	19 (12)
Cheumatopsyche	71 (12)	29 (5)	74 (39)	26 (14)	83 (15)	17 (3)	82 (42)	18 (9)
Ephemeroptera	45 (86)	55 (104)	57 (267)	43 (199)	63 (117)	37 (68)	72 (221)	28 (87)
Rhithrogena	58 (54)	42 (39)	77 (143)	23 (43)	82 (37)	18 (8)	80 (67)	20 (17)
Heptagenia	27 (6)	73 (16)	51 (20)	49 (19)	81 (17)	19 (4)	67 (8)	33 (4)
Ephemerella	71 (5)	29 (2)	58 (55)	42 (40)	81 (13)	19 (3)	76 (56)	24 (18)
Baetis	74 (17)	26 (6)	50 (1)	50 (1)	90 (18)	10 (2)	100 (2)	0 (0)
Paraleptophlebia	9 (4)	91 (40)	32 (45)	68 (95)	36 (29)	64 (51)	64 (86)	36 (48)
Diptera	32 (12)	68 (26)	37 (16)	63 (27)	47 (25)	53 (28)	48 (20)	52 (22)
Total	45 (115)	55 (143)	57 (355)	43 (256)	61 (168)	39 (107)	71 (305)	29 (126)

activity between the two channels (Figure 20, Appendix C). Drift was fairly constant throughout the night with slight peaks appearing mostly at dawn. Relatively few insects were collected in noon samples. A sharp 2.5 C rise in water temperature occurred shortly before the end of the base flow period (Figure 13), but did not affect drift. Clear skies and moonlight probably depressed behavioral drift the night prior to flow manipulation.

Noon samples, taken about 2 hours after discharge was reduced 90% to 0.03 m^3/s (1 ft^3/s) in the test channel revealed no differences in drift density between the channels. There was, however, nine times fewer insects captured in test drift samples as in control samples. The lack of apparent drift response at midday was reversed during the nighttime sampling. With the onset of darkness, insect drift density in the test channel was five times higher than in the control (Appendix C). Midnight and dawn samples indicated that drift density remained high throughout the night. Drift rates in the test channel were substantially below control levels. Insect drift density on the fourth night of reduced flow remained much larger in the test channel with peaks occurring at dusk and dawn (Appendix C). By the end of the first week of the experiment, differences between test and control drift densities were similar to those seen during the base flow period. By the end of the test, 2 weeks after the initial reduction, drift densitites in the test channel were similar to the control, however, drift rates in the test channel were still much lower than in the control (Figure 20).

Baetis and *Ephemerella* nymphs were the major taxa comprising drift during the base flow period (Appendix C). No clear pattern of drift was established for *Baetis* as peak drifting occurring at dusk in the control

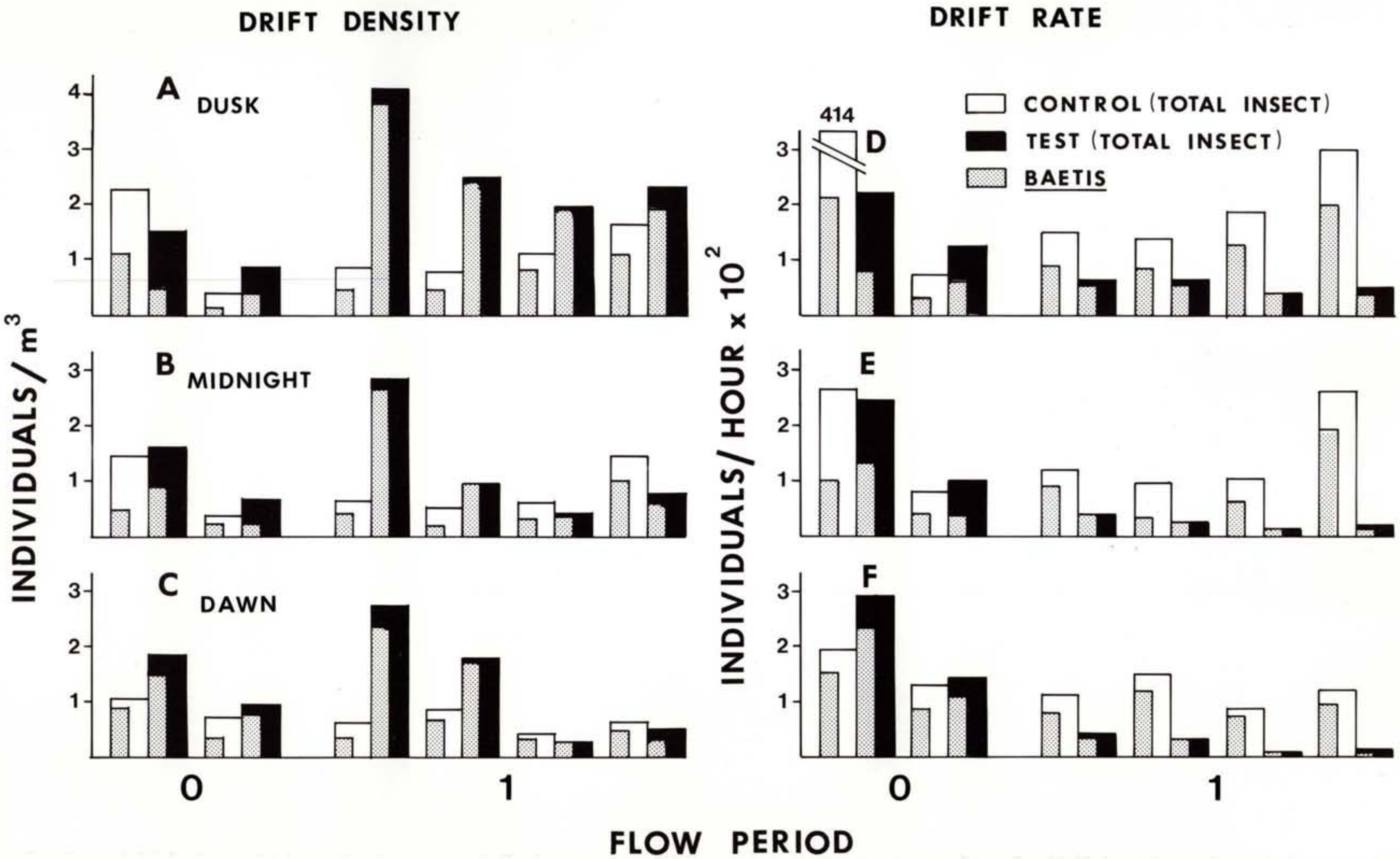


Figure 20. Total insect and *Baetis* drift density and rate (A, D), midnight (B, E) and dawn (C, F), respectively, spring 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.28 m^3/s; 1 = 0.03 m^3/s. Control flow = 0.28 m^3/s.

channel and at dawn in the test on the first night of sampling. One week later peaks occurred in both channels at dawn. *Ephemerella* drift patterns were more consistent with highest drift at dusk of both nights.

The large increase in behavioral drift that occurred the first night of low flow conditions was due to the response of *Baetis* (Figure 20). *Baetis* nymphs accounted for 95% of the total nighttime drift in the test channel during the following week. At the same time, *Baetis* represented only 63% of the drift in the control channel. After 2 weeks of reduced flow, *Baetis* still accounted for 77% of the test drift. Drift of *Ephemerella*, which was often greater than that of *Baetis* prior to flow reduction, nearly ceased under low flow conditions (Appendix C). After the first base flow sample period, drift of *Ephemerella* in the control channel remained consistent in both numbers drifting and the time of peak drifting throughout the experiment. Two other organisms, *Rhithrogena* and the dipteran *Simulium*, were commonly taken in the drift during the base flow period. Both groups continued to be represented consistently in control drift samples, but virtually disappeared from drift in the test channel (Appendix C).

Benthic Insect Standing Crop

A discharge reduction of 90% produced no significant changes in benthic abundance in either run or riffle habitats. Benthic densities in the run habitat of both channels were almost unchanged during the experiment (Figure 21, Table 8). Insect density on the control riffle increased 33% while density on the test riffle increased by only 8%. Relative to the control, it appears the abundance of insects on the test riffle was somewhat depressed in response to low flow conditions.

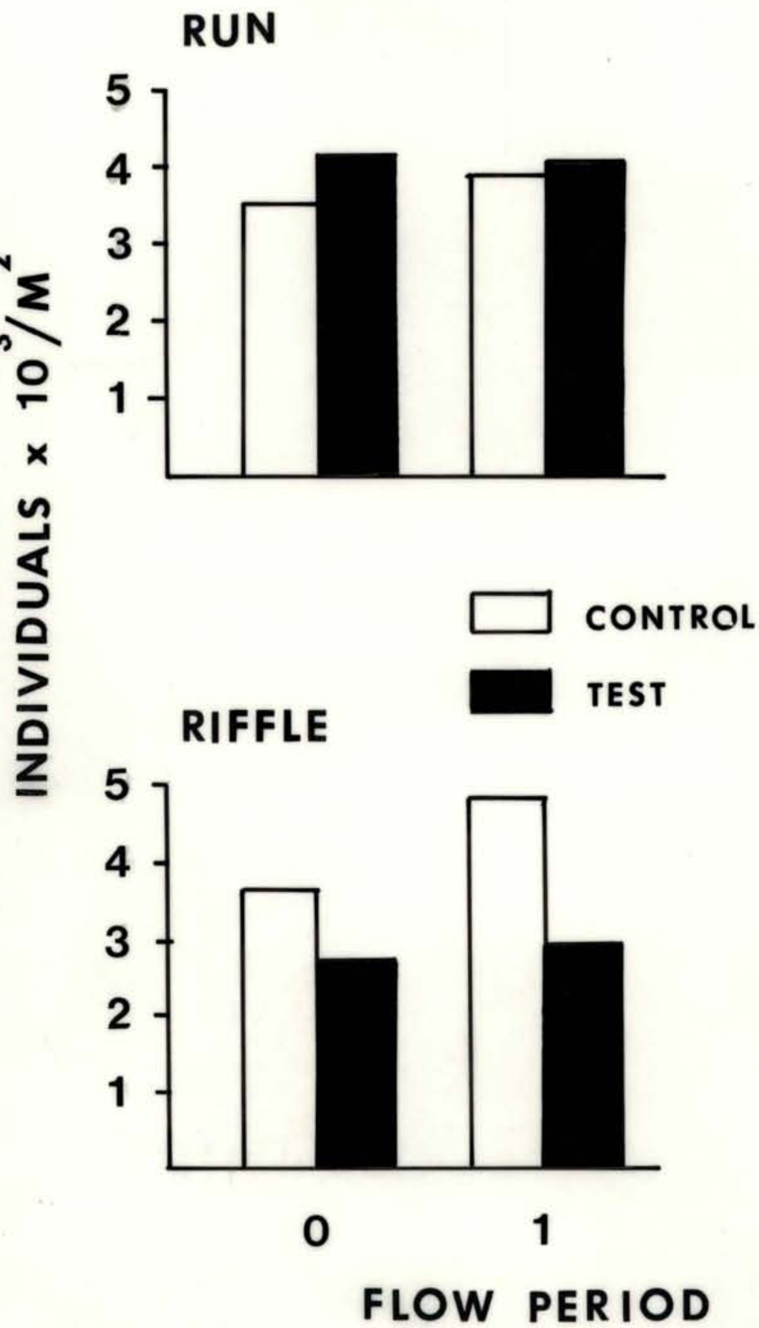


Figure 21. Mean insect densities (no/m^2) on run and riffle habitats, spring 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.28 m^3/s; 1 = 0.03 m^3/s. Control flow = 0.28 m^3/s.

Table 8. Mean densities (no/m^2) and relative abundance (% total) in run and riffle habitats during the spring 1979 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Control discharge = 0.57 m^3/s.

Organism	Test discharge (m^3/s)	Location: Control Run No.	%	Control Riffle No.	%	Test Run No.	%	Test Riffle No.	%
Cheumatopsyche	.28	0	0	684	19	17	< 1	436	16
	.03	79	2	262	5	11	< 1	219	7
Lepidostoma	.28	17	< 1	264	7	0	0	232	8
	.03	8	< 1	417	9	0	0	47	2
Rhithrogena	.28	151	4	721	20	17	< 1	770	28
	.03	137	3	1008	21	0	0	743	25
Ephemerella	.28	366	10	1039	28	151	4	608	22
	.03	872	22	1198	24	219	5	632	21
Baetis	.28	124	3	302	8	33	< 1	259	9
	.03	137	3	872	18	0	0	775	26
Chironomidae larvae	.28	2814	79	232	6	3879	93	135	5
	.03	2586	66	607	12	3817	93	312	11
Other	.28	75	2	307	11	108	3	425	12
	.03	61	1	244	8	119	3	531	11
Total	.28	3578	100	3664	100	4170	100	2744	100
	.03	3935	100	4893	100	4107	100	2970	100

Significant changes in the density of indvidual genera occurred for two taxa in the control channel and three insect groups in the test channel (Table 4). Due to the influence of sample variability, the outcome of some statistical tests is questionable. *Baetis* and chironomid larvae densities increased significantly in the control riffle while *Baetis* increased and *Cheumatopsyche* and *Lepidostoma* decreased significantly on the test riffle (Table 8). *Baetis* also decreased significantly in the test run. The density of *Baetis* nymphs in the riffle increased 195% between sample periods in both channels. This increase on the test riffle was unexpected because of the high drift of *Baetis* in the test channel during low flow conditions. *Lepidostoma* numbers declined significantly on the test riffle while abundance on the control riffle nearly doubled.

Changes in the relative abundance of the different insect taxa, except *Lepidostoma*, were similar in test and control riffles (Table 8).

The significant increase in chironomid larvae only in the control riffle and the significant decline in *Cheumatopsyche* only in the test riffle are questionable. On both the test and control riffles there was a 160% increase in density of chironomid larvae. *Cheumatopsyche* declined 50-60% in both channel riffles. These changes occurred regardless of flow conditions and because of sampling variability were significant in only one channel.

Changes in individual biomass of the major taxa (Table 9) were primarily a result of growth of insects; larger, older age classes predominated. No weight pattern existed during the base flow period, however, during the reduced flow period, weights for genera from the test riffle were lower than corresponding weights from the control riffle.

Table 9. Mean biomass per individual (mg dry weight) and density (no/m^2) of selected insect genera, spring 1979 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.28 m^3/s; 1 = 0.03 m^3/s. Control flow = 0.28 m^3/s.

		Flow Period 0		Flow Period 1	
		mg	no/m^2	mg	no/m^2
Cheumatopsyche	Control	1.030	684	1.528	436
	Test	1.206	262	1.060	219
Lepidostoma	Control	.196	264	.257	232
	Test	.212	417	.208	17
Rhithrogena	Control	1.870	721	1.732	770
	Test	.826	1008	1.568	743
Ephemerella	Control	.734	1039	.849	608
	Test	.584	1198	.768	632
Baetis	Control	.618	302	.735	259
	Test	.512	872	.615	775

Table 10. Diversity, evenness, number of genera and density (no/m^2) of insects in run and riffle habitats during the spring 1979 reduced stream experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Chironomidae omitted from calculations of diversity, evenness and number of genera but included in density.

	Discharge (m^3/s)	Diversity	Evenness	Number of genera	Density (no/m^2)
Run					
Control	.28	2.00	.67	8	3578
	.28	1.81	.51	12	3935
Test	.28	1.81	.72	6	4170
	.03	.94	.41	5	4107
Riffle					
Control	.28	2.75	.65	19	3664
	.28	2.81	.66	19	4893
	.28	2.80	.68	17	2744
Test	.03	2.50	.60	18	2970

Cheumatopsyche and *Lepidostoma* showed weight losses (-12% and -2%, respectively) in the test channel during the reduced flow period while weight gains occurred in the control (48% and 31%, respectively). *Rhithrogena* and *Ephemerella* had greater weight gains in the test channel than in the control (90 vs. -7%, 31 vs. 15%, respectively). *Baetis* nymphs had a 20% increase in biomass in both channels.

Low flow conditions had no noticeable effect on diversity, evenness, or the number of genera on the test riffle (Table 10). There was a drop in diversity and evenness in the test run, but this may have resulted from substrate differences as much as from flow conditions. Also, if chironomid larvae, representing 93% of the fauna in run habitat, had been included in diversity there probably would have been no change.

Summer 1979 Experiment

Drift

Drift rates and densities during the summer 1979 experiment were higher than in previous experiments. The summer behavioral drift pattern showed increasing drift activity at dusk with a peak in activity at midnight (Appendix D). Drift then decreased at dawn and was lowest during the day. Base flow period drift samples showed similar drift densities in the test and control channels (Figure 22, Appendix D). Behavioral drift during the first night of base flow sampling was small. Cloud cover and moonlight conditions were comparable to those a week later when drift densities were from three to seven times higher. This higher drift activity was more representative of drift in the control channel prior to the loss of control flows.

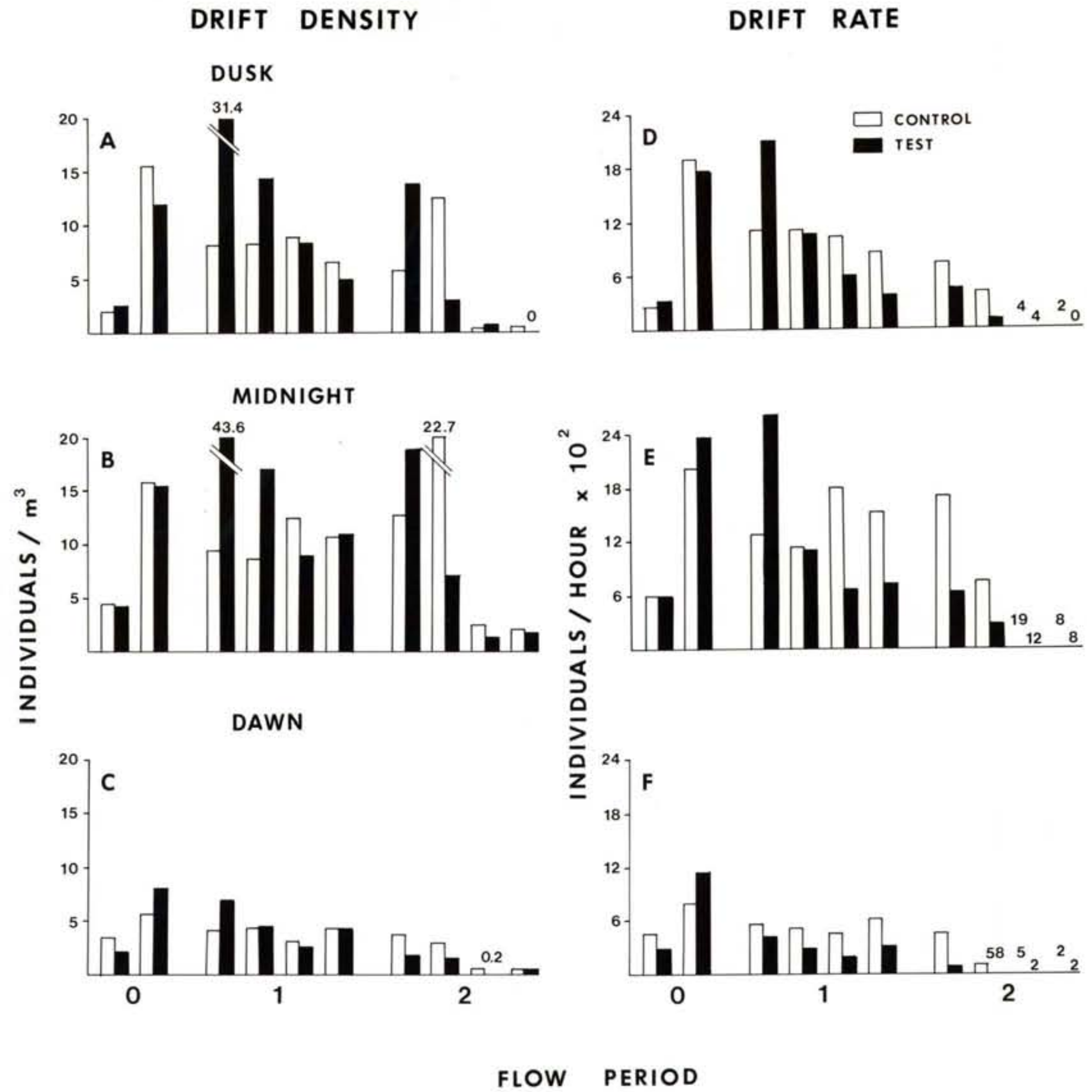


Figure 22. Total insect drift density and rate at dusk (A, D), midnight (B, E) and dawn (C, F), respectively, summer 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.28 m^3/s; 1 = 0.03 m^3/s. Control flow = 0.28 m^3/s. Flow period 2 = 0.01 m^3/s (both channels).

A 50% reduction in discharge from 0.28 to 0.14 m^3/s (10 to 5 ft^3/s) produced catastrophic drifting in the test channel at midday when test drift density was over three times larger than the control level. Nighttime drift density, however, increased four-fold over control levels and nearly three-fold over the previous night's (base flow period) levels. Over 2,600 organisms were collected in the midnight test sample compared to 1,281 in the control (Appendix D). As with previous experiments, the effect of flow reduction was to increase the magnitude of behavioral drift, but not to alter timing of drift pattern. Drift occurring in the test channel on the third night following flow reduction was still higher than control levels, but was substantially less than on the first night. A return to normal behavioral drift, i.e., drift densities approximately equal in both channels, occurred by the end of 1 week of reduction flows.

During the second week of flow period 1 there was a 5 C rise in water temperature (Figure 13). The change, as were other temperature changes during the experiment, was similar in both channels. Invertebrate drift during this period was unaltered by the higher temperatures (Appendix D).

When flows were reduced to 0.06 m^3/s (2 ft^3/s), catastrophic drift occurred at noon following the morning reduction (Appendix D). Although drift density increased, drift rate was below the control level. Drift activity peaked at midnight then dropped sharply at dawn, when drift appeared to be depressed relative to the control (Figure 22).

Because of water supply problems, flow in the control channel was reduced 50% (0.14 m^3/s, 5 ft^3/s) on the second day of flow period 2. The test discharge was held at approximately 0.06 m^3/s (2 ft^3/s)

during this sampling period. Catastrophic drifting in the control channel produced drift densities two times higher than prior to the loss of flow. All samples were affected except the dawn sample when drift was depressed. At the same time, drift activity in the test channel was much less than we would have expected from the previous 3 day trends.

By day 4 of the flow period we were unable to maintain either test or control flows at the desired level. For the next 11 days a flow of approximately 0.01 m^3/s (0.5 ft^3/s) in each channel was maintained. Drift samples taken at 1 week and 2 weeks into the flow period collected few organisms. Drift samples collected on the final day of the experiment captured a total of 13 and 11 insects in the control and test channels, respectively (Appendix D). Behavioral drift pattern, with a peak at midnight, was not altered.

Baetis, *Simulium*, and *Ephemerella* were the major components of the drift during the summer 1979 test. *Baetis* responded to the first flow reduction with increased daytime drifting. At dusk, *Baetis* drift density in the test channel was four times larger than in the control (Figure 23). Three nights later the dusk and midnight drift densities were still double the control level. During the last week of the flow period, *Baetis* drift density in the reduced flow channel was similar to density in the control channel.

A flow reduction to 0.06 m^3/s (2 ft^3/s) in the test channel produced only minor increases in behavioral drifting. By the fourth day of the second reduction period the drift of *Baetis* was substantially reduced. Drift densities in the control channel were unchanged despite the 50% reduction in flow 2 days eariler. During the very low flow conditions of the final two sampling periods only two *Baetis* nymphs were collected.

Ephemerella responded to the first flow reduction with only a minor increase of midnight drifting (Appendix D). Throughout the remainder of the flow period no differences in drift in the two channels were observed. Increased behavioral drifting in response to the second flow reduction occurred at dusk and midnight (Figure 23). *Ephemerella* drift increased greatly in the control channel after the control flow was reduced; drift rate and density in midnight samples 2 days after flow reduction were the highest observed for *Ephemerella* during the experiment. *Ephemerella* drift was negligible during the period of very low flows.

Short-term increases in drift of *Simulium* followed each flow reduction (Appendix D). As with other organisms, *Simulium* was taken in higher numbers the night following the reduction and had returned to near normal drift levels by the next sampling period. Increased daytime drifting of *Simulium* was observed following unscheduled flow decrases in the second reduction period, but the behavioral pattern of peak drifting at dusk was unaltered. No *Simulium* were collected during the last week when flow remained at 0.01 m^3/s (0.5 ft^3/s).

Cheumatopsyche drift was unaffected by the first flow reduction (Appendix D). However, relatively high numbers of *Cheumatopsyche* drifted at dusk following the reduction to 0.06 m^3/s (2 ft^3/s) on day 201-202. By 4 nights into the second reduced flow period drift of *Cheumatopsyche* in the test channel had returned to levels similar to those observed before flow reductions; dusk drift in the control increased greatly due to the unscheduled, reduced flow conditions. *Cheumatopsyche* drift was negligible during the last week of the test when flow was 0.01

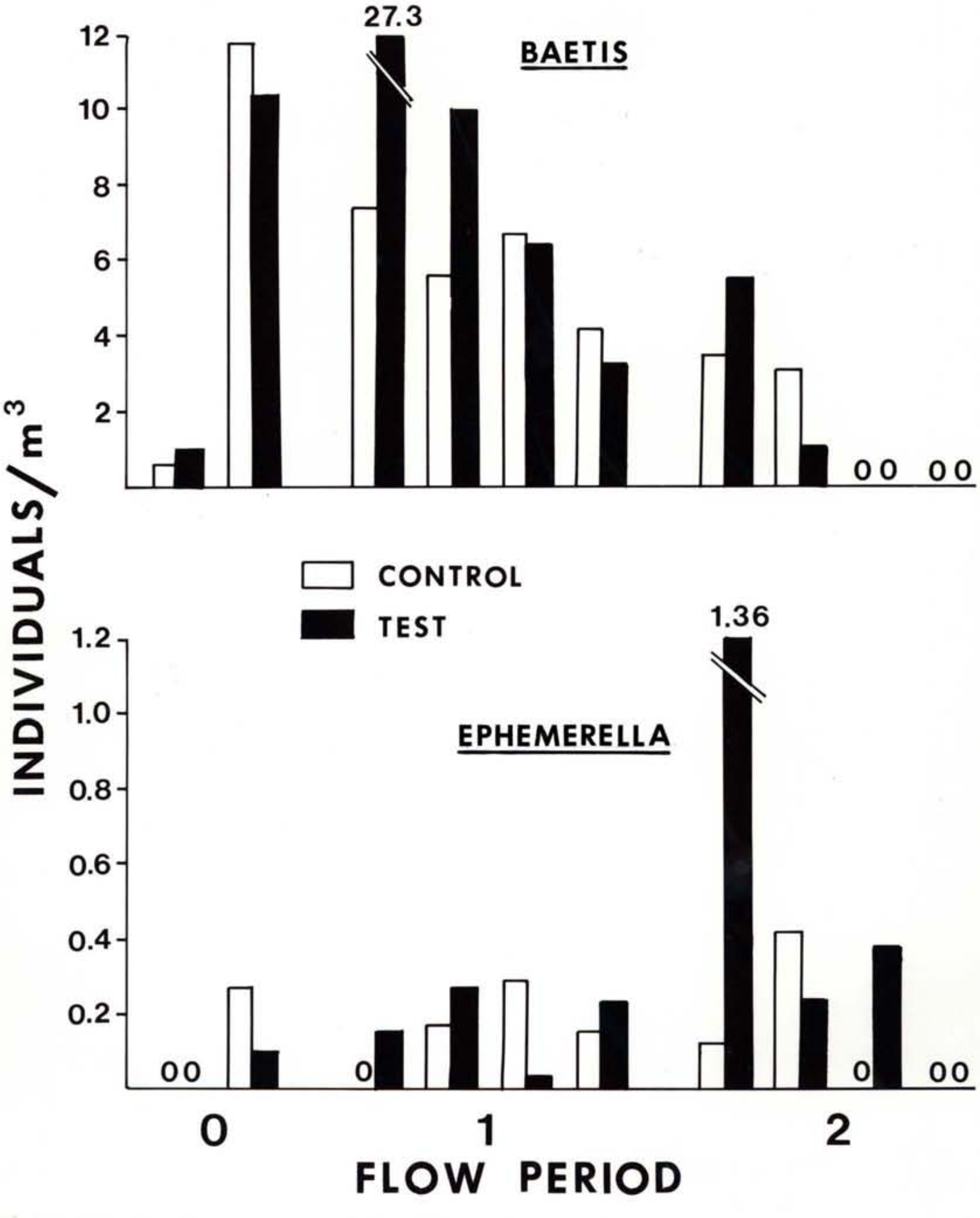


Figure 23. Dusk drift density of *Baetis* and *Ephemerella*, summer 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.28 m^3/s; 1 = 0.03 m^3/s. Control flow = 0.28 m^3/s. Flow period 2 = 0.01 m^3/s (both channels).

m^3/s (0.5 ft^3/s). *Hydropsyche* did not respond to scheduled flow reductions but drift did increase when flow in the control channel had to be reduced.

Benthic Insect Standing Crop

Overall, we found no significant differences in total insect densities in the run or riffle habitats of either the test or control channels during the summer 1979 experiment. A decline in population density of 22% in the control run and 6% in the test run was observed between the base flow period and flow period 1 (0.14 m^3/s, 5 ft^3/s). Density in the run habitat declined another 13% in the control and 81% in the test by the end of the experiment (Figure 24, Table 11). The large decline in the test run was a result of a 94% decrease in chironomid larvae. Total insect abundance on both the test and control riffles also declined throughout the experiment (Figure 24). A decrease of 27% and 12% on the control and test riffles, respectively, occurred between the base flow period (0.28 m^3/s, 10 ft^3/s) and flow period 1 (0.14 m^3/s, 5 ft^3/s). Densities decreased again, 35% in the control and 12% in the test, by the end of the experiment.

Significant changes in population densities were found for seven insect groups in the control channel and six groups in the test channel (Table 4). All taxa showing significant changes, except chironomid larvae, were confined to riffle habitats. While the patterns of change differed for individual genera, the pattern shown by each genera was similar in both channels. This indicated that life history phenomenon strongly influenced abundance during the reduced flow tests. Individual organism weight and density of selected aquatic insect genera (Table 12)

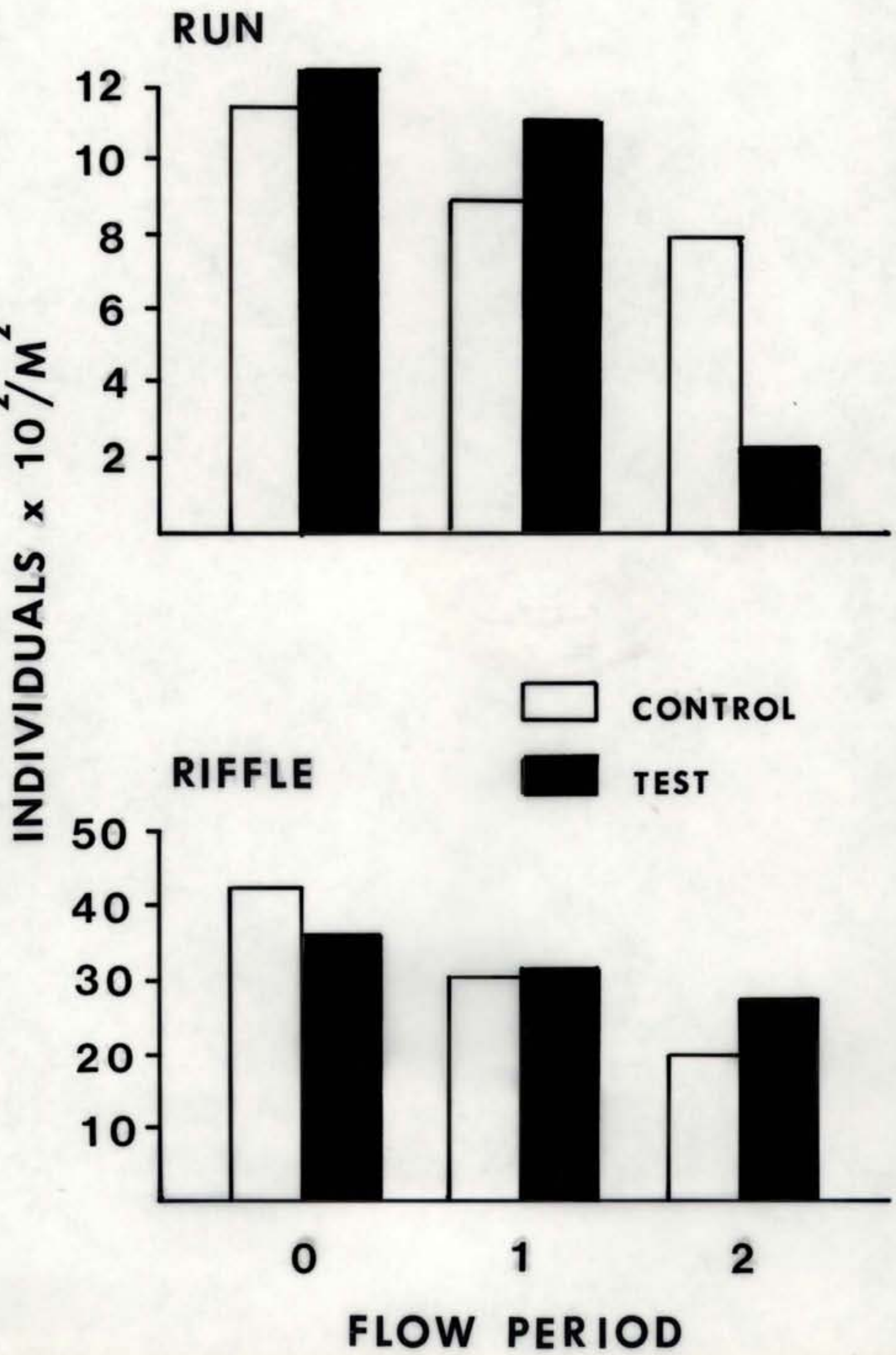


Figure 24. Mean insect densities (no/m^2) on run and riffle habitats, summer 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.28 m^3/s; 1 = 0.03 m^3/s. Control flow = 0.28 m^3/s. Flow period 2 = 0.01 m^3/s (both channels).

Table 11. Mean insect densities (no/m^2) and relative abundance (% total) in run and riffle habitats, summer 1979 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Control discharge = 0.28 m^3/s during first two flow periods and 0.01 m^3/s during last flow period.

Organism	Test discharge (m^3/s)	Control Run No.	Control Run %	Control Riffle No.	Control Riffle %	Test Run No.	Test Run %	Test Riffle No.	Test Riffle %
Cheumatopsyche	.28	0	0	54	1	0	0	36	< 1
	.14	0	0	165	5	0	0	126	4
	.01	0	0	269	13	0	0	11	< 1
Hydropsyche	.28	0	0	54	1	4	< 1	18	< 1
	.14	7	< 1	897	29	4	< 1	707	22
	.01	0	0	216	11	0	0	26	< 1
Heptagenia	.28	0	0	87	2	18	1	187	5
	.14	14	2	101	3	54	5	262	8
	.01	14	2	208	10	0	0	359	13
Ephemerella	.28	0	0	259	6	29	2	205	6
	.14	33	4	208	7	22	2	158	5
	.01	0	0	524	26	4	2	259	9
Baetis	.28	65	6	1302	31	69	5	933	26
	.14	0	0	54	2	11	< 1	33	1
	.01	0	0	8	< 1	0	0	0	0
Paraleptophlebia	.28	0	0	0	0	0	0	29	< 1
	.14	4	< 1	0	0	40	3	65	2
	.01	22	3	79	4	47	20	1224	44
Chironomidae larvae	.28	460	40	1005	24	761	61	1281	35
	.14	678	76	1051	34	1033	88	1471	46
	.01	650	81	460	23	61	27	495	18
Other	.28	621	54	1460	35	370	30	922	26
	.14	158	18	592	19	18	2	348	11
	.01	115	14	241	12	119	52	416	15
Total	.28	1145	100	4218	100	1249	100	3609	100
	.14	894	100	3067	100	1180	100	3167	100
	.01	780	100	2002	100	230	100	2787	100

Table 12. Mean biomass per individual (mg dry weight) and density (no/m^2) of selected insect genera, summer 1979 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods: 0 = 0.28 m^3/s; 1 - 0.17 m^3/s. Control flow = 0.28 m^3/s. Flow period 2 = 0.01 m^3/s (both channels).

		Flow Period 0		Flow Period 1		Flow Period 2	
		mg	no/m^2	mg	no/m^2	mg	no/m^2
Cheumatopsyche	Control	1.640	54	.222	165	.197	269
	Test	1.011	36	.064	126	--[a]	11
Hydropsyche	Control	1.120	54	.314	897	.993	216
	Test	2.240	18	.279	707	.700	26
Heptagenia	Control	1.519	87	.238	101	1.626	208
	Test	1.228	187	.528	262	.882	359
Ephemerella	Control	1.404	259	.251	208	1.238	524
	Test	1.463	205	.222	158	1.031	259
Baetis	Control	.297	1302	.300	54	--	8
	Test	.440	933	.340	33	0	0
Paraleptophlebia	Control	0	0	0	0	.095	79
	Test	.850	29	.010	65	.097	1224

[a] Not enough organisms for weight measurement.

provided insights into life history events taking place during the experiment. *Cheumatopsyche* numbers increased 250% in the test channel and 200% in the control while individual biomass declined 94% and 86%, test and control, respectively, between the base flow period and the end of flow period 1. Increased numbers and decline in individual biomass indicated recruitment of small individuals to the populations. By the end of flow period 2 (0.01 m^3/s, 0.5 ft^3/s), densities on the control riffle had further increased by 63% while test densities declined 91%; populations in both channels were comprised of smaller individuals. The significant increase in abundance of *Hydropsyche* larvae during the first reduced flow period was also accompanied by a sharp decline in individual weight. The situation was reversed by the end of the experiment when lower densities were composed of larger individuals.

A non-significant increase in *Heptagenia* nymphs occurred during the first reduced flow period as smaller organisms entered the sample, however, the significantly higher densities at the end of the experiment were composed of mostly large individuals (Table 12). Significant changes in *Ephemerella* abundance occurred only on the control riffle, but the pattern of change was similar in both channels. A decline in both numbers and individual biomass during the 50% reduction period was a result of adult emergence and the presence of smaller individuals. Densities and individual biomass estimates increased during the final reduction period. This increase in individual biomass was a result of the presence of *Ephemerella hecuba* nymphs which were not collected earlier in the experiment. These large sized nymphs masked, weight wise, the presence of increased numbers of smaller individuals. Emergence of *Baetis* adults resulted in the decline from high initial densities of *Baetis* nymphs to numbers near zero by the end of the test. *Paraleptophlebia* increased significantly during the experiment. A few large individuals of *Paraleptophelbia* were taken from the test riffle during the base flow period while none were collected from the control. Larger numbers of *Paraleptophlebia* observed during the rest of the test, especially during flow period 2, were a result of the recruitment of many very small individuals. Similar significant changes in chironomid larvae on the test and control riffles and the test run would indicate emergence as the primary factor affecting density.

Diversity and evenness values changed little during the experiment (Table 13). Diversity values were highest during the first reduced flow period at all sampling locations except the control riffle where diversity peaked at the end of the experiment. The great abundance of *Paraleptophlebia* nymphs on the test riffle at the end of the experiment lowered the diversity at that time.

Vertical Distribution of Streambed Benthos

The canisters used for the summer experiment had been in the substrate for 10 months and had accumulated a considerable amount of fine particles. When the initial canisters were removed during the base flow period, 31% of the insects in the test canisters were found in the lower level, about double the amount (17%) in the lower level of the control canisters (Table 14). The last set of canisters was removed after reduced flows in the Grande Ronde River had prevented us from maintaining the desired flow levels in both channels. The vertical distribution of insects in the control channel was similar to the distribution under base

Table 13. Diversity, evenness, number of genera and density (no/m^2) of insects in run and riffle habitats during the summer 1979 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Chironomidae omitted from calculations of diversity, evenness and number of genera but included in density.

	Discharge (m^3/s)	Diversity	Evenness	Number of genera	Density (no/m^2)
Run					
Control	.28	0	--	1	1145
	.28	2.48	.87	8	894
	.01	2.17	.99	5	780
Test	.28	1.68	.72	5	1249
	.14	2.21	.80	7	1180
	.01	1.68	.73	5	230
Riffle					
Control	.28	2.21	.53	18	4218
	.28	2.62	.67	15	3067
	.01	2.76	.68	17	2002
Test	.28	2.25	.56	16	3609
	.14	2.60	.65	16	3167
	.01	2.07	.62	10	2787

Table 14. Percent and abundance of benthic insects in canister samples from riffles at depth zones of 0.0-7.5 cm (upper) and 7.5-17.5 cm (lower), summer 1979 reduced stream discharge experiment at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Start = July 5, end = August 3. Number of individuals in parentheses.

	Test				Control			
	Start		End		Start		End	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Plecoptera	57 (4)	43 (3)	0 (0)	0 (0)	67 (2)	33 (1)	0 (0)	0 (0)
Trichoptera	100 (5)	0 (0)	75 (6)	25 (2)	100 (3)	0 (0)	92 (23)	8 (2)
Ephemeroptera	70 (65)	30 (28)	85 (57)	15 (10)	88 (29)	12 (4)	90 (37)	10 (4)
Ephemerella	83 (5)	17 (1)	89 (8)	11 (1)	67 (2)	33 (1)	94 (17)	6 (1)
Baetis	69 (53)	31 (24)	100 (10)	0 (0)	91 (21)	9 (2)	100 (1)	0 (0)
Paraleptophlebia	50 (1)	50 (1)	83 (35)	16 (7)	100 (1)	0 (0)	80 (4)	20 (1)
Diptera	68 (52)	32 (25)	74 (17)	26 (6)	80 (35)	20 (9)	61 (27)	39 (17)
Total	69 (126)	31 (56)	82 (82)	18 (18)	83 (70)	17 (14)	79 (88)	21 (24)

flow conditions. However, in the test channel the distribution had shifted more to the upper level (18% in lower level) and was similar to the control (21% in lower level). Total insect abundance in the test channel canisters had declined 55% while numbers increased 33% in the control (Figure 25). There were no major shifts in depth distribution of individual genera as a result of the discharge changes. *Baetis* nymphys and dipterans, mostly chironomid larvae, were the most abundant organisms in the canisters at the start of the experiment. By the end of the test, *Ephemerella* and *Paraleptophlebia* mayflies and the dipterans were the most abundant groups.

Discussion

Incremental reductions in discharge of 50%-95% caused increased drift of aquatic macroinvertebrates during all tests. The magnitude and duration of increased behavioral drift varied with season, amount of flow reduction, taxa, and developmental stage of aquatic invertebrates affected. A reduction in drift rate occurred during low flow conditions of each experiment. Although significant changes in benthic abundance were noted for some taxa following periods of reduced discharge, we found no significant change in abundance of total benthic organisms during any experiment. Vertical distribution of benthos within a riffle substratum was unaffected by surface flow reductions.

Increased behavioral drift, as manifested by high drift densities, followed each discharge reduction. This finding is similar to those reported by other investigators (Pearson and Franklin 1968; Minshall and Winger 1968; Radford and Hartland-Rowe 1971b; Peters 1973; Brusven and MacPhee 1976; Gore 1977). Increased behavioral drifting continued for 3

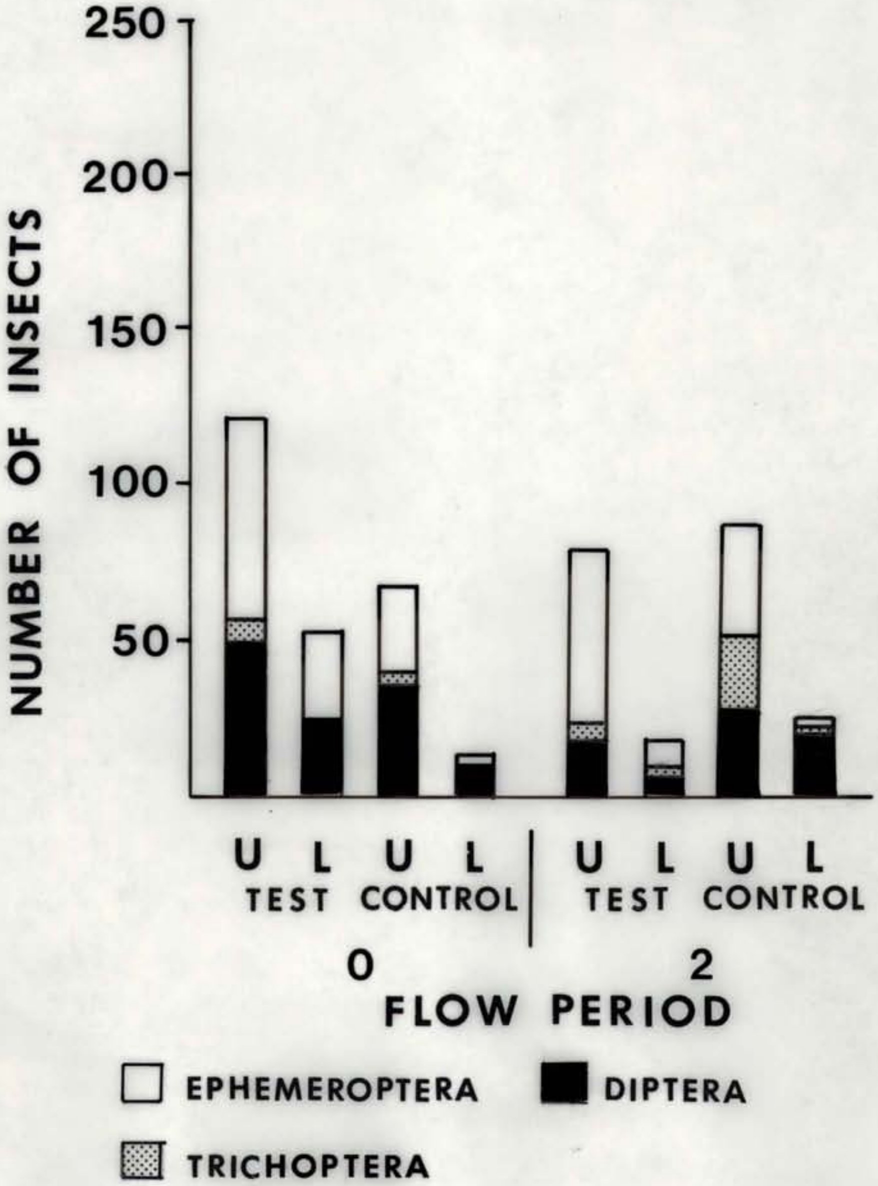


Figure 25. Vertical distribution of insects in canister samples from riffles at interstitial depth zones of 0.0-7.5 cm (U) and 7.5-17.5 cm (L), summer 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Flow periods: 0 = 0.28 m^3/s; 2 = 0.01 m^3/s (both channels).

to at least 7 days depending on season, amount of reduction, and genera affected. In the fall experiment drift densities generally remained high for at least 1 week. Flow periods of longer duration would have been desirable at this time. In effect we were placing additional stress on an already unstable community. One week was sufficient for community restabilization in the spring and summer.

Baetis and *Ephemerella* were the most abundant drift organisms and were most affected by discharge reduction. *Baetis*, noted for its high propensity to drift (Lehmkuhl and Anderson 1972), responded to most flow reductions with increased drift activity. Discharge reductions of 85% or more in the fall and spring produced sharp increases in nighttime drift of *Baetis*. Increased drift following an 85% flow reduction in the fall produced a statistically significant decrease of *Baetis* on the test riffle. During the reduced flow period of the spring experiment, *Baetis* was virtually the only taxon represented in the test channel drift. Bovee (1975) suggested that under conditions of reduced discharge the velocity over riffle areas may not be high enough to remove invertebrates from the substrate. This could be especially true in the spring when most invertebrate nymphs are large in size, only invertebrates with a high drift propensity, like *Baetis*, would be found in the drift. Increased nymphal activity and abundance in the summer produced the highest levels of behavioral drift we observed in any of our experiments as *Baetis* responded to a 50% flow reduction.

Observed changes in the behavioral drifting of *Ephemerella* followed reductions of 85% or more. Response varied considerably with season. In the fall, large numbers of recently hatched *Ephemerella* nymphs were present in the benthos. *Ephemerella* showed no immediate response to an

85% reduction to 0.08 m^3/s (3 ft^3/s); high behavioral drifting was delayed for nearly a week. The high drift response continued after a subsequent reduction to 0.03 m^3/s (1 ft^3/s) (95%). In the spring, behavioral drifting of *Ephemerella* all but ceased in response to low flow conditions. Increased behavioral drift, beginning at dusk, followed a reduction to 0.06 m^3/s (2 ft^3/s) in the summer. This response was short-term as normal level of drift occurred 3 nights later. A comparison of the individual biomass of *Ephemerella* and periods of high behavioral drift indicate that smaller individuals dominated in the benthos at the time of high drifting. Life stage appears to be an important factor in how *Ephemerella* responds to changes in discharge.

Lehmkuhl and Anderson (1972) suggested that mayfly drift was determined by a complex of interdependent factors including life cycle, behavior of the species, and microhabitat. In summer and fall most species were found in riffle areas with rapid current. In winter and early spring some species had moved to backwater areas with low velocity. Seasonal changes in microhabitat selection have also been noted for caddisfly larvae (Cummins 1964). Flow reductions, with associated low velocities, would have a greater affect on drift in summer and fall when nymphs are associated with high velocity. Low flows in winter and spring would affect drift less. With the exception of *Baetis* drift in the spring, our data tends to support this hypothesis.

Sudden reductions in stream discharge can cause a reversal of the normal negative phototaxis of stream insects and produce increased drift during daylight hours (Minshall and Winger 1968). Discharge manipulations lasted 2-4 hours in our experiments. In spring, when our largest single reduction was made, no increased daytime drift was found, however, in summer higher daytime drift accompanied both reductions. The diurnal period of drift, with peak activity at dusk in fall and spring and at midnight in summer, was unaltered in all experiments.

Drift was monitored at the upper and lower ends of the channels, but only the downstream results have been presented. Data from upstream and downstream stations were similar in magnitude, timing, and duration of increased drifting. Differences between the test and control channels were also similar at the upper and lower stations. The upper nets were intended to collect only drift coming into the channels with the source water. Because of high velocities and turbulence associated with the incoming water, the upper nets were placed approximately 6 m (6.6 ft) downstream from the upstream weirs. Organisms responding to flow reductions, and originating between the upstream net and weir, were collected by the upstream net, thus producing data similar to the downstream station.

Incremental reductions in discharge did not significantly affect benthic abundance in either run or riffle habitats. Hafele (1978) came to the same conclusion from similar experiments in an Oregon coastal stream. Invertebrate densities in the run habitat remained fairly constant during each experiment. Dominant fauna inhabiting the run habitat were typically forms adapted to low current velocity. Many insect typical of the riffle habitat occurred in the run habitat in the fall, but the channels were still "young" and pebble-cobble substrate was the dominant type. This substrate presented suitable habitat for many erosional invertebrate forms. Over the winter, deposition of fine organics and inorganics altered the run habitat.

No consistent trend in benthic abundance was observed in the riffle habitat. Benthic density increased under low flow conditions in the fall and also increased in relation to the control. Both of these findings agree with McClay (1968) and Hafele (1978). However, density decreased uniformly in both test and control during the summer experiment, which also occurred during the same time period as the McClay and Hafele studies. Low flow conditions had no affect on spring riffle density.

Overall, it would appear that seasonal life history phenomena played an important role in determining benthic abundance. Riffle densities followed a typical pattern of annual change; stable springtime density, a decline in early to mid-summer due to adult emergence, and a rapid rise in early fall from larval hatch (Hynes 1970). Recruitment to populations of *Cheumatopsyche*, *Rhithrogena*, *Heptagenia*, *Ephemerella*, and *Paraleptophlebia* accounted for the density accretions in the fall. The greater population growth in the test channel relative to the control may be evidence that low flow conditions were benefical at that time of year. Increased density was not a result of crowding as wetted parimeter decreased as Corning (1969) had found. Because of the rectangular configuration of the channels, the amount of potential benthos habitat dewatered (primarily silt impacted bank areas) was minor. Diminishing benthos abundance due to population turnover masked changes that may have resulted from low discharge during the summer.

While life history events were an important influence on invertebrate abundance, the effects of reduced discharge were also evident. Although benthic densities increased on both the test and control riffles during the spring experiment, the increase in the control riffle was four-fold greater than in the test channel. This was due to a large increase in the abundance of *Lepidostoma* and *Rhithrogena* on the control riffle while the numbers of both taxa declined on the test riffle. Several taxa experienced population changes in the test channel during the summer test that were not reflected in the control, but since both channels had similar flow conditions during the last flow period these changes cannot be conclusively related to low flows. *Cheumatopsyche*, *Hydropsyche*, and *Ephemerella* were affected the most. These effects of reduced streamflow resulted form habitat alteration.

Changes to other than optimum conditions of depth and velocity following flow reduction have been suggested as reasons for increased behavioral drifting (Minshall and Winger 1968; Gore 1977) and altered community composition (Gore 1977). As streamflow diminishes, locations with optimal conditions at high flow may not remain as optimal habitat at low flows. Philipson (1969) found that small temporary flow reductions had little affect on established populations of *Hydropsyche instabilis*. However, larger changes or prolonged exposure to small changes caused *H. instabilis* to leave the established positions and to actively search for favorable conditions. The consequence of this movement could be increased drifting due to exposure, emigration of individuals unable to locate suitable habitat (Bishop and Hynes 1969), competition for limited areas of optimal habitat (Walton et al. 1977), and increased population density at optimal locations (Dimond 1967).

We investigated the depth and velocity preferences of selected benthic invertebrates inhabiting the channels using part of the procedure outlined by Gore (1978). This procedure is "based on the assumption that diversity and/or number of individuals in a given species is highest at the optimum condition and will exhibit a distribution around this optimum point."

The conditions for optimum community diversity (COCD) were 36 cm/s (1.17 ft/s) current velocity at 22 cm (0.7 ft) depth (Figure 26). Centroids for nine genera of invertebrates in ou study which were either common in the benthos or displayed definite drift response are also shown. These values agree with depth and velocity criteria in the literature for small wadeable streams (Surber 1951; Needham and Usinger 1956; Kennedy 1967; Giger 1973; Hooper 1973; Kimble and Wesche 1975). However, due to the limited range of depths and velocities sampled during the study, the centroid values may not be representative of aquatic insects in general. Using these centroid values, we compared the drift response of several invertebrates to depths and velocities on the test riffle associated with several discharges investigated. At 0.17 m^3/s (6 ft^3/s) the associated depth and velocity (at benthic sample locations) on the test riffle were 13 cm (0.4 ft) and 50 cm/s (1.6 ft/s), respectively. The centroids for *Baetis* are above these values; *Baetis* was the dominant taxon in the drift at this flow level in the fall.

Depth and velocity values of 10 cm (0.3 ft) and 40 cm/s (1.3 ft/s) were associated with a discharge of 0.14 m^3/s (5 ft^3/s) in the summer. Centroids for *Baetis*, *Cheumatopsyche*, *Hydropsyche*, and *Rhithrogena* are higher than these values and *Baetis*, *Cheumatopsyche*, and *Rhithrogena* responded with increased drift after a reduction to 0.14 m^3/s (5 ft^3/s). Although the response of *Baetis* was dramatic, the response of *Cheumatopsyche* and *Rhithrogena* was small. At a discharge of 0.08 m^3/s (3 ft^3/s) riffle depths and velocities averaged 9 cm (0.29 ft) and 33 cm/s (1.0 ft/s), respectively. During the fall experiment the

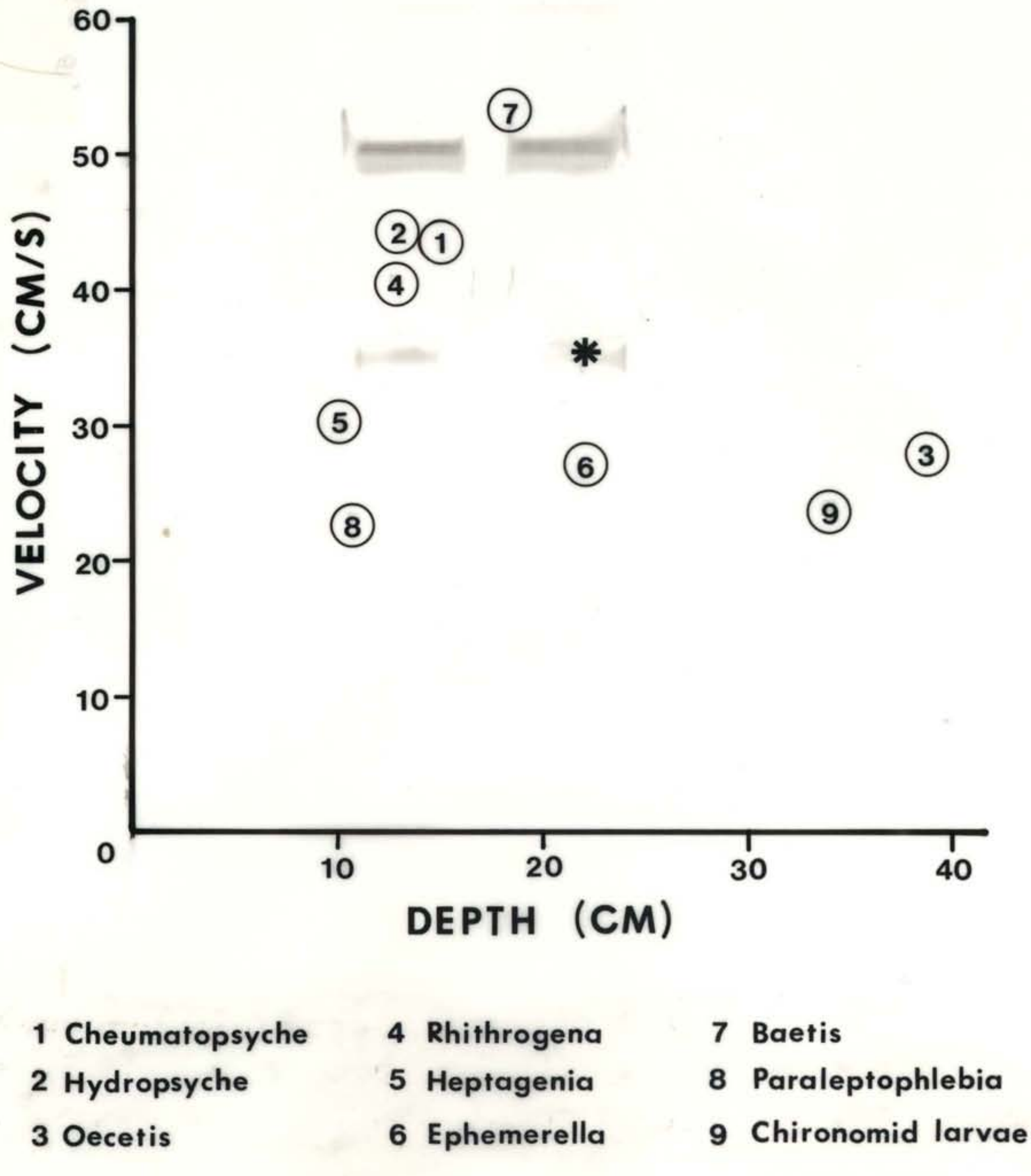


Figure 26. Centroids of optimum conditions of depth and current velocity for selected insects during reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, 1978-1979. * = Centroid for conditions of optimum community diversity (COCD). Test channel only.

greatest drift response occurred at this discharge as *Cheumatopsyche*, *Hydropsyche*, *Oecetis*, *Rhithrogena*, *Ephemerella*, and *Baetis* responded with increased drifting. Only *Oecetis* and *Ephemerella* have centroids below the associated velocity and, for both taxa, increased behavioral drift came at the end of the flow period. This delayed response appears similar to the response Philipson (1969) observed for *Hydropsyche* after a prolonged exposure to a small change in flow. We took no benthic samples during the short time a 0.06 m^3/s (2 ft^3/s) flow was maintained in summer 1979. Depths and velocities were 8 cm (0.26 ft) and 29 cm/s (0.94 ft/s), respectively. *Cheumatopscyhe* and *Ephemerella* drift increased following a reduction to this discharge. Finally, the mean depth (7 cm, 0.23 ft) and velocity (24 cm/s, 0.78 ft/s) at discharge of 0.03 m^3/s, 1 ft^3/s) were below the centroids of *Cheumatopsyche, Hydropsyche, Oecetis, Rhithrogena, Ephemerella,* and *Baetis* and all increased drift at this level of discharge in the fall. Only *Baetis* drift increased at 0.03 m^3/s (1 ft^3/s) in the spring. As long as the depth and velocity associated with optimum community diversity were maintained, there was generally little change in drift, with the exception of *Baetis*.

If increased behavioral drift was a mechanism by which invertebrates attempted to abandon the channels in search of more suitable habitat, it would follow that benthic abundance would have declined, however, this was seldom the case. It appears that the result of increased behavioral drifting, in response to reduced flow, was not an attempt to vacate the channels, but instead, was a redistribution within the channels as organisms moved to areas that fulfilled their habitat needs. For example, the caddisfly *Oecetis* appeared to shift from run to riffle areas during low flow conditions in the fall. Drift distances reported by Waters (1965) and McLay (1970) would allow for organisms to drift the length of the channels, however, Elliot (1967, 1971) and Townsend and Hildrew (1976) concluded that drifting organisms return to the substrate in a very short time, usually within 1-4 m (3-13 ft). Increased behavioral drifting would seem to be a natural survival adaptation to reduced streamflow, particularly in a stream channel where large portions of streambed are dewatered and invertebrates are subject to stranding (Kroger 1973; Brusven et al. 1974).

Benthic sampling may not have been intensive enough for complete interpretation of the response of aquatic insects to reduced flows (Resh 1979). Attempts were made to reduce sample variability, by stratifying by habitat zones, but variability remained high. Increasing the sample size from two to three did not substantially reduce variability. The high variability was due to the nonnormal, nonrandom distribution of aquatic invertebrates, and analysis required the use of non-parametric statistical techniques (Downing 1979). Uniformity of substrate in each of the habitat zones had little affect on population aggregation. Also, a sampler with a large sample area tends to mask the many very localized factors affecting micro-distribution.

Benthos use of the hyporheic zone was unaffected by the amount of flow above the substrate. Morris and Brooker (1979) found no change in vertical distribution during periods of low flow. The range of interstitial velocities is very small even though the range of surface velocities may be large (Williams and Hynes 1974). While the majority of the insects were in the upper level (Gilpin and Brusven 1976; Poole and Stewart 1976), all insect groups were found in both levels. In the fall, dipterans, primarily chironomids, and *Paraleptophlebia* were most often taken in the lower level; in the summer all groups had greater representation in the upper level. The small number of organisms collected in the summer was due to the long period of time the canisters had remained in the substrate (Morris and Brooker 1979) and the large amount of siltation that had occurred during that time period.

There are other factors related to reduced stream discharge that were not considered in this study that would affect invertebrate populations. Because the channels are only 60 m long, there was no change in water temperature at low flow (Figure 13), but in many natural streams, particularly in the arid western United States where water usage is a major concern, high water temperatures accompanying low flow could be detrimental to stream invertebrate fauna. Siltation of the substrate (Kraft 1972) and increased density of aquatic macrophytes and epilithic algae (Williams and Winget 1979) have also been related to low discharge. These factors become more important the longer flows remain low. In just 2 weeks of low flows during the fall experiment there was a noticeable accumulation of organics in the test runs. Heavy accumulations of fine organics and inorganics in the run areas also occurred during 5 months of low flow during the winter of 1978-79.

Although discharge reductions caused increased invertebrate drifting, the short-term effects of reduced stream flow on benthic populations appear to be small. Stream dwelling invertebrates have developed a wide range of tolerance that allow adaptation to changes in their physical environment. Within an organism's range of tolerances exists a set of optimal conditions which will determine the selection of microhabitat. Hydraulic variables, such as water velocity, interact with many of the factors that determine invertebrate distribution. Reduction of stream discharge alters hydraulic conditions and therefore alters all other distributional factors. The degree to which these alterations vary from the optimal habitat conditions will determine the response, and possibly the fate, of the organisms.

Summary

We found that discharge reductions were followed by an immediate increase in drift density and rate as habitat conditions changed. Within 1 or 2 weeks drift densities returned to control levels but drift rates were depressed in the test channel. We documented no significant differences in total insect abundance following reduced flow tests even though the drift indicated that insects were evacuating the channel. Based on our findings, it appears that a major impact of reduced discharge is to reduce the availability of fish food in the drift.

Total insect drift density (no/m^3 of water sampled) increased above control levels during all fall 1978 flow reduction periods. The response to reduced flows was most evident at dusk and midnight. The 50% flow reduction (0.28 m^3/s; 10 ft^3/s) had the least affect on drift. At the 85% reduction (0.08 m^3/s; 3 ft^3/s) insect drift density was much increased, averaging six times more than control levels; drift was nearly eight times the control level at dusk of the first day. *Baetis* and *Ephemerella* mayflies and chironomid and simulid dipterans were the major components of the increased drift. After 1 week drift densities were still higher in the test channel. The final flow reduction to 0.03 m^3/s (1 ft^3/s) also resulted in increased drifting in the test channel.

When considering fish food availability, the drift rate or number of insects drifting past a point per time period may be more important than drift density. Drift rates at dusk during fall 1978 tests increased following reductions to 0.14 m^3/s (5 ft^3/s) and 0.08 m^3/s (3 ft^3/s) but returned to control levels after 1 week. During the 0.03 m^3/s (1 ft^3/s) flow period, however, drift rates were reduced 50% or more as compared to drift rates in the control channel and did not return to control levels. Therefore, the amount of food available in the drift was substantially reduced during the 0.03 m^3/s (1 ft^3/s) flow period.

The four incremental reductions in discharge tested resulted in no statistical differences in total benthic insect abundance in either the test or control run or riffle habitats. There was, however, an increase in the abundance of insects in both the test and control riffles. Significant changes in some taxa were observed.

During the spring 1979 test aquatic insects responded similarly to reduced flow. During the base flow period (0.28 m^3/s; 10 ft^3/s) insect drift densities in the two channels were nearly equal. When flows were reduced to 0.03 m^3/s (1 ft^3/s) in the test channel, drift density at dusk increased to five times that in the control channel and densities remained high throughout the night, as indicated by midnight and dawn samples. The mayflies *Baetis* and *Epheremella* were the aquatic insects most affected by reduced flow. After 1 week of the reduced flow, differences between test and control drift densities were similar to those observed during the base flow period; this similarity continued for the remainder of the test.

Drift rates during the spring 1979 test were low throughout the reduced flow period. On the day of flow reduction, drift rate in the test channel was about one half the rate in the control, even though the drift density was five times larger. During the 2 week test period, drift rates in the control channel increased, while they decreased in the test channel, resulting in a reduced number of organisms available as fish food.

No significant change in benthic abundance in either run or riffle habitats was documented in spring 1979 tests. Insect density on the control riffle increased 33% while density on the test riffle increased by only 8%, indicating that abundance may have been depressed on the test riffle. Some significant changes in abundance of individual taxa were observed.

Drift densities and rates during the summer tests were larger than in previous experiments. Drift activity increased at dusk with a peak at midnight. A 50% reduction in flow resulted in a four fold increase in nighttime drift density. By the end of 1 week of low flow, drift densities were similar in test and control channels. Drift rate, however, had decreased to about one half the control level. As with other tests, the effect of flow reduction was to increase the magnitude of behavioral drift without altering the drift pattern and to decrease the drift rate. Overall, we found no significant differences in total insect densities in the run or riffle habitats of either the test or control channels.

CHAPTER 5
EFFECTS OF REDUCED STREAM DISCHARGE ON FISH POPULATIONS

Reduced stream flow appears to negatively affect abundance and biomass of salmonids (Smoker 1953; Kraft 1968; Burton and Wesche 1974), but little information documenting this relationship is available (Giger 1973). Reduced flow may decrease available habitat and food, and can affect all life stages of salmonids: incubation, rearing, migration and spawning (Stalnaker and Arnette 1976). Successful completion of each life stage is necessary for perpetuation of a population. Fish spend a relatively large proportion of time in the rearing phase, and for many salmonids all or a crucial part of this phase is spent in streams. Accordingly, the rearing phase is quite important when considering the effects of reduced stream flow on salmonid populations. Little information is available on the realtionship between stream discharge and rearing success.

The objectives of this portion of the study were to determine:

1) the relationship between juvenile rainbow-steelhead trout (*Salmo gairdneri*) abundance, in numbers and biomass, and increments of reduced stream discharge; and
2) the order of importance of depth, velocity, cover and food in limiting abundance of juvenile rainbow-steelhead trout at increments of reduced stream discharge.

The influence of flow reduction on juvenile rainbow-steelhead trout was determined by comparing emigration rates of stocked fish from the constant discharge control channel and from the incrementally reduced discharge test channel. We assumed that increased rates of emigration from a stream indicate a reduction in the area of optimum rearing habitat (Chapman 1966; Bjornn 1971; Giger 1973; Hooper 1973).

The order of importance of depth, velocity, cover and food in limiting abundance of juvenile rainbow-steelhead trout at increments of reduced stream discharge was examined by monitoring measurable physical parameters and changes in food organism abundance in both the control and test channels. We also observed fish behavior and locations with subsequent measurement of physical attributes of these locations. The importance of each measured environmental factor as it related to the response of the trout population to reduced flow was determined by comparing changes in each parameter with changes in fish population abundance. We tested the hypothesis that physical habitat would become limiting as flows were reduced and that changes in fish population abundance could be related to changes in specific physical components of the environment. This assumption has often been used (Boussu 1954; Kraft 1968; Lewis 1969; Stewart 1970; Burton and Wesche 1974; Nickelson and Reisenbichler 1977; Nickelson and Hafele 1978), and is the basis for two methods for the assessment of effects of reduced streamflow upon fish populations (Nickelson 1976; Bovee and Cochnauer 1977).

Methods

Critical Levels of Flow Reduction

We evaluated the response of juvenile rainbow-steelhead trout to incremental flow reduction by monitoring emigration during tests. Discharge in both channels was held at the base flow level for 1 to 3 weeks and then each channel was stocked with trout in excess of anticipated carrying capacity. Emigrant fish were restocked for a 3 to 7 day acclimation period, in anticipation of the fishes initial propensity to move due to displacement. A stabilization period of 4 to 7 days followed the acclimation period, during which flows were unchanged and emigrants were not restocked. During the stabilization period emigration rates decreased and the populations were assumed to have stabilized to carrying capacity. Flow in the test channel was then reduced slowly over a 3 hour period. Each flow reduction period lasted 1 to 3 weeks, dependent upon the experiment (Table 2). The control channel flow was constantly maintained at the base flow level. Upstream and downstream fish traps were monitored twice daily throughout the experiment and fish remaining in the channels following a test were retrieved by electrofishing.

Experimental fish were either of hatchery origin or wild stock from Wildcat Creek, a nearby tributary of the Grande Ronde River (Figure 6). Wild fish were collected by electrofishing using a backpack electroshocker. Fish were transported to the experimental channels by tank truck, anesthetized with MS 222 (tricainemethane sulfonate), and measured, weighed and fin clipped. Experimental fish were then held in live buckets until they recovered from the anesthetic and then released in the appropriate channel. Size grading of fish to each channel was kept as random as possible. The minimum size of trout stocked was chosen to be 80 mm, which we felt to be the minimum size which could be efficiently collected in our upstream and downstream traps.

As fish left the experimental channels during tests, length, weight and condition of each trout were recorded. Condition of trout was noted as healthy, injured/diseased or dead. Trapped fish were released either into the Grande Ronde River or Wildcat Creek.

Immigration of nonstocked fish was prevented by the downstream trapping structures. Although some nonstocked fish did enter the channels from the upstream end, few of the fish took up residence in the channels (Table 15) and most passed through the channels and into the downstream traps.

Table 15. Numbers and biomass of nonstocked fish retrieved by electrofishing at the end of the fall 1978 and spring 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

	Control		Test	
	Number	Weight (g)	Number	Weight (g)
Fall 1978	5	132.3	0	0.0
Spring 1979	10	67.3	12	128.5

Fall 1978 Experiment

Our first experiment was completed during August-October 1978 (Table 2). Rainbow-steelhead trout from Wildcat Creek were stocked during the first 3 days of the experiment. A total of 281 and 282 fish were stocked in the control and test channels, respectively. Fish ranged in size from 81 to 291 mm, but most were between 100 and 150 mm (Figure 27). Total weight of fish stocked in each channel was approximately equivalent, with the test channel receiving slightly more biomass (Table 16).

The base flow level used in the fall 1978 experiment was approximately 0.57 m^3/s (Table 2). This flow represented the designed average daily flow level for the configuration of each channel. Flows were reduced in the test channel 50, 75, 90 and 95% during this experiment, which corresponds to 0.28, 0.17, 0.08 and 0.03 m^3/s. To reduce potential seasonal effects, duration of each reduced flow period was 1 week. Results of this experiment indicated that the 1 week test flow duration

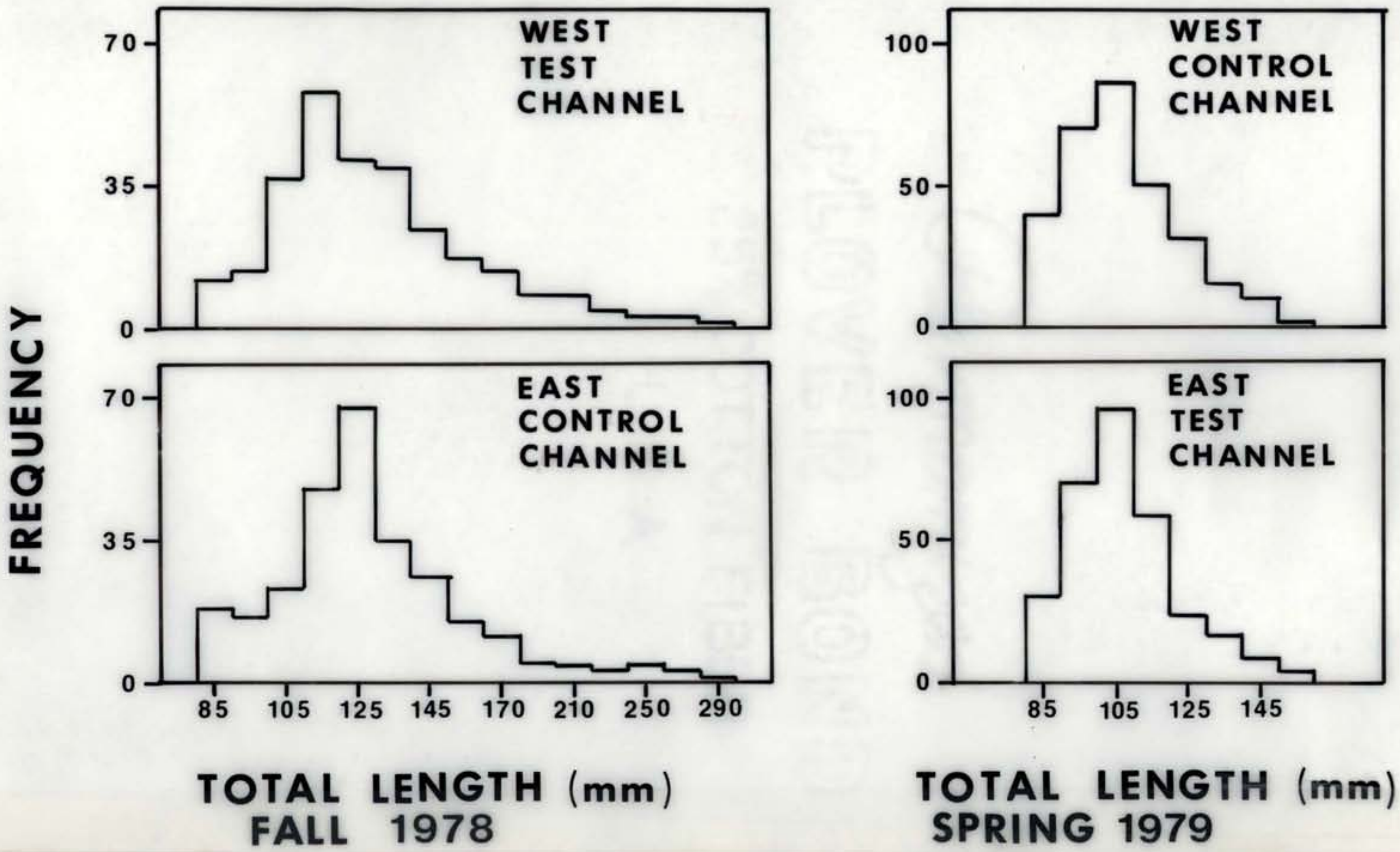


Figure 27. Length frequency of rainbow-steelhead trout (*Salmo gairdneri*) stocked in each channel during the fall 1978 and spring 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

Table 16. Total weight (g) of rainbow-steelhead trout (*Salmo gairdneri*) stocked, trapped and retrieved during fall 1978, spring and summer 1979 reduced stream discharge experiments. Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

	Fish Biomass (g)							
	Fall 1978		Spring 1979		Summer 1979			
	Wild		Hatchery		Wild		Hatchery	
	East control	West test	West control	East test	East control	West test	East control	West test
Stocked	7278.5	7403.9	3386.2	3571.5	3040.5	2225.5	5167.8	4927.5
Trapped								
0.57 m^3/sec	2143.0	1526.9	--	--	--	--	--	--
0.28 m^3/sec	218.6	763.2	1163.9	1038.3	555.3	629.0	1554.1	1441.1
0.17 m^3/sec	59.1	598.2	--	--	454.4	669.6	469.0	570.2
0.08 m^3/sec	294.7	595.8	--	--	--	--	--	--
0.03 m^3/sec	40.4	713.9	122.1	500.4	--	--	--	--
Total reduction	612.8	2671.7	122.1	500.4	454.4	669.6	469.0	570.2
Total	2755.8	4198.6	1286.0	1538.7	1007.7	1298.6	2023.1	2011.3
Retrieved	4095.6	2272.6	1842.7	1280.0	--	--	--	--

did not allow sufficient time for total response of experimental fish to reduced flow conditions.

Water temperatures during the first experiment were similar between the two channels throughout the experiment (Figure 13). The test channel temperature appeared to be lower than the control, but this difference was not significant as mean water temperatures for each channel were within two standard errors of each other (Table 17), except for the base flow and the fourth reduced flow period, in which a substantial amount of data were missing for the test channel due to thermograph malfunction. There was a substantial overall decrease in water temperature throughout most of the experiment, except for an increasing trend during the last half of the third flow reduction period (Figure 13). Water temperatures were monitored with recording thermographs, accurate to 0.25 C. Statistics were computed from hourly records taken from thermograph charts.

Spring 1979 Experiment

Our second experiment was completed during March-April, 1979 (Table 2). Because of high water conditions in Wildcat Creek we used juvenile steelhead trout from the Wallowa County Fish Hatchery, Enterprise, Oregon, in our test. The hatchery stock were first generation progeny of wild lower Snake River steelhead. We stocked 305 fish in each channel on the first day of the experiment. The fish ranged in size from 80 to 158 mm, but most were between 90 and 120 mm (Figure 27). Slightly more biomass of trout was stocked in the test channel than in the control (Table 16).

The base flow used for this experiment was approximately 0.28 m^3/s (Table 2). This flow was used instead of the 0.57 m^3/s base flow used

Table 17. Water temperature statistics for the fall 1978, spring and summer 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Asterisks (*) denote missing data.

		Water temperature (C)							
		Control				Test			
		Mean	S.E.	Min.	Max.	Mean	S.E.	Min.	Max.
Fall 1978									
Flow period	0	17.62	0.10	13.6	21.2	16.41	0.12	13.2	19.6
	1	14.18	0.13	11.5	18.0	13.97	0.13	11.3	17.8
	2	12.00	0.14	8.8	15.8	11.77	0.14	8.4	15.7
	3	13.23	0.18	9.4	18.2	12.90*	0.18	9.3	17.9
	4	12.87	0.13	9.0	16.2	11.13	0.18	8.9	12.2
Spring 1979									
Flow period	0	5.39*	0.05	3.9	8.0	5.14	0.04	3.8	7.8
Flow period	1	6.71	0.05	4.7	10.0	6.48*	0.04	4.5	9.5
Week	1	5.89	0.04	4.7	6.8	5.66	0.04	4.5	6.5
	2	6.54	0.06	5.0	7.9	6.32	0.05	5.0	7.5
	3	7.69	0.06	6.1	10.0	7.48*	0.06	6.0	9.5
Summer 1979									
Flow period	0	13.46	0.10	8.3	18.6	13.55	0.09	8.6	18.6
Flow period	1	19.26	0.13	15.1	25.8	19.13	0.14	15.0	25.8
Week	1	17.86	0.08	15.1	20.1	17.73	0.09	15.0	20.2
	2	20.67	0.20	15.2	25.8	20.52	0.21	15.0	25.8

in the fall 1978 experiment because preliminary analyses of the depths and velocities in each channel at both flow levels indicated that more area of optimum rearing habitat for juvenile steelhead trout was available at the 0.28 m^3/s than at the 0.57 m^3/s flow level. Only one reduced flow level was tested (0.03 m^3/s), because of the anticipated but unpredictable rise of the Grande Ronde River due to spring runoff, which caused water to backup into the downstream end of each channel. The duration of the reduced flow was 3 weeks.

Water temperature during the second experiment was consistently lower in the test channel throughout the experiment (Figure 13). This difference was statistically significant in all cases (Table 17). During this experiment the test channel was the east experiment channel, and due to its positioning it did not receive the afternoon sun. At this time of year direct solar radiation versus no direct radiation could account for the differences between the two channels. Flow reduction did not affect this difference (Figure 13). The temperatures in both channels were quite low during the baseflow period, and did not substantially increase until the last week of the flow reduced period.

Summer 1979 Experiment

Our third experiment was conducted during June-July, 1979 (Table 2). We stocked 105 and 102 wild rainbow-steelhead trout from Wildcat Creek in the control and test channels, respectively. Since we were unable to obtain an adequate number of wild fish we supplemented wild stock with hatchery fish from Dworshak National Fish Hatchery, Ahsahka, Idaho. A total of 245 and 248 hatchery trout were stocked in the control and text channels, respectively, bringing the number in each channel up to 350 fish. The wild fish ranged in size for 95 to 209 mm, but most were between 110 and 170 mm (Figure 28); hatchery trout ranged from 85 to 181 mm, and most were between 100 and 160 mm. Due to the random nature of stocking procedures a greater proportion of large fish (170 to 210 mm) were stocked in the control channel as compared to the test. This resulted in more biomass of both wild and hatchery fish in the control than in the test channel (Table 16).

The base flow used in the summer experiment was 0.28 m^3/s (Table 2), with a 2 week test flow of 0.17 m^3/s. The original test schedule called for further flow reductions to 0.08 and 0.03 m^3/s. However, low flows in the Grande Ronde River, in addition to sediment deposition in our diversion channel resulted in an inadequate water supply to continue tests. The fish trapping phase was discontinued after 20 July.

Water temperature during this experiment was similar in the two channels and in no case did mean water temperature vary between channels by more than two standard error units (Figure 13, Table 17). Water temperature increased throughout the experiment.

Determinants of Response of Trout to Reduced Flow

The order of importance of depth, velocity, cover and food in limiting trout abundance at increments of reduced discharge was examined by comparing trout abundance changes to changes in measured physical parameters and food abundance and by observing fish behavior and quantifying microhabitat characteristics.

Measurement of physical characteristics of our simulated streams and aquatic insect sampling techniques are described in other sections of

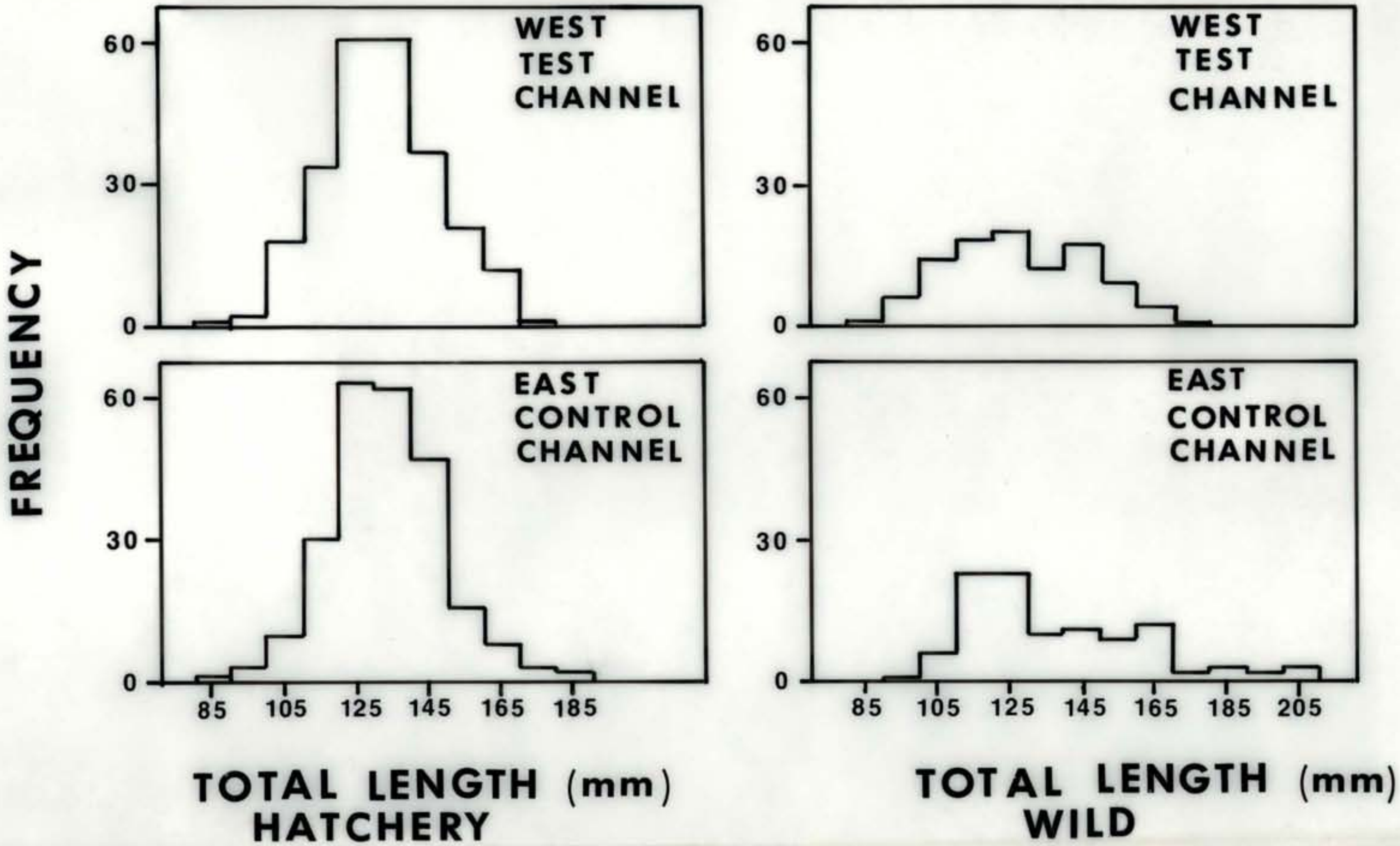


Figure 28. Length frequency of wild and hatchery rainbow-steelhead trout (*Salmo gairdneri*) stocked in each channel during the summer 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

this report.

Changes in depth, velocity and wetted perimeter were compared to trout abundance changes. Physical parameter data for these comparisons were collected from the 16 velocity profile transects in each channel at the five flow levels tested.

Only changes in total drift rate and density of food organisms were used for comparisons. Benthic sample data were not used as juvenile rainbow-steelhead trout are primarily drift feeders (Chapman and Bjornn 1969; Waters 1969). Only dusk and dawn sample data were used as it was felt midnight samples would not represent food available to trout. Sample times chosen for these comparisons excluded samples taken immediately after flow reductions, as trout migrating at this time were probably responding to the flow reduction itself, not to changes in food abundance.

Fish behavior was either observed by underwater snorkeling at the end of tests or from overhead observation posts during tests. Snorkeling observations were taken at the 0.57 m^3/s and 0.03 m^3/s flow levels in the control and test channels, respectively, during 4-6 October 1978. Turbidity and low flow prevented snorkeling observations in spring and summer 1979 tests, respectively. Overhead observations were taken at the 0.17 m^3/s flow level in the test channel during 17-18 July 1979. Observations were not made at the 0.28 m^3/s flow level due to inadequate water supply after 20 July 1980. During observations each fish's approximate size, relation to other fish, location (including distance from the substrate when snorkeling), association to cover rocks and feeding behavior was recorded. Territoriality was determined when interactions were frequent enough to define a defended area. Territory size was estimated as the approximate diameter of the defended area. Aggregations of fish, if present, were described in terms of number of fish and general behavior of the aggregation.

Microhabitat characteristics were examined by measurement of physical parameters associated with each mapped fish location. Parameters measured at fish locations were depth to the nearest 3 mm (0.01ft) as determined with a top-setting rod; mean velocity (at 0.6 depth), to the nearest 3 mm/s (0.01 ft/s), with a direct readout water current meter; substrate composition (Appendix F), according to the index of Bovee and Cochnauer (1977); and surface turbulence rating, in which 0 denoted no turbulence; 1, low turbulence; 2, moderate turbulence; and 3, high turbulence. Additionally, depth and mean velocity (at 0.6 depth) were measured at 61 and 152 cm (2 and 5 ft) upstream of each fish location. Microhabitat characteristics were only examined for fish locations observed at the 0.17 m^3/s flow level during the summer, 1979 experiment.

Numerical and Statistical Analyses

All numerical and statistical analyses were carried out on the University of Idaho's IBM 370/145 computer. The statistical computer package of the Statistical Analysis System (SAS Institute 1979) was used for all computations. A specialized test available in the SAS package called FUNCAT, which "models functions of categorical responses as a linear model", was used to compare the relative changes in fish abundance between the control and test channels at the end of each test flow period. The particular statistic tested was termed percent remaining, which was calculated as the ratio of the estimated number of fish remaining in each channel at the end of a reduced flow period to the estimated number of fish remaining in each channel at the end of the stabilization or base flow period, multiplied by 100. The functional response used in the FUNCAT procedure was the default, linear logistic (logit) response. The response variable was the categorical response of the number of fish which emigrated from the channel and the number of fish which remained in the channel at each particular flow level. Additionally a contrast statement was used so that effects at each reduced flow level (during the fall 1978 experiment) could be compared to the base flow period, rather than just the default comparison to the final flow period. The FUNCAT procedure was also used to test the effect of flow reduction upon the direction of fish emigration (upstream or downstream), and the effect of fish stock (hatchery or wild) on reduced flow response of fish during the summer 1979 experiment. Chi-square statistics from contingency tables were used to make individual comparisons of the percent remaining statistic as affected by discharge change and fish stock. The estimated probabilities (P) used for decision making were either given directly by SAS or estimated from standard statistical tables. The P values represented the probability that the observed test statistic could occur entirely due to chance.

Results

Critical Levels of Flow Reduction

Fall 1978 Experiment

Substantially more fish migrated from the test channel during all four flow reduced periods than emigrated from the control channel (Figure 29). No particular flow reduction more severely affected trout emigration than any other. However, the short duration of each flow reduction

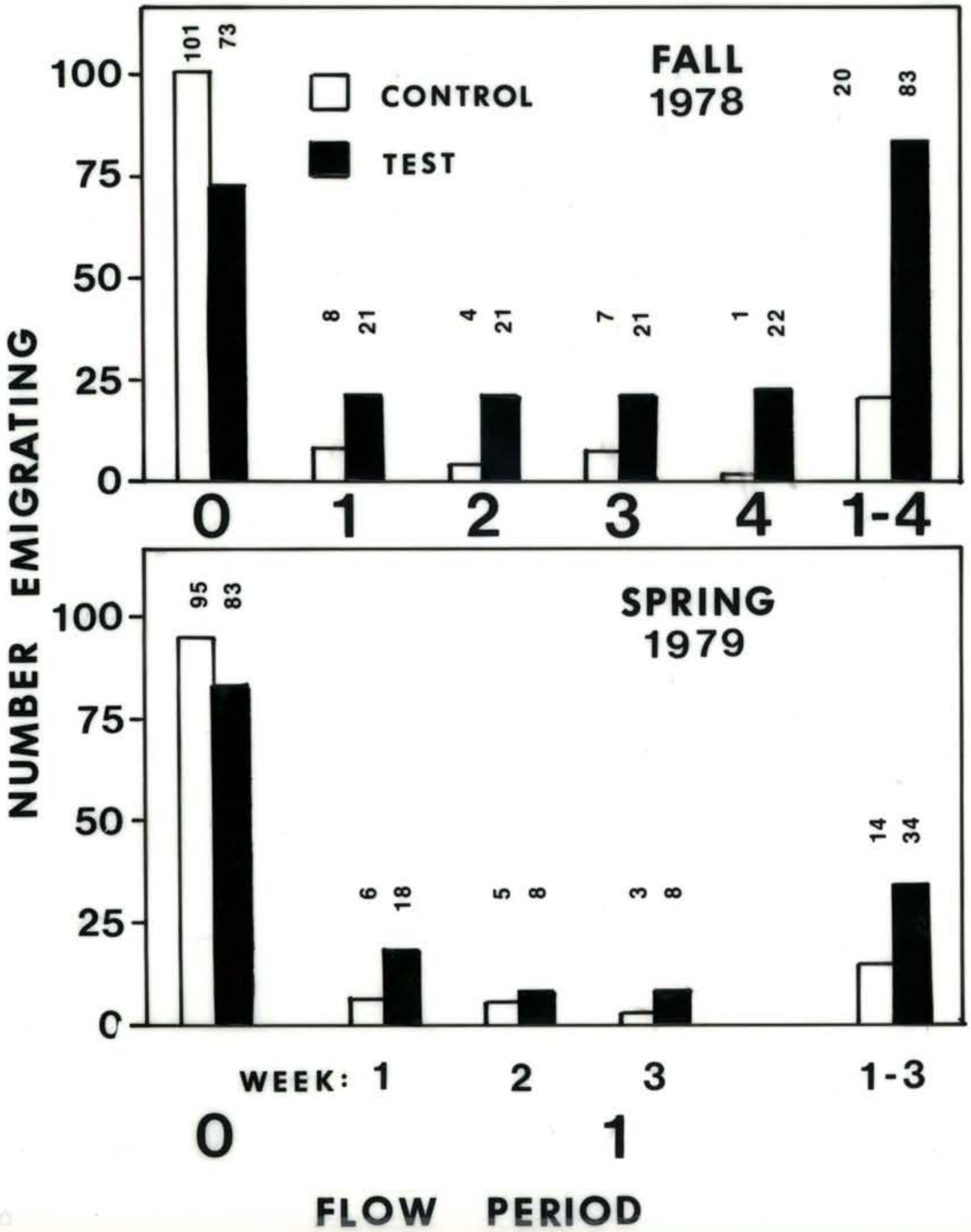


Figure 29. Number of stocked rainbow-steelhead trout (*Salmo gairdneri*) emigrating from each channel during the fall 1978, and spring 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods are: fall 1978: 0 = 0.57 m^3/s, 1 = 0.28 m^3/s, 2 = 0.17 m^3/s, 3 = 0.08 m^3/s, 4 = 0.03 m^3/s; spring 1979: 0 = 0.28 m^3/s, 1 = 0.03 m^3/s. Control flows are: fall 1978, 0.57 m^3/s; spring 1979, 0.28 m^3/s.

period probably did not allow for the full response of trout to each flow tested, as the rate of emigration from the test channel was similar throughout each reduced flow period and did not level out before the initiation of another flow reduction (Figure 30).

Due to a substantial difference in the number of trout which emigrated from each channel during the base flow period (Figure 29), we assumed that there was a difference in carrying capacity between the channels. Accordingly, comparisons between channels were made in terms of percent remaining statistic, with the estimated number of trout remaining at the end of the base flow period defined as 100%. The test channel had consistently and significantly ($P < 0.10$) lower values of percent fish remaining than did the control channel during the fall 1978 experiment (89% and 59% in the control and test channels, respectively, following the last flow reduction; (Figure 31 and Table 18). Fish abundance in the test channel at the end of each reduced flow period was significantly lower than abundance in the control channel, but no flow reduction appeared to affect fish emigration more strongly than any other.

Total biomass of trout migrating from each channel exhibited patterns similar to individual emigration. Due to the small number of fish migrating from the control channel during the reduced flow periods, however, there was a greater variation in biomass emigrating from this channel than existed for individual numbers (Table 16 and Figure 29).

Size distribution of trout emigrating from each channel throughout the experiment was fairly similar (Figure 32). Ninety-seven percent of the small fish (80 to 110 mm) migrated from the control channel during the base flow period compared to 89 percent during this same period from

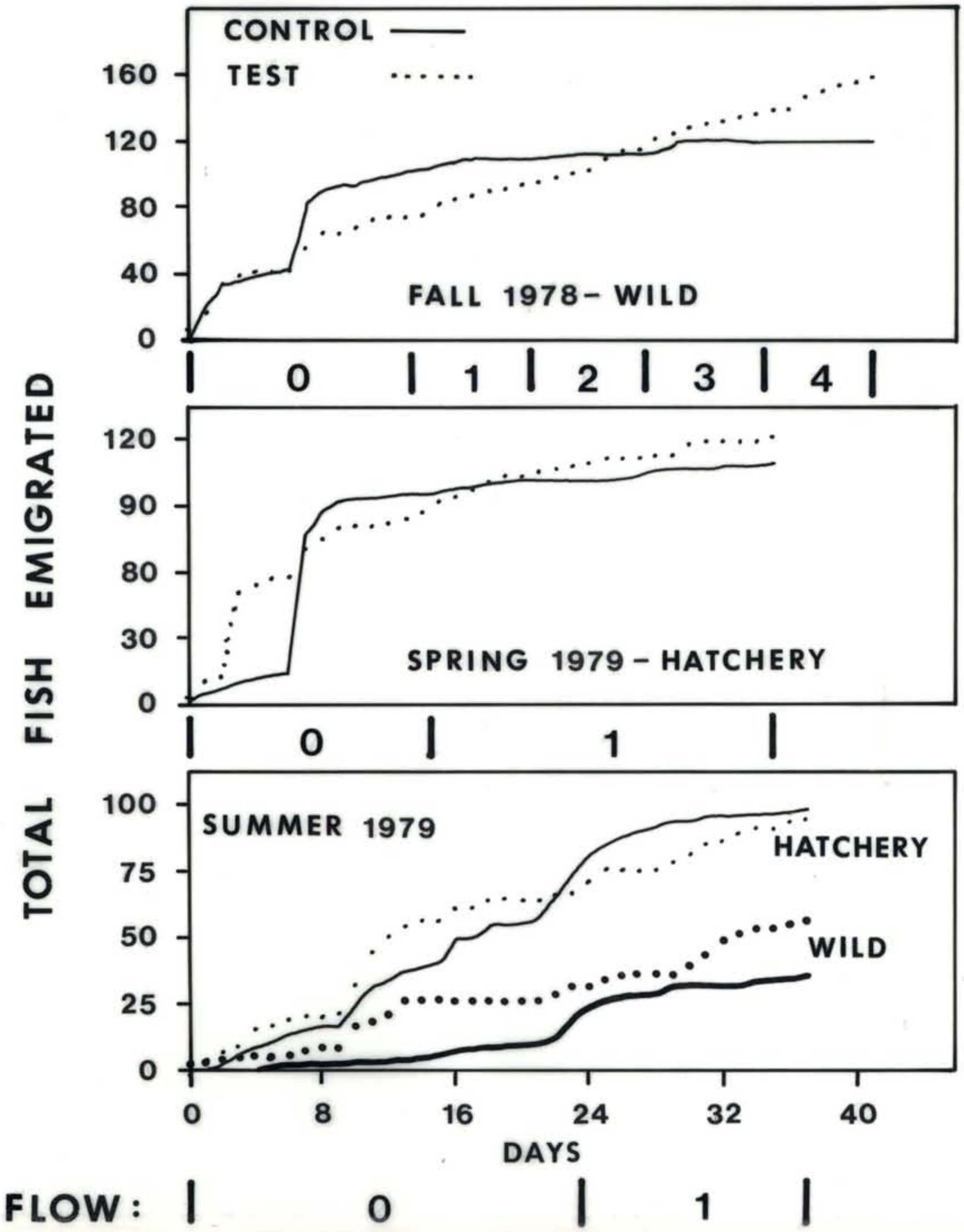


Figure 30. Cumulative number of stocked rainbow-steelhead trout (*Salmo gairdneri*) trapped by day in each channel during the fall 1978, spring, and summer 1979, reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods are: fall 1978: 0 = 0.57 m^3/s, 1 = 0.28 m^3/s, 2 = 0.17 m^3/s, 3 = 0.08 m^3/s, 4 = 0.03 m^3/s; spring 1979: 0 = 0.28 m^3/s, 1 = 0.03 m^3/s; summer 1979: 0 = 0.28 m^3/s, 1 = 0.17 m^3/s. Control flows are: fall 1978, 0.57 m^3/s; spring and summer 1979, 0.28 m^3/s.

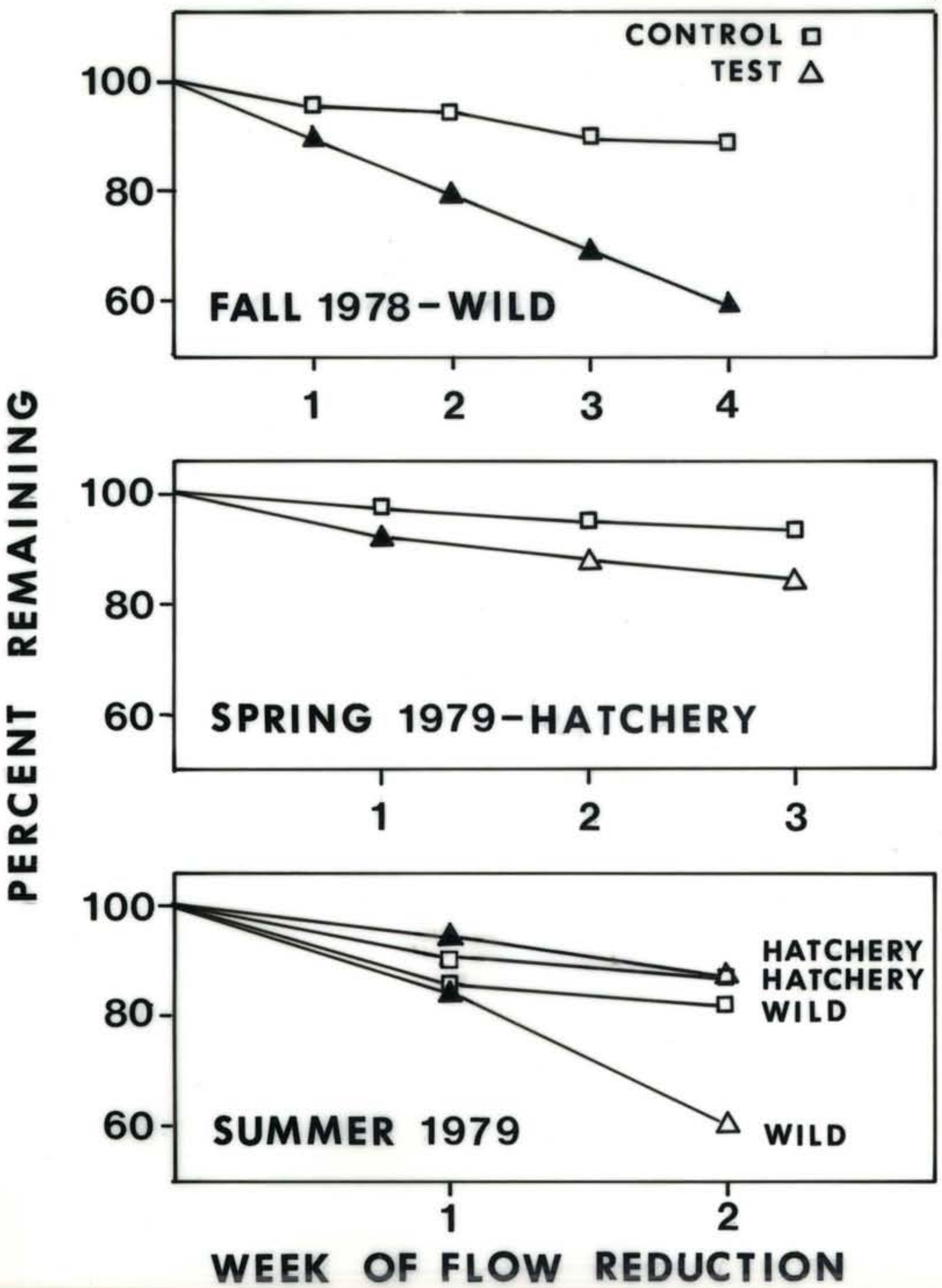


Figure 31. The percent of stocked rainbow-steelhead trout (*Salmo gairdneri*) remaining in each channel after each week of flow reduction during the fall 1978, spring, and summer 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Darkened triangles refer to flow reductions: fall 1978, control flow of 0.57 m^3/s, week 1 = 0.28 m^3/s, week 2 = 0.17 m^3/s, week 3 = 0.08 m^3/s, week 4 = 0.03 m^3/s; spring 1979, control flow of 0.28 m^3/s, week 1-3 = 0.03 m^3/s; summer 1979, control flow of 0.28 m^3/s, week 1-2 = 0.17 m^3/s.

Table 18. Estimated probabilities (P) that the observed percent fish remaining statistic could have occurred by chance alone, during the fall 1978, spring and summer 1979 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. FUNCAT refers to a specialized test from the SAS Institute (1979).

Comparison	Statistical test	Estimated probability (P)
Fall 1978		
0.57 to 0.28 m^3/s	Contingency table	0.0001
0.28 to 0.17 m^3/s	FUNCAT	0.0001
0.14 to 0.08 m^3/s	FUNCAT	0.0001
0.08 to 0.03 m^3/s	FUNCAT	0.0816
Channel	FUNCAT	0.0001
Spring 1979		
0.28 to 0.03 m^3/s	FUNCAT	0.0001
Channel		0.7100
Summer 1979		
0.28 to 0.17m^3/s	FUNCAT	0.005
Channel	FUNCAT	0.0139
Stock	FUNCAT	0.0445
Stock and Flow Change	FUNCAT	0.0001
Control hatchery	Contingency table	
Remained		> 0.10
Emigrated		> 0.10
Control wild	Contingency table	
Remained		1.0
Emigrated		1.0
Test hatchery	Contingency table	
Remained		> 0.10
Emigrated		> 0.10
Test wild	Contingency table	
Remained		> 0.005
Emigrated		$.05 < P < 0.025$

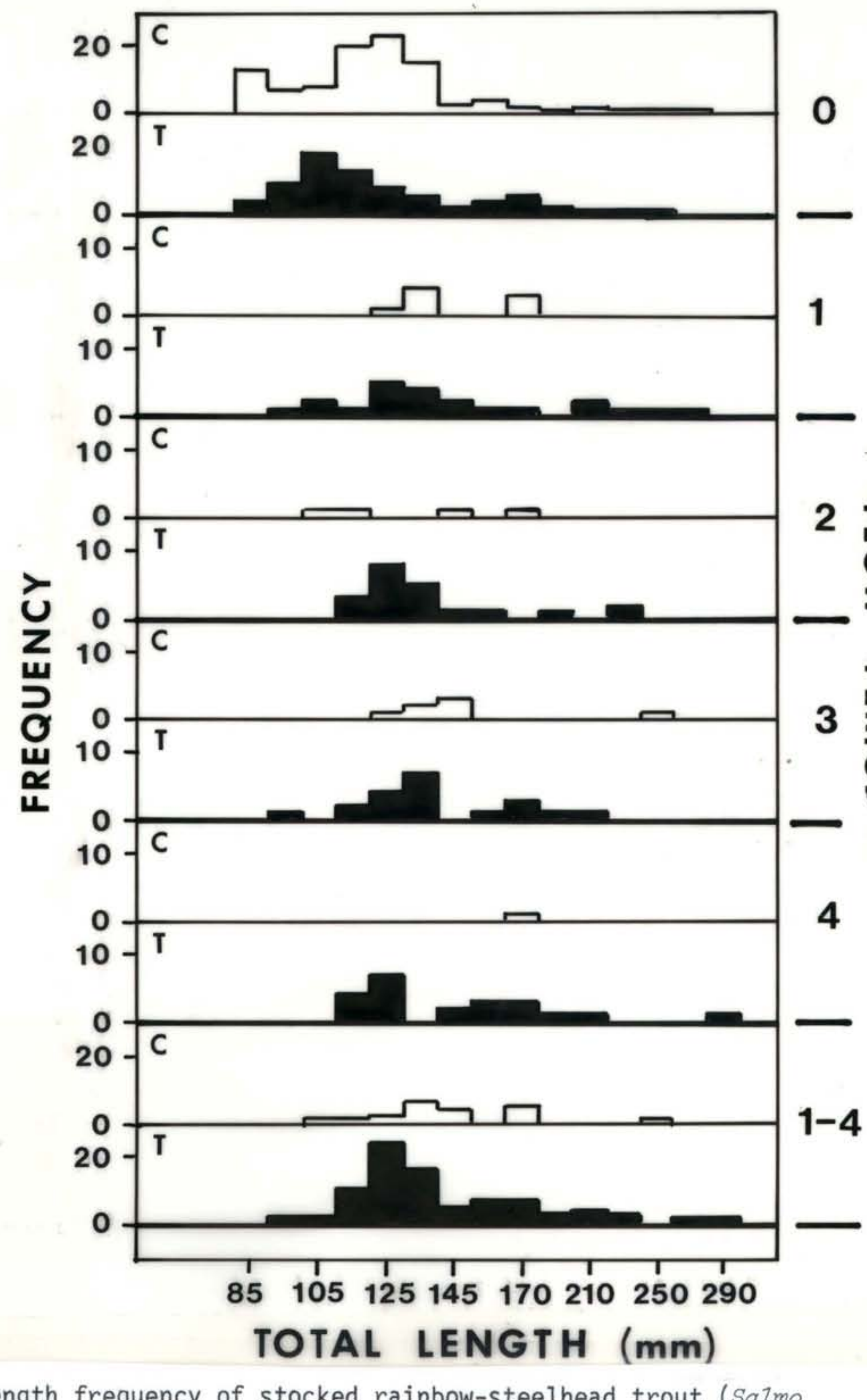


Figure 32. Length frequency of stocked rainbow-steelhead trout (*Salmo gairdneri*) trapped in each channel for each flow period and for all reduced flow periods during the fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods are: 0 = 0.57 m^3/s; 1 = 0.28 m^3/s; 2 = 0.17 m^3/s; 3 = 0.08 m^3/s; 4 = 0.03 m^3/s. Control flow was 0.57 m^3/s.

the test channel. During flow reduction periods, 13 large fish (180+ mm) migrated from the test channel compared to only one large fish from the control channel. Size distribution of fish retrieved at the end of the experiment corroborated this observation (Figure 33).

Total number of fish retrieved was 129 and 91 from the control and test channels, respectively. Biomass of trout remaining in the control channel was 1.8 times more than in the test channel (Table 16). Total number of fish accounted for (trapped and retrieved) was 250 and 248 or 89 and 88% of the original number stocked in the control and test channels, respectively.

Direction of emigration of healthy trout was primarily downstream in both channels throughout the experiment (Figure 34). There was a non-significant ($P > 0.10$) tendency for greater upstream movement in the test than in the control channel, especially during the fourth flow reduction period (Figure 34 and Table 19). The particular channel, regardless of discharge, had little affect upon direction of migration.

Spring 1979 Experiment

More trout migrated from the test than from the control channel during the 3 weeks of flow reduction in spring 1979 (Figure 29). The rate of emigration was fairly constant out of the test channel throughout the reduced flow period (Figure 30). The test channel had a significantly ($P < 0.0001$) lower value of percent fish remaining than did the control channel during the experiment (93.3% and 84.7% in the control and test channels, respectively; Figure 31 and Table 18). The percentage of

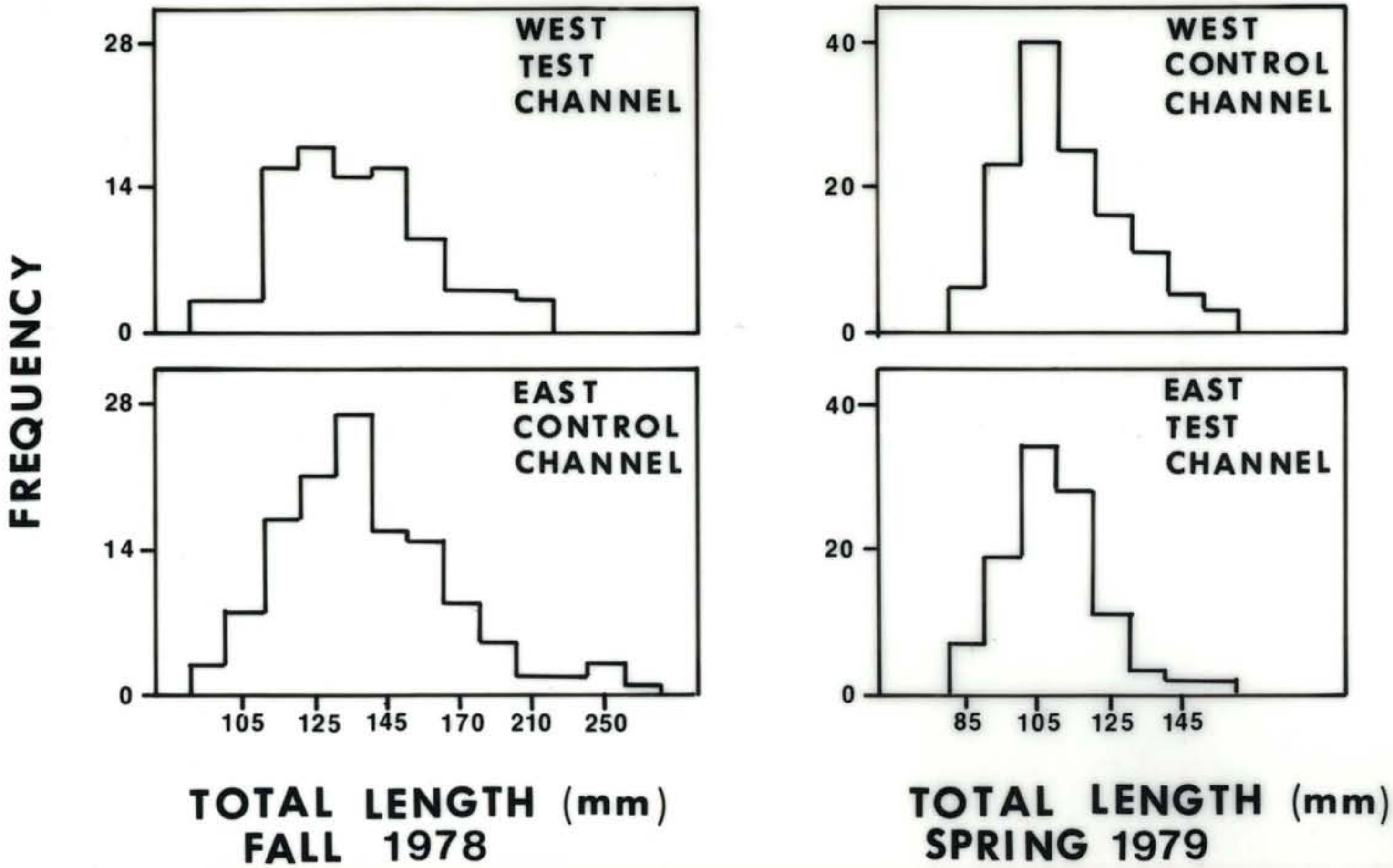


Figure 33. Length frequency of stocked rainbow-steelhead trout (*Salmo gairdneri*) retrieved by electrofishing each channel at the end of the fall 1978 and spring 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

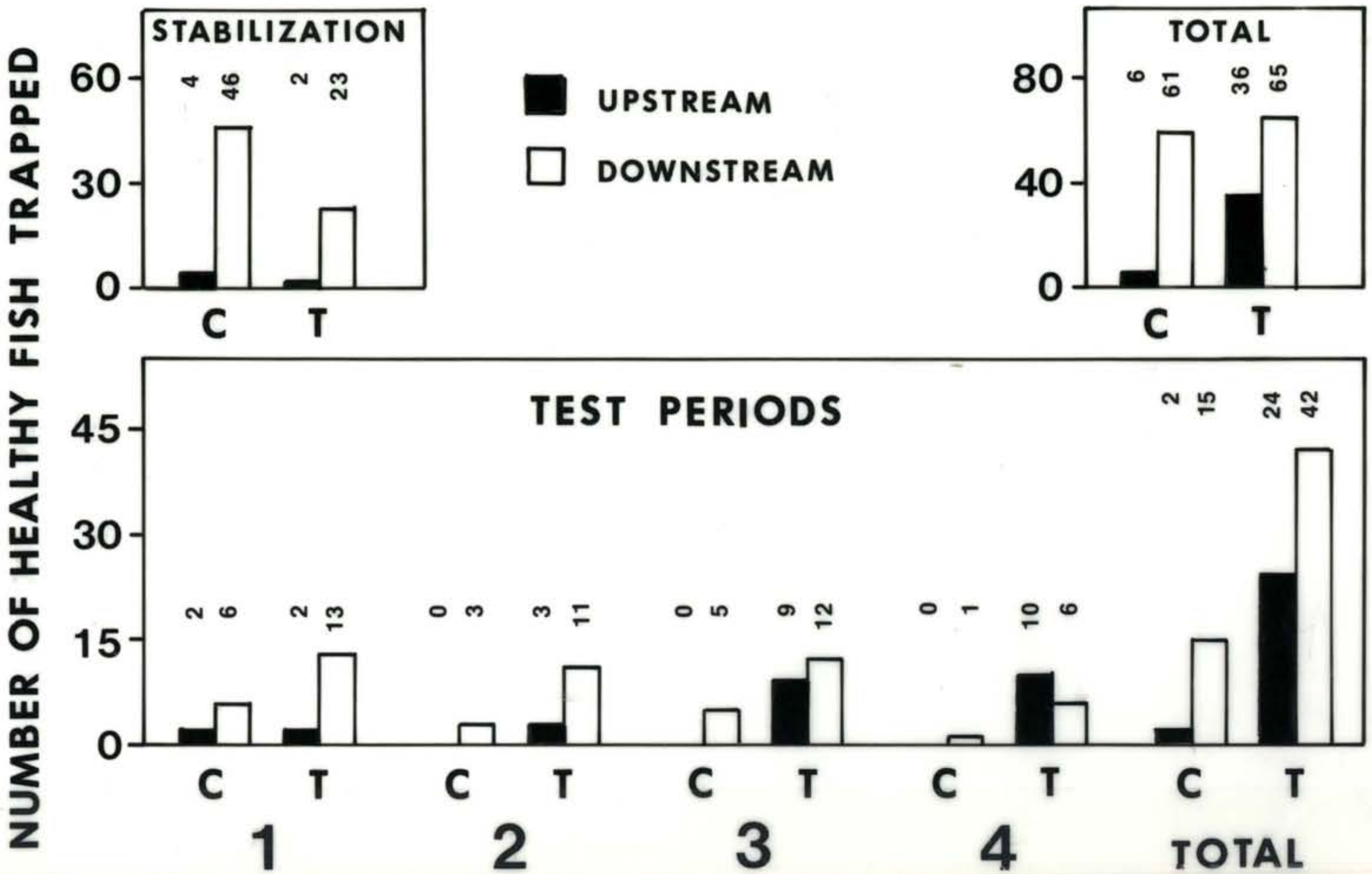


Figure 34. Number of healthy stocked rainbow-steelhead trout (*Salmo gairdneri*) trapped in each channel according to direction of emigration for the fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods are: stabilization = 0.57 m^3/s; 1 = 0.28 m^3/s; 2 = 0.17 m^3/s; 3 = 0.08 m^3/s; 4 = 0.03 m^3/s. Control flow was 0.57 m^3/s.

Table 19. Estimated probabilities (P) that the observed value of trout moving upstream versus downstream, as affected by discharge, stock and channel, could have occurred by chance alone, during the fall 1978, spring and summer 1979 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. FUNCAT refers to a specialized test from the SAS Institute (1979).

Comparison	Statistical test	Estimated probability (P)
Fall 1978		
0.57 to 0.38 m^3/s	FUNCAT	0.1328
0.28 to 0.17 m^3/s	FUNCAT	0.9845
0.14 to 0.08 m^3/s	FUNCAT	0.2993
0.08 to 0.03 m^3/s	FUNCAT	0.2516
Channel	FUNCAT	0.5024
Spring 1979		
0.28 to 0.03 m^3/s	FUNCAT	0.0001
Channel	FUNCAT	0.0635
Summer 1979		
Stock	FUNCAT	0.3694
0.28 to 0.17 m^3/s	FUNCAT	0.7902
Channel	FUNCAT	0.0132

remaining in the test channel at the end of the spring experiment was substantially greater than at the end of the fall experiment.

During the base flow period more trout emigrated from the control channel than from the test channel (Figure 29). However, this difference was not consistent during the entire base flow period (Figure 30). The greater number of trout emigrating from the test channel during the acclimation period was due to accidentally leaving a closure board on the downstream trap in place on day 2, which resulted in the death or injury of 39 fish. Fortunately, this loss of fish was offset by a substantial emigration from the control channel on day 7, after the end of the acclimation period.

Total biomass of trout emigrating from each channel during the spring 1979 experiment paralleled the number of individuals emigrating (Table 16, Figure 29). Size distribution of emigrants from each channel was only moderately different (Figure 35). Eighty-five percent of the smaller fish (80 to 100 mm) migrated from the control channel during the base flow period, while 91 percent of the smaller fish migrated from the test channel during this same period. Five larger trout (130+ mm) migrated from the test channel during the reduced flow period, while no trout this large migrated from the control channel. The size distribution of fish retrieved at the end of the experiment corroborated this observation (Figure 33).

The total number of fish retrieved at the end of the test was 129 and 106 from the control and test channels, respectively. Biomass of trout remaining in the control channel was 1.4 times larger than biomass of trout in the test channel (Table 16). The total number of fish

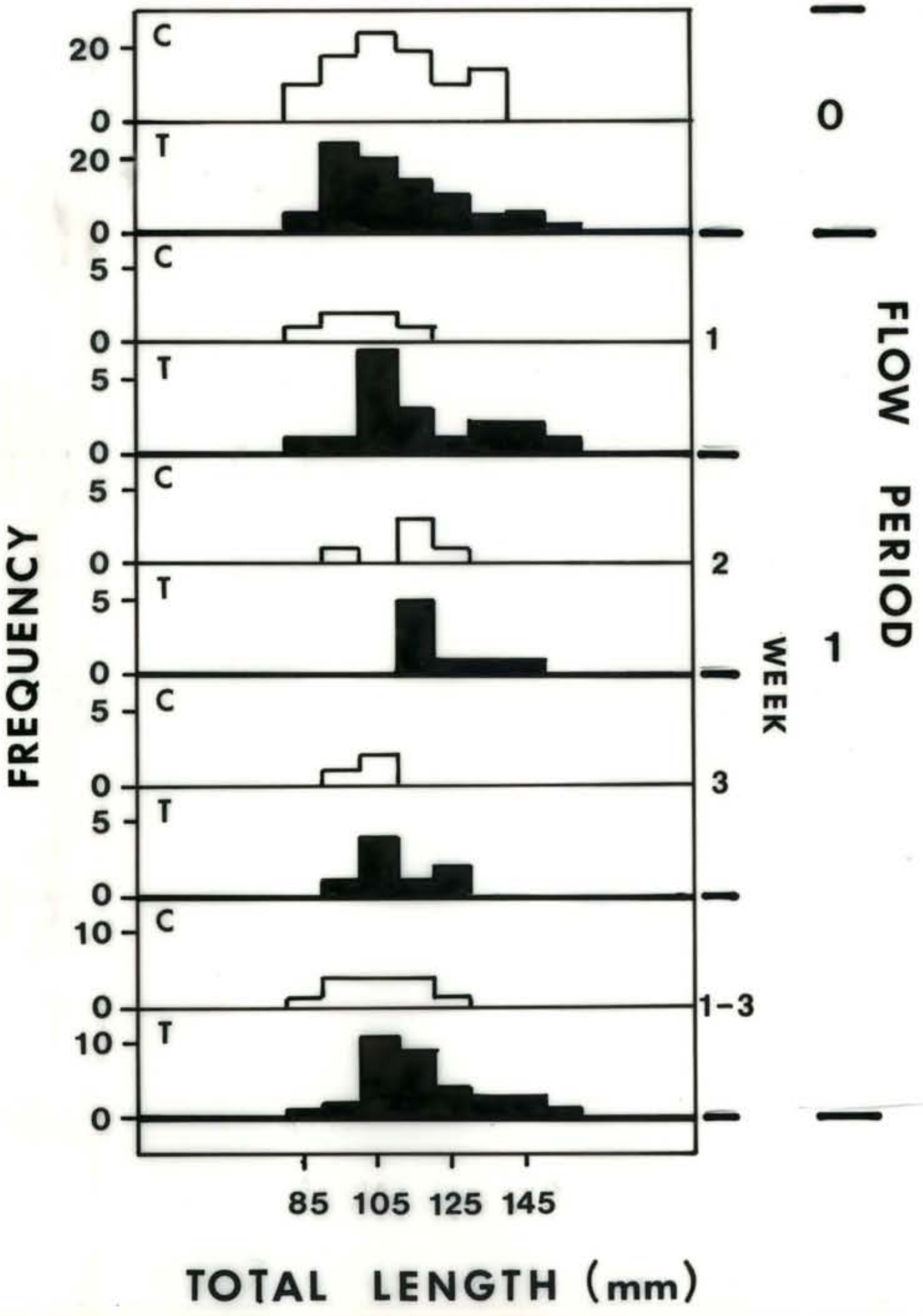


Figure 35. Length frequency of stocked juvenile steelhead trout (*Salmo gairdneri*) trapped in each channel by flow period and for weekly totals of the reduced flow period during the spring 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods are: 0 = 0.28 m^3/s; 1 = 0.03 m^3/s. Control flow was 0.28 m^3/s.

accounted for was 238 and 223 or 78 and 73% of the original number stocked in the control and test channels, respectively.

During the spring 1979 flow reduction period more healthy trout migrated in the upstream direction (Figure 36). There was significant (P = 0.0001) affect of discharge reduction on direction of emigration with 74% of the healthy fish migrating upstream in the test channel versus 69% in the control channel (Table 19).

Emigration of healthy trout was primarily in the downstream direction during the spring 1979 base flow period (Figure 36). The apparent smaller proportion of fish migrating downstream in the test channel during the stabilization flow was due to the accidental mortality of 39 trout in the test channel on day 2, as mentioned above. These trout were not included in the upstream and downstream comparison, accordingly comparisons of movement during this period are meaningless.

Summer 1979

Flow reduction during our third experiment more severely affected wild trout than hatchery trout (Figure 37). About the same numbers of hatchery trout migrated from each channel during the reduced flow period, while almost twice as many wild trout migrated from the test than from the control. The greatest effect upon wild trout migration occurred during the second week of flow reduction (Figure 30 and 37). The percentage of wild trout remaining in the test channel at the end of the reduced flow period was significantly ($P < .05$) lower than control wild fish or control and test hatchery fish (test wild: 60.6%; control wild: 82.4%; test hatchery: 87.0%; and control hatchery: 86.9%) (Figure 31 and Table 18). Percent remaining of control wild and hatchery and test

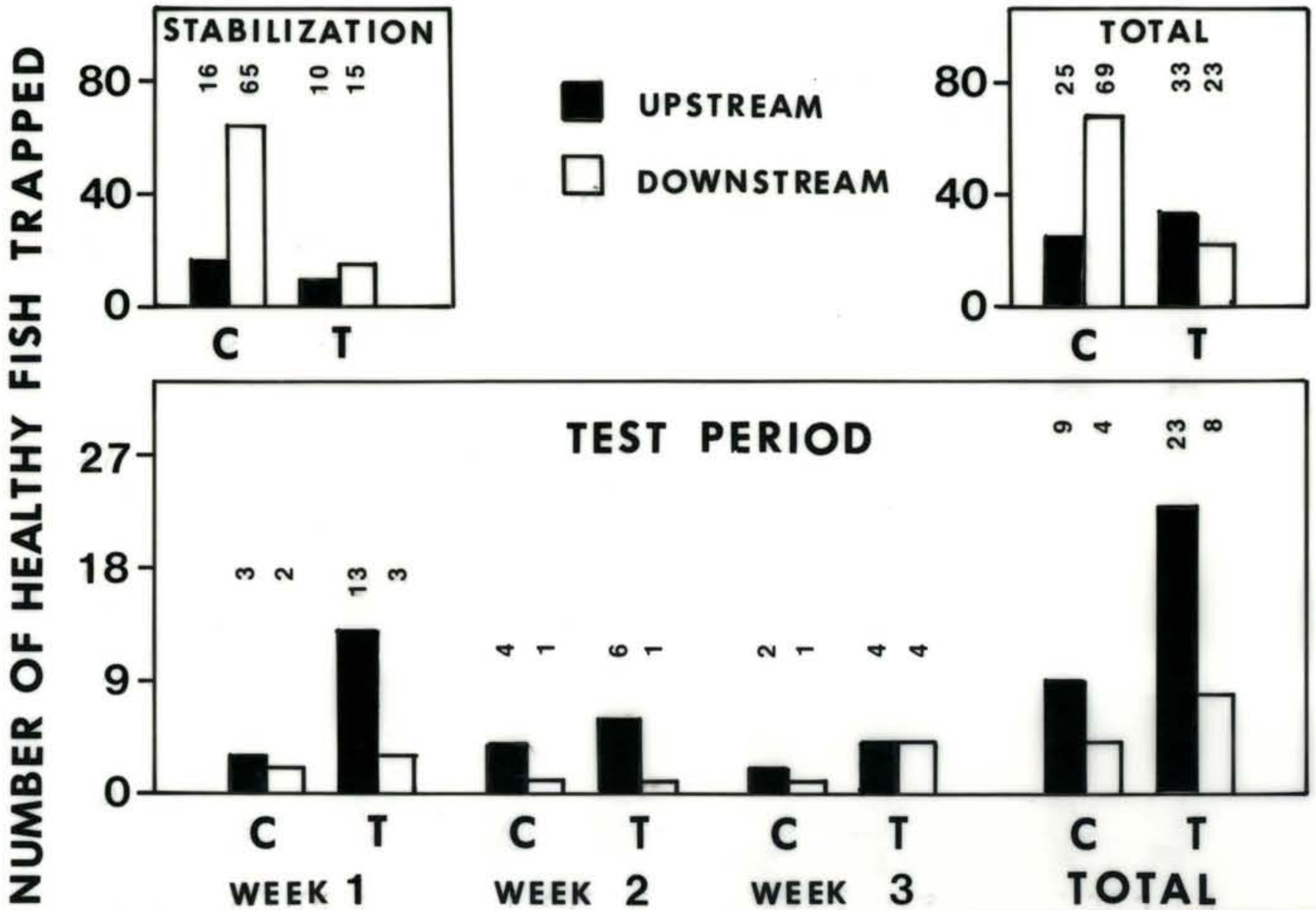


Figure 36. Number of healthy stocked steelhead trout (*Salmo gairdneri*) trapped in each channel according to direction of emigration during the spring 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River near Troy, Oregon. Test flows are: stabilization = 0.28 m^3/s; test period = 0.03 m^3/s. Control flow was 0.28 m^3/s.

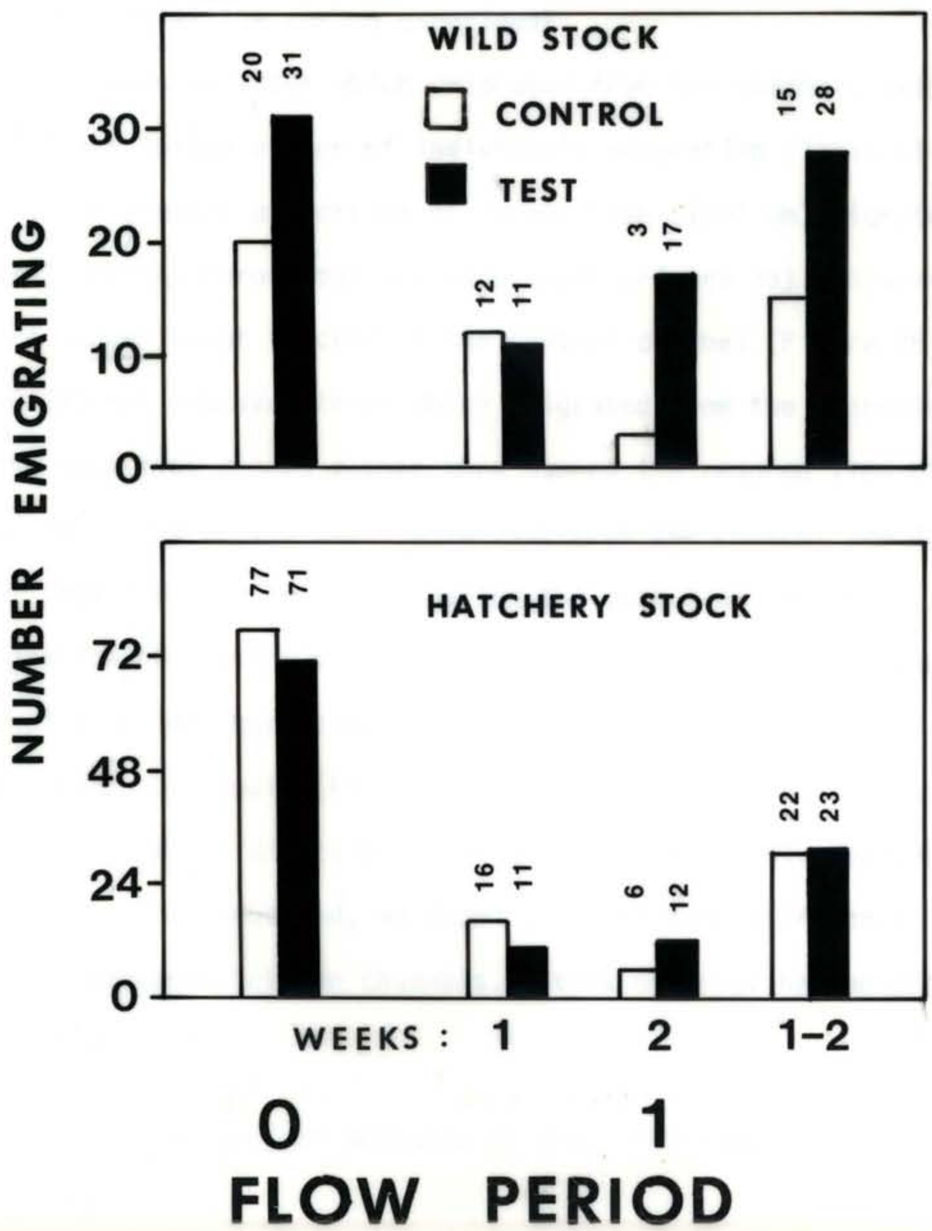


Figure 37. Number of stocked rainbow-steelhead trout (*Salmo gairdneri*) emigrating from each channel during the summer 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods are: 0 = 0.28 m^3/s; 1 = 0.17 m^3/s. Control flow was 0.28 m^3/s.

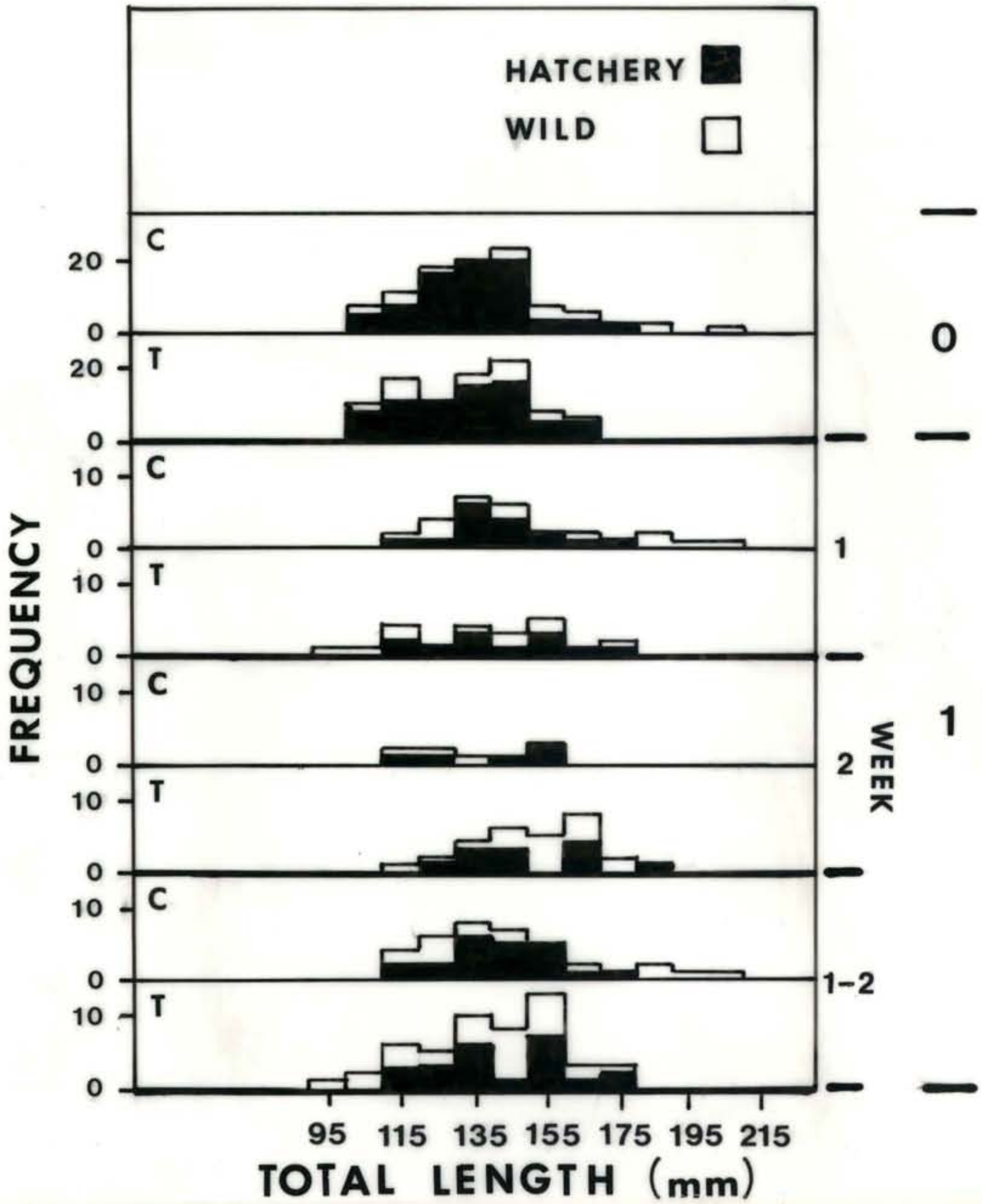


Figure 38. Length frequency of stocked rainbow-steelhead trout (*Salmo gairdneri*) trapped in each channel by flow period during the summer 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flow periods are: 0 = 0.28 m^3/s; 1 = 0.17 m^3/s. Control flow was 0.28 m^3/s.

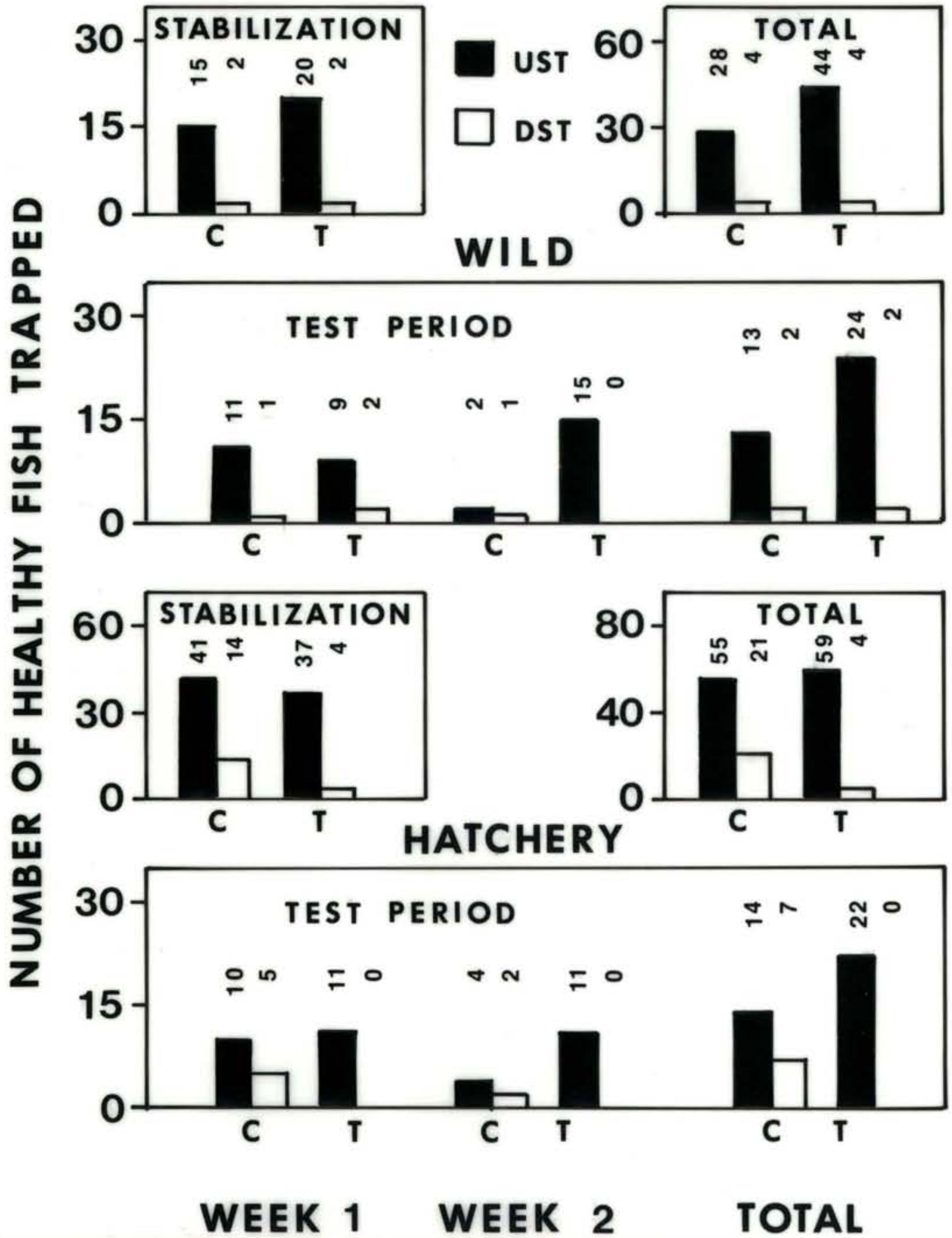


Figure 39. Number of healthy stocked rainbow-steelhead trout (*Salmo gairdneri*) trapped in each channel according to direction of emigration during the summer 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Test flows are: stabilization = 0.28 m^3/s; test period = 0.17 m^3/s. Control flow was 0.28 m^3/s.

interactions were rare. Feeding was primarily from surface and mid-water drift.

Thirty-six trout were observed in the test channel at the 0.03 m^3/s reduced flow level, during 4 hours of snorkeling and 1.5 hours of overhead observation. The fish were generally located in the runs, specifically under the upstream side of cover rocks, and within 1 cm from the substrate (0-10.69 cm). Most fish exhibited a high degree of local orientation, but since agonistic interactions were rarely observed (2 per hour of observation), territoriality could not be determined. Feeding took place primarily on surface drift.

Relative changes in mean depths in the runs with flow reduction appeared to be most closely related to relative changes in fish abundance of the test channel during fall 1978 (Figure 40). Relative depth changes in the runs coincided exactly with relative fish abundance changes for the reduction of 0.28, 0.17 and 0.08 m^3/s in the runs, and were only different by 5.2% at the 0.03 m^3/s reduction. For the entire test channel, relative wetted perimeter changes most closely approximated relative changes in trout abundance, as is the case in the riffles and the riffle to run transitions, while relative depth changes in run to riffle transitions most closely approximated fish abundance changes. As trout were most often observed in the runs at both the 0.57 and 0.03 m^3/s flow levels, depth changes would appear to be the parameter of greatest significance to changes in relative trout abundance. However, fish density (no/m^2) changes could be entirely explained by changes in total surface areas (Figure 41) in the test channel.

The relative decrease in drift rates of food organisms was greater than the decrease in fish abundance in the test channel for all four

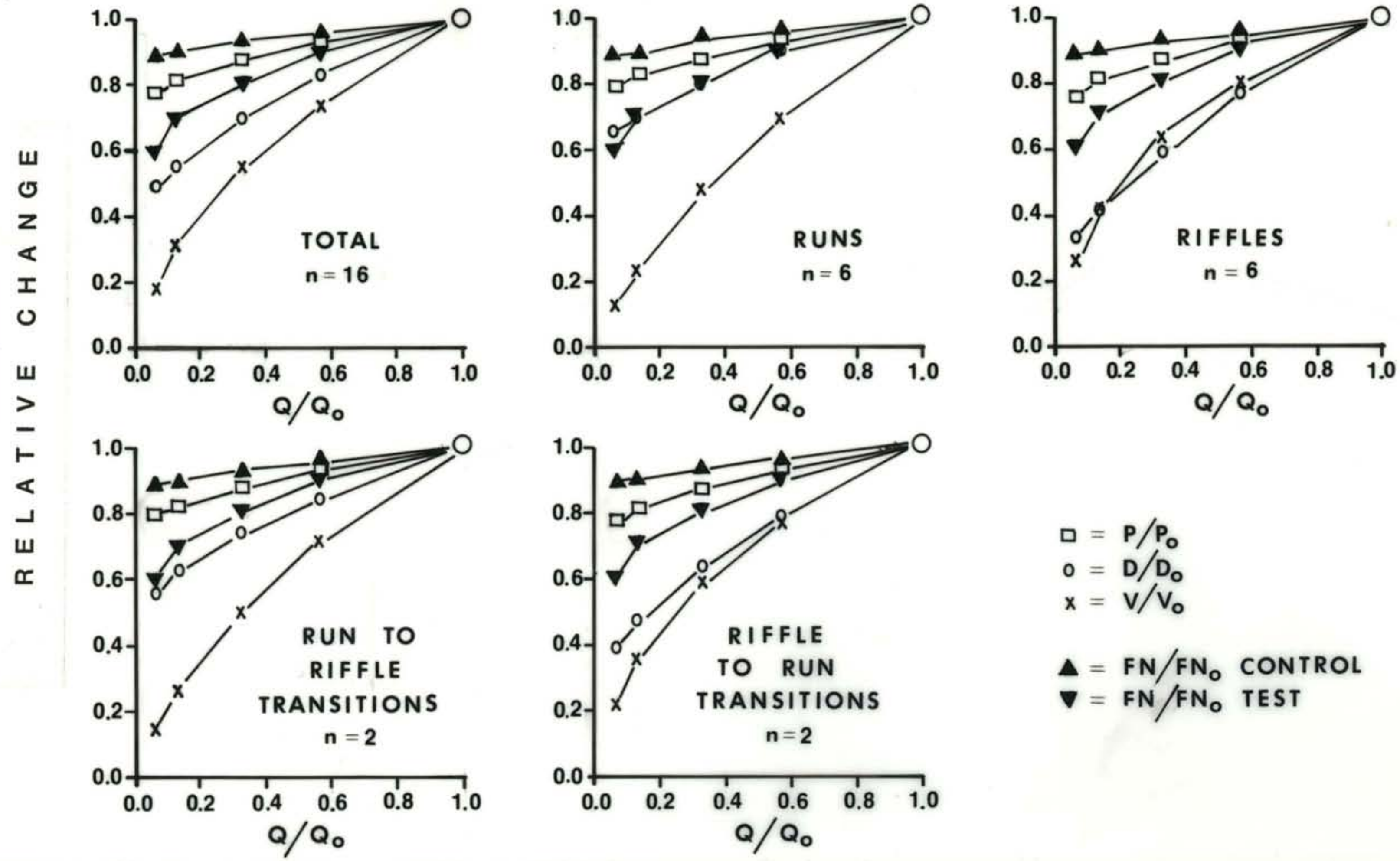


Figure 40. Mean relative changes in wetted perimeter (P/P_0), depth (D/D_0), velocity (V/V_0) and numbers of stocked rainbow-steelhead trout (*Salmo gairdneri*) (FN/FN_0) during the fall 1978 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Q_0 refers to the base flow of 0.57 m^3/s; values for all statistics are set equal to one at the base flow level.

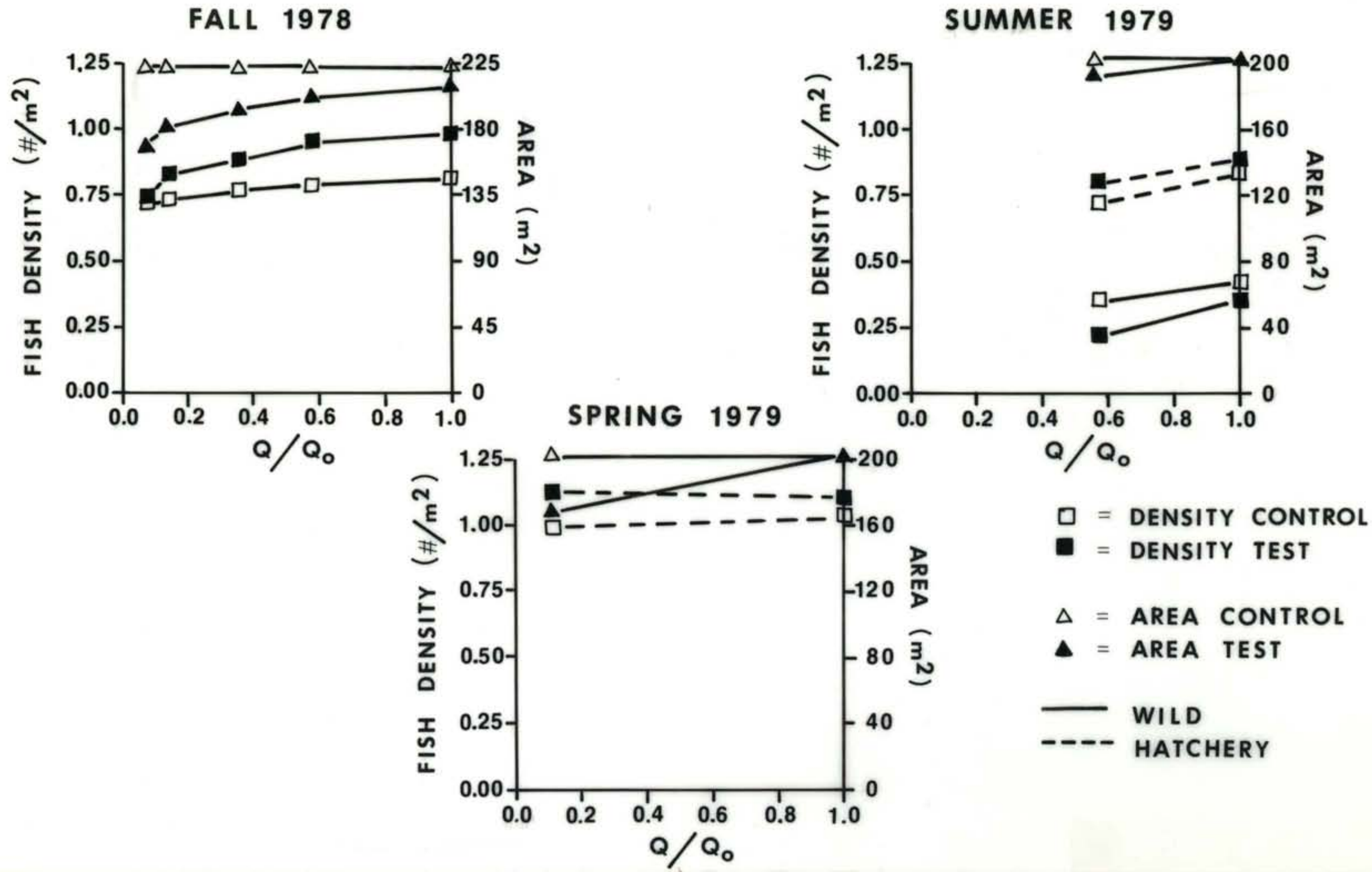


Figure 41. Density of stocked rainbow-steelhead trout (*Salmo gairdneri*) and total surface area of each channel for each relative change in discharge during the fall 1978, spring, and summer 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Q_0 values are: fall 1978 = 0.57 m^3/s; spring and summer 1979 = 0.28 m^3/s.

reduced flow periods (Figure 42). However, as one trout would feed on more than one insect per hour, the lesser relative trout abundance change could be correlated with the observed relative insect drift change. Drift density actually increased over levels observed at the 0.28 m^3/s flow level, and did not appear to be correlated in any way with changes in trout abundance.

Spring 1979

Relative changes in wetted perimeter of the test channel, in total and by habitat, appeared most closely related to relative trout abundance changes (Figure 43). Both depth and velocity changed much more drastically at the reduced flow (From 0.28 to 0.03 m^3/s) than did changes in fish abundance. Fish density actually increased with reduced flow, due to a relatively minor change in absolute abundance and a decrease in total surface area (Figure 41).

The relative change in drifting insect rates was greater than that observed for trout abundance (drift rate: 21% of pre-reduction levels; fish abundance: 85% of pre-reduction levels). Drift density increased in the test channel over pre-reduction levels, but to a lesser extent than did the control channel over the same period, and could possibly be related to trout abundance changes.

Summer 1979

Twenty-six trout were observed during 13 hours of overhead observation at the 0.17 m^3/s reduced flow level in the test channel during the summer experiment. The trout were generally located in the runs and were closely associated with cover rocks. Aggregations of trout were not

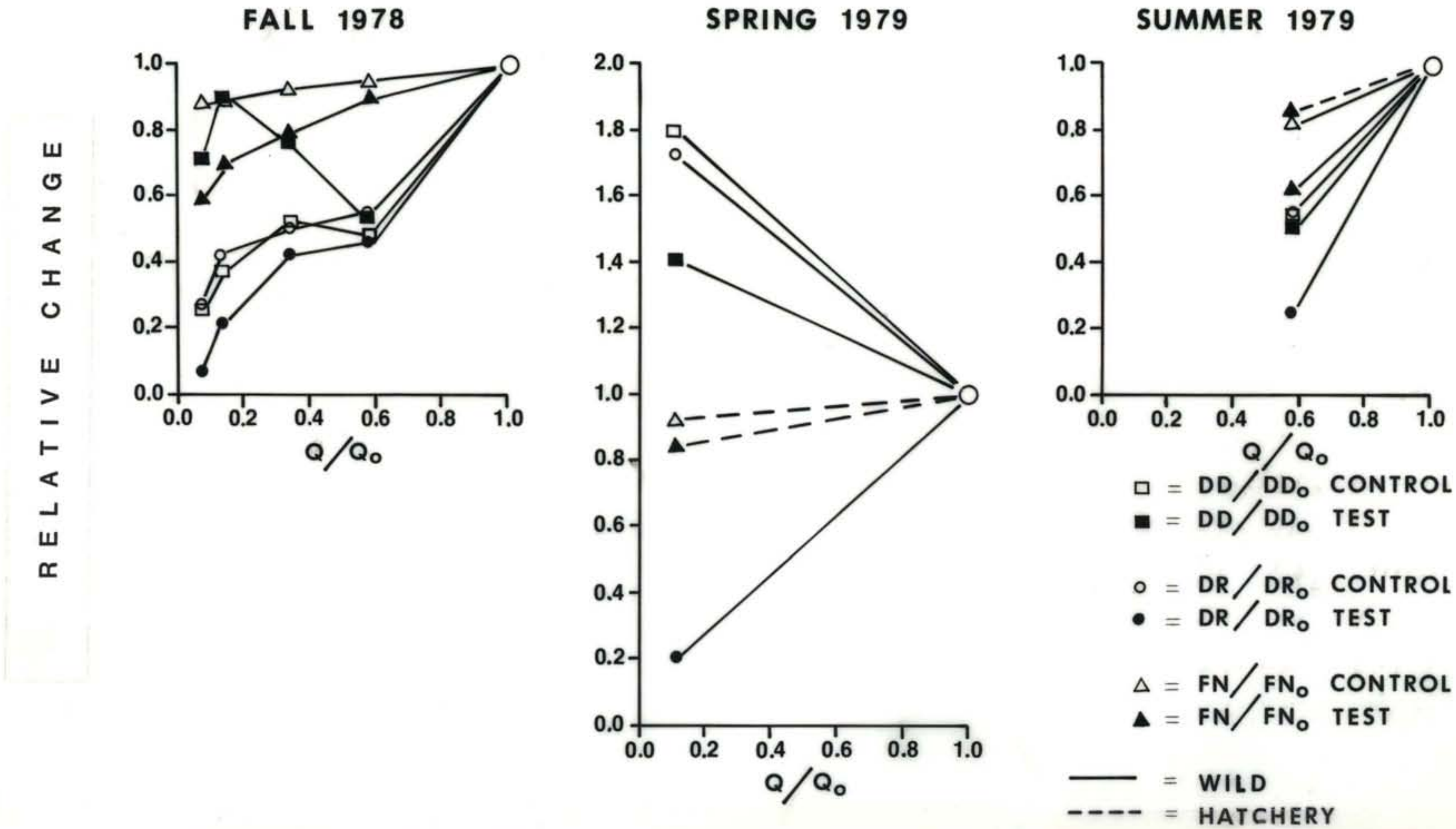


Figure 42. Mean relative changes in drifting insect density (DD/DD_0) and rates (DR/DR_0) and numbers of stocked rainbow-steelhead trout (*Salmo gairdneri*) (FN/FN_0) during the fall 1978, spring, and summer 1979 reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Q_0 values are: fall 1978 = 0.57 m^3/s; spring and summer 1979 = 0.28 m^3/s; values for all statistics are set equal to one at the base flow level.

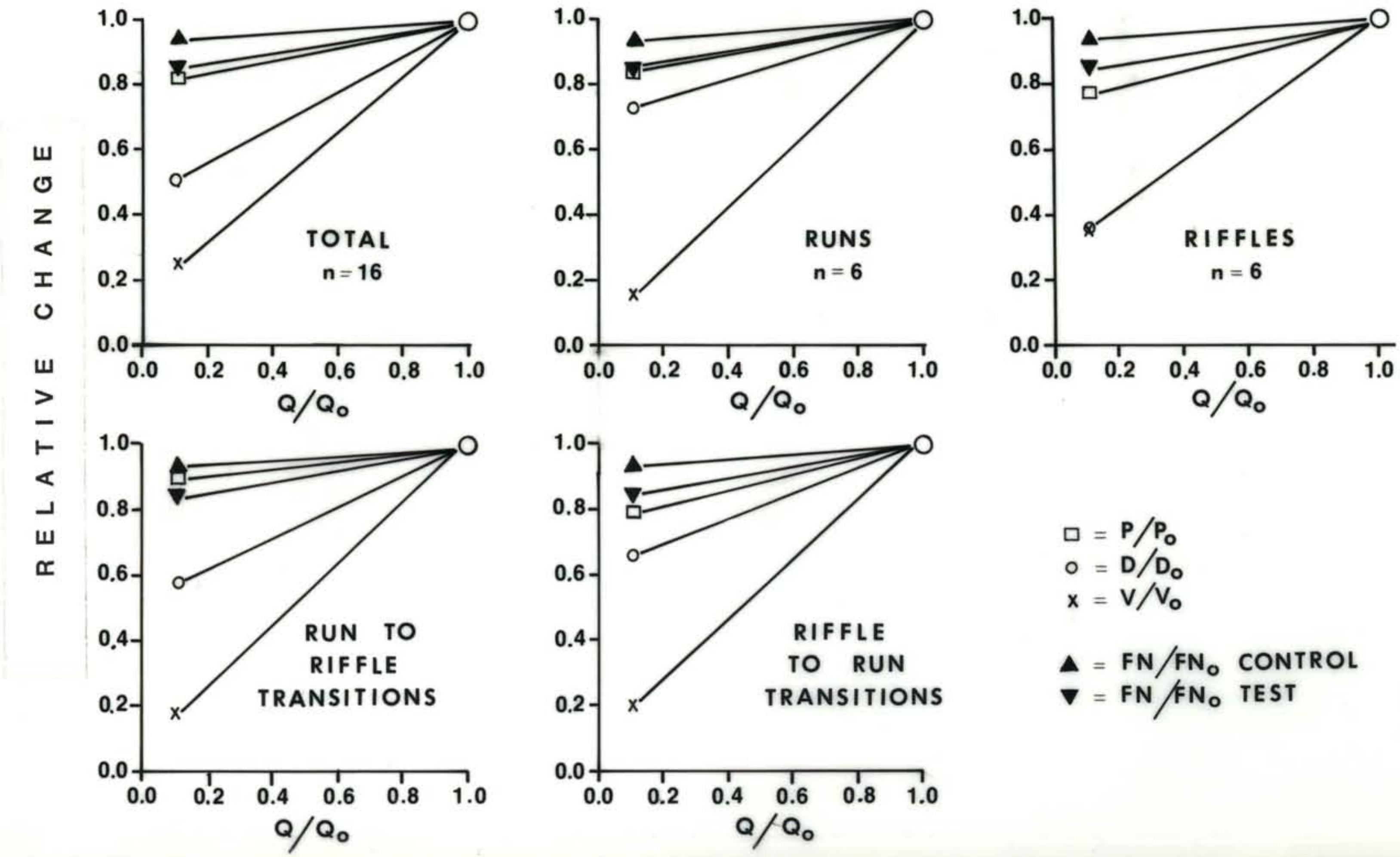


Figure 43. Mean relative changes in wetted perimeter (P/P_0), depth (D/D_0) velocity (V/V_0) and numbers of stocked steelhead trout (*Salmo gairdneri*) (FN/FN_0) during the spring 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. $Q_0 = 0.28\ m^3/s$; values for all statistics are set equal to one at the base flow level.

observed. Territories were defined in four occasions, approximately 61 cm in average diameter.

The 26 trout observed were associated with 35 different locations. The mean depth and velocity at these locations was 41.3 cm and 16.8 cm/s (range 11.6 to 49.1 cm depth and 0.0 to 48.2 cm/s velocity). Surface turbulence at fish locations was rather low (mean 0.29; range 0 to 1; scale of 0 to 3). Substrate composition in areas occupied by fish was primarily a mixture of cobble and sand with a mean rating of 5 (range 4 to 8) (Appendix F). This combination of substrate was the predominant type available in each channel. Depths and velocities 61 cm upstream from fish locations averaged 38.25 cm and 15.34 cm/s, which were typically shallower and slower than at the fish locations, while depths and velocities 152 cm upstream were typically shallower and faster than those observed at the fish location (means of 35.2 cm and 18.67 cm/s). Hatchery trout could not be distinguished from wild trout by overhead observation.

The relative change in wild trout abundance during summer 1979 tests was most closely approximated by changes in velocity for the one flow reduction tested (0.28 to 0.17 m^3/s), both in terms of the total channel and by all habitats except the riffles (Figure 44). However, none of the relative changes in depth, velocity, or wetted perimeter equalled the greater change of relative fish abundance. Hatchery trout were unaffected by reduced flows tested. Fish density for both hatchery and wild trout did not substantially decrease from pre-reduction levels, especially when compared to the reductions observed in the control channel over the same period (Figure 41).

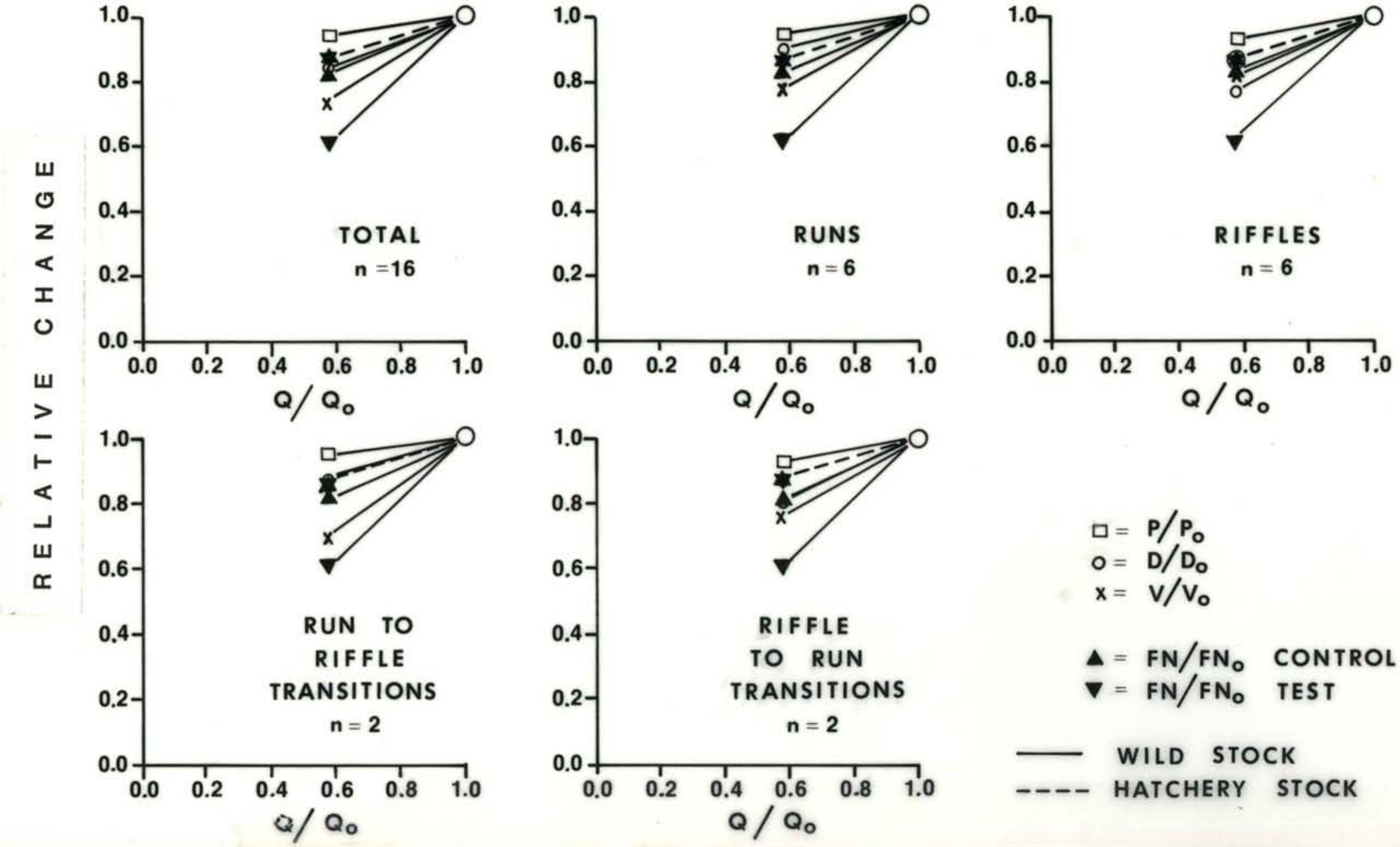


Figure 44. Mean relative changes in wetted perimeter (P/P_0), depth (D/D_0), velocity (V/V_0) and numbers of stocked rainbow-steelhead trout (*Salmo gairdneri*) (FN/FN_0) during the summer 1979 reduced stream discharge experiment, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. $Q_0 = 0.28\ m^3/s$; values for all statistics are set equal to one at the base flow level.

The relative decrease in insect drift rates was greater than the reduction in wild trout abundance in the test channel (drift rate: 24.8% of pre-reduction levels; wild trout: 60.6% of pre-reduction levels). Drift density levels were only slightly depressed in the test channel compared to control levels and were probably not related to the large reduction in wild trout abundance.

Discussion

Juvenile rainbow-steelhead trout responded to reduced flows tested by decreased abundance (in numbers and biomass) in all three experiments (Figure 31 and Table 16). The largest decrease in trout abundance was observed after the 95% flow reduction (to 0.03 m^3/s) during the fall 1978 experiment and after the second week of the 50% flow (to 0.17 m^3/s) reduction during the spring 1979 experiment. Kraft (1972) and Krueger (1979) reported similar negative effects of flow reduction on trout abundance. Hatchery trout were essentially unaffected by the reduced flows tested.

Brook trout (*Salvelinus fontinalis*) numbers in run sections of Blacktail Creek, Montana were reduced to 52% after 3 months of 90% flow reduction (Kraft 1972). Populations in the control flow runs were reduced to 20% during the same time period. However, the number of brook trout remaining in the reduced flow section pools of Blacktail Creek actually increased. Thus fish can respond to reduced flows by changing their locations within the stream and/or suffering increased mortality or reduced growth due to predation, stress or stranding. Accordingly, the percent remaining statistic reported for our three experiments is an expression of the degree of fish movement, but not necessarily a measure of the number of fish that might remain in an entire stream affected section by water withdrawal.

Krueger (1979) reported that 87% of the wild and 91% of the hatchery juvenile chinook salmon (*Oncorhynchus tshawytscha*) remained in an experimental channel after flow was reduced 66% for 24 hours. A subsequent 24 hour reduction of 95% of the initial flow resulted in only 53% wild and 46% hatchery fish remaining. Unfortunately, Krueger had no control channel and could not ascertain the amount of emigration which would have occurred without any flow reduction. The decrease in fish numbers in Kreuger's experiments after only 48 hours of flow reduction was rather large in comparison to the decreases of 59, 85 and 61% for our fall, spring and summer (wild trout only) experiments after more than 14 days of flow reduction (Figure 31).

All four reduced flow levels tested during fall 1978 had similar effects on relative trout abundance. This fall test was the only experiment with multiple flow reductions. Both Kraft (1972) and Krueger (1979) found flow reductions of 90 and 95% more severe than reductions of 75 and 66%, respectively. Their results coincided with Wesche's (1973) conclusion that a breaking point in the effect of reduced stream discharge occurs between 75% and 87.5% flow reduction from average daily flow (ADF). The correspondence of the control flows used by Kraft (1972) and Krueger (1979) to an average daily flow is unknown. The control flow level of 0.57 m^3/s used in the fall experiment coincided with the designed average daily flow characteristics of our experimental channels. The lack of any breaking point in effects of incremental reduction in stream flow, even at 95% flow reduction (0.03 m^3/s), during the fall experiment is possibly due to short duration (1 week) of our test flows. Total surface area decreased only 20% at the 5% ADF (0.03 m^3/s) (Figure 41) as compared with the values observed by Wesche (1973) of 51.1% and 34.6% surface area reduction at 12.5% ADF for Hog Park and Douglas Creeks, respectively. In Krueger's (1979) study, total surface area at 95% flow reduction decreased 32%. The greater decrease in surface area with flow reduction observed in these studies was due to different channel configuration. The lack of any breaking point in relative trout abundance in our tests may be due to our run-riffle channel structure.

White (1976) predicted minimal loss of optimum habitat in the Teton River, Idaho, due to proposed discharge reductions. His prediction depended upon the Teton's rectangular cross-section, run-riffle configuration, minimal bank cover, and predominantly rubble-boulder instream cover. Except for the larger size of the Teton River (ADF of 11.1 m^3/s), White's description could easily fit the channels. The lack of a severe affect or breaking point on relative trout abundance, even at the 95% flow reduction level, in our experiments coincides with White's prediction.

Generally, fish density (numbers/m^2) was only minimally affected by reduced stream discharge (Figure 41). Density was greater in the test than the control channel for the base flow level and the first three reduced flow levels during the fall 1978 experiment, but relative decrease in density was larger for the test than for the control channel. Densities increased in comparison to base flow levels in the test channel in spring 1979. The rather low movement rate of these fish combined with the decrease in surface area resulted in increased densities even though relatively fewer fish remained in the test as compared to the control (Figures 31 and 41). Krueger (1979) also found an increase in fish densities of both wild and hatchery fish at the 66% flow reduction. However, the short duration (24 h) of his flow reduction test probably did not allow enough time for the full affect of the reduction. Kraft's (1972) data indicated that in 10 of 12 cases fish density increased with flow reduction (Table 20) indicating a redistribution and/or tolerance to increased crowding.

Optimum habitat for rearing of stream-dwelling trout appears to have the following characteristics: 1) feeding stations or focal points, which have low to moderate water velocity at the actual fish location but associated with nearby areas of moderate to high velocity carrying adequate amounts of drifting food items (Kalleberg 1958; Wickham 1967; Jenkins 1969); 2) fright or predator avoidance cover (Hartman 1963; Baldes and Vincent 1969; Jenkins 1969; Wesche 1973, 1974; Enk 1977; Devore and White 1978); 3) nighttime resting habitat, primarily consisting of areas which protect the fish from downstream displacement (Edmundson et al. 1968); and, 4) overwinter habitat (Chapman and Bjornn 1969; Bustard and Narver 1975). The drift feeding behavior of most stream-dwelling salmonids (Waters 1969) results in fish maintaining a definite station within a stream for feeding, which in turn promotes a high degree of territoriality or intraspecific aggressive behavior (Chapman 1966). Accordingly visual isolation between conspecifics is also an attribute of optimum rearing habitat (Kalleberg 1958). The key aspect of all these requirements is cover, especially in the form of

Table 20. Fish densities in the runs and pools of controlled flow sections of Blacktail Creek, Montana. Table adapted from Tables 1 and 2 of Kraft (1972).

Section (habitat)	Flow (m^3/s)	Fish density ($\#/m^2$) 1966	Fish density ($\#/m^2$) 1967
A			
Run	0.99	0.431	0.252
	0.08	0.492	0.287
Pool	0.99	0.426	0.352
	0.08	0.588	0.527
B			
Run	0.99	0.332	0.249
	0.08	0.492	0.094
Pool	0.99	0.330	0.364
	0.08	0.383	0.404
C			
Run	0.99	0.395	0.488
	0.08	0.641	0.202
Pool	0.99	0.424	0.226
	0.08	0.550	0.373

structures such as undercut banks, boulders or rubble. Structures in the stream can act to create areas of optimum velocity and provide fright cover and visual isolation.

Effects of reduced stream discharge on cover and the associated aspects of trout rearing habitat are dependent upon the extent and duration of the reduction. Obviously flow reductions impact bank cover directly. Undercut banks are often dewatered with flow reduction, and can be quite detrimental to species such as brown trout (*Salmo trutta*), which tend to be highly dependent upon bank cover (Wesche 1973; Enk 1977). Instream cover can also be decreased by reduced discharge. For example, reduced and less variable depths and velocities may lead to a reduction in the number of stream sites having the optimum rearing characteristics.

Snorkeling and overhead observation of trout during fall and summer experiments confirm the importance of cover as it related to reduced discharge. At reduced flow levels (0.17 m^3/s and 0.03 m^3/s) trout were closely associated with cover rocks. We feel that this association was for the purpose of predator protection. Our observations suggest that if abundance of available cover rocks had been decreased by reduced flow tests, the reduction in trout abundance would have been more severe than observed.

Depth and velocity as physical components of juvenile trout rearing habitat are quite important. However, relative changes in trout abundance as affected by depth or velocity changes with reduced flow was not clear cut in our three experiments. Depth appeared to be most closely related to fish abundance changes in the fall 1978 experiment (Figure 40) while, wetted perimeter was most closely associated to trout abundance changes in the spring 1979 experiment (Figure 43). The actual response of trout to reduced flow in the spring experiment, however, was too minimal to be of any practical significance. During the summer 1979 experiment, velocity most closely explained changes in wild trout abundance associated with reduced flow. This relationship was not good, however, (Figure 44) indicating that the other factors were influencing the response.

Flow reductions may also lead to changes in the abundance or availability of food as evidenced by reduced drift rates (Figure 42). During our experiments drift rates were reduced 8 to 25% and were well below the reduction (fall and summer) or increase (spring) of rates observed in the control channel over the same time period. Accordingly, food availability could have become an important limiting factor determining the trout's response to reduced flow. However, based upon the size response of fish emigrating, it appears that physical factors become limiting before food; if food was the primary limiting factor larger fish should have had a territorial advantage over smaller fish forcing emigration of the smaller fish. However, we observed the opposite response.

Effects of low flow vary with the duration of the reduced flow period. Burton and Wesche (1974) indicated that in small Wyoming streams "good trout populations" were found in streams where the 25% ADF level was exceeded an average of 55% of the time during the summer months; poor populations were characteristic of streams in wich the 25% ADF level was exceeded only 15.8% of the time. Results of our spring 1979 experiment indicated that response of the trout populations to flow was not complete even after 3 weeks of flow reduction (Figure 30). If increased rates of emigration of trout from the test channel, as compared to the control, can be taken as a measure of the reduction of number of sites having optimum habitat characteristics, then reduction of flow for any extended period of time may lead to reduced growth rates, increased stress, and probably increased predation; eventually leading to reduced numbers of trout per length of stream.

The habitat requirements of most trout species are known to vary with the season (Hartman 1963; Chapman and Bjornn 1969; Bustard and Narver 1975; Gibson 1978). The effect of reduced stream discharge would be expected to vary with season, not only because of varying habitat requirements, but also because of physical differences of the streams themselves at different seasons of the year. Reduced flow in the winter would be expected to increase the amount of stream ice. During spring runoff reduced stream flow may decrease turbidity, and reduce the chances of downstream displacement of fish. The spring experiment results indicated that reduced streamflow may actually be less severe in its effect on trout populations during this time of year (Figure 31). A number of difficulties arise in analyzing this possibility. Due to the comparatively short length of our channels, the normally high turbidity levels of the Grande Ronde River water during runoff was not decreased substantially in the channel with reduced flow. Turbidity may in itself act as a cover item both in terms of predator protection or visual isolation. Increased visual isolation of conspecifics due to turbidity can lead to reduced territory size or reduced emigration and hence, to increased fish density (Kalleberg 1958). Possibly the relatively high turbidity levels in the channels during the spring experiment increased visual isolation and allowed for larger density of fish even at reduced stream discharge.

In a long section of stream, however, decreased flow would be expected to reduce turbidity.

Water temperatures during the three experiments were substantially different from each other (Figure 13). However, temperature differences between channels were only significant during the spring 1979 experiment, due to probable differences in solar radiation (Table 17). Temperature differences were never greater than 1 C and were not increased by flow reduction. Accordingly, water temperature was not a factor of concern in possibly explaining the differences between control and test channel trout migration. However, temperature in a natural stream could increase substantially during reduced flow periods.

Use of only hatchery trout in our spring experiment makes interpretation of seasonal effects difficult since a difference in response of wild and hatchery fish was observed in summer (Figure 31). Hatchery trout are usually considered to be at a competitive disadvantage compared to wild trout (Miller 1958). However, this is probably only true when comparing hatchery nonresident trout with wild resident trout (Miller 1958) or when fish densities are approximately at normal wild levels (Fenderson and Carpenter 1971). Neither of these requisites were met in the summer experiment, as both the wild and hatchery trout were nonresidents of the channels and the overall density within the channels were initially quite high (0.35 and 0.88 fish/m^2 for wild and hatchery, respectively, for a total of 1.23 fish/m^2). Fenderson et al. (1968) indicated that hatchery Atlantic salmon (*Salmo salar*) are more aggressive than wild salmon when allowed to compete in aquaria. Chapman (1962) indicated aggressive behavior was the prime cause of increased emigration of coho salmon (*Oncorhynchus kisutch*) from artificial stream channels.

Our results from spring and summer experiments indicated that reduced stream flows do not substantially affect abundance of hatchery trout. Lack of any discernable response of hatchery trout in the summer experiment (Figure 31) was probably a result of their higher tolerance of crowding (Fenderson and Carpenter 1971) and the lack of social density regulation through dispersal (Symons 1969; Jenkins 1971). Low emigration rates, however, do not preclude the possibility of reduced growth rates. Fenderson and Carpenter (1971) indicated that high levels of aggression observed in hatchery Atlantic salmon interfered with feeding in aquaria. Sosiak et al. (1979) observed a higher level of stomach fullness in wild versus hatchery Atlantic salmon in streams. The combination of high density tolerance and aggressive interference of feeding suggest that hatchery trout would probably be adversely affected by reduced discharge. Li and Brocksen (1977) indicated that increased density leads to higher metabolic rates, accordingly the plausibility of decreased growth rates for hatchery trout at reduced stream discharge is increased. Accordingly, effects of reduced stream discharge upon hatchery trout cannot be ascertained by merely comparing emigration rates; additional data on feeding habits, growth and incidence of disease would be needed.

Summary

Three reduced stream discharge experiments were conducted during fall 1978, spring 1979 and summer 1979 at the Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. Experiments were designed to determine the relationship between juvenile rainbow-steelhead trout (*Salmo gairdneri*) abundance, in numbers and biomass, and increments of reduced stream discharge; and the order of importance of depth, velocity, cover and food in limiting abundance of trout at increments of reduced stream discharge.

Trout population abundance was reduce to 90.0, 79.9, 69.9 and 59.3% of the base flow level after weekly flow reductions to 50, 25, 10 and 5% of base flow level in the test channel during the fall 1978 experiment. Wild trout from a nearby tributary of the Grande Ronde River were used as experimental fish, with a total of 281 and 282 fish initially stocked in the control and test channels, respectively. Juvenile rainbow-steelhead numbers in the constant flow control channel decreased only to 95.6, 93.3, 89.4 and 88.9% during the same time period. The base flow discharge during the fall experiment was approximately 0.57 m^3/s (20 ft^3/s). Population abundance reductions in the test channel were significantly different ($P < 0.10$) for all four flow reductions as compared to population reductions in the control channel.

First generation progeny of wild steelhead trout, obtained from the Wallowa County Fish Hatchery, Enterprise, Oregon, were used during the spring 1979 experiment, with a total of 305 fish stocked in each channel. The abundance of hatchery trout decreased only 15.3% during a 3 week test of 90% reduction in flow from the base flow condition (base flow 0.28 m^3/s [10 ft^3/s]). Populations in the constant flow control channel decreased 6.7% during this same period. Control and test channel trout population reductions were statistically different ($P = 0.0001$), but the difference was not practically significant (only a 8.6% difference).

A combination of wild rainbow-steelhead trout and hatchery steelhead from the Dworshak National Fish Hatchery, Ahsahka, Idaho, were used during the summer 1979 experiment. Approximately twice as many hatchery trout were stocked in each channel (245 and 248 in the control and test channels, respectively) as wild trout (105 and 102 in the control and test channels, respectively). Hatchery trout did not respond to a 50% flow reduction after 2 weeks in the test channel (base flow level of 0.28 m^3/s [10 ft^3/s]); the test channel population was reduced to 87.0% of the base flow level, while the control channel population decreased to 86.9% of the base flow level. During the same period, the wild trout population was reduced to 60.6% of the base flow level in the test channel as compared to 82.4% for control channel population. The test wild trout population reduction was significantly ($P < 0.05$) greater than either the control wild trout or control and test hatchery trout population reductions.

During all three reduced stream discharge experiments smaller trout (80-110 mm) tended to emigrate from both channels early in each experiment, usually before any flow reductions. More larger trout (180+ mm for the fall and 130+ mm for the spring) migrated from the reduced flow channel than from the control flow channel during flow reduction periods during the fall and spring experiments. Due to unequal stocking of large trout into each channel during the summer experiment, reduced discharge effects on large trout could not be determined.

The pattern of effect of discharge reduction upon biomass of trout was essentially the same as that observed for trout numbers. However, the greater apparent effect of flow reduction upon migration of larger trout led to greater overall effects upon trout biomass than was observed for trout numbers. Trout biomass retrieved at the end of the fall experiment in the control channel was 1.8 times larger than the biomass in the test channel. During the spring experiment 1.4 times as much trout biomass was retrieved from the control channel as from the test channel. Trout were not retrieved from the channels at the end of the summer experiment.

Direction of emigration (upstream versus downstream) was not affected by flow reduction during the fall experiment, in which trout migrated primarily in the downstream direction. During the spring experiment there was a significant ($P < 0.0001$) affect of discharge reduction on the direction of emigration. Trout primarily migrated in the downstream direction before flow reduction, while they migrated in the upstream direction after flow reduction. During the summer experiment trout primarily migrated in the upstream direction throughout the experiment with no significant ($P > 0.05$) affect of flow reduction upon direction of emigration. Stock of trout did not significantly ($P > 0.05$) affect emigration direction. Comparing the three experiments, trout tended to migrate more in the downstream direction during the fall 1978 experiment than during either the spring or summer 1979 experiments. This difference may have been due to seasonal differences or to a change in the upstream weir design constructed between the fall and spring experiments.

Comparison of changes in trout abundance with flow reduction to changes in depth, velocity, wetted perimeter and food abundance indicated that depth and food (in terms of insect drift rates) were most closely related to trout abundance changes in the test channel during the fall experiment. Wetted perimeter changes were most closely related to trout population abundance changes in the test channel during the spring experiment. In the summer experiment, velocity and drift rate changes were most closely related to changes in wild trout population abundance with flow reduction. The change in wild trout population abundance in the test channel was greater in magnitude than any of the observed changes in depth, velocity, wetted perimeter and food abundance. Lack of response of hatchery trout to reduced flow during this experiment precluded comparisons.

Snorkeling and overhead observation of trout at the base flow level (0.57 m^3/s) and the 95% flow reduction level (0.03 m^3/s), during the fall experiment, indicated trout were primarily located in the run sections of the channels. Trout in the reduced flow channel were closely associated with cover rocks while trout in the control channel were observed to be in open sections of the stream. Overhead observation of trout at the 50% flow reduction level (0.17 m^3/s) during the summer 1979 experiment indicated that trout were again distributed mainly in the run areas and closely associated with cover rocks. Fish locations during the summer experiment were typically 41.3 cm in depth (minimum: 11.6 cm, maximum: 49.1 cm) and had mean velocities of 16.8 cm/s (minimum: 0.0 cm/s, maximum: 48.2 cm/s). Substrate composition at fish locations was primarily a mixture of cobbles and sand.

CHAPTER 6
HYDRAULIC ASSESSMENT OF REDUCED STREAM DISCHARGE AND EVALUATION OF THREE HYDRAULIC SIMULATION MODELS

Most currently used instream flow assessment methodologies use hydraulic information to analyze aquatic habitat changes resulting from changes in streamflow. Hydraulic simulation models, based on theoretical equations of open channel hydraulics, have been developed to predict changes in hydraulic parameters of fish habitat resulting from changes in stream discharge. Empirical equations, most notably the Manning equation, are commonly used in these simulation model. Certain assumptions are included in the development and use of the models about such parameters as type of flow (i.e., uniform steady flow), slopes, roughness, velocity distributions and discharge. As long as the various assumptions used are reasonably consistent with actual observations and experience, they are ammenable to the analytical treatment of theoretical hydraulics (Chow 1959).

Several assumptions used in open channel flow are based on observations and experience gained from studies of flow in pipes and small laboratory flumes. The question arises as to applicability of these assumptions to natural channels. Some problems encountered in natural channels that may lead to erroneous application of various assumptions include:

1. Irregular cross section shape.
2. Position of the water surface changes from place to place as well as with time.
3. The slopes of the water surface and the bottom, the depth of flow, and the discharge which are interdependent, vary with respect to time and place.
4. Roughness varies from place to place as well as with depth, making selection of proper friction coefficients very difficult.

5. Velocity is not uniformly distributed in the channel section because of friction along channel walls, the presence of the free surface, and non-linear channel alignment.

In our relatively large experimental flume with near natural stream configuration, some of the above stated variations were eliminated (i.e., the position of the water surface could be held constant). Hence, the hydraulic parameters that were measured varied only from place to place in the channel and not with time. Further, by manipulating flows, the water surface position could be reproduced, allowing additional measurements whenever required. These conditions made it possible to measure the hydraulic conditions present in the channel at a specific flow with an intensity seldom possible in a natural stream channel where the flow is usually changing from day to day and often from hour to hour.

If hydraulic simulation models are to be used in methodologies for making instream flow recommendations, we must be confident that the models are producing reasonably accurate predictions of hydraulic conditions as they would actually exist at a given flow. The best biological criteria when interfaced with erroneous hydraulic parameters could result in streamflow recommendations that are wholly inadequate both in amount and in timing. With hydraulic data collected from our experimental channel, a means was provided for judging the applicability and effectiveness of the models, assumptions and procedures used in the various simulation models. Further, it should provide an evaluation of the useful range of predictability and an indication of those parameters which affect accuracy the most.

Objectives of this phase of the project were: 1) to assess the primary hydraulic characteristics (such as velocity, roughness, slopes of the water surface and energy grade lines, etc.) associated with incremental streamflow reductions; and, 2) to evaluate the validity and utility of selected hydraulic simulation models currently being used in methodologies for instream flows, especially with respect to predictions of stage-discharge relationships, depths and velocities.

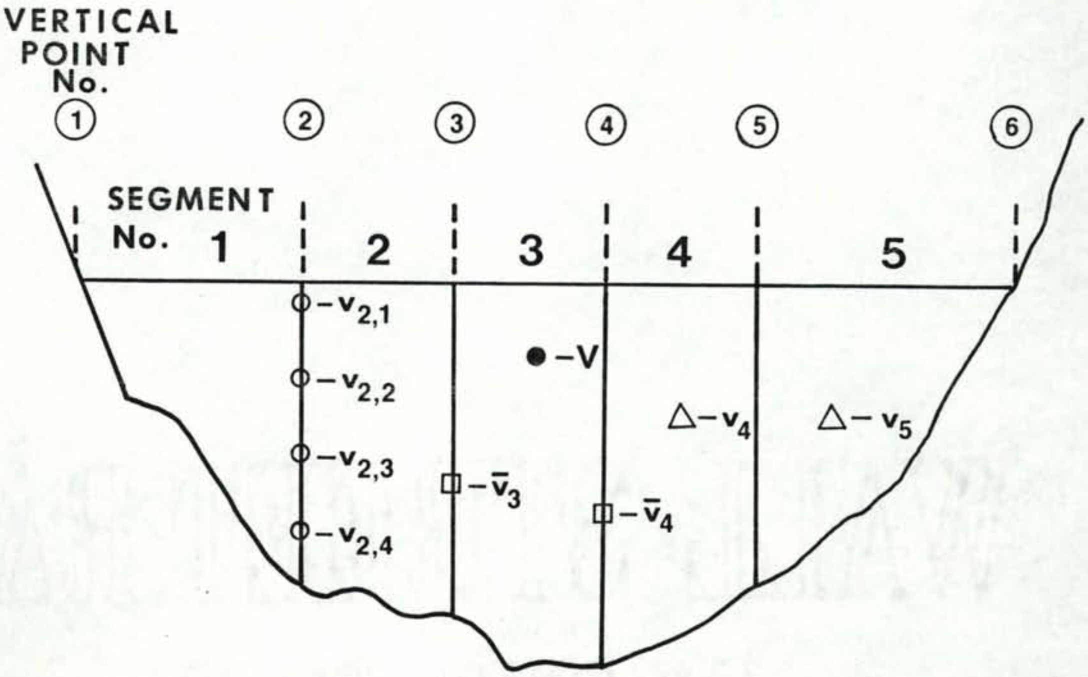
Definition of Hydraulic Terms and Equations

The various terms used to describe open channel flow are defined below. Units of measure are given in the English system, and conversion factors for the metric system follow. Equations used to determine the quantitative values of the hydraulic terms are provided where appropriate.

Velocity

Velocity refers to the speed and direction of a particle as it moves a distance in an interval of time. Velocity is a vector quantity, and the units are feet per second (ft/sec), 1.0 ft/sec = 30.48 cm/sec = 0.304 m/sec. For practical purposes, the term velocity, when used to describe water movement, generally refers to the velocity vector as being parallel to banks and bed of the stream, and, thus, one dimensional flow is implied (versus the more general situation of multi-dimensional movement which is extremely difficult to analyze).

Four velocity terms are used in this report to describe the flow of water through a cross section: point velocity, average point velocity, average segment velocity, and average cross sectional velocity (Figure 45). A point velocity v_{ij} is the rate at which water is moving past a specific point in the cross section and is referenced by its horizontal (i) and vertical (j) position. This point velocity is a temporal mean velocity. A set of point velocities in a single vertical position,



○ – v_{ij} = Point velocity at i-th horizontal point, j-th vertical point

□ – $\bar{v}_i$ = Average point velocity at i-th horizontal point

△ – v_x = Average segment velocity of segment x

● – V = Average cross sectional velocity

Figure 45. Definition of velocity terms

measured from the surface to the channel bed, defines a velocity profile. Average point velocity ($\overline{v}_i$) is the average rate water is moving past a specific vertical referenced by its horizontal position. The average point velocity is the mean of point velocities at a vertical section. Average segment velocity (v_x) is the average rate of water moving through a segment (subdivision) of the cross section. The segment is defined as the area bounded by two adjacent verticals. To be consistent with the hydraulic simulation models, the average segment velocity is one half the sum of the average point velocities at the segment bounds. Average cross sectional velocity (V) is the average rate water is moving through the entire area of the cross section and is obtained by dividing the total discharge, Q, by the cross sectional area, A.

Discharge

Discharge (also referred to as "flow") is the rate movement of a volume of water through a specific cross section area. The units are cubic feet per second (cfs), 1.0 cfs = 0.028 m^3/sec.

The equation of continuity for steady flow of an incompressible fluid is:

$$Q = AV$$

where,

Q = Discharge

A = Area of cross section

V = Average velocity component at a right angle to the cross section

This equation can be applied to a segment of a cross section to determine the discharge of that segment if the area and velocity of the segment have been determined. By summing the discharge through each segment, the total discharge is obtained. The average velocity through the cross section can then be computed by rearranging the continuity equation to:

$$V = Q/A$$

Classification of Flow

Open channel flow may be classified as steady or unsteady, uniform or nonuniform. For the purpose of this paper, only two types of flow will be considered, steady uniform flow and steady nonuniform flow, since other types rarely occur or are extremely difficult to analyze.

Steady uniform flow occurs when the discharge is constant with respect to time, and the depth is constant everywhere along the length of the channel. Strictly speaking, velocity stays the same in magnitude and direction throughout the whole of the section under consideration; however, for practical purposes, the flow is uniform if it possesses a constant average velocity (the velocity distribution across the stream is unaltered in the reach). This type of flow is rare for natural channels, but it is often assumed to be the steady uniform flow condition for computational purposes. The results are approximate and general when this assumption is made.

Steady nonuniform flow occurs when discharge does not change with time, but the flow depth and the average velocity changes from section to section. When the change in depth is gradual, the flow is said to be gradually varied flow.

Energy and Gradients in Open Channel Flow

Methods for analyzing open channel flow frequently require an orderly accounting procedure for evaluating energy levels as one proceeds either upstream or downstream. The total energy of water passing through a cross section (Figure 46) is the sum of the energy associated with pressure (depth, y); energy associated with elevation (z); and the energy associated with velocity, kinetic energy ($V^2/2g$). The velocity head is generally greater than the value computed by the expression $V^2/2g$, where V is the average cross sectional velocity, because of nonuniform distribution of velocities over a channel section caused by viscous drag near the solid boundaries. By the addition of an energy coefficient (also known as the Coriolis coefficient) α, the true velocity head may be expressed as $\alpha(V^2/2g)$ Chow 1959; Henderson 1966). The total energy head at a channel cross section of small slope may be written:

$$H = z + y + \alpha \frac{V^2}{2g}$$

where,

H = Total energy head

z = Elevation of the channel bed

y = Average depth of the cross section

V = Average cross sectional velocity

g = Acceleration of gravity

α = Velocity distribution coefficient

This is a form of the well known Bernoulli energy equation. For practical purposes, z + y equals the water surface elevation (Figure 46).

The velocity distribution coefficient is computed (assuming the velocity to be constant within each segment of the cross section) by the equation:

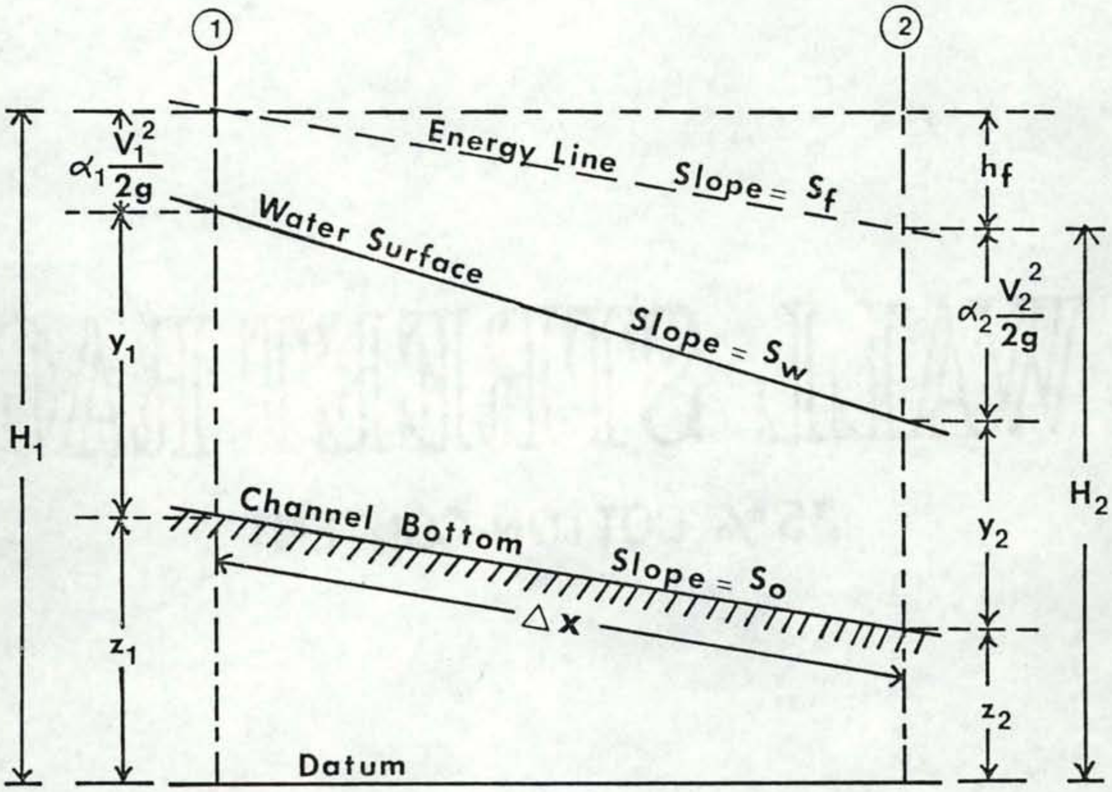


Figure 46. Energy in gradually varied open channel flow (from Chow 1959).

$$\alpha = \frac{\Sigma v_x^3 a_x (\Sigma a_x)^2}{\Sigma (v_x a_x)^3} = \frac{v_1^3 a_1 + v_2^3 a_2 + \ldots + v_n^3 a_n}{V^3(a_1 + a_2 + \ldots + a_n)}$$

where,

$$V = \frac{v_1 a_1 + v_2 a_2 + \ldots + v_n a_n}{a_1 + a_2 + \ldots + a_n}$$

and,

v_x = average segment velocity

a_x = area of the segment

x = 1,2,...,n; segments

Referring to Figure 46, the slope of the energy line is known as the energy gradient (S_f) and is:

$$S_f = \frac{H_1 - H_2}{\Delta x} = \frac{h_f}{\Delta x}$$

The slope of the Water Surface (S_w) is known as the hydraulic gradient and is:

$$S_w = \frac{(Z_1 + y_1) - (Z_2 + y_2)}{\Delta x}$$

The slope of the channel bottom (S_o) is:

$$S_o = \frac{Z_1 - Z_2}{\Delta x}$$

With uniform flow, $S_f = S_w = S_o$.

Geometric Elements

Geometric elements are properties of a cross section that can be defined entirely by the geometry of the section and depth of flow (Chow 1959). These elements are used extensively to evaluate flows in open channels and are defined below:

Stage (St): the elevation of vertical distance of the water surface above a reference datum, either arbitrary or known (such as feet above sea level).

Top Width (T): the width of the free surface, taken perpendicular to the flow.

Cross Sectional Area (A): the water area perpendicular to the normal flow of water; the units are square feet (ft^2), 1.0 ft^2 = 0.0929 m^2

Wetted Perimeter (P): the distance of wetted contact along the bottom and sides of a channel cross section, usually measured in a plane at right angles to the direction of flow, with units in feet (ft), 1.0 ft = 0.304 m.

Hydraulic Radius (R): the ratio of the cross sectional area to its wetted perimeter:

$$R = \frac{A}{P}$$

Hydrualic Depth (Dm): the ratio of cross sectional area to the top width; is equivalent to the mean depth:

$$Dm = \frac{A}{T}$$

Section Factor for Uniform Flow Computation ($AR^{2/3}$): the cross sectional area multiplied by two thirds power of the hydraulic radius.

Uniform Flow Equation

The formula commonly used to evaluate uniform flow is the Manning equation:

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

where,

V = Average velocity in the channel

R = The hydraulic radius

S = The slope of the energy grade line

n = Roughness coefficient which accounts for the roughness and sinuosity of the channel which includes not only the effect of roughness of bed, but also that of all obstructions that may retard the water

This equation can be used in several different ways. Combining the Manning equation with the continuity equation (Q = V/A), we obtain the following:

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

Further, the roughness coefficient can be calculated if V is known by:

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

The Manning equation can be applied to cross sectional segments in a similar manner as to the whole cross section by substituting the mean depth of the segment ($d_x = a_x/w_x$) for R. This application is not entirely correct since the channel segment is assumed to be rectangular, and S_f is assumed to be constant for all segments. However, for regular cross sections, the errors are considered minimal.

For further explanation and discussion of the above terms, equations and definitions, the reader is referred to texts by Chow (1959); Henderson (1966); and King and Brater (1963) which were heavily relied upon for the above narrative.

Description of Hydraulic Simulation Models

A hydraulic simulation model is not the same as a methodology for assessing instream flow requirements of aquatic organisms, recreation, or wildlife. Hydraulic simulation models are methods of predicting the hydraulic variables of the physical habitat at different flows. Hydraulic parameters, interfaced with some type of biological criteria to assess the suitablity of habitat becomes a methodology (in whole or in part) for assessing instream flow requirements of living organisms. The differentiation is made to point out that this portion of the study is an evaluation and assessment of the ability to predict hydraulic variables at different discharges, using available hydraulic models.

The hydraulic simulation models evaluated in this study were:

1. Instream Flow Group Program 01, Version A (IFG-01A) a modified version of the U.S. Forest Service R-2 Cross Program. This model calculates certain average parameters for a single cross section. Two types of equations are used to calculate discharge for a given stage, the Manning equation and the stage-discharge relationships (a rating curve approach). Required calibration details include one known discharge and water surface elevation, slope of the energy grade line, and cross sectional bed elevations, using the Manning equation option. At least two known discharges and water surface elevations (preferably three or more) are required when using the stage-discharge option. Model output includes stream discharge, average velocity, cross sectional area, average depth, hydraulic radius, width of water surface, wetted perimeter, and widths having specified depths (Milhous 1978).
2. The Bureau of Reclamation Water Surface Profile Program (WSP), also referred to as IFG-2, designating model modifications for compatibility with the Instream Flow Group's habitat evaluation program (IFG-3). This is a multiple transect model which

utilizes the Manning equation and energy concepts assuming gradually varied flow. Calibration requirements include at least one known discharge and water surface elevation, energy slope, and cross sectional bed elevations (cross sectional profile). This model is calibrated by adjusting Manning's n (roughness coefficient) until the water surface elevations and velocities approximate those measured in the field. Thus, at least one set of velocity measurements are required for each cross section to be analyzed and must be identified with the water surface elevation at the time of measurement. Model outputs include cross section subdivisions, (maximum of 9) and average velocities in subdivisions, water surface elevations, conveyance areas, top widths, hydraulic radii, discharge, thalweg elevation at each cross section, thalweg slope, and transect location by station.

3. Instream Flow Group Program Number 4 (IFG-4), which uses a stage-discharge relationship (a rating curve approach). Required model inputs include water surface elevation and a set of velocities at specified intervals for each cross section at a minimum of two different discharges, bed elevations for each cross section, distance between cross sections and an estimate of substrate composition at each velocity measurement point. For each flow applied to a particular cross section, model outputs include depth, average velocity, and substrate information, for each cross sectional segment (Main 1978a).

The IFG-1 Program is a basic hydraulic simulation program that uses a minimum amount of field data, which means no velocity measurements need be taken (unless discharge is unknown). The model also has the advantage of using data collected by sag-tape procedures, which often gives one person the ability to collect all field data. However, the model is capable of predicting only average cross sectional parameters, which is a distinct drawback when an investigator wishes to examine a specific segment of a cross section. For example, if an investigator were interested in hydraulic parameters adjacent to the stream banks rather than the whole cross section of the stream, such an investigation would not be possible using IFG-1.

The IFG-4 and WSP computer programs are more complex hydraulic simulation models that require more data input (WSP requires a minimum of one set of flow measurements; IFG-4 requires a minimum of two sets of flow measurements). These models predict average parameters of a cross section, as well as partitioning the cross section into segments and predicting average segment parameters.

Computer programs of the above hydraulic simulation models are maintained at the University of Idaho Computer Services Center. The University's computer is an IBM 370/45. Programs are IBM versions, updated as of March, 1979.

Methods

Hydraulic parameters and channel characteristics were measured in the two large artificial stream channels. Hydraulic measurements were taken at the base flow of 19.65 cfs and at four incremental reductions representing 57, 33, 14, and 6 percent of the base flow. These are the same flows at which tests on fish and macroinvertebrates were conducted in late 1978.

A continuous stage recorder, located in the downstream run, was used to monitor streamflow (water surface elevations). Using the stage recorder, water surface elevations were controlled and monitored to the nearest 0.005 ft (0.152 cm). When data were being collected, the stage recorder was checked each hour and adjustments made to flow if a change in water surface elevation was noted. As a result, discharge was constant for all measurements taken at a given test flow.

Thirty eight transects were established at approximate 5.0 ft (1.5 m) intervals along the stream channels. Sixteen of these transects were chosen to represent runs, riffles, and transitions (Figure 47) where the following data were collected at each test flow:

1. Velocity profiles; depths and point velocities measured at 1.0 ft (0.3 m) horizontal and 0.1 ft (0.03 m) vertical intervals respectively,
2. Bed elevations to determine the geometric shape of the cross section using standard surveying techniques,
3. Water surface elevations.

These 16 transects are referred to as velocity profile transects and abbreviated VP, with VP-T referring to the four transects in the transition zones. The VP transects are numbered in a downstream direction with a VP-T transect having the same number as the adjacent VP transect upstream. Transect location, channel configuration of riffle-run-riffle-run in a downstream direction, transect identification, bed profile at the thalweg, water surface profile at 19.65 cfs, depth of substrate, and the arbitrary datum are shown in a profile view of the stream channel (Figure 47).

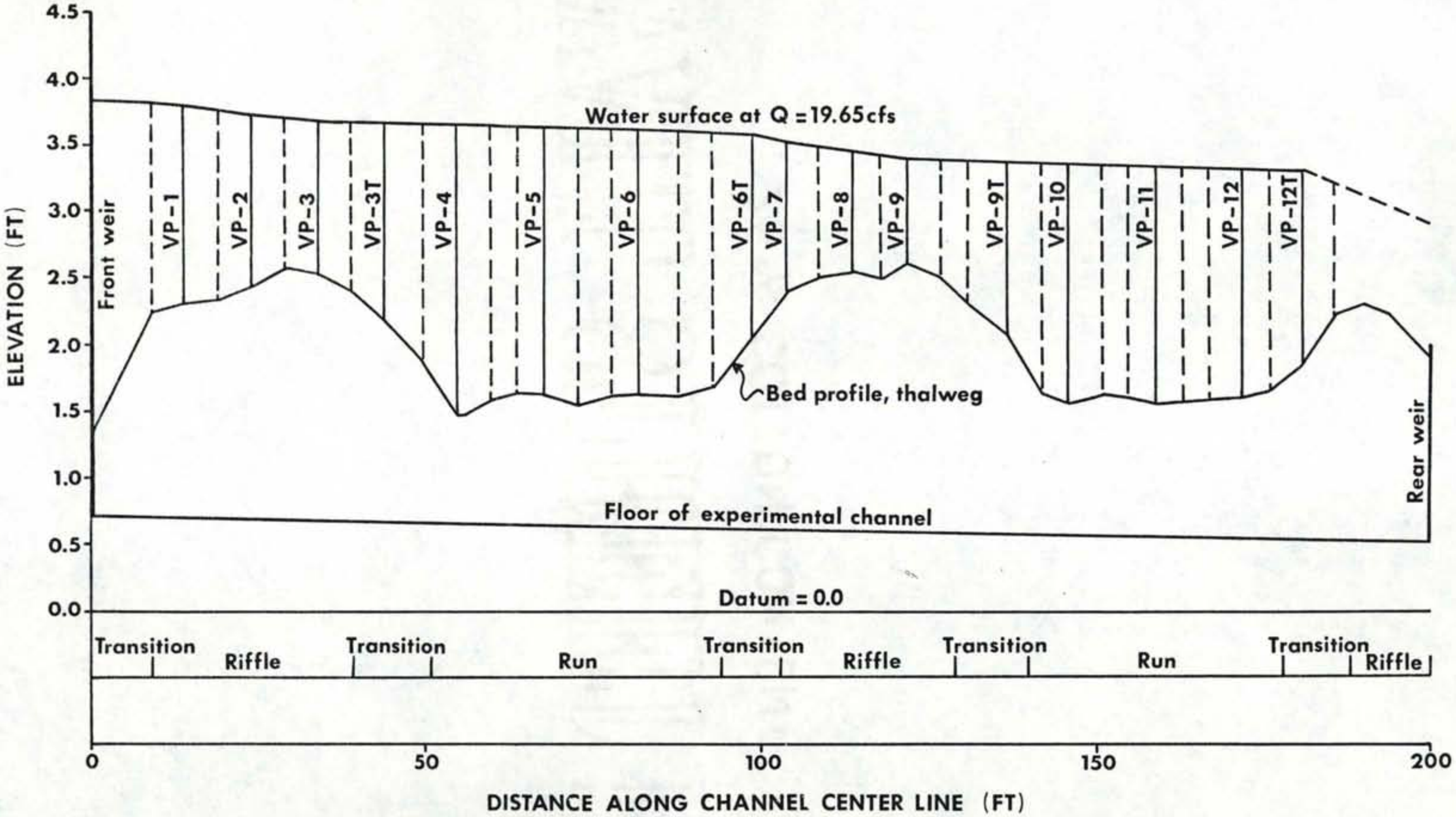


Figure 47. Profile of west channel at the thalweg with a flow of 19.65 ft^3/s, showing locations of velocity profile transects, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

At two velocity profile transects, one in the downstream riffle (VP-9) and one in the downstream run (VP-12) (Figure 47) supplemental measurements were taken at six additional flows. Data collected were water surface elevations and velocity profiles, with depths and point velocities measured at 0.5 ft (0.15 m) horizontal and 0.1 ft (0.03 m) vertical intervals. At the 22 remaining transects, bed elevations were surveyed, depths and average point velocities (at 0.6 depth) were measured at 1.0 ft (0.3 m) horizontal intervals, and water surface elevations determined. At all transects, substrate was categorized using a description of the bottom type (i.e., silt, sand, etc.) (Appendix F).

Determination of Hydraulic Parameters

Velocity

The position of each vertical section in a cross section where velocities were measured was fixed by reference to a fixed point on the bank. These vertical sections also corresponded with the surveyed points defining the geometric shape of the cross section.

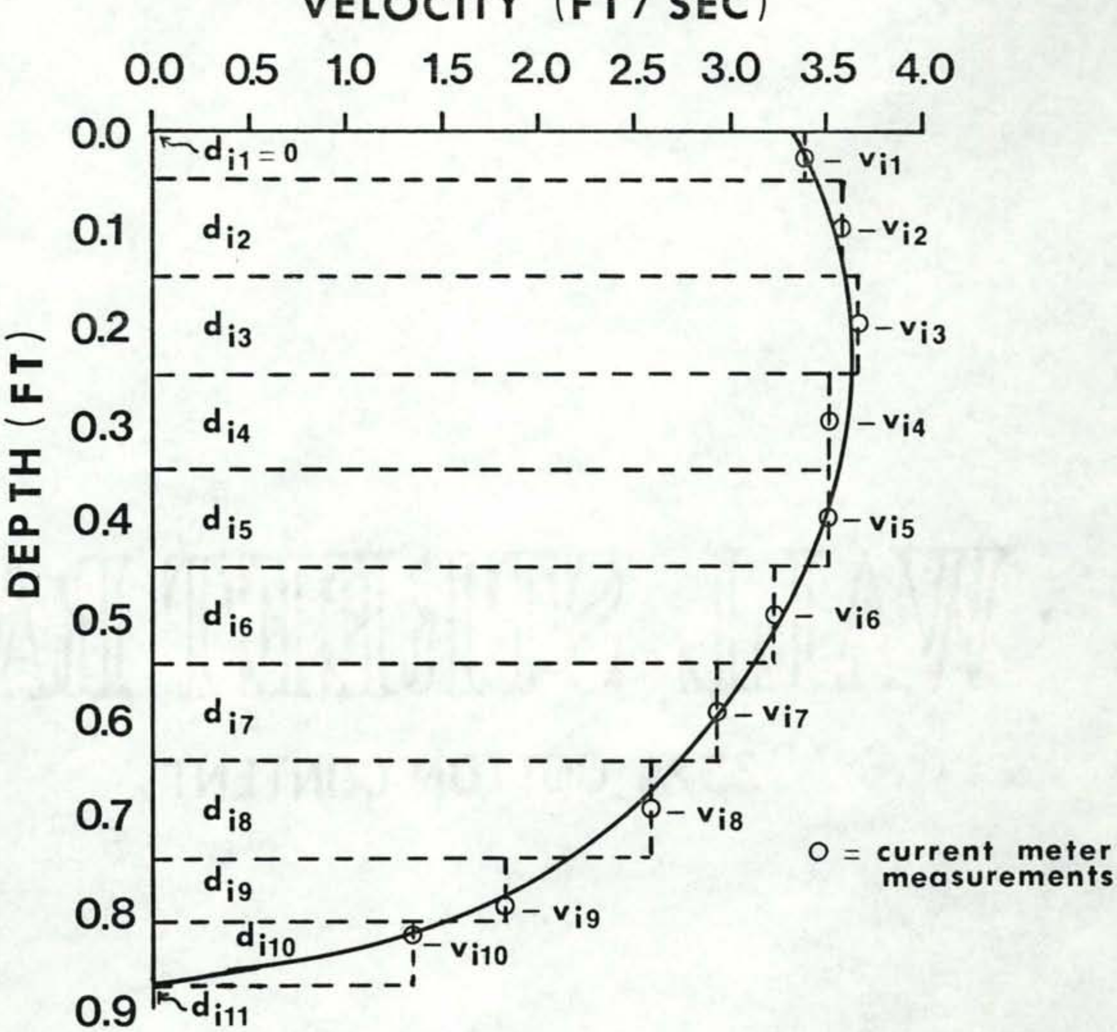
Velocities and depths were measured with a Marsh McBirney Model 201 electronic current meter with the velocity probe mounted on a top setting wading rod. Measurements of velocities at the bed of the channel were taken at a minimum of 0.07 ft (2.1 cm) above it because the probe mounting prevented a lower measurement.

An average point velocity is usually approximated by a velocity measurement at 0.6 depth when the depth of water is less than 2.5 ft (0.76 m). For most stream investigations, this approximation is adequate. However, several situations in a stream may reduce the accuracy, such as large obstructions, greatly varied substrate, and eddies, and effects will vary from place to place, as well as from one flow to another. To eliminate or reduce the effect of such influences and for purposes beyond the scope of this report, the more precise method of computing the average point velocity from a set of point velocities in the same vertical (velocity profile) was used for those transects designated VP.

A method for determining the average point velocity (Hoyt and Grover, 1927) involves calculating the approximate area of a velocity profile curve bounded by its axis and dividing by the total depth of water (Figure 48). Another method is to measure the area of curve with a planimeter and divide by the depth (Buchanan and Somers 1968). Several velocity curves were plotted and areas measured with a planimeter. The areas were also computed by the method presented in Figure 48. The variation in areas of the velocity profile curves obtained by the above two methods was a maximum of 5%. Hence, to facilitate analysis of the large number of velocity profiles, the computational method was used. Average segment velocities (v_x) were computed by averaging two adjacent average point velocities ($\overline{v_i}$).

Discharge

Discharge was computed by calculating the area of each segment in a cross section, multiplying each segment by its average segment velocity, and summing the resulting segment discharges (Figure 49). Dividing the discharge by the sum of the segment areas gave average cross sectional velocity. This method (mean section method) of determining discharge and, subsequently, the average cross sectional velocity, is essentially the same method utilized in hydraulic simulation models.



$$\bar{v}_i = \left[\sum_{j=1}^{m} v_{ij}\left(\frac{d_{ij} - d_{(ij-1)}}{2} + \frac{d_{(ij+1)} - d_{ij}}{2}\right)\right] \Big/ d_i$$

where,

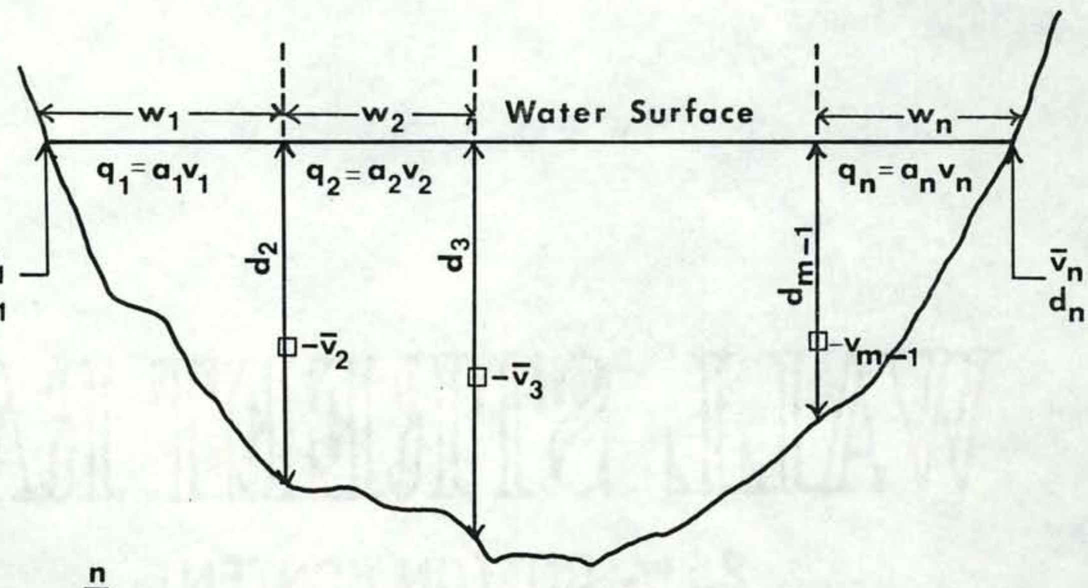
$\bar{v}_i$ = average point velocity

v_{ij} = point velocity

d_{ij} = depth from surface of v_{ij}

d_i = total depth

Figure 48. Definition sketch of method used to determine average point velocities from the velocity profile at segment x.



$Q \;\; \sum_{x=1}^{n} q_x$ where,

$q_x = a_x v_x$ where,

$a_x \approx w_x(d_i + d_{i+1})/2$ and

$v_x = \bar{v}_i + \bar{v}_{i+1}/2$

i = 1,2···, m vertical points

x = 1,2···, n segments

□ = location of average point velocity

$V = Q/A$ where

$A = \sum_{x=1}^{n} a_x$

Figure 49. Definition sketch of method used to compute discharge (Q) average cross sectional velocity (V), and cross sectional area (A).

Slope of Energy Grade Lines

Total energy head (H) was computed for each velocity profile transect using the equations presented in the introductory section on energy and gradients in open channel flow. The energy head was computed with and without the velocity distribution coefficient (α). Plotting the value of total energy head for each transect at a particular flow defined the energy grade line of the stream channel at that flow.

Slope of the energy grade line (S_f) was computed by dividing the increase in the energy head (h_f), moving upstream, by the distance (Δx). The distance between abrupt increases or decreases in h_f defined Δx (discriminative changes in the slope of the plotted energy grade line). All transects within x were assumed to have the same energy slope.

Geometric Elements

The geometric elements were computed using a program developed by Croley (1977) for use in programmable calculators. Mean depth (d_x) and area (a_x) were computed for all segments in the velocity profile transects at each flow by:

$$d_x = (d_i = d_{i+1})/2$$

and,

$$a_x = d_x w_x$$

where,

subscript x indicates the segment

subscript i indicates bed elevation point (segment bound)

Segment area times the two-thirds power of the mean segment depth replaces the section factor ($AR^{2/3}$) in uniform flow computations.

Manning's Roughness Coefficient

The roughness coeffient (n) was calculated for all velocity profile transects, using Manning's equation in the form:

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

Terms in the above equation were defined previously. When n values were needed for cross sectional segments, the above equation was used in the following form:

$$n_x = \frac{1.49}{V_x} d_x^{2/3} S_f^{1/2}$$

where,

n_x = roughness coefficient

d_x = mean depth of the segment

v_x = average segment velocity

$S_f^{1/2}$ = energy slope of the cross section

Streamflow Characteristics

Dimensionless curves for V/V_o, A/A_o, $AR^{2/3}/A_oR_o^{2/3}$ and P/P_o were established to examine their relationships with incremental reductions Q/Q_o (the subscript "o" indicates the base flow condition). Change in Manning's n and energy slopes were collated with reductions in streamflow. Variations of Manning's n and discharge are compared to changes in mean depth.

Hydraulic Simulation Models

This section describes the methods used in calibration of the hydraulic simulation models and procedures used in evaluation of model predictions. In additions, methods and procedures used within the models to evaluate open channel flow are described where appropriate.

All three hydraulic models require horizontal and vertical coordinates defining the shape of the cross section. The horizontal coordinates are referenced to a point on the left stream bank. The vertical coordinates are elevations above an arbitrary datum.

When the elevation of the water surface is defined, the geometric elements of the cross section are readily computed. The accuracy in predicting the geometric elements associated with a given flow becomes a matter of correctly defining the water surface location and an adequate number of coordinate pairs defining the cross sectional shape that have been measured accurately.

Assuming that the geometric elements are determined correctly by the models, the major effort in hydraulic simulation becomes one of being able to correctly relate discharge to velocity and water surface elevation (depth).

IFG-1

The hydraulic simulation using the IFG-1 model is dependent on the specification of water surface elevations of interest to predict associated discharges and velocities. To compare predicted with measured parameters, only those water surface elevations where flow measurements are available were used.

Stage-Discharge Relationship: The IFG-1 model was tested at each velocity profile transect in the west experimental channel, using the stage-discharge relationship:

$$Q = a(St - StZF)^b$$

where,

Q = discharge
St = stage (elevation of the water surface)
StZF = stage of zero flow (elevation were flow is zero)
a and b = constants

The logarithmic form of this equation is:

$$\log Q = b \log (St\text{-}StZF) + \log a$$

which is the equation of a straight line where slope is expressed by b and the intercept on the discharge axis is equal to log a (the value of discharge at the point on the straight line where St-StZF is equal to one).

The stage of zero flow was estimated from a profile view of the streambed at the thalweg (Figure 47), which shows a hydraulic control in the vicinity of VP-9 with an elevation of 2.67 ft, suggesting this value should be used as the stage of zero flow for VP-1 through VP-9. The Running method described by Wisler and Brater (1959) was used to determine the stage of zero flow at VP-3, at VP-5 and VP-9, and at VP-12. This method indicates the best estimate of the stage of zero flow for VP-3 and both upstream transects is 2.67 ft, VP-3 through VP-9 is 2.78 ft, and all transects downstream of VP-9 is 2.46 ft.

The logarithmic equation was calibrated with the five test flows, associated water surface elevations and the stage of zero flow estimated in the field. The discharge was then predicted for each stage associated with a test flow. This procedure was repeated using the estimates for stage of zero flow obtained from the profile view of the bed at the thalweg and with values obtained by the Running method. To evaluate the effects of estimates of the stage of zero flow on the predictive ability of the equation, the mean absolute error was determined for the five predicted flows at each VP transect and each trial by:

$$\text{Mean Error (\%)} = \Sigma \frac{|\text{Error (\%)}|}{n}$$

where,

$$\text{Absolute Error (\%)} = \left| \frac{Q_m - Q_p}{Q_m} \right| \times 100\%$$

and,

Q_m = the measured discharge

Q_p = the predicted discharge

n = number of flows predicted

To evaluate accuracy of discharge predictions for flows not included in the calibration process of the stage-discharge relationship, various combinatons of flow data were used to calibrate the equation (i.e., three intermediate flows, two intermediate flows). Discharge predictions were made for all five test flows (including those used in calibration) and compared to the measured discharge. No restrictions were placed on the range of extrapolation, though it should be noted Bovee and Milhous (1978) suggest certain restrictions depending on the number of flows used in calibration.

Manning's Equation: Through a simulation run utilizing the Manning's equation option, the energy slope and the roughness coefficient n are held constant, and only the section factor ($AR^{2/3}$), computed from the given water surface elevations, is variable. Manning's formula as used by the model becomes:

$$Q = CmAR^{2/3}$$

where,

$$Cm = \frac{1.49S_f^{1/2}}{n}$$

In other words, Cm is calculated from a given discharge and water surface elevation and then used to calculate the discharge at other levels of flow.

The IFG-1 model using this option was calibrated with the conditions measured at one test flow and discharges predicted for the water surface elevations associated with the other four flows. This process was repeated for each test flow.

In the evaluations of accuracy, only those flows that fell within the range 0.4 to 2.5 times the calibration flow were used (Table 21). This follows recommendations for the useful range of extrapolation using Manning's equation (Bovee and Milhous 1978).

Table 21: Experimental flows, where hydraulic predictions were evaluated, that are within the recommended range of extrapolation, 0.4 to 2.5 times the calibration flow. Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

Calibration Flow (cfs)	Test Flow which Predictions are Based on
19.65	11.15
11.15	19.65 6.45
6.45	11.15 2.67
2.67	6.45 1.26
1.26	2.67

Water Surface Profile Model (WSP)

Calibration of the WSP hydraulic simulation model requires the water surface elevation associated with a known discharge (calibration discharge) for each transect in the stream reach to be simulated. The most downstream transect of each simulated reach should be located at a hydraulic control. Manning's roughness coefficient (n) must be supplied for each transect and must be related to the calibration discharge. When one n value per transect is used, the simulation process involves only average cross sectional parameters. When more than one n value is supplied (which requires specification of the horizontal distances associated with each n value), average segment parameters are also simulated.

Calibration of the WSP model consists of predicting water surface elevations at each transect and then comparing the predicted values against measured water surface elevations. When predicted values deviate by more than an acceptable magnitude (i.e., greater than $\pm$ 0.05 ft) from measured values, adjustments to n values are made, and the process is repeated until predicted water surface elevations are acceptable. When a transect has more than one segment, adjustment of n values must include consideration of effects on average segment velocities so that the predicted values are the same as the measured values at the calibration flow.

When the calibration process is completed, other streamflows of interest may be simulated by specifying the discharge and the associated water surface elevation or the discharge and the energy slope at the most downstream transect. Manning's n can be modified from the calibration case for each flow simulated. However, the degree of modification is the same for all transects.

To evaluate the WSP model, the cross sectional bed elevations and water surface elevations of the 16 VP transects were used in calibration. Each transect was treated as one segment (i.e., one n value per transect) with initial roughness coefficients as originally computed. The model was considered calibrated when the predicted water surface elevations of the calibration flow were within ± 0.03 ft of the measured water surface elevations. To achieve water surface elevations within the above stated range required minor adjustment to n values since the energy slope is computed between each transect rather than the average of all transects between distinct changes in the energy grade line.

After the model was calibrated, the remaining four test flows were simulated. Measured water surface elevations at VP-12T (most downstream transect) were the basis for flow simulations (Figure 50). Each of the five test flows was used as the calibration flow with the remaining test flows simulated, and at each calibration, two simulation runs were made, producing a total of 10 simulation runs. One simulation run at each calibration was made holding n values constant through the range of flows simulated. In the second simulation, n values were modified. The value of the modifier was the average percent deviation of all transect n values at a given simulated flow from n values associated with the calibration flow. For example, if the calibration flow was 6.45 cfs, the simulated flow 2.67 cfs and the n values of all transects at 2.67 cfs averaged 30% greater than the n values at 6.45 cfs, the modifier would be 1.30 and would cause an increase of the calibration n values (at 6.45 cfs) of 1.30 times, for the simulation run at 2.67 cfs.

To evaluate segment velocity predictions, each VP transect was divided into nine segments (except the four transition zone transects), with

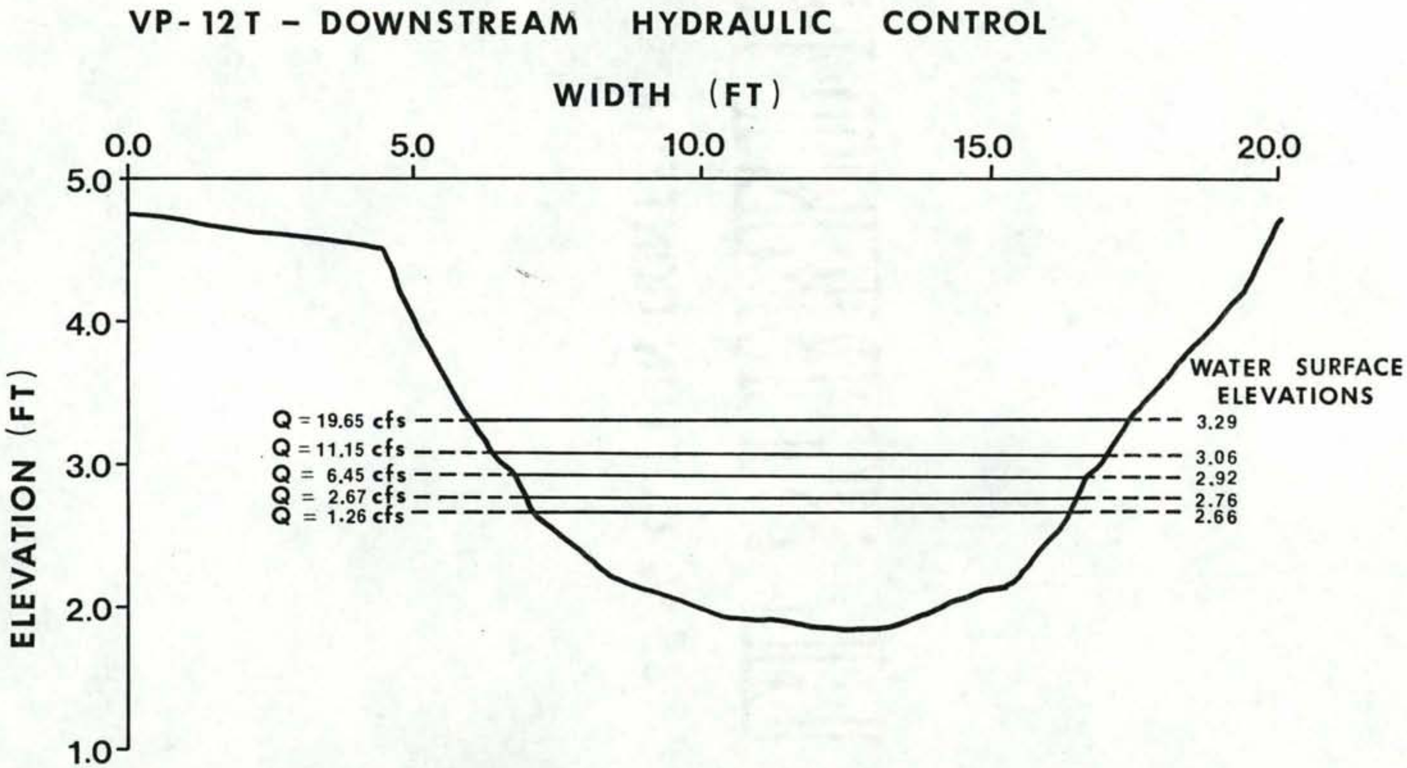


Figure 50. Cross section of most downstream VP (12T) transect showing five test flows with associated water surface elevations, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

one segment located above the water line. The segment above the water line was required to interface output with the IFG-3 habitat model but was not a specific requirement of the WSP program. The IFG-3 habitat model is a physical habitat analysis model based upon velocity, depth and substrate preferences of fish (Main 1978b).

For each of the eight segments in a transect, the discharge, area, and wetted perimeter were computed at 19.65 cfs. Manning's n was then calculated for each segment.

The model was calibrated at 19.65 cfs in the same manner as previously described. However, with eight n values per transect, consideration to segment velocity adjustments, as well as water surface elevations, was required. Flows at 11.15, 6.45 and 2.67 cfs were simulated while holding n constant and again with modified n values.

Average cross sectional velocities and average segment velocities predicted using the WSP model were compared to measured values. Magnitude and frequency of errors were analyzed by calculating the percentage error as an absolute value using the equation:

$$\text{Error } (\%) = \frac{V_m - V_p}{V_m} \times 100$$

where,

V_m = measured average velocity (segment and cross sectional)

V_p = predicted average velocity (segment and cross sectional)

IFG-4

The IFG-4 hydraulic simulation model was developed for the purpose of providing the velocity distribution (segment velocities) and depth of water at specified flows to the IFG-3 habitat model. This model predicts the stage (water surface elevation) at a specified discharge of interest for each transect being simulated. The relationship used to predict the discharge is essentially the same as used in the IFG-1 model and is of the form:

$$St = a\ Q^b + StZF$$

In the calibration process, the equation is used in logarithmic form:

$$\log\ (St - StZF) = b\ \log\ Q + \log\ a$$

The same requirements and methods for calibration and use of this form of the equation exist as presented in the section for IFG-1.

To predict the segment velocities, an equation that requires two or more segment velocities in the calibration process is used and is of the form:

$$v_x = a_x Q^{b_x}$$

where,

v_x = average segment velocity

Q = discharge through the cross section

a_x and b_x = constants of least square regression

The logarithmic form of the equation is:

$$\log\ v_x = b_x\ \log\ Q + \log\ a_x$$

When negative segment velocities are involved in the calibration process, a semi-log fit of v_x versus Q is used.

For segments with only one calibration velocity, Manning's n is calibrated for the segment by the equation:

$$n_x = \frac{1.49}{v_x}\ d_x^{2/3}\ S_f^{1/2}$$

Velocity predictions are made at other flows holding Manning's n, as calculated, constant, using the equation:

$$v_x = \frac{1.49}{n_x} d_x^{2/3} S_f^{1/2}$$

In both equations, the model assumes a constant value for the energy slope of 0.0025. For segments with no velocity measurements, an n value must be supplied (or if no value is given, the model assumes a value of 0.06), and Manning's equation is used to compute the velocity.

With the prediction of the water surface elevation, the area and depth of each segment is computed. With the predicted average segment velocity, the discharge through each segment can be calculated. The sum of all segment discharges is then compared to the specified flow of interest, and a velocity correction factor is computed and applied if they do not agree. For example, if the computed discharge from predicted segment velocities was 19.0 cfs and the specified flow of interest was 20.0 cfs, a correction factor of 1.05 would be obtained ($20 \div 19 = 1.05$).

To evaluate the IFG-4 model, the 16 VP transects were used for calibration and evaluation of predictions. Various flow combinations were used in the calibration process. After each calibration, all five test flows were simulated.

The stage-discharge relationship was evaluated using stage of zero flow values as described in the IFG-1 section. The segment velocity-discharge relationship was evaluated with and without the velocity correction factor.

The velocity-discharge equation, $\log v_x = b_x \log Q + \log a_x$ was calibrated with various measured velocity-discharge pairs. Predictions were compared with measured values without any correction. The same measured velocity-discharge pairs were used in calibration of the computer program. The predicted average segment velocities from the program were compared to measured values. This process provided a means of evaluating the predictive ability of the equation by itself, and as it is used as part of the entire hydraulic simulation model.

Effect of Reducing the Number of Transects

In the evaluation of the hydraulic simulation models, we also examined how many transects are needed to adequately describe the hydraulic parameters of depth and velocity in the stream reach of interest. To investigate this problem, the IFG-4 model was calibrated with hydraulic data from 38 transects in one experimental channel (16 transects were used to evaluate accuracy of predictions by each of the hydraulic simulation models) at five flows. The IFG-4 model thus calibrated was interfaced with the IFG-3 Habtat model (Main 1978b).

The IFG-3 model interfaces hydraulic data with probability of use of habitat by specific life stage of a fish species. Curves are constructed on the premise of probability that individuals of a species will select a certain combination of hydraulic conditions associated primarily with depth and velocity (Bovee and Cochnauer 1977). The IFG-3 model computes the surface areas represented by the segment depths and velocities of each transect (in this case, the length half way to the next upstream and downstream transects) and multiplies them by the probability of use in regard to velocity and depth. The summation of the values associated with each segment area of all transects in the stream reach is referred to as the weighted usable area. The amount of change, at a given flow, in the weighted usable area was used to evaluate the effect of reducing the number of transects used to define a stream reach.

Results and Discussion

Channel Hydraulic Properties

Velocity: Average segment velocities computed from point velocities were compared with average velocities measured at 0.6 depth. For all flows, measured average velocities at 0.6 depth tended to be higher than the computed average of the velocity profile. T-tests were used for comparison of average point velocities (paired observations) from both methods (Table 22). Probability of a larger value of t is without consideration to sign. If sign were considered, the probabilities would be halved.

The 0.6 depth meaurement of average point velocities is a commonly used procedure because its use decreases field time and computational requirements. Chow (1959) notes that this is a simple method and approximate. In most situations, it is probably accurate enough. Our study results support this conclusion, at least in the case at the experimental channels. Rarely did the differences between the two values exceed 0.3 ft/sec and usually were within 0.1 ft/sec.

Discharge

Discharge for the base flow and four incremental reductions was 19.65 (100%), 11.15 (57%), 6.45 (33%), 2.67 (14%) and 1.26 (6%) cfs respectively and was determined by averaging the computed discharge of 12 velocity profile transects for each flow. The computed discharges for a given flow were fairly consistent from one cross section to the next (Table 23). The low variances and standard deviations support the conclusion of consistent discharge and velocity measurements from one transect to another.

Table 22. T-tests for differences in average point velocities between computed values from point velocity measurements (velocity profiles) and measured values at 0.6 depth at a riffle and a run transect, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, 1979.

	Discharge (cfs)					
	20.6	14.4	9.6	4.1	1.6	0.8
VP-9: Riffle						
Average of calculated $\overline{v}_i$ ($\overline{X}_1$)	2.476	2.451	1.944	1.425	0.913	0.582
Average of measured $\overline{v}_i$ ($\overline{X}_2$)	2.672	2.647	2.093	1.554	0.952	0.625
$\overline{d}$ [a]	-0.196	-0.196	-0.149	-0.129	-0.039	-0.043
$S_{\overline{d}}$ [b]	0.0262	0.0247	0.0242	0.0155	0.0197	0.0212
d.f. [c]	21	18	18	16	13	5
Computed t [d]	7.481	7.935	6.157	8.323	1.980	2.028
Probability of a larger t	<0.001	<0.001	<0.001	<0.001	0.05-0.10	0.05-0.10
VP-12: Run						
$\overline{X}_1$	1.334	1.057	0.804	0.447	0.224	0.113
$\overline{X}_2$	1.335	1.091	0.838	0.473	0.269	0.137
$\overline{d}$	-0.001	-0.034	-0.034	-0.026	-0.045	-0.024
$S_{\overline{d}}$	0.0208	0.0151	0.0183	0.0112	0.0065	0.0033
d.f.	22	21	20	19	27	17
Computed t	0.048	2.252	1.858	2.321	6.878	7.273
Probability of a larger t	>0.50	0.02-0.05	0.05-0.10	0.02-0.05	<0.001	<0.001

[a] Mean of the sample differences = ($\overline{X}_1$-$\overline{X}_2$) - average of measured $\overline{v}_i$ ($\overline{X}_2$) are reported to three decimal places as a result of computations, this does not imply such an accuracy in actual velocity measurements.

[b] Standard deviation of the mean differences = $\sqrt{S_X^2/N}$.

[c] Degrees of freedom = N-1.

[d] Computed t values = $\overline{d}/S_{\overline{d}}$.

Table 23. Mean discharge (ft^3/s), range, variance, standard deviation and coefficient of variability of the base flow and four incremental reductions computed from twelve velocity profile transects in the west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, 1978.

		Flow reduction			
	Base	57%	33%	14%	6%
Mean discharge	19.65	11.15	6.45	2.67	1.25
Range	20.80-18.59	11.72-10.66	6.88-6.01	3.12-2.27	1.47-1.02
Variance	0.69	0.16	0.07	0.07	0.02
Standard deviation	0.83	0.40	0.26	0.26	0.13
Coefficient of variability (%)	4.2	3.6	4.1	9.8	10.1

Water Surface and Energy Profiles

Because of the low velocities in our experimental channel, the inclusion of the velocity distribution coefficient in computations that define the gradient of the energy line, had little overall effect on the outcome of energy slope values. The average slope of the energy line from VP-1 to VP-12T (Figure 51) was increased by 5.8% at 19.65 cfs (from 0.00307 to 0.00325) with the inclusion of the velocity distribution coefficient (α) in total head computations. At a flow of 19.65 cfs, the energy slope in the downstream riffle (VP-7 to VP-10) is increased 8.1% (0.00499 to 0.00539). The effects of the velocity distribution coefficient on the determination of the energy gradient are even less at the lower flows and velocities.

Values for the velocity distribution coefficient (α) in general, increased with decreasing discharge and ranged from 1.08 at VP-9 with 19.65 cfs to 2.75 at VP-10 with 1.26 cfs. Coefficients increased with the increase in size and number of roughness elements affecting the flow through a cross section.

Values for velocity distribution coefficients are reported to vary from about 1.03 to 1.36. However, much higher values occur near pronounced irregularities in channel alignment and in the vicinity of large obstructions (Chow 1959; King and Brater 1963). Of 76 calculated velocity distribution coefficients, 54% were within the range 1.03 to 1.36, 37% were in the range of 1.36 to 2.00, and 9% of the values were above 2.00. The apparent reason for the presence of large coefficients is the occurrence of eddies (negative velocities) related to relatively large roughness elements, especially in the runs where eddy effects are more pronounced at low flows.

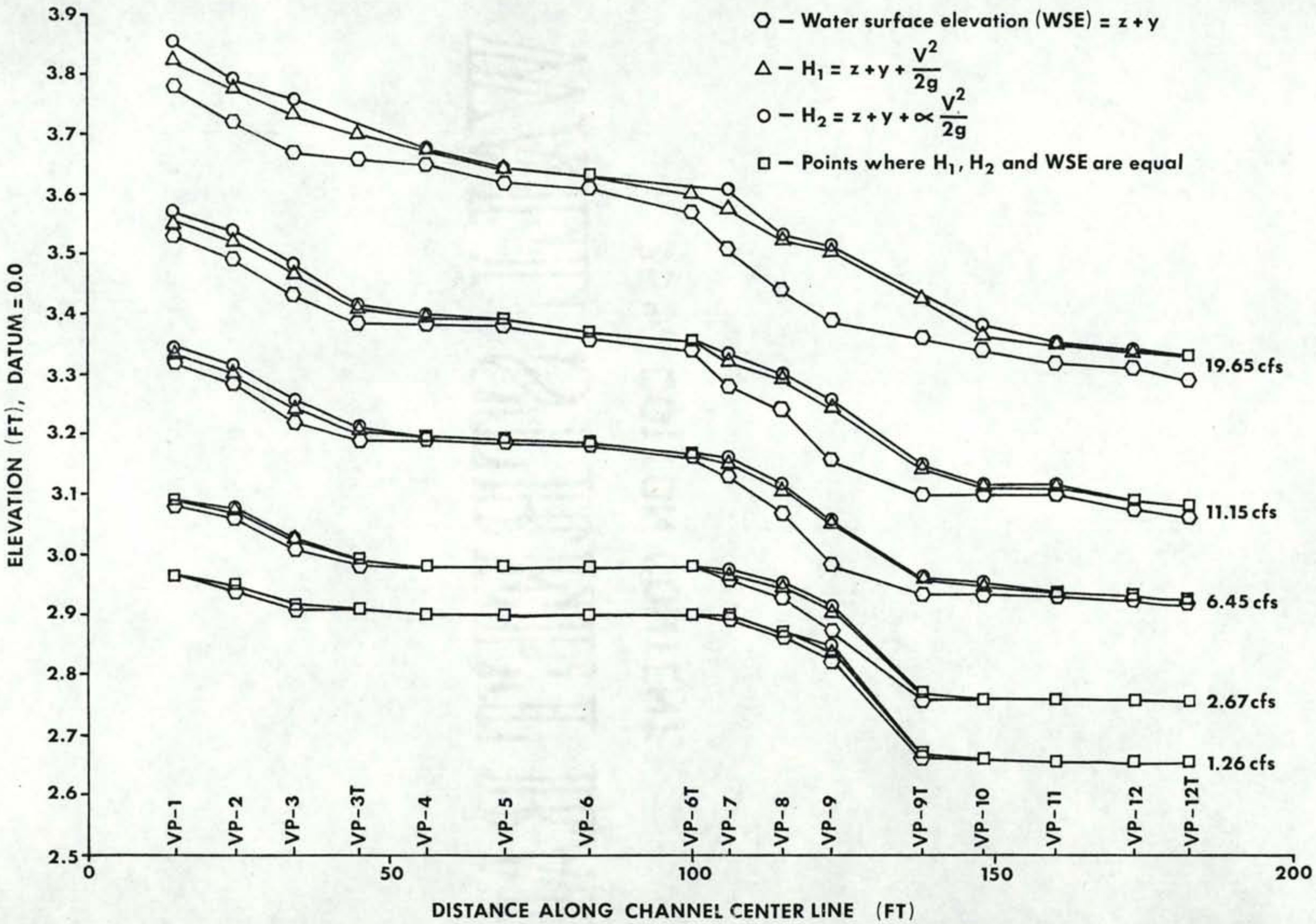


Figure 51. Comparison of the energy grade lines (H_1 and H_2) and hydraulic grade line (WSE) at the five experimental flows, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

The increase in total head ($h = z + y + \alpha\ V^2/2g$) as a result of including the velocity distribution coefficients (α) in the computations was more pronounced in the riffles than in the runs and at higher flows versus lower flows (Figure 51). This result is primarily due to greater kinetic energy ($V^2/2g$) associated with high flows and the higher velocities over riffles.

For channels of regular cross section and fairly straight alignment, the effect of nonuniform velocity distribution on the computed velocity head is small, especially in comparison with other uncertainties involved in the computation (Chow 1959). The results using the velocity distribution coefficient were of minor significance and had little effect on the computed velocity head, agreeing with Chow's statement. Therefore, the velocity distribution coefficient was assumed to be unity. Energy slopes used in all other computations in this report were derived from energy grade lines defined by $H = z + y + V^2/2g$.

According to concepts of conservation of energy, the total energy head from one cross section must be equal to the total energy head of the next downstream cross section plus the intervening losses, or in symbols:

$$Z_1 + y_1 + V_1^2/2g = Z_2 + y_2 + V_2^2/2g = h_f$$

where,

h_f = energy loss due to friction

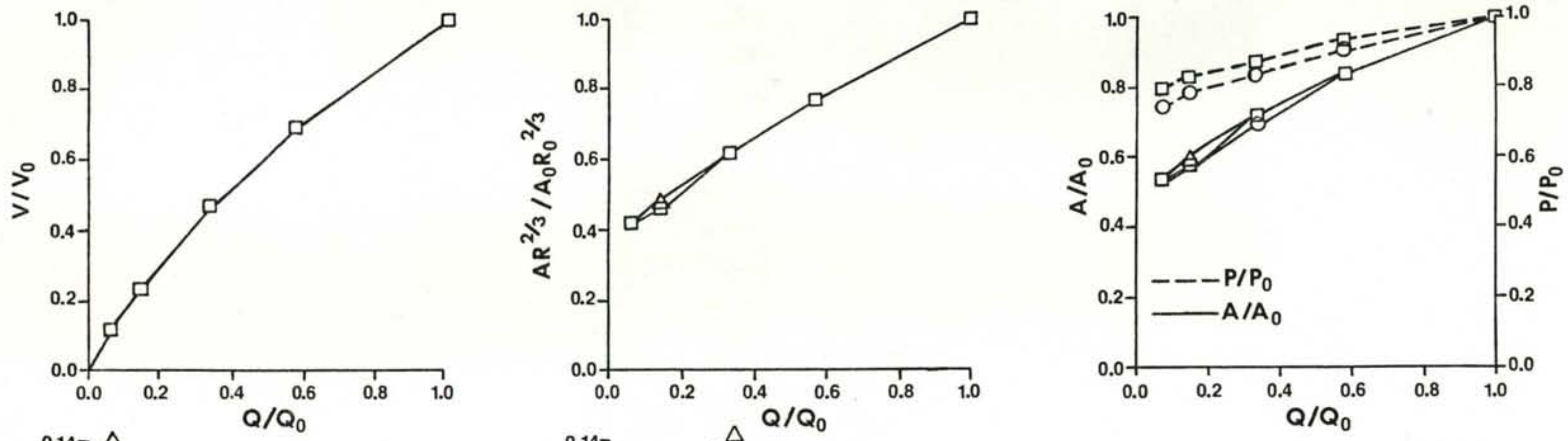
Since h_f divided by the length between cross sections equals the slope of the energy line, the slope is the expression of energy dissipation through friction. Using uniform flow equations in natural streams, an assumption is often made that the energy slope equals the water surface slope since the theory states $S_w = S_f = S_o$. However, in natural streams, uniform flow is not the usual case, and, when possible, the slope of energy line should be used since the equations (Chezy and Manning) are expressions of energy loss.

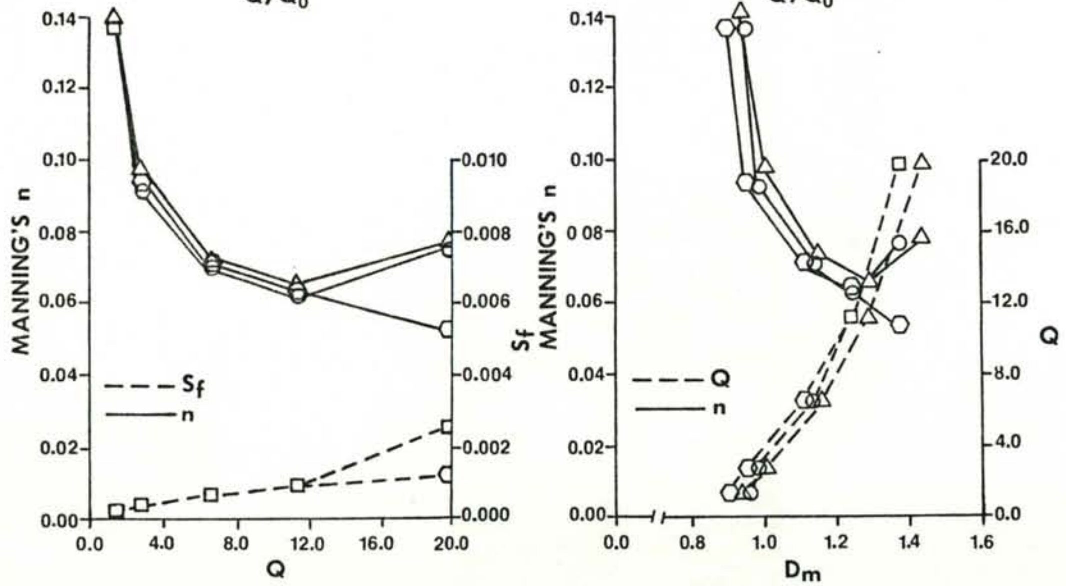
An examination of the water surface and energy profiles (Figure 51) shows that in the runs (VP-4, 5, 6 and VP-10, 11, 12), the gradient of the water surface and of the energy line is similar through the range of flows. In the riffles (VP-1, 2, 3 and VP-7, 8, 9), large differences between the gradients were observed (Figure 51). The difference decreases as discharge decreases. This suggests that selection of energy slope, S_f, values should be carefully considered as they may be substantially different than water surface slopes through stream reaches with considerable energy dissipation.

Streamflow Characteristics

In runs, average cross sectional velocity was the parameter most affected by reduced discharge, showing an average 88% reduction with a 94% reduction in discharge (Figures 52 and 53). Section factor, area, mean depth, and wetted perimeter followed with an average reduction of 61%, 48%, 36%, and 21% respectively.

Average cross sectional velocity, section factor, cross sectional area and wetted perimeter changed at about the same rate from transect to transect in runs, although each parameter did not change at the same rate for a particular transect. In general, rate of change increased with decreasing discharge for the four parameters. These results reflect the regularity of the steep-sided cross section from transect to transect in the runs (Figure 54). Changes in the four parameters are as expected for the steep-sided channel cross section.





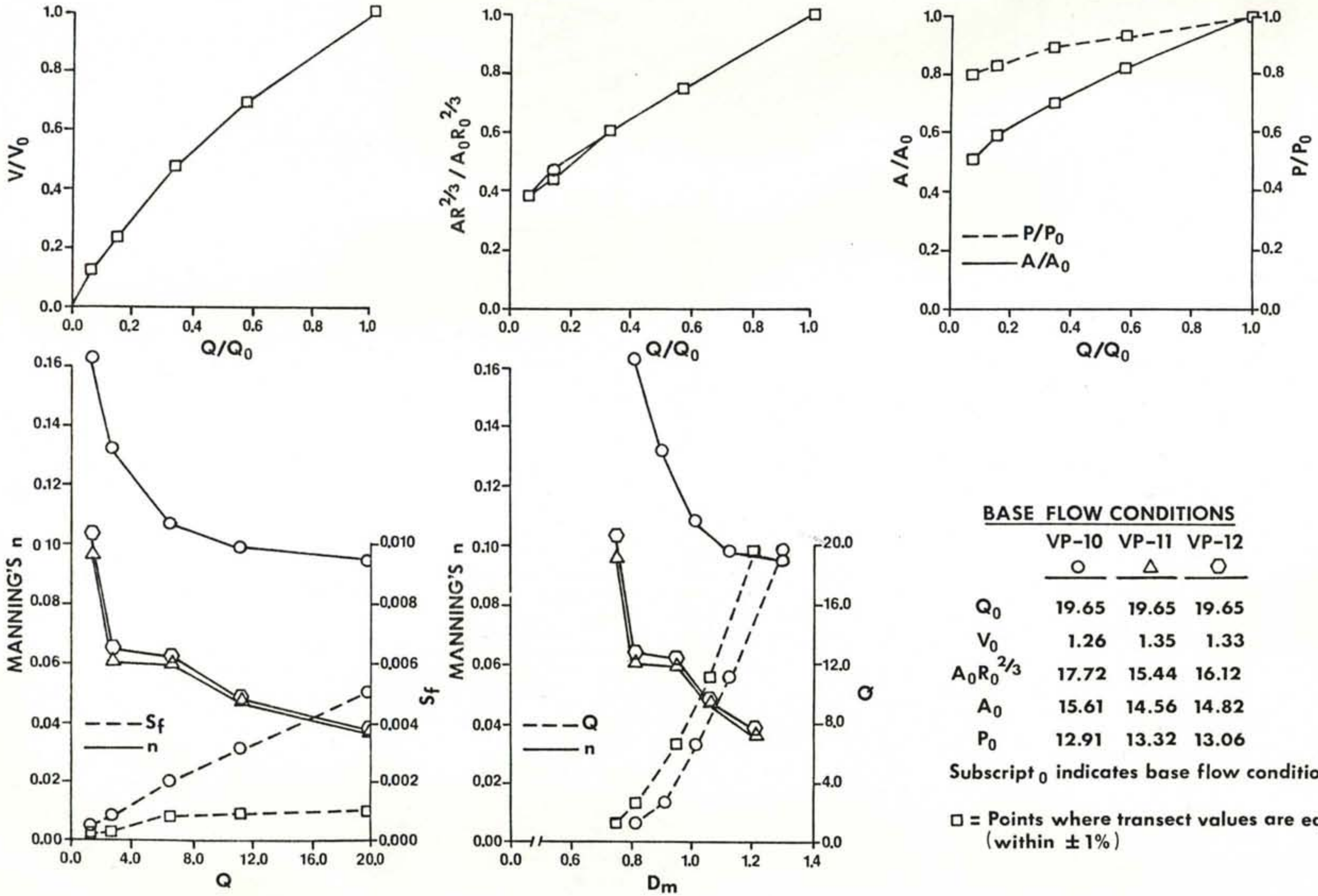
BASE FLOW CONDITIONS

	VP-4 ○	VP-5 △	VP-6 ⬡
Q_0	19.65	19.65	19.65
V_0	1.16	1.17	1.16
$A_0R_0^{2/3}$	19.75	20.17	19.85
A_0	16.95	16.85	16.92
P_0	13.48	12.87	13.31

Subscript $_0$ indicates base flow conditions.

□ = Points where transect values are equal (within ± 1%)

Figure 52. Stream flow characteristics; discharge (Q), average cross section velocity (V), section factor ($AR^{2/3}$), area (A), wetted perimeter (P), mean depth (D_m), Manning's roughness coefficient (n), and energy slope (S_f), of VP-4, 5 and 6, the upstream run, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.



BASE FLOW CONDITIONS

	VP-10 ○	VP-11 △	VP-12 ⬡
Q_0	19.65	19.65	19.65
V_0	1.26	1.35	1.33
$A_0R_0^{2/3}$	17.72	15.44	16.12
A_0	15.61	14.56	14.82
P_0	12.91	13.32	13.06

Subscript $_0$ indicates base flow conditions.

□ = Points where transect values are equal (within ± 1%)

Figure 53. Stream flow characteristics; discharge (Q), average cross section velocity (V), section factor ($AR^{2/3}$), area (A), wetted perimeter (P), mean depth (D_m), Manning's roughness coefficient (n), and energy slope (S_f), of VP-10, 11 and 12, the downstream run, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

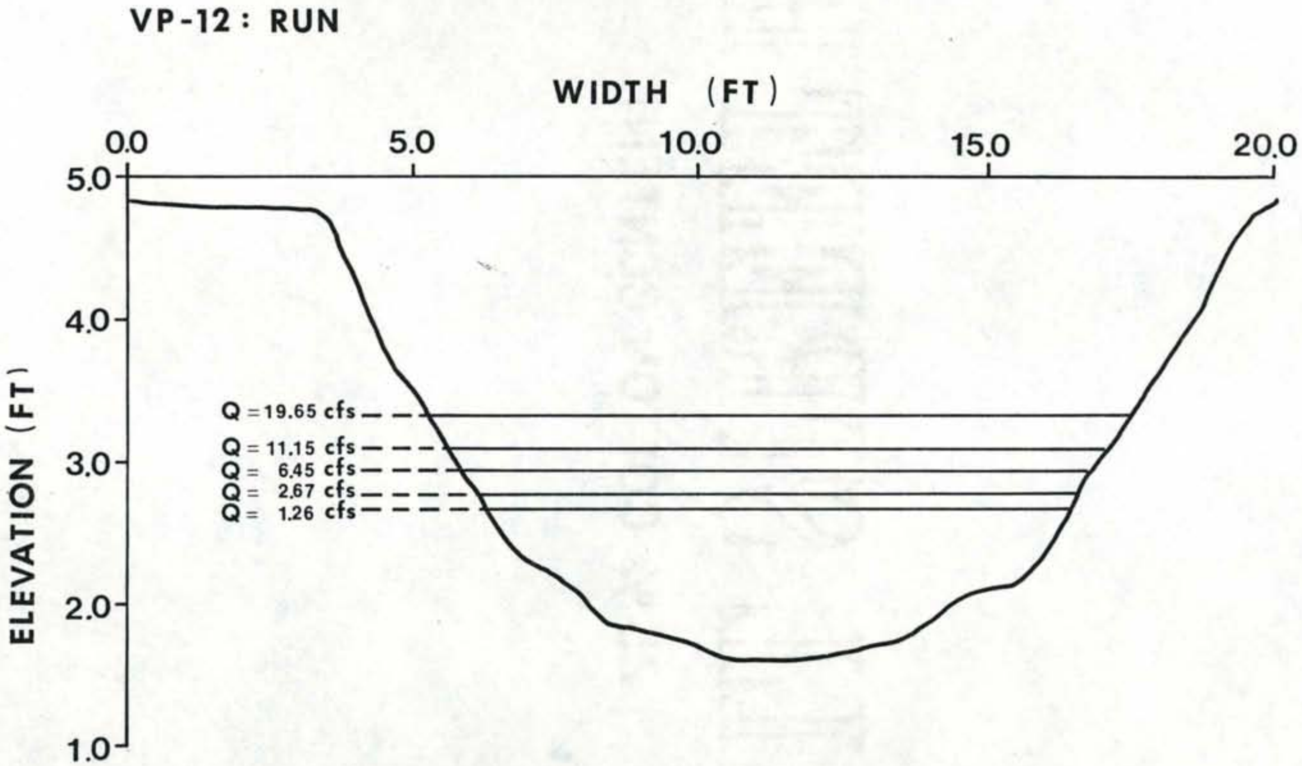


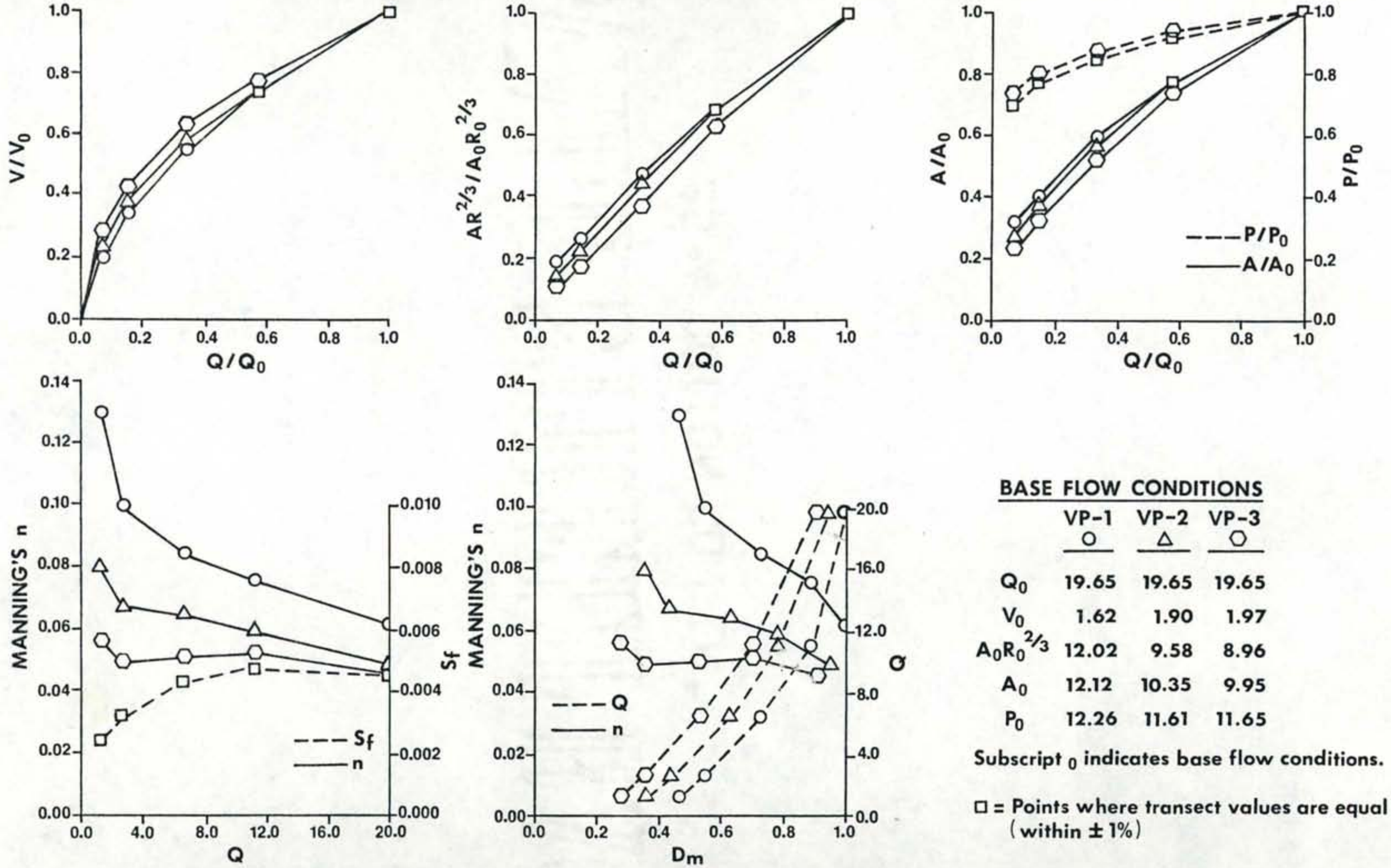
Figure 54. Typical cross sectional shape of a run transect at five test flows, west channel Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

At riffle transects, the section factor generally showed the greatest change with an average reduction of 87% (Figures 55 and 56). Average cross sectional velocity, area, mean depth, and wetted perimeter had average reductions of 74%, 73%, 67%, and 25% respectively. However, at the lowest flow (6% of beginning flow), the velocity was the parameter most affected, followed by area, mean depth, section factor and wetted perimeter with an average reduction of 16%, 9%, 7%, 6% and 6% respectively.

The two riffles were unlike the runs in the extent of parameter change. In the riffles, areas, section factors and wetter perimeters all changed more in response to discharge than in runs (Figures 55 and 56). This difference in response was due to the shallower cross section of the riffles. The response of velocity to changes in discharge was less in riffles than in runs, particularly for the initial flow reductions.

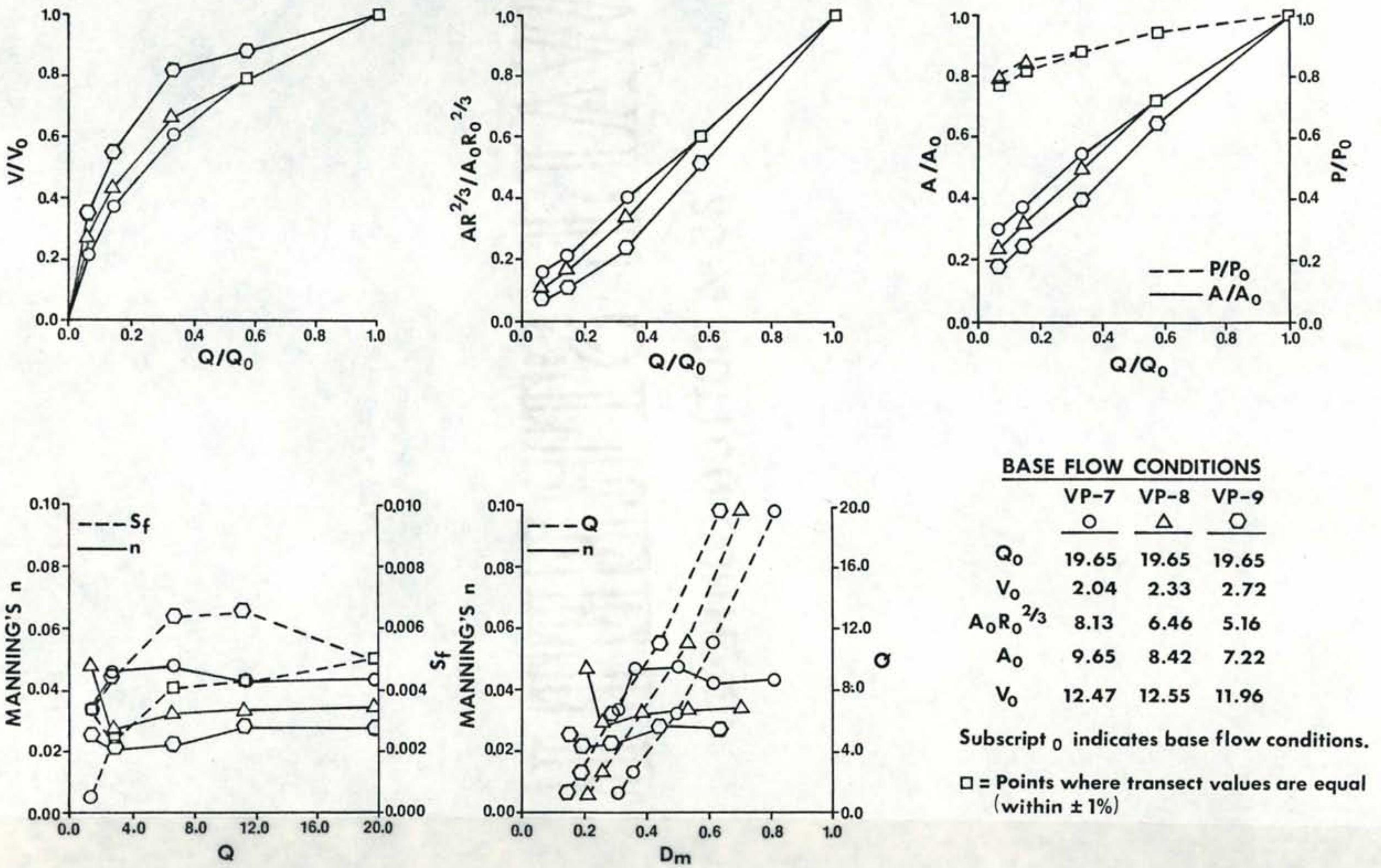
A rapid rate of change in the section factor resulted in relatively small rate of change in velocity. This effect can be seen in the velocity and section factor curves for VP-9 (Figure 56). At the first two flow reductions, the section factor decreased at a rapid rate while change in velocity was gradual. At the third and fourth reductions, the rate of change in the section factor became small, and the velocity decreased at a very rapid rate. Similar effects were observed in the curves of cross sectional area. Wetted perimeter changed at approximately the same rate for each transect, with an increase in the rate of change at the fourth flow.

Parameters most affected in contracting transitions (the transitionary stream reach leading from a run to a riffle where cross sectional area is decreasing) were velocity followed by the section factor, area,



	VP-1 ○	VP-2 △	VP-3 ⬡
Q_0	19.65	19.65	19.65
V_0	1.62	1.90	1.97
$A_0R_0^{2/3}$	12.02	9.58	8.96
A_0	12.12	10.35	9.95
P_0	12.26	11.61	11.65

Figure 55. Stream flow characteristics; discharge (Q), average cross section velocity (V), section factor ($AR^{2/3}$), area (A), wetted perimeter (P), mean depth (D_m), Manning's roughness coefficient (n), and energy slope (S_f), of VP-1, 2 and 3, the upstream riffle, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.



BASE FLOW CONDITIONS

	VP-7 ○	VP-8 △	VP-9 ⬡
Q_0	19.65	19.65	19.65
V_0	2.04	2.33	2.72
$A_0R_0^{2/3}$	8.13	6.46	5.16
A_0	9.65	8.42	7.22
V_0	12.47	12.55	11.96

Subscript $_0$ indicates base flow conditions.

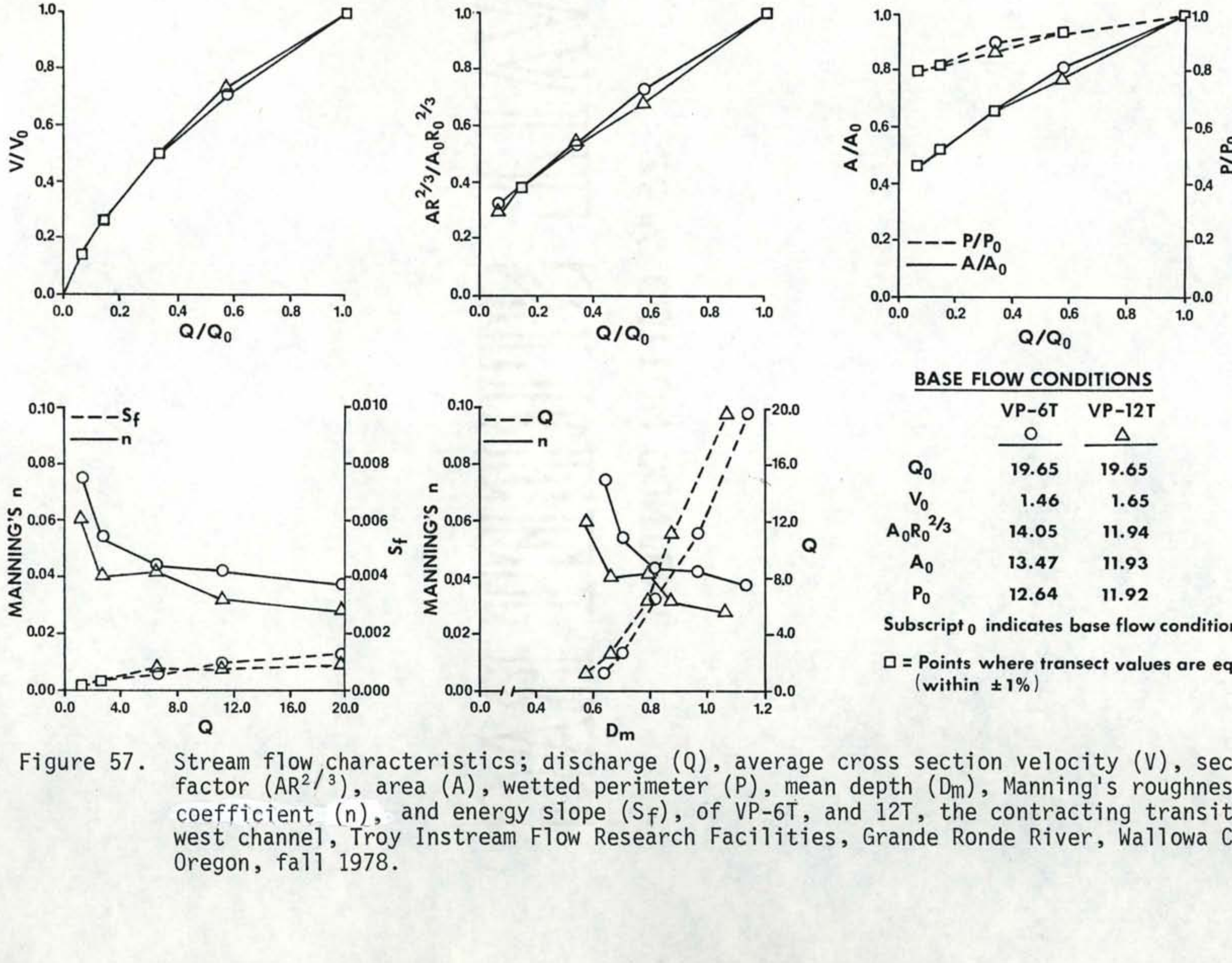
□ = Points where transect values are equal (within ± 1%)

Figure 56. Stream flow characteristics; discharge (Q), average cross section velocity (V), section factor ($AR^{2/3}$), area (A), wetted perimeter (P), mean depth (D_m), Manning's roughness coefficient (n), and energy slope (S_f), of VP-7, 8 and 9, the downstream riffle, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

and mean depth with average reductions of 86%, 71%, 55% and 45% respectively (Figure 57). The expanding transitions (the transitionary stream reach leading from a riffle to a run where cross sectional area is increasing), however, were highly variable in the parameter most affected by decreasing discharge (Figure 58). For VP-3T, the velocity changed the most, followed by the section factor, area, and mean depth, with reductions of 82%, 79%, 64% and 57% respectively for a 94% reduction in discharge. For VP-9T, the section factor was most affected, followed by velocity, area, and mean depth with reductions of 86%, 76% 73% and 65% respectively. Least affected at all transitional transects and flows was wetted perimeter with an average reduction of 21%.

Manning's n generally decreased as discharge increased (Figures 52, 53, and 55). Roughness values at VP-4 and 5, however, decreased at the first flow reduction (Figure 52). The large n values at VP-10 (Figure 53) were attributed to a greater energy slope combined with a greater mean depth than the other two transects in the run. The energy slope and the large roughness values at VP-10 indicated a substantial loss of energy at this location in the stream channel. Large increases in Manning's n at all run transects, especially the fourth flow reduction, were judged to be the effect of increases in relative roughness. Large roughness elements (boulders, diameter > 1.0 ft) located in the runs protrude through the water surface at low flows.

Manning's n values for the downstream riffle were quite different from those calculated for the other sections. Except for the last flow reduction, the values were relatively constant. This riffle was relatively free of large roughness elements which accounts for the stability in n values. Changes in energy slope were a result of the changing



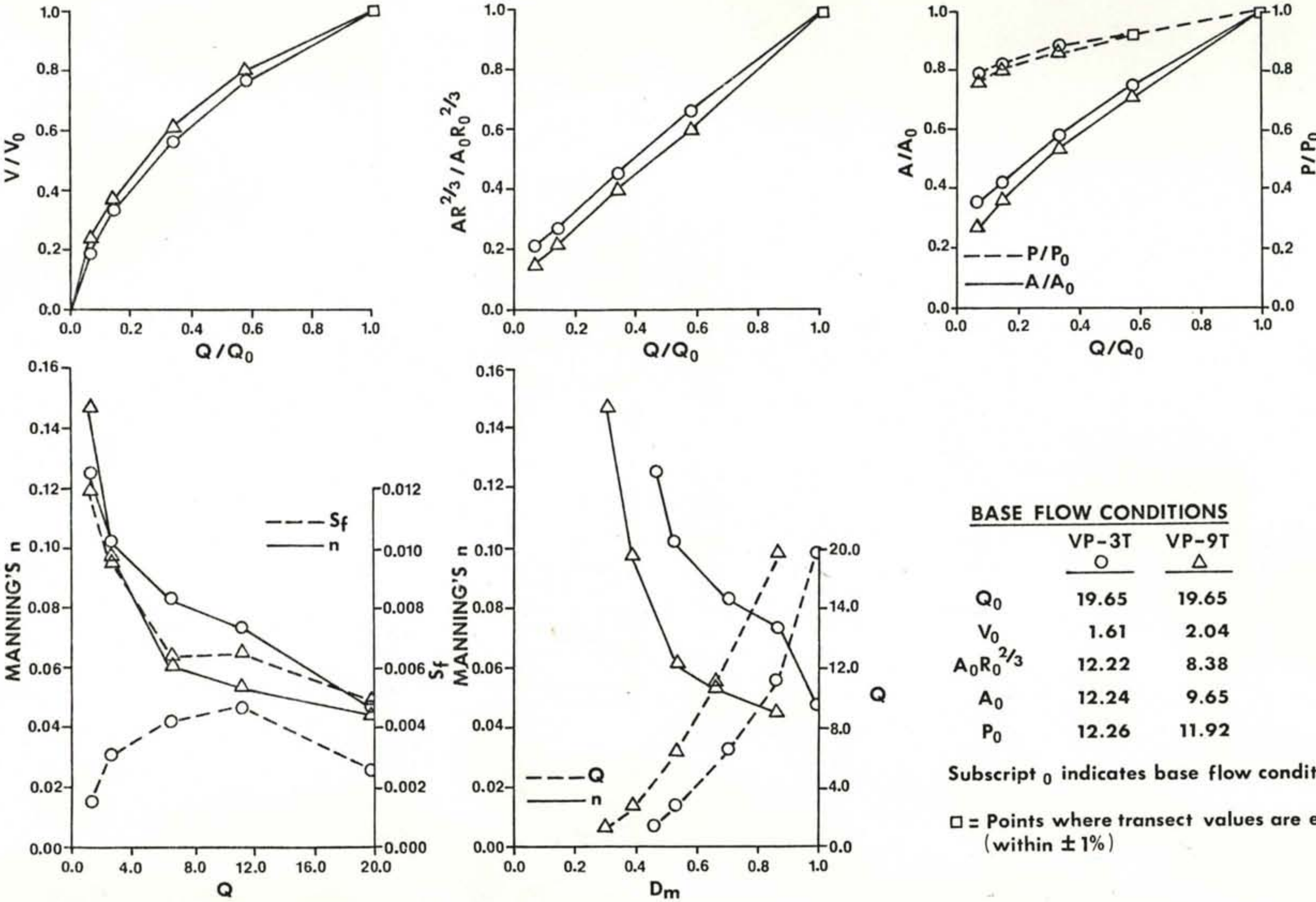
BASE FLOW CONDITIONS

	VP-6T ○	VP-12T △
Q_0	19.65	19.65
V_0	1.46	1.65
$A_0R_0^{2/3}$	14.05	11.94
A_0	13.47	11.93
P_0	12.64	11.92

Subscript $_0$ indicates base flow conditions.

□ = Points where transect values are equal (within ±1%)

Figure 57. Stream flow characteristics; discharge (Q), average cross section velocity (V), section factor ($AR^{2/3}$), area (A), wetted perimeter (P), mean depth (D_m), Manning's roughness coefficient (n), and energy slope (S_f), of VP-6T, and 12T, the contracting transitions, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.



BASE FLOW CONDITIONS

	VP-3T ○	VP-9T △
Q_0	19.65	19.65
V_0	1.61	2.04
$A_0R_0^{2/3}$	12.22	8.38
A_0	12.24	9.65
P_0	12.26	11.92

Subscript $_0$ indicates base flow conditions.

□ = Points where transect values are equal (within ± 1%)

Figure 58. Stream flow characteristics; discharge (Q), average cross section velocity (V), section factor ($AR^{2/3}$), area (A), wetted perimeter (P), mean depth (D_m), Manning's roughness coefficient (n), and energy slope (S_f), of VP-3T and 9T, the expanding transitions, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

influence of the hydraulic control on this riffle and was the reason for the decrease in the n value at VP-7 at the last flow reduction, when an increase would have been expected. This indicates little loss of energy at VP-7 at the lowest flow.

Dimensionless curves of velocity and section factor for non-transitional transects were grouped in regard to position (upstream, middle or downstream) within a stream reach (Figure 59). These curves show very little variation in the rate of change of velocity or section factor as a result of location. These curves also show the generally different response of velocity and section factor to changes in discharge between riffles and runs. This is, the velocity response to changes in discharge was more rapid in runs than in riffles. Likewise, the section factor response to changes in discharge was larger in riffles than in runs.

Predicted velocity and cross sectional area were the parameters most influenced by reduced discharge in the Teton River, Idaho (White 1976). Other investigators have shown that velocity is proportionally more affected by changes in stream discharge levels than are other hydraulic characteristics (Leopold and Maddock 1953; Elser 1972; Banks et al. 1974; Wesche 1973). Our results at Troy experimental channels, in general, agree with the above findings, especially at reduced streamflows. However, a hydraulic parameter change with decreased discharge is dependent upon cross sectional shape. Stream reaches that are shallow and wide (relative to depth) may initially show substantial changes in parameters other than velocity as streamflow decreases. Deep narrow channels, at first, will show rapid velocity reduction and small changes in other hydraulic parameters, but, at lower flows, velocity will change

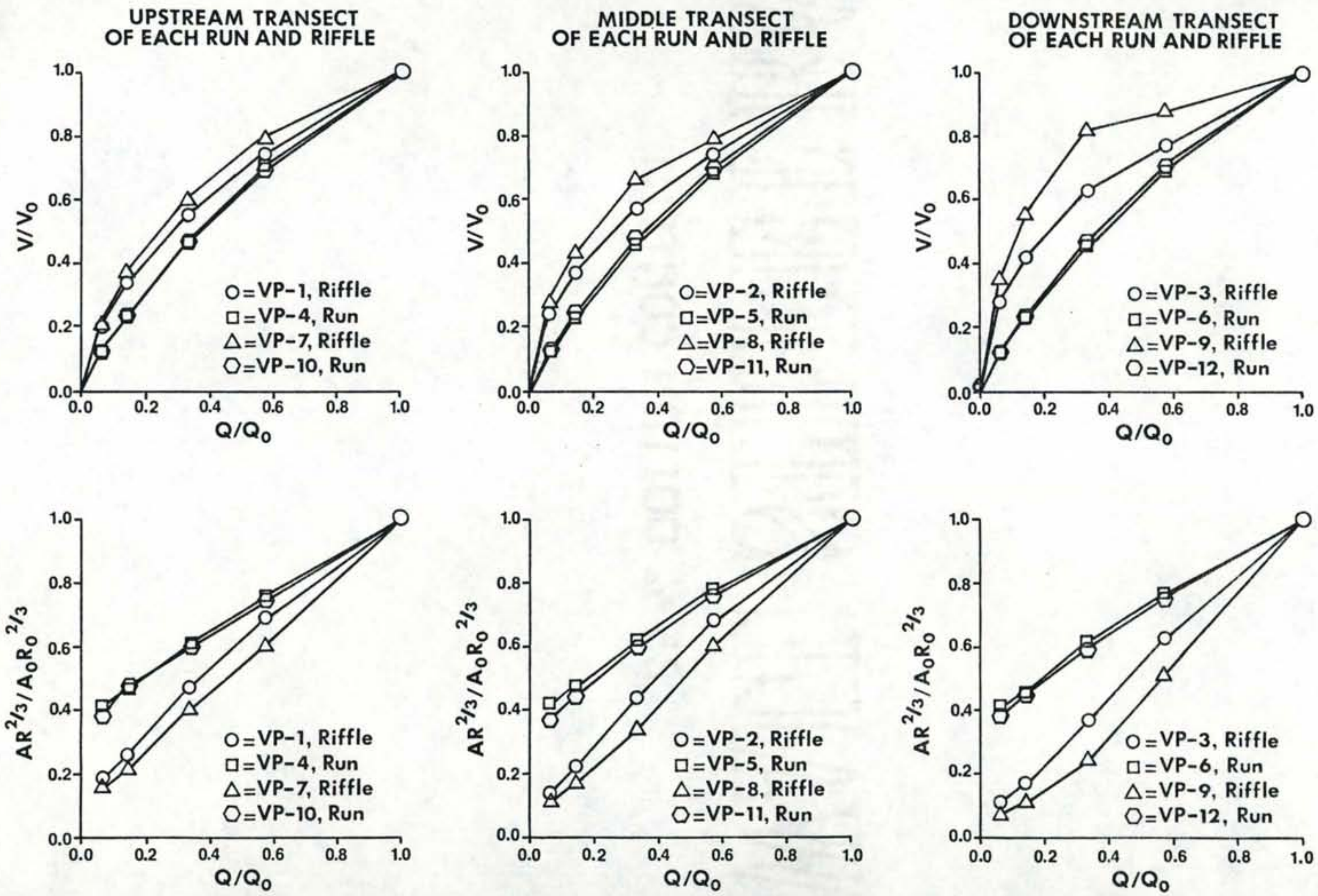


Figure 59. Velocity (V) and section factor ($AR^{2/3}$) versus discharge (Q) for non-transitional stream reach, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

very little, while other parameters show increased rates of change.

Hydraulic Simulation Models

IFG-1 Model

Predicted values for cross sectional area, wetted perimeter, hydraulic radius, hydraulic depth, maximum depth, and width of the water surface agreed with the measured and calculated values within ± 1.0% for all five flows evaluated. Since stage is the model input, the predicted geometric elements will be as accurate as the data used to define the geometric shape of the channel. This leads to the more important question of how well the model predicts the discharge and average cross sectional velocity associated with a given stage. It should be recognized that the percent error in predicted discharge will result in the same percent error in the predicted average cross sectional velocity. This is a result of the direct variation of discharge and velocity with constant cross sectional area (based on the continuity equation). Therefore, in the evaluation of this model, generally, only discharge was examined. Results were interpreted as the variation (in percent) of both discharge and velocity.

Stage discharge equation: Velocity has been reported to be the most important hydraulic parameter (assuming adequate temperature) to aquatic organisms (Hynes 1970; Giger 1973; Hooper 1973; Bovee 1975). The purpose of using the stage-discharge curve is to extend the discharge - area continuity relation beyond the measured values so velocity of unmeasured flows can be determined.

If the stage of zero flow is unknown, or any value other than zero is used in the logarithmic equation (log Q = b log (St - StZF) + log a), no advantage is obtained over that of ordinary plotting (Wisler and Brater 1959). The three methods used to determine the stage of zero flow (field determination, from a plot of the stream thalweg, and the Running method) were used to calibrate the stage-discharge equation or, more specifically, define the intercept of the stage-discharge curves. The correlation resulting from the use of different stage of zero flow values is expressed as the mean percent deviation of the measured flows from the curve defined by linear regression; in other words, the mean percent error for predicted versus measured discharge (Table 24).

Calibration of the equation with stage of zero flow from the Running method resulted in the least amount of error, with mean percent error ranging from 4.3 to 0.7 percent for five predicted discharges per transect. When calibrated with values estimated from the thalweg profile, the results were nearly as good as the Running method, with mean percent error ranging from 12.0 to 0.7 percent. The stage of zero flow as determined in the field gave the poorest results, ranging from 21.7 to 4.3 percent mean error. Although the mean percent error may not seem excessive in the calibration using the field determined stage of zero flow, it should be noted that absolute percent error for a predicted discharge versus the measured will generally increase as it gets further from the mid-range of calibration discharges.

The stage-discharge equation appears to be an extremely accurate method of relating discharge to stage that will result in acceptable average cross sectional velocity predictions. It would be expected that for most uses of this method, the number of transects would not be large,

Table 24. Mean percent error and standard percent deviation of predicted discharges using three methods to determine the stage of zero flow used in the stage-discharge equation $Q = a(St=StZf)^b$, (IFG-1), west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. For each determination of stage of zero flow the equation was calibrated with the five test flows and associated water surface elevations. Predictions of five discharges were made using the calibration water surface elevations with mean percent error computed from absolute percent errors.

Transect	StZF*-field determination VP-1 to VP-12T = 2.30 ft		StZF - determined from profile view of the thalweg VP-1 to VP-9 = 2.67 ft VP-9T to VP-12T = 2.46 ft		StZF - determination by the Running method VP-1 to VP-3 = 2.67 ft VP-3t to VP-9 = 2.78 ft VP-9T to VP-12T = 2.46 ft	
	Mean error (%)	Std. dev. (%)	Mean error (%)	Std. dev. (%)	Mean error (%)	Std. dev. (%)
VP-1	6.5	4.92	2.3	0.95	2.3	0.95
VP-2	5.8	3.14	2.4	1.45	2.4	1.45
VP-3	9.2	5.51	3.3	1.75	3.3	1.75
VP-3T	13.8	6.96	6.4	4.03	2.7	1.24
VP-4	12.5	6.96	5.5	4.05	3.8	1.52
VP-5	11.3	6.78	4.7	4.31	4.3	2.47
VP-6	12.4	5.94	4.8	3.92	3.1	1.95
VP-6T	12.4	6.46	5.3	2.82	2.3	1.39
VP-7	16.0	7.06	8.6	5.13	3.5	3.59
VP-8	15.8	9.66	8.9	4.42	3.2	1.43
VP-9	21.7	13.14	12.0	8.29	2.5	2.42
VP-9T	7.2	2.38	1.8	1.21	1.8	1.21
VP-10	4.3	1.97	0.7	0.59	0.7	0.59
VP-11	5.4	3.14	1.0	0.90	1.0	0.90
VP-12	5.8	2.12	1.3	0.75	1.3	0.75
VP-12T	7.0	3.48	2.9	1.60	2.9	1.60

* Stage of zero flow= feet above 0.0 datum.

and the Running method or trial and error method of determining stage of zero flow would be recommended if at least three flows were measured. If time or resources allow measurement of only two flows, extreme care should be used in locating the hydraulic control that determines stage of zero flow for each transect. When used with caution, calibration with two flows yields reliable results, but the range of extrapolation will necessarily be reduced.

<u>Manning's equation:</u> Discharge predictions, using Manning's equation, that were less than 0.4 or more than 2.5 times the calibration flows were extremely unreliable. Even when predicted flows were within the above range, they were much less accurate than the predictions using the stage-discharge relationship.

Grouping the transects as to riffle and run and computing absolute percent error for each prediction indicates that the Manning's equation method is more accurate for riffles than runs (Table 25). Of 48 discharge predictions for the six riffle transects, 59% were within 20% of the measured flow, with 17% being within 10%. The 48 discharge predictions from the six run transects had no predictions within 20% of the measured flows and only 27% within 30%.

We found that discharge predictions were most accurate in riffles when specific riffle and run transect groups were analyzed (Table 26). Percent error of predictions of flows larger than the calibration flow were more accurate than predictions of smaller flows. However, when absolute deviation in predicted discharge is considered, predictions less than the calibration flow were usually closer to known flows than were higher predictions.

Table 25. Number and percentage of occurrence of predicted discharges using the Manning equation within specified intervals of absolute percent error based on measured discharges (IFG-1), west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

Error in percent	Number of predicted discharges in error bracket	Percent of predicted discharges in error bracket
	RIFFLE	
0-10	8	17
10-20	20	42
20-30	11	23
30-40	6	12
40-50	2	4
50-60	0	0
60-70	1	2
	RUN	
0-20	0	0
20-30	13	27
30-40	11	23
40-50	12	25
50-70	0	0
70-80	4	8
80-90	7	15
90-100	0	0
100+	1	2

Table 26. Predicted discharges using the Manning equation with predictions limited to 0.4 to 2.5 times the calibration discharge (IFG-1), west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon.

	Calibration flow (cfs)							
	19.65	11.15		6.45		2.67		1.26
	Flow for which discharge is being predicted							
Transect	11.15	19.65	6.45	11.15	2.67	6.45	1.26	2.67
Riffle								
VP-1	13.57	16.15	7.56	9.52	3.65	4.72	1.88	1.79
VP-2	13.31	16.46	7.28	9.88	3.27	5.27	1.72	1.96
VP-3	12.41	17.66	6.60	10.90	3.02	5.70	1.64	2.05
Mean error	17.5%	14.7%	10.8%	9.4%	24.1%	18.9%	38.6%	27.6%
Run								
VP-4	15.14	14.47	8.88	8.10	4.84	3.56	2.40	1.40
VP-5	15.41	14.22	8.94	8.05	4.84	3.51	2.33	1.42
VP-6	15.12	14.49	8.93	8.05	4.83	3.56	2.37	1.42
Mean error	36.5%	26.8%	38.2%	27.7%	81.2%	45.1%	87.8%	47.1%
Riffle								
VP-7	11.84	18.51	7.41	9.71	3.44	5.00	2.06	1.64
VP-8	12.00	18.26	6.40	11.23	3.28	5.24	1.88	1.79
VP-9	9.98	21.95	5.18	13.88	3.08	5.60	1.68	2.00
Mean error	8.1%	8.2%	11.8%	12.7%	22.4%	18.1%	48.7%	32.2%
Run								
VP-10	14.86	14.74	8.99	8.00	4.95	3.48	2.21	1.53
VP-11	14.95	14.66	8.77	8.20	4.77	3.61	2.24	1.50
VP-12	14.65	14.96	8.96	8.02	4.86	3.55	2.21	1.52
Mean error	32.9%	24.8%	38.1%	27.6%	82.0%	45.0%	76.2%	43.2%

The error associated with flow predictions using Manning's equation is partially the result of holding Manning's n constant and can be understood by observing the computed n values versus discharge (Figure 60) and slope of the energy line versus discharge (Figure 61). For the downstream riffle (VP-7, 8 and 9), the roughness coefficient versus discharge curve is relatively flat, with little change from one discharge to the next, while substantial changes occur in the runs; hence, the better predictions in the riffles. A further problem using this approach is due to the assumption of a constant energy slope.

There might be some advantage to making a provision in the model for adjusting roughness coefficients from the calibration case. To use such a provision would require some expertise in knowing how much adjustment was needed for a given cross section. There are also several equations available for calculating the roughness coefficient. One presented by Chow (1959, p 207) was given minimal use in this study and seemed to yield fairly accurate values (as compared to calculated values). The form of this equation is as follows:

$$n = \frac{(x-1)y^{1/6}}{6.78(x+0.95)}$$

where,

n = Manning's roughness coefficient

x = average point velocity

y = mean depth

Several other methods of estimating the roughness coefficient are available with varying accuracy (Chow 1959; Bovee and Milhous 1978; Bray 1979).

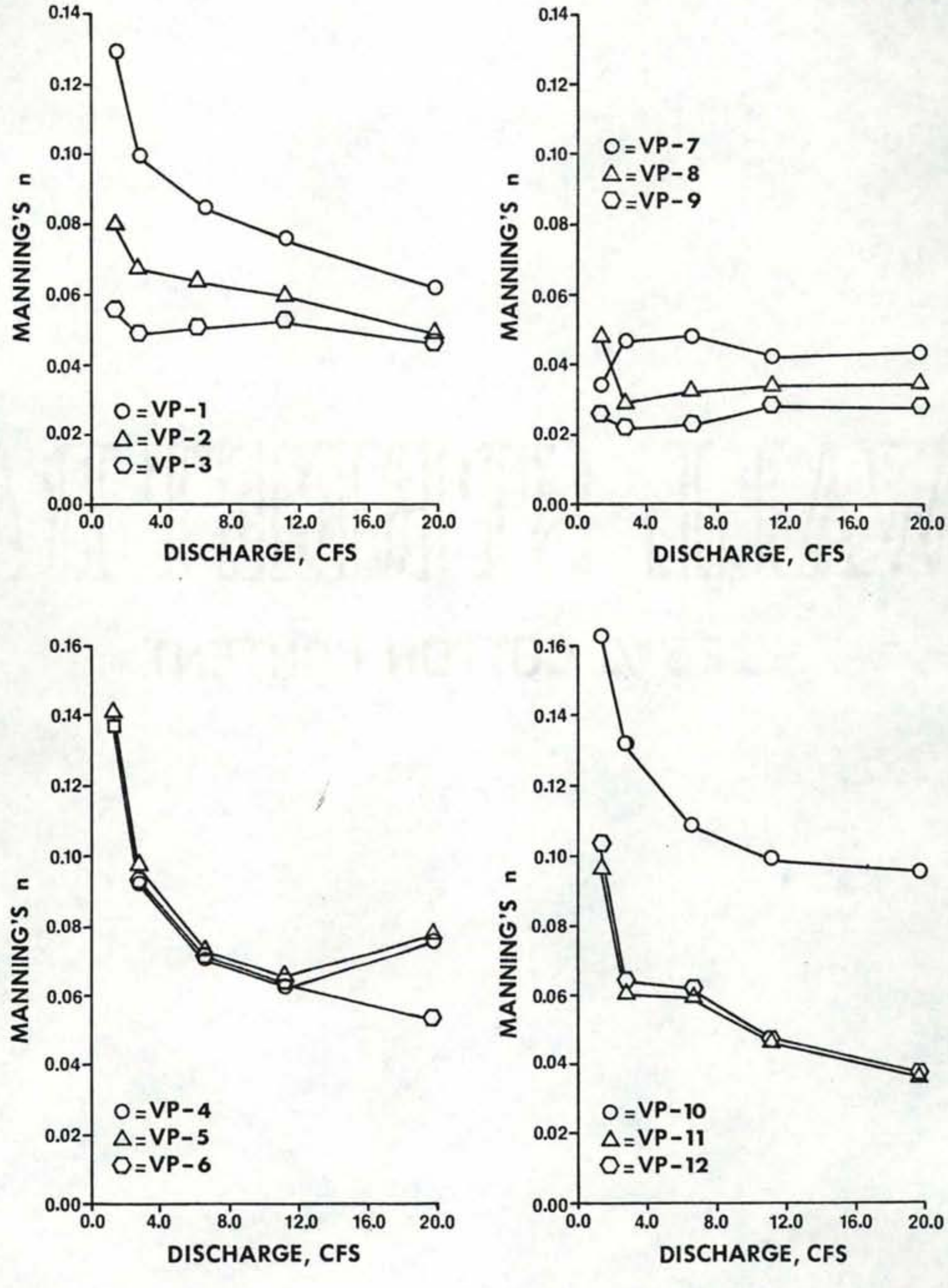


Figure 60. Relationship between Manning's roughness coefficient (n) and discharge (Q) in riffle and run reaches, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

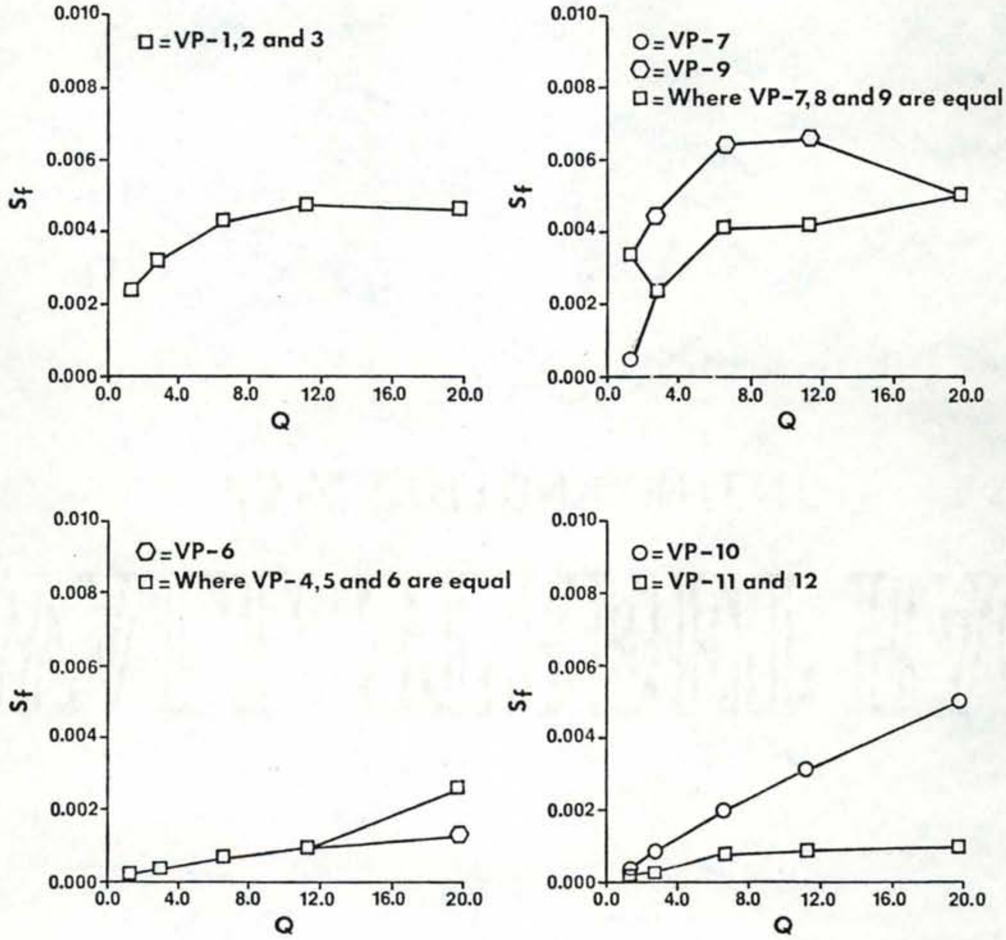


Figure 61. Relationship between the energy slope (S_f) and discharge (Q) in riffle and run reaches, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

Usability of IFG-1: The stage-discharge method allows excellent discharge predictions for a given stage if proper care is given to calibrating the equation, especially in regard to determination of stage of zero flow. With accurate discharge predictions, velocity is also accurately predicted. As previously stated, geometric elements are accurately predicted for a given stage. Using a properly calibrated stage-discharge equation, the model accurately predicts average cross sectional parameters over a relatively large range of flows. The Manning equation option provides adequate discharge (and velocity) predictions in riffle areas, over a limited range. Predictions in runs may be of questionable accuracy.

The question arises at this point as to what is an adequate prediction of discharge and velocity. In an attempt to clarify this question, predicted versus measured velocities are presented for four transects, one at the downstream end of each riffle and run, using both the stage-discharge equation and the Manning equation (Figures 62 and 63). The stage discharge relationship predicted velocities within 10% of measured velocities over the range of flows investigated (Figure 62). Errors outside this range (10%) would probably not be acceptable. Predicted velocities based on the Manning equation are not acceptable at the 10% level of error. The final assessment as to what is an adequate discharge or velocity prediction depends upon how well defined the biological (or other) criteria are that will be interfaced with the hydraulic predictions.

The IFG-1 model may be used in several ways. If a stream is gauged and no substantial inflow occurs between the gauging station and the transects being evaluated, the water surface elevation is all that need be taken at the particular transects of interest to get adequate data for

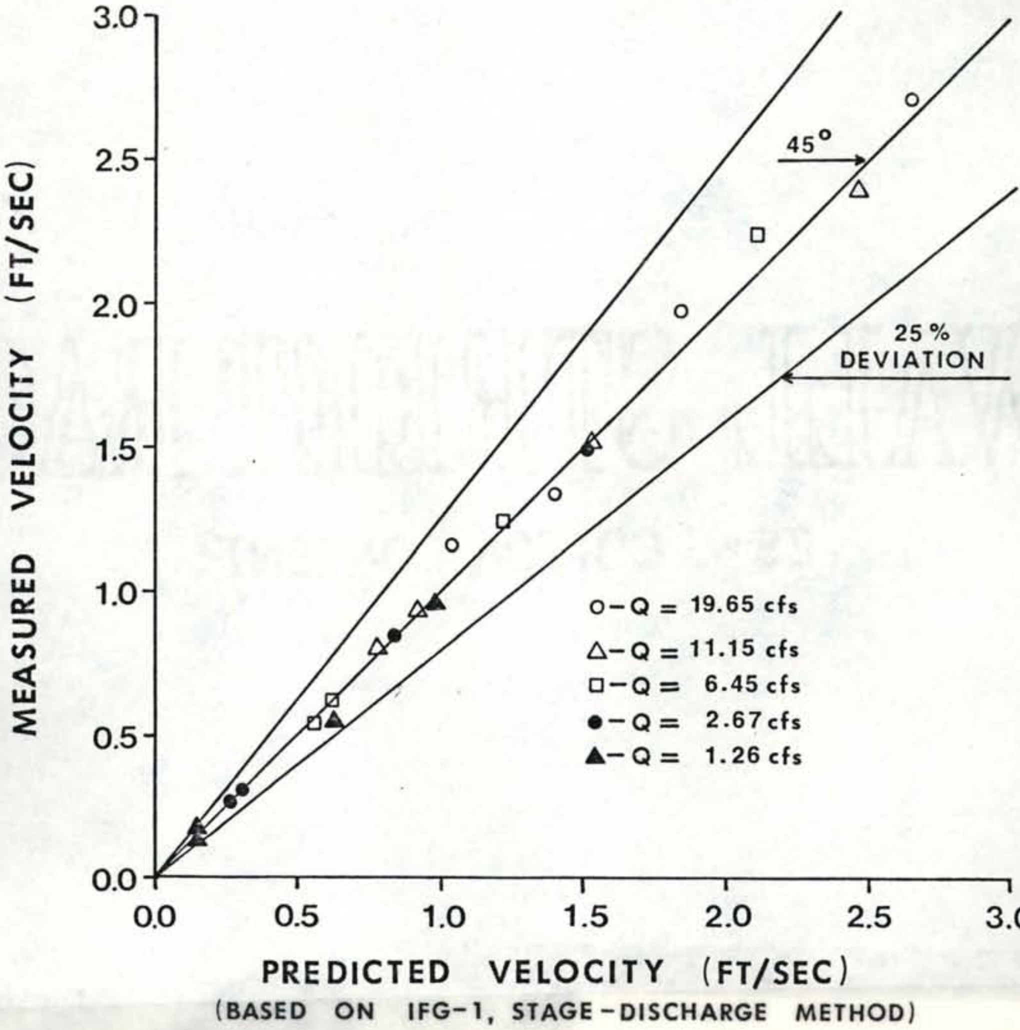


Figure 62. Comparison of predicted with measured average cross sectional velocities using the IFG-1 model, stage-discharge option; calibrated with stage-discharge pairs at 11.15, 6.45, and 2.67 ft^3/s, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

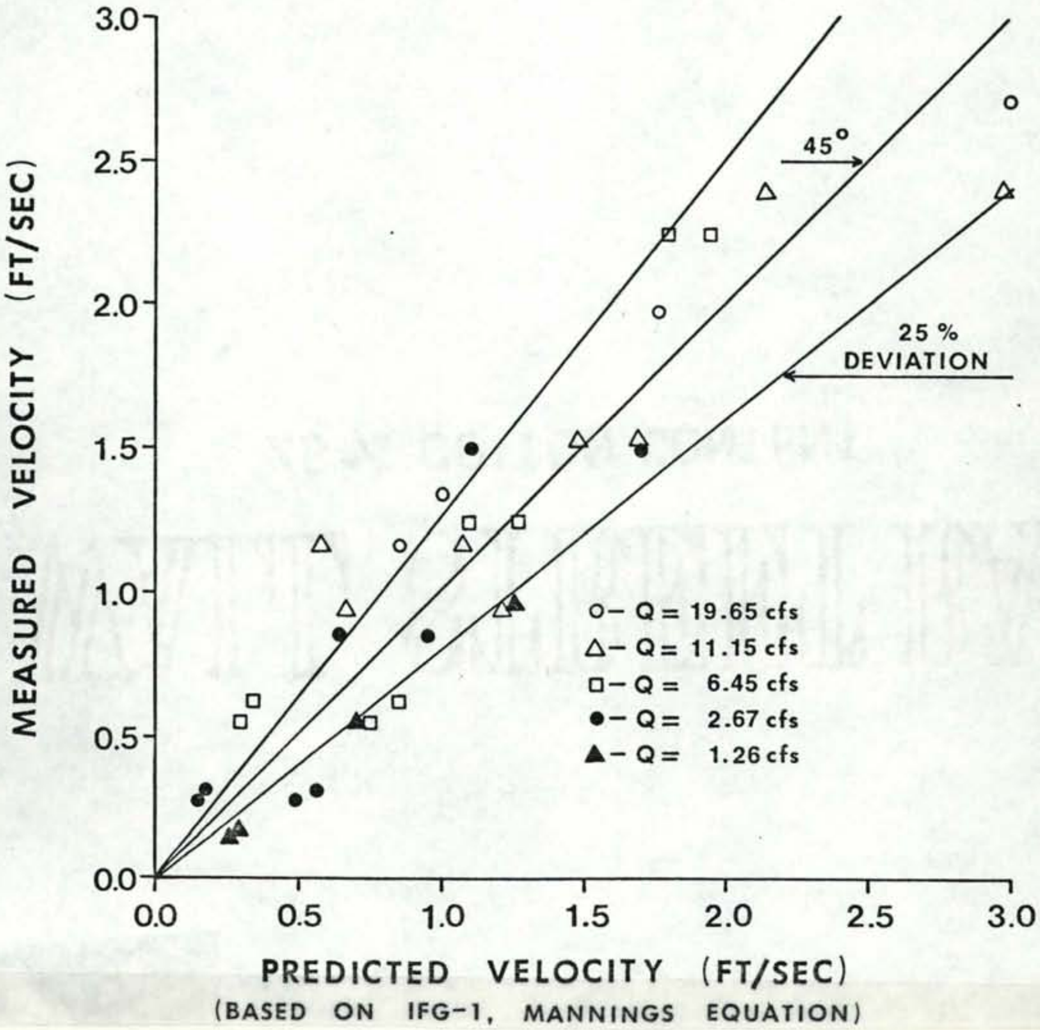


Figure 63. Comparison of predicted with measured average cross section velocities using the IFG-1 model, Manning's equation option, calibrations based upon Table 21 criteria, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

using the stage-discharge option. This assumes that cross sectional bed elevations and an accurate stage of zero flow have been determined. With one set of flow measurements per transect, Manning's equation can be used to select those transects that require more exact and detailed hydraulic information.

This model using the stage-discharge relationship should give excellent results when calibrated properly. On larger rivers or streams with uniform substrate, the Manning equation can be used effectively on riffles and, to a lesser extent, on runs where roughness coefficients are expected to have a relatively constant value. Results must be treated with the realization that they are approximate.

WSP Model

Predicted values for conveyance areas (cross sectional areas), top widths and hydraulic radii agreed with measured and calculated values within the accuracy of predicted water surface elevations. Using this model, discharge is provided as model input and water surface elevations predicted. Therefore, the predicted geometric elements will be as accurate for a given discharge as the predicted water surface elevations.

Percent error associated with predicted geometric parameters in relation to error in predicted water surface elevation is dependent upon the shape of the cross section. In a rectangular shaped cross section, percent error associated with predicted cross sectional area is the same as percent error in predicted depth as determined from the predicted water surface elevation. The error associated with the predicted water surface elevation translated into area is the same error that will occur for predicted velocities. This leads to the important question of how well the model predicts water surface elevations, given the discharge through the stream reach being simulated.

Water surface elevations: In general, predictions of water surface elevations at flows lower than the calibration flow were more accurate than those for higher flows (Figure 64, A-F). This implies that the model should be calibrated at flows higher than those for which hydraulic predictions are required. Overall, predictions using modified n values were more accurate than using constant n values. With a properly calibrated model, a wide range of flows can be simulated, especially in the decreasing direction.

The water surface elevations associated with 1.26 cfs are presented only at the simulation run where it was used as the calibration flow. This flow was simulated at other calibration flows, but the predicted water surface elevation at VP-9 jumped from 0.2 to 0.5 ft above the measured value, resulting in all water surface elevations upstream having a similar error. This leads to very unrealistic predictions of all other parameters at this flow. Hence, this flow was excluded from further evaluation.

A great deal of effort was required to properly calibrate this model, especially at the early stages of familiarization. To calibrate the model using a single n value per transect of $\pm$ 0.03 ft required about 15 simulation runs. As familiarity with the model increased, this was reduced to 5 or 6 simulation runs. To properly calibrate the model with eight roughness coefficients (one for each segment) per transect required about 30 simulation runs. Undoubtedly, with experience, the number of simulation runs required to calibrate the model could be reduced.

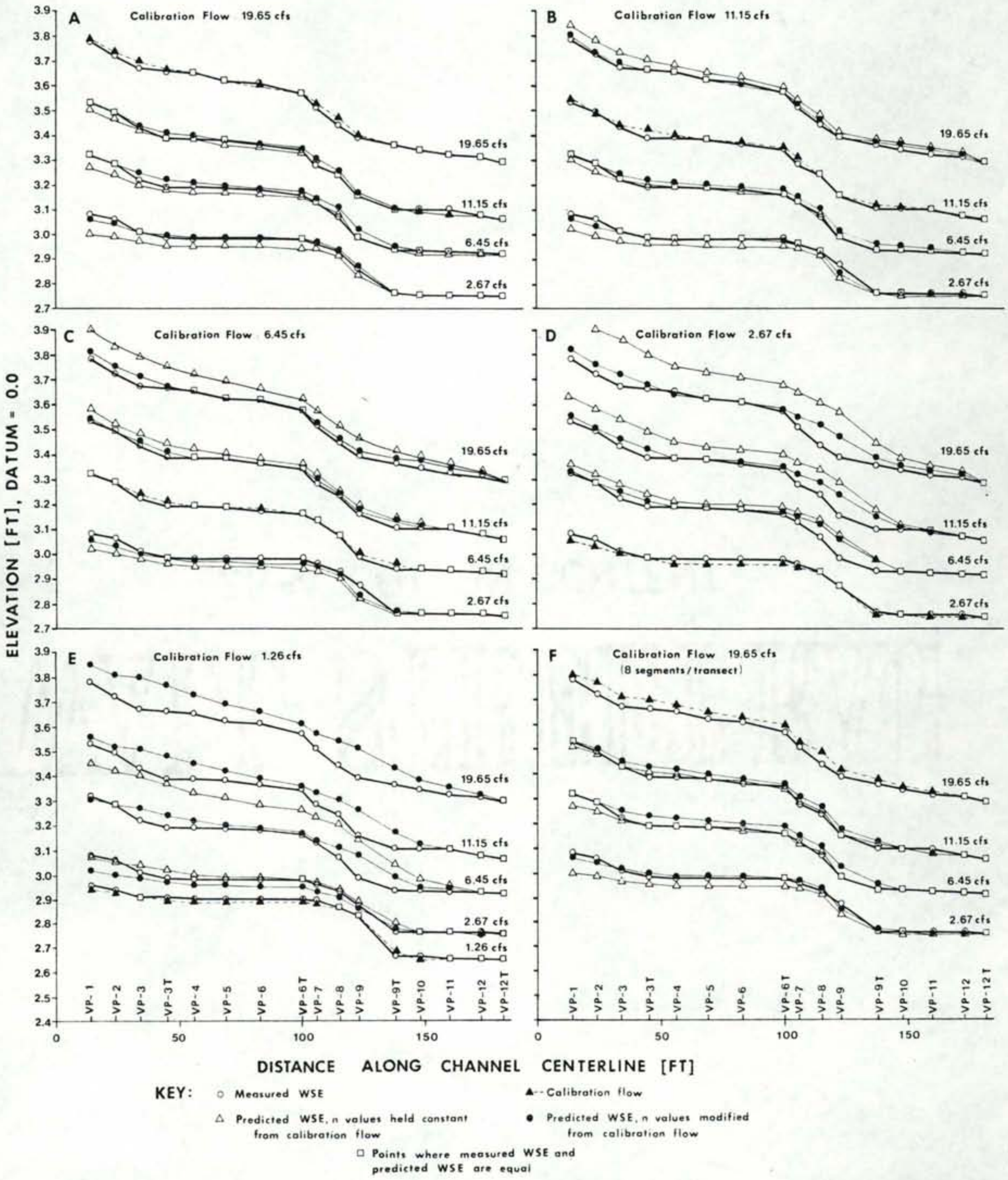


Figure 64. Comparison of measured and predicted water surface elevations using the WSP hydraulic simulation model calibrated at 19.65 ft^3/s (A), 11.15 ft^3/s (B), 6.45 ft^3/s (C), 2.67 ft^3/s (D), 1.26 ft^3/s (E), and 19.65 ft^3/s with transects divided into 8 segments (F), west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

The calibration process must proceed in an upstream direction. Modifying a roughness coefficient resulted in the greatest change in predictions at the next upstream transect with decreasing degree of change further upstream. At the transect where the roughness coefficient was modified, little or no change occurred at downstream transects.

Velocity: The general trend of predicted velocities at the calibration case of 1.26 cfs was to be lower than the measured average cross section velocities (Figure 65). Deviation of predicted values increased as the discharge increased. When the model was calibrated at 19.65 cfs, the predicted velocities agreed favorably with measured velocities at the higher discharges (Figure 65). At 2.67 cfs, the predictions were generally lower than measured.

Relatively high mean percent error was associated with a calibration flow of 1.26 cfs, but the standard deviation was quite low, indicating relatively good agreement between predicted velocity and measured velocity at the calibration flow (Table 27). In fact, only four of the predicted velocities deviated more than 0.1 ft/sec from the measured values, and eight deviated less than 0.05 ft/sec.

Accuracy of water surface elevation and velocity predictions follow the same trend. The largest errors in predicted velocities occurred at transects in the downstream riffle where the greatest errors in predicted water surface elevation occurred.

With proper calibration, the WSP model predicted acceptable average cross sectional velocities over a wide range of flows. Predictions were generally more accurate when the roughness coefficient was modified from the calibration flow. Good accuracy was also obtained when n was held constant and predictions were made for flows lower than the calibration

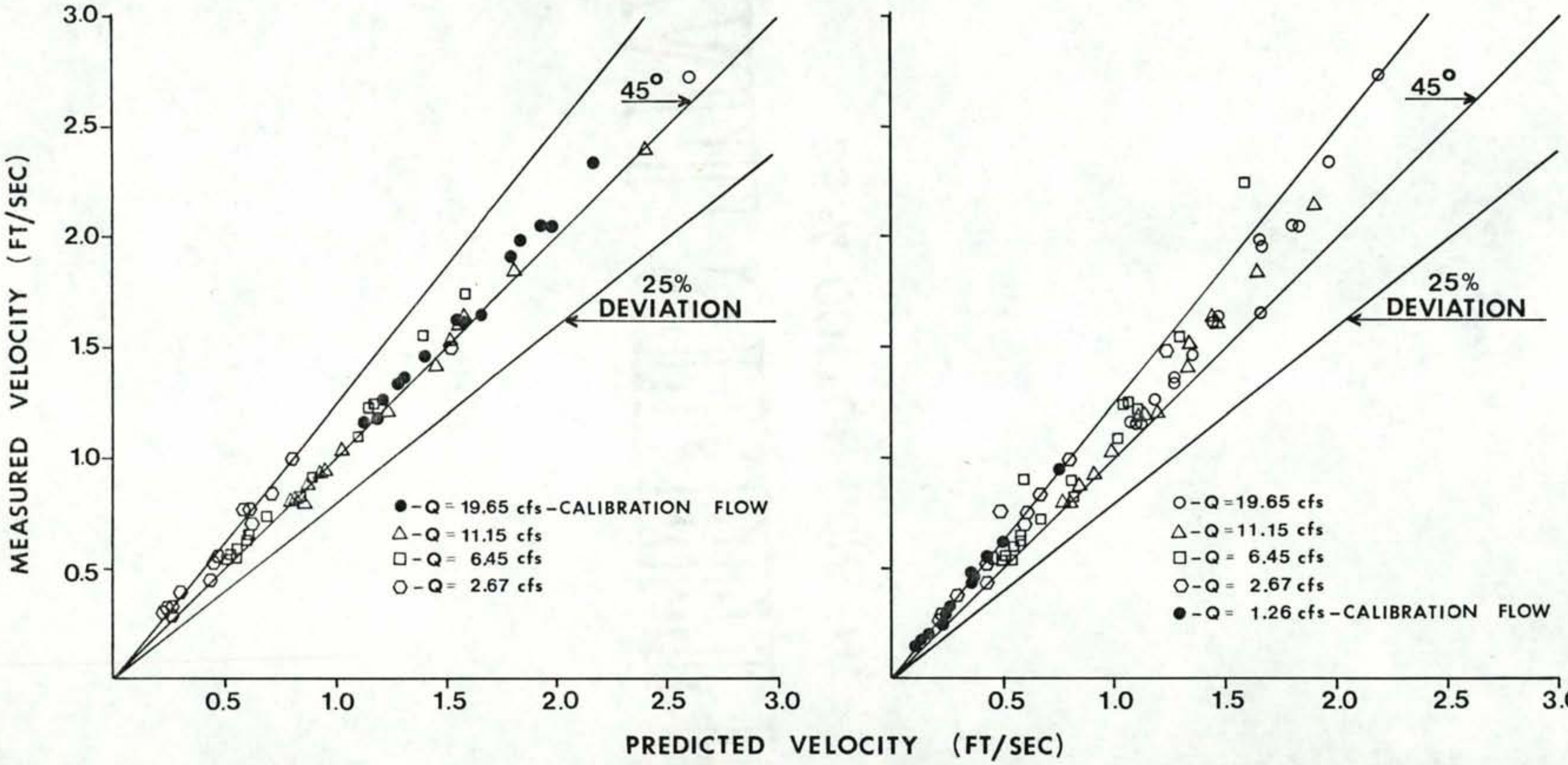


Figure 65. Comparison of predicted and measured average cross section velocities using the WSP model calibrated at 19.65 ft^3/s and 1.26 ft^3/s, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

Table 27. Mean percent error, variance and standard deviation of predicted average cross sectional velocities at specified flows for fifteen VP-transects (excludes VP-12T) in the west channel, Troy Experimental Flow Facility, Grande Ronde River, Wallowa County, Oregon, fall 1978, using the Water Surface Profile Model (WSP).

	Error statistics of velocity predictions at indicated flow (cfs)				
	19.65	11.15	6.45	2.67	1.26
Calibration flow: 1.26 cfs					
Mean error (%)	9.6	6.9	10.5	20.3	18.4
Variance (S^2)	20.9	25.3	41.7	16.0	14.2
Standard dev. (S)	4.6	5.0	6.5	4.0	3.8
Calibration flow: 19.65 cfs					
Mean error (%)	3.9	1.7	4.7	18.1	--
Variance (S^2)	2.7	3.6	7.4	38.1	--
Standard dev. (S)	1.6	1.9	2.7	6.2	--

discharge. Predicting flows higher than the calibration discharge and holding n constant resulted in error almost double that associated with using a modified roughness coefficient.

The predicted average segment velocities were compared with measured segment velocities at a riffle and a run transect (Figure 66). The calibration flow was 19.65 cfs, and the roughness coefficients were modified. The magnitude in absolute percent error of measured versus predicted velocities and frequency of error were computed for the eight segments at each transect and each simulated flow and grouped as to riffle and run transects (Figure 67). The trend was for increasing error in percent as discharge of simulated flows decreased. All VP transects had similar predicted velocity versus measured velocity distributions to those presented in Figure 66.

The average segment velocity predictions using the WSP model are considered to be reliable, considering the number of variables involved in calibration that can lead to erroneous predictions. The model provided satisfactory predictions over a wide range of flows lower than the calibration flow. Predicted segment velocities were more accurate in riffles than in runs, a result of relatively small, constant roughness coefficients through the range of flows that were tested.

Usability of the WSP Model: Certain features in the WSP model made evaluation difficult. One problem involves the rounding within the model of many predicted and calculated parameters to whole numbers. While this is probably not a problem in larger streams and rivers, analysis of small streams and low flows becomes difficult, especially when the transect is divided into several segments. When discharge becomes less than 0.5 cfs in a segment, the program output indicates zero discharge through the

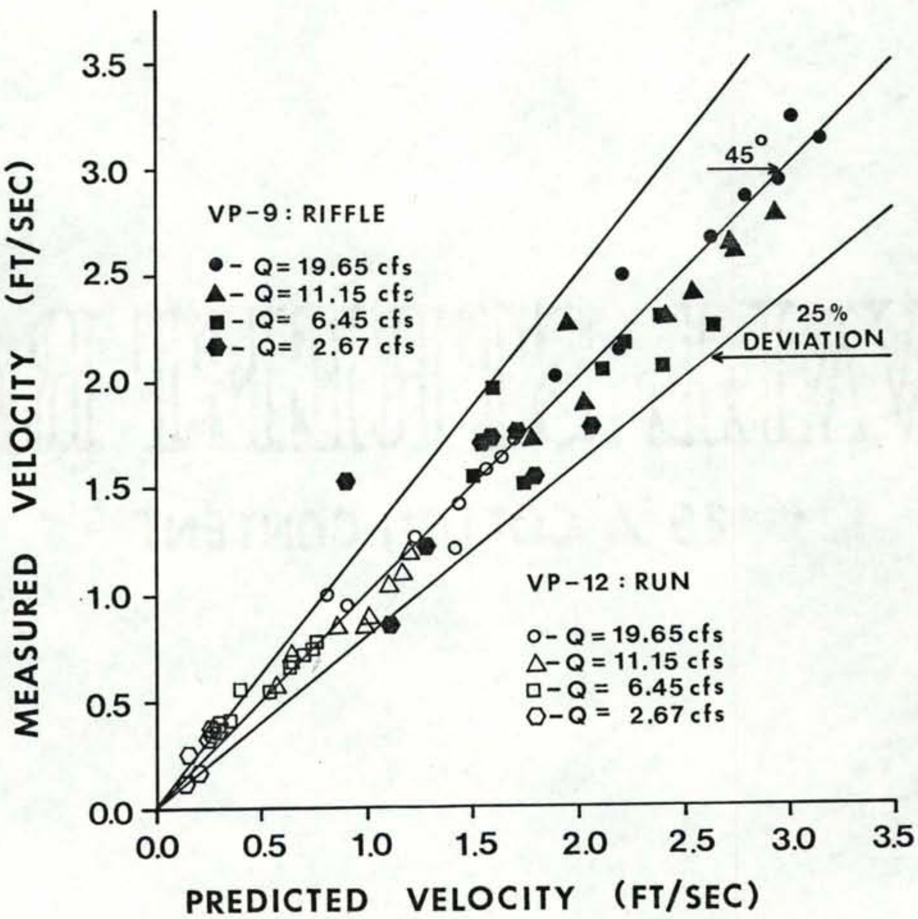


Figure 66. Comparison of predicted average segment velocities with measured velocities for a run transect (VP-12) and a riffle transect (VP-9) using the WSP hydraulic simulation model calibrated at 19.65 ft^3/s with eight segments per transect, west channel, Troy Instream Flow Research Facilities, Grand Ronde River, Wallowa County, Oregon, fall 1978.

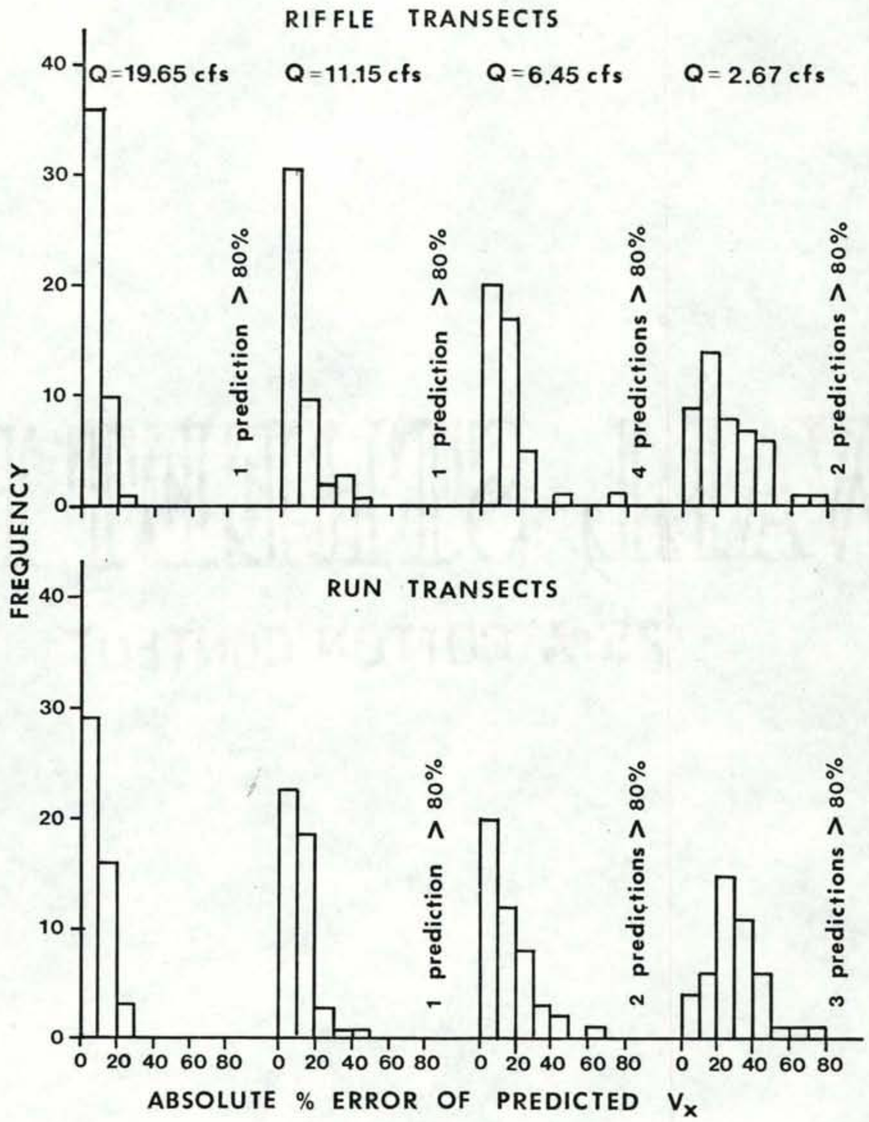


Figure 67. Magnitude in absolute percent error of measured versus predicted average segment velocities and frequency of error at 12 velocity profile transects with 8 segments per transect using the WSP hydraulic simulation model, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

segment. Similarly, program output for the conveyance area of a segment is zero when the computed area becomes less than 0.5 ft^2. Even though segment velocities are given when other factors are zeroed, interpretation becomes difficult, and when this occurs during calibration, adjustment of n values becomes difficult to estimate. Use of this model on small streams and for low flow analysis could be enhanced by changing output to tenths for those parameters that are output as whole numbers.

Another limitation of this version of the model is the number of segments (nine) which the cross section may be divided into. In our experimental channel, nine segments more than adequately define the hydraulic components of a given transect, but several situations can be imagined where more subdivisions would be advantageous. For instance, below an island or bar in a stream, an investigator may wish to study hydraulic conditions near the stream banks in relation to fry habitat or nursery areas which require several segments near both stream banks. He may further wish to investigate adult or juvenile habitat or food production just below the island or on a bar which could require several more segments.

A provision in the model for modifying roughness coefficients at each individual transect, rather than having to modify in the all or none mode, would further enhance the use of the model. The problem encountered at VP-9T when simulating the flow of 1.26 cfs (as previously discussed) would have been readily solved if the roughness coefficient at that transect could have been modified to a different degree than the others.

One other difficulty in using this model occurs in the selection of discharge - water surface elevation pairs at the most downstream transect for alternate flow simulations. The model will accept estimates of the energy slope at a specified discharge (or held constant from some measured or calculated value over a range of discharges) and simulate the conditions accordingly. This method was not evaluated in this study, and accuracy is unknown. It would be suspected that substantial error might occur using this method due to the reported unpredictable variability in the energy slope from one flow to the next (Bovee and Milhous 1978). An estimate of the elevation of the water surface for a given discharge may also be made using the various uniform flow and gradually varied flow equations with the realization that it is approximate. The most accurate method would be to develop a stage-discharge relationship through field measurements at the most downstream transect (hydraulic control). On a gaged stream, this would be relatively easy since alternate water surface elevations - discharge data needed to develop the curve would require water surface elevation measurements only.

Using the WSP model provides the capability of simulating an entire reach of stream, bringing to focus the interrelated hydraulic parameters of several habitat types. This allows evaluation of the changing hydraulic conditions as one moves downstream (or upstream) as well as through a range of flows, since changing conditions at one transect are reflected in the adjacent transects, as well as those further along.

This model provides the advantage of simulating a relatively wide range of flows with only one set of flow measurements. This range can be extended by measuring parameters at more than one flow level.

The WSP model requires considerable effort to properly calibrate and should be calibrated to reflect accuracy of the field measurements. For example, accepting water surface elevation predictions within ± 0.10 ft of measured values when field measurements are believed to have an accuracy of $\pm$ 0.05 ft is allowing unnecessary introduction of error into hydraulic predictions.

IFG-4 Model

The IFG-4 model is used primarily to predict segment depths and velocities for designated discharges and to interface these, along with substrate values, with the IFG-3 habitat model (Main 1978b). Evaluation of this model will be directed primarily to depth and average segment velocity predictions.

To investigate the accuracy and potential for error in the equation $v_x = a_x Q^{b_x}$, measured average segment velocity - discharge pairs were plotted logarithmically (log v on log Q) for various segments at transects VP-9 (riffle) and VP-12 (run) (Figure 68). Curves are the result of linear regression of log v_x on log Q. Segments are numbered from left to right, looking downstream. There are 13 segments in each transect at 19.65 cfs.

Deviation of values from a straight line relationship was larger near the stream banks than in the center of the channel (i.e., seg. 3 vs seg. 6 at VP-9 and seg. 3 vs seg. 8 in Figure 68). Also, less deviation was observed for the run transect segments than for the riffle transect segments.

Examination of how the regression line would change if various flow - velocity combinations were used to define it provides insight to the potential for erroneous predictions. For example, using the measured velocities at 19.65, 11.15, and 6.45 cfs to define the regression line for seg. 3, VP-9 (Figure 68), then predicting velocity at 2.67 and 1.26

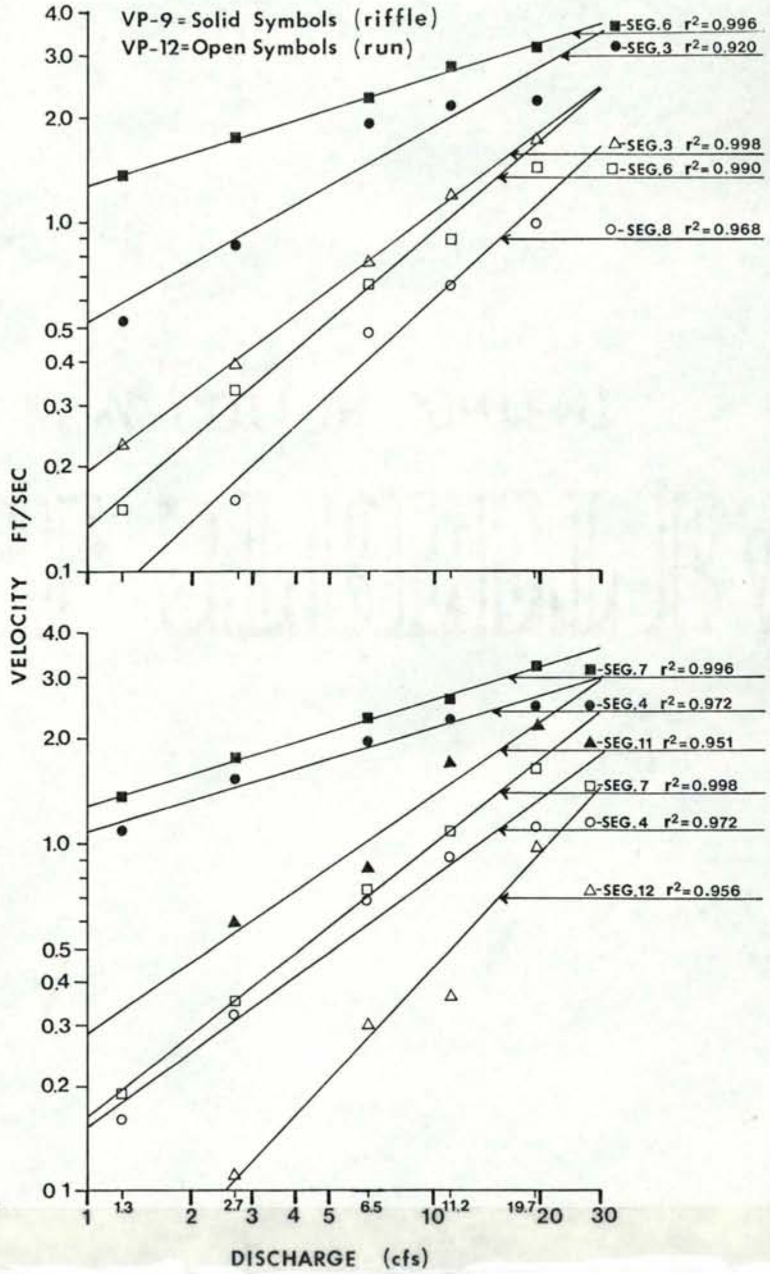


Figure 68. Log-log plot of measured average segment velocities versus total discharge through a cross section used to evaluate the equation $v_x = a\,Q^{b_x}$ in the IFG-4 hydraulic simulation model, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

cfs, produced substantial error in predictions (measured 0.86 ft/sec vs predicted 1.73 ft/sec at 2.67 cfs). The correlation coefficient (r) for this regression was 0.94 and probably would not draw much attention in analysis of the calibration details output by the model. Therefore, the calibration regression coefficients should not be overly relied upon to estimate how good the prediction result should be. This was the most extreme situation for the segments presented. However, there were several combinations where the same thing occurred with the magnitudes of error somewhat less. The measured velocity, predicted velocity (resulting from calibration flows of 11.15, 6.45, and 2.67 cfs) and absolute percent error at each segment of transect VP-9 and VP-12 at the five test flows are provided for further clarification (Table 28).

Errors in velocity predictions made by Manning's equation do not appear serious. In most cases, an examination of the model results will indicate segments where velocity predictions are inadequate and a better estimate of the roughness coefficient can be supplied.

Segments with only one velocity measurement provided in calibration resulted in calculated roughness coefficients that ranged from 0.026 to the extraordinary value of 196.98. Results of predicted velocities at these segments (using Manning's equation) were usually unsatisfactory, with predictions of 0.0 to 0.05 ft/sec when, in fact, they should have been much higher. For segments with no velocity measurements, a roughness coefficient of 0.06 was used (this default value within the program can be changed) with results that were variable but much better than when n was calcuated.

Predicted segment velocities for the calibration flows of 11.15, 6.45, and 2.67 cfs agreed, for the most part, with the measured

Table 28. Measured (V_m) and predicted (V_p) average velocities (predictions from the IFG-4 model calibrated at 11.15, 6.45, and 2.67 ft^3/s), and absolute percent error for five flows at a riffle (VP-9) and a run (VP-12) transect, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

	Discharge (cfs)														
	19.65			11.15			6.45			2.67			1.26		
Segment	Vm	Vp	% error	Vm	Vp	% error	Vm	Vp	% error	Vm	Vp	% error	Vm	Vp	% error
VP-9: Riffle															
1	0.85	0.31	64												
2	1.97	1.46	26	1.11	1.13	2	0.90	0.91	1	NM[a]	0.70	--			
3	2.21	3.97	80	2.15	2.49	16	1.91	1.62	15	0.86	0.89	3	0.52	0.68	31
4	2.49	2.95	18	2.26	2.35	4	1.96	1.93	2	1.53	1.54	1	1.08	1.61	49
5	2.93	3.60	23	2.63	2.70	3	2.06	2.10	2	1.55	1.53	1	1.21	1.47	21
6	3.12	3.71	19	2.77	2.85	3	2.25	2.27	1	1.73	1.72	1	1.35	1.71	27
7	3.23	3.41	6	2.60	2.71	4	2.29	2.22	3	1.76	1.78	1	1.36	1.85	36
8	2.85	3.05	7	2.40	2.49	4	2.17	2.10	3	1.73	1.75	1	1.24	1.90	53
9	2.66	2.84	7	2.29	2.35	3	2.04	2.02	1	1.71	1.72	1	1.03	1.90	84
10	2.48	2.79	13	2.15	2.23	4	1.87	1.84	2	1.47	1.48	1	0.44	1.56	255
11	2.17	2.75	27	1.70	1.64	4	0.85	1.03	21	0.59	0.53	10	NM	0.38	--
12	1.04	0.02	98	0.68	0.01	99									

Table 28. Continued.

	Discharge (cfs)														
	19.65			11.15			6.45			2.67			1.26		
Segment	Vm	Vp	% error	Vm	Vp	% error	Vm	Vp	% error	Vm	Vp	% error	Vm	Vp	% error
VP-12: Run															
1	0.12	0.21	75												
2	0.55	0.25	55	0.19	0.19	0	0.14	0.15	7	NM[a]	0.09	--	NM	0.06	--
3	0.98	1.27	30	0.66	0.75	14	0.48	0.44	8	0.16	0.18	13	0.06	0.08	33
4	1.11	1.39	25	0.91	0.97	7	0.69	0.67	3	0.32	0.35	9	0.16	0.19	19
5	1.22	1.24	2	0.85	0.90	6	0.65	0.64	2	0.32	0.35	9	0.16	0.20	25
6	1.43	1.29	10	0.89	0.93	4	0.66	0.66	0	0.33	0.36	9	0.15	0.21	40
7	1.64	1.65	1	1.09	1.12	3	0.74	0.76	3	0.35	0.38	9	0.19	0.20	5
8	1.72	1.75	2	1.19	1.20	1	0.77	0.81	5	0.39	0.41	5	0.23	0.22	4
9	1.58	1.50	5	1.03	1.06	3	0.72	0.74	3	0.37	0.39	5	0.20	0.22	10
10	1.27	1.78	40	0.85	0.96	13	0.54	0.51	6	0.16	0.18	13	0.12	0.07	42
11	1.13	1.77	57	0.74	0.87	18	0.48	0.43	10	0.11	0.13	18	0.02	0.05	150
12	0.97	0.65	33	0.36	0.42	17	0.30	0.27	10	0.11	0.13	18	0.06	0.06	0
13	0.38	0.04	89	0.03	0.02	33	0.05	0.05	0						

[a] NM = No measurement.

(calibration) velocities (Figure 69). Predicted velocities at 19.65 and 1.26 cfs followed the pattern observed in evaluation of the velocity - discharge equation; the closer the segment was to the bank, the greater the error of predicted velocity.

With the IFG-4 model calibrated at 11.15 and 2.67 cfs, the overall predicted average segment velocities were about the same as the previous case (Figure 70). The interpolated predictions at 6.45 cfs were accurate, as were predictions for the calibration flows. This indicates calibration with two flows, when done with care, will provide reliable results.

When magnitude in absolute percent error of measured versus predicted segment velocities and frequency of occurence were analyzed, velocity predictions were better in riffles than runs (Figure 71). This result confirms the decreased effect of bank roughness on the logarithmic relation of segment velocities and discharge in the shallower cross sections.

Most of the velocity predictions with an absolute percent error greater than 60 percent were predicted by Manning's equation (Figure 71). Even though the end segments of the cross section represent only a small fraction of the flow (in usual situations), it is apparent that they do not represent the true conditions. Thus, Manning's n values should be supplied by the model user when calculations result in roughness coefficients that are inadequate.

Negative velocities to 0.5 ft/sec were measured with a Marsh McBirney electronic current meter in eddies behind and near rocks. When these negative velocoties were used in calibration of the model, care had to be exercised if no positive values were included at an alternate

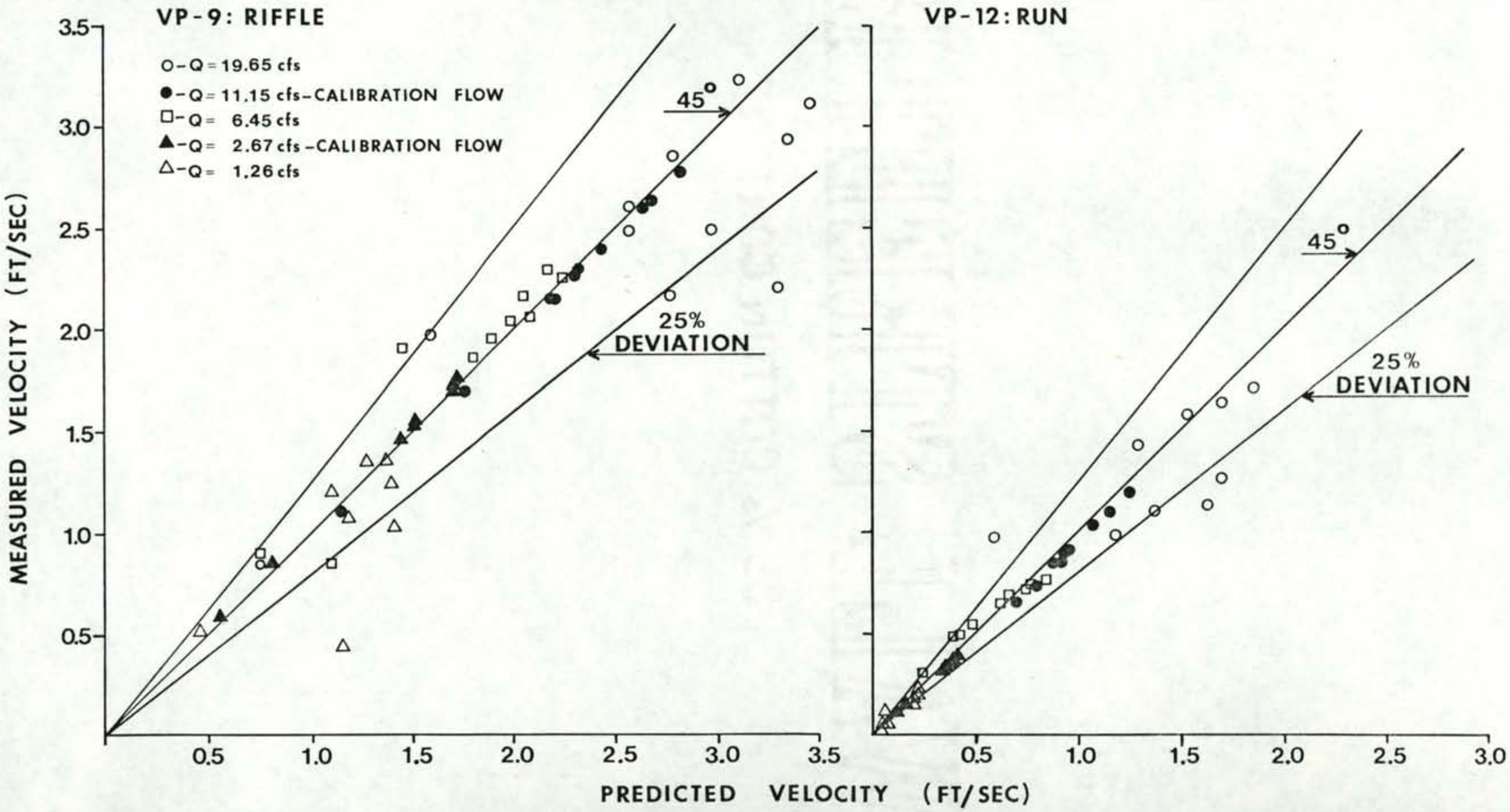


Figure 69. Comparison of predicted average segment velocities with measured velocities using IFG-4 model calibrated at 11.15, 6.45, and 2.67 ft^3/s for a riffle (VP-9) and a run (VP-12) transect, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

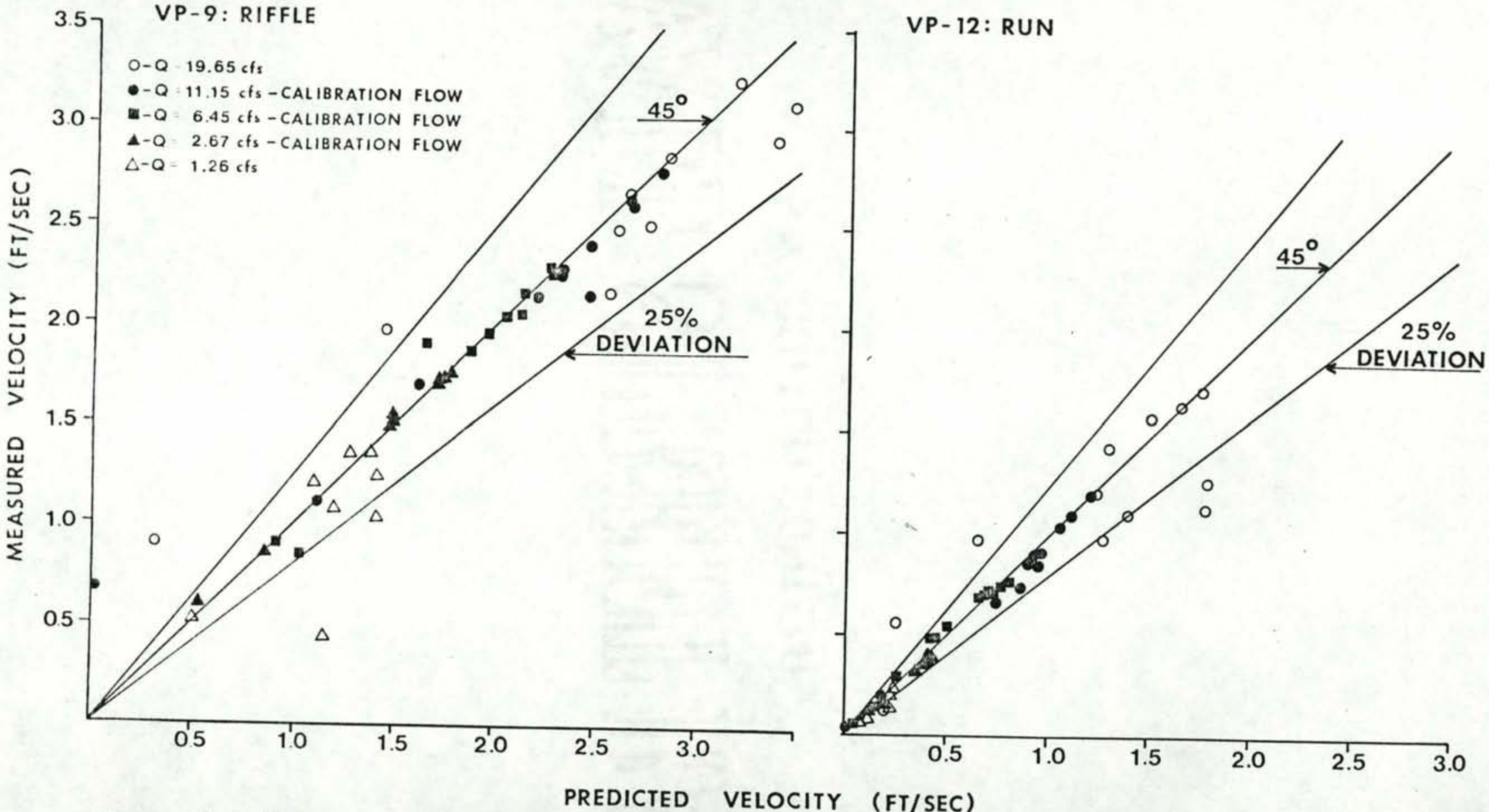


Figure 70. Comparison of predicted average segment velocities with measured velocities using IFG-4 model calibrated at 11.15 and 2.67 ft^3/s for a riffle (VP-9) and a run (VP-12) transect, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

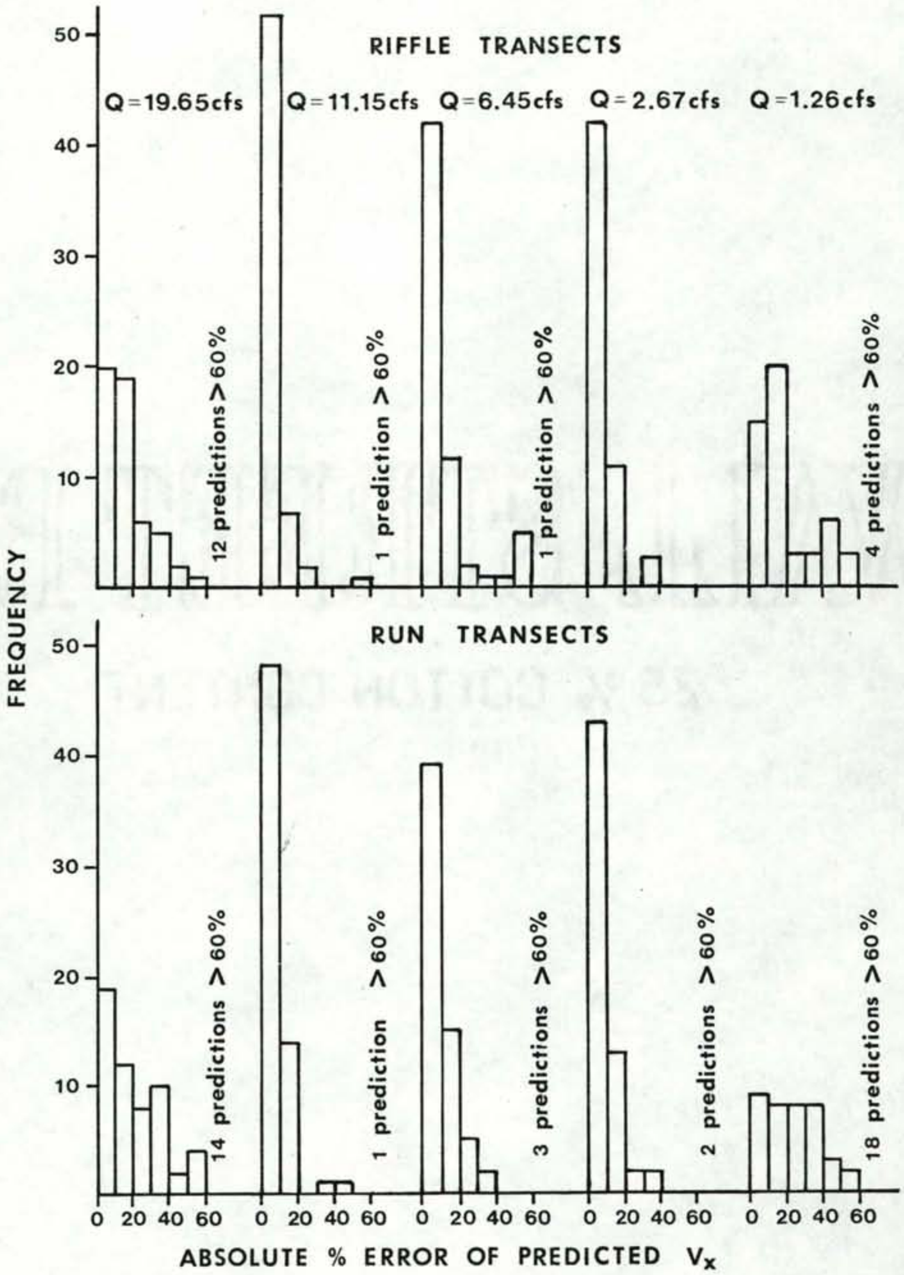


Figure 71. Magnitude in absolute percent error of measured versus predicted average segment velocities at 12 velocity profile transects using IFG-4 hydraulic simulation model calibrated at 11.15, 6.45, and 2.67 ft^3/s, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

calibration flow. If flows larger than the largest calibration flow were simulated, and in reality, the water velocity has become positive, the predicted velocity will remain negative. This results from the semi-logarithmic equation $v_x = a + b \log Q$ used in the IFG-4 model to predict average segment velocities when one or more negative average segment velocities are used in the calibration process. When flows at lower than the lowest calibration flow are simulated, the water velocity may in reality approach zero. However, the predicted velocity will be more negative than the negative value used in the lowest calibration flow regardless of whether or not a positive value was included in the calibration. When negative values are used in the calibration of the IFG-4 model, the segments involved should be examined and consideration given to the discharges to be simulated. The model appears to give good results when interpolation of velocity is required. If velocities must be extrapolated, good results can be expected when the flow is larger than the lowest calibration flow, and the velocity is positive at the largest calibration flow. Results are usually poor when extrapolation occurs for flows lower than the lowest calibration flow when negative velocities are involved. In this case, it may be best to treat all velocities as zero or positive values.

Main (1978a) suggested that the range of extrapolation using the IFG-4 hydraulic simulation model should be no less than 25 percent below the lowest calibration flow and no more than 30 percent above the largest calibration flow. We exceeded this range for all predictions and found that for those segments where velocities deviate little from the regression line (Figure 68), a wide range of extrapolation was possible. For those segments with a great deal of variation, the range of extrapolation was dependent on which flows were chosen for calibration. We also found that if three or more flows were used in calibration, the range could safely be extended in most cases.

Predicted values of depth were as accurate as the prediction of stage (water surface elevation). The stage - discharge equation ($St = a Q^b + StZF$) gave the best stage predictions when calibrated with stage of zero flow as determined from the Running method (Table 29). Like the stage - discharge equation used in the IFG-1 model, accuracy appears to be excellent in relating stage to discharge with reliability of predictions again linked directly to determination of stage of zero flow. In fact, the only difference between the two models is in application. In the IFG-1 model, discharge is defined as the dependent variable while stage is the dependent variable in the IFG-4 model.

Erroneous predictions of stage result in inaccurate predictions of segment depths and areas. The percent error in predicted segment depth (since it approximates a rectangle) translates into the same percent error in predicted segment area and segment discharge but does not directly affect the predicted velocity. Summing the segment discharges (the discharges resulting from predictions made for the requested discharge) gives a prediction discharge for the cross section. Dividing the requested discharge (the discharge for which a simulation of hydraulic features is required) by the predicted discharge results in a ratio referred to as the velocity adjustment factor. Multiplication of the predicted velocities by the velocity adjustment factor results in a predicted discharge that is the same as the one requested. When the adjustment factor deviates from 1.00 by more than ± 10%, additional measurements or data manipulation are required (Main 1978a).

Table 29. Predicted stage for five test flows at a riffle (VP-9) and a run (VP-12) transect, from the equation (St-StZF) = aQ^b (as used in the IFG-4 model), west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, 1978. Stage of zero flow estimated by three methods (field estimate, thalweg profile, and running method).

Q cfs	Measured stage (ft)		Stage of zero flow (ft) 2.30[a/]	2.67[b/]	2.78[c/]
			Predicted stage (ft)		
VP-9: Riffle					
19.65	3.39		3.31	3.34	3.39
11.15	3.16		3.17	3.16	3.15
6.45	2.99		3.06	3.03	3.00
2.67	2.88		2.90	2.89	2.88
1.26	2.83		2.80	2.82	2.83
		StZF =	2.30	2.46	2.46
VP-12: Run					
19.65	3.31		3.28	3.30	3.30
11.15	3.08		3.09	3.09	3.09
6.45	2.93		2.95	2.93	2.93
2.67	2.76		2.77	2.76	2.76
1.26	2.66		2.65	2.66	2.66

a/ StZF estimated from field measurements.

b/ StZF estimated from the bed profile at the thalweg.

c/ StZF estimated from the Running Method.

Analysis of segment velocity predictions where the velocity adjustment factor was applied showed no increase in accuracy of velocity predictions. If an adjustment factor other than 1.0 is computed and if the predicted velocities are assumed to be correct, then the depth prediction must be wrong. Adjusting the predicted velocities by application of the velocity adjustment factor so that the predicted discharge matches the requested discharge does little to improve the more important parameter of depth (in regard to purpose of interface with IFG-3) and actually causes error in the final average segment velocity predictions.

If depth is predicted correctly, then error in predicted discharge can be attributable to velocity. We found that some velocity predictions were higher than measured, and others were lower (Figure 67-68). Here again, adjustment of these velocities (by application of the velocity adjustment factor) to correct the predicted discharge to match the requested discharge does little overall good, since some predicted velocities will be made more accurate while others will be made less accurate.

In the remaining situation where both predicted depth and segment velocities are in error, it is possible that by adjusting velocities so that predicted discharge matches the requested discharge, an improvement in predicted segment velocity might occur, but it seems just as likely that the error will be increased. Thus, application of the velocity adjustment factor as used in the IFG-4 model appears inappropriate.

The best solution to the preceeding dilemma is to be as accurate as possible in collecting and analyzing the data used to calibrate the stage-discharge equation. If a user is confident of his calibration of this aspect of the model, he can then attribute error to the appropriate parameters, thus improving the predictions, rather than merely shifting the error from one prediction to the next.

When the IFG-4 model is interfaced with the IFG-3 habitat analysis model, and weighted usable areas are predicted, depth appears to be as critical as velocity in estimating the probability of use. An examination of probability of use curves for the family Salmonidae (Bovee 1978), shows that for many life stages, a very small error in depth (i.e., 0.1 ft) causes a substantial change in the probability value. Thus (assuming the curves correctly define habitat requirements), a substantial error in predicted weighted usable area can occur when depth predictions are erroneous.

Between the parameters of depth and velocity, depth is the easier to control and limit error in predictions. Hence, extreme care is necessary to accurately determine stage of zero flow, discharge through the stream reach of interest, and precise stage (water surface elevations) measurements, which requires precise surveying techniques.

It should be pointed out that this model has an optional depth correction feature. When in use, depths are adjusted in a manner similar to velocity adjustments. It does not take effect until the velocity adjustment factor deviates from 1.00 by more than $\pm$ 10 percent. This aspect of the model was not evaluated.

Usability of IFG-4: The IFG-4 hydraulic simulation model requires substantial hydraulic information to calibrate (a minimum of two sets of data at alternate flows, with three or more recommended). However, this model is easy to calibrate and use, with good documentation available. Additional hydraulic data are easily added or removed. A particular advantage in using this model is the great versatility in the number of segments into which a cross section can be divided.

To insure the best results, it is advisable to graph a few segment velocity - discharge pairs and calculate the regression line. An examination of the log-log plots should help to determine if additional field measurements are required or if adjustments should be made to decrease errors in velocity predictions. These plots could help to determine what range of extrapolation is feasible, as well as to provide confidence in predictions, or lack of it, as simulations of requested discharges become further removed from the calibration discharges.

Effect of Reducing the Number of Transects

Reducing the number of transects used to describe the hydraulic parameters of depth and velocity from 38 to 4 resulted in little overall loss of information in our run-riffle channel as long as the major types of reach (i.e., riffle and run) were included in the analysis (Figure 72). These results are based upon use of the IFG-3 habitat model in our west experimental channel and the probability of use curves for rainbow-steelhead trout fry and juveniles (*Salmo gairdneri*) (Bovee 1978).

Assuming weighted usable area at a particular discharge was best described by 38 transects, we examined what the loss in accuracy would be if the number of transects were reduced. Reducing the number of transects from 38 to 16 (VP transects) resulted in little change in weighted usable area for either life stage. With a reduction to 12 VP transects (excludes transition zone transects), a definite decrease occurred in the weighted usable area curve for steelhead juveniles (average 13% decrease) with relatively minor changes occurring for steelhead fry. When the

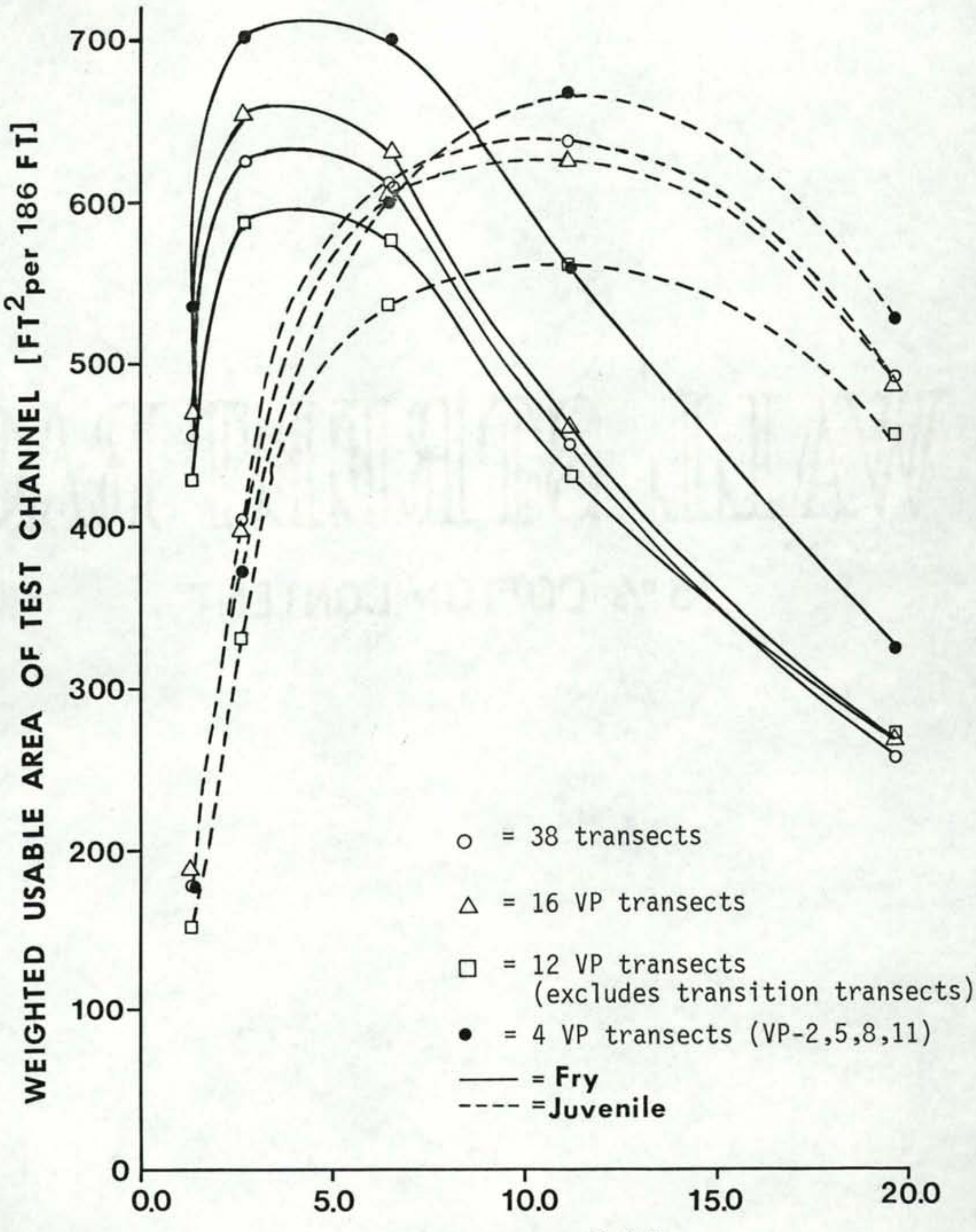


Figure 72. Changes in weighted usable area, for fry and juvenile rainbow-steelhead trout (*Salmo gairdneri*), as a result of reducing the number of transects used to describe the hydraulics of a stream reach, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

number of transects was reduced to four (VP-2, 5, 8 and 11), a substantial increase in weighted usable area occurred for steelhead fry; for juveniles, the curve was variable but became almost identical at the last flow reduction, to the standard based on 38 transects.

Evaluating percent change in weighted usable area, resulting from reducing the number of transects analyzed, we found the greatest change observed was 24.5 percent with four transects (Table 30). While this might seem to be a substantial difference in predictions, it probably is not significant when uncertainties in velocity and depth predictions are considered.

When the rate of change of the four curves at each life stage with decreasing discharge are compared, differences are thought to be, on the whole, insignificant (Table 31). The reason is that the relationship between standing crop (or biomass) and weighted usable area is assumed to be one to one (Bovee and Cochnauer 1977). Thus, an analysis of the weighted usable area for these two life stages with any one of the four curves of each would appear to yield very similar flow recommendations for a given life stage.

By decreasing the number of transects used to define the hydraulic parameters, 16 VP transects adequately examine most of the depth and velocity conditions as compared to 38 (Figure 47). When the number is reduced to 12 transects and the transition zones excluded from analysis at least two distinct habitat (hydraulic) types are excluded, namely the expanding and contracting transitions. When we drop to four transects, each sampling only major habitat type (i.e., riffle and run), we can see where several minor types are ignored. For example, the zone near VP-10 where water velocity is rapidly decreasing as it comes off the riffle,

Table 30. Percent change in calculated weighted usable area (WUA) for fry and juvenile steelhead trout (*Salmo gairdneri*) resulting from reducing the number of transects from 38 (100% WUA) to 4 at five discharges, west channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978.

Discharge (cfs)	Number of transects			
	38	16	12	4
Steelhead fry WUA percent change				
19.65	0	+3.9	+4.8	+18.5
11.15	0	+2.5	-4.3	+24.5
6.45	0	+3.7	-5.4	+15.1
2.67	0	+4.8	-6.1	+12.4
1.26	0	+3.3	-6.1	+17.7
Steelhead juveniles WUA percent change				
19.65	0	-1.4	-7.6	+6.9
11.15	0	-1.9	-12.0	+4.7
6.45	0	-1.4	-12.2	-1.9
2.67	0	-1.6	-18.4	-8.3
1.26	0	+5.8	-14.6	-0.3

Table 31. Rate of change (%) in calculated weighted usable area (WUA) for fry and juvenile steelhead trout (*Salmo gairdneri*) resulting from four incremental flow reductions with the number of transects being reduced from 38 to 4, Troy experimental Channels, Grande Ronde River, Wallowa County, Oregon, fall 1978.

Discharge reduction (cfs)		Number of transects			
From	To	38	16	12	4
Steelhead fry WUA rate of change (%)					
19.65	11.15	+74.2	+71.8	+59.0	+83.0
11.15	6.45	+35.3	+36.9	+33.8	+25.1
6.45	2.67	+2.5	+3.6	+1.8	+0.2
2.67	1.26	-27.2	-28.2	-27.3	-23.8
Steelhead juvenile WUA rate change (%)					
19.65	11.15	+29.3	+28.6	+23.0	+26.5
11.15	6.45	-4.2	-3.7	-4.4	-10.2
6.45	2.67	-33.8	-34.0	-38.5	-38.1
2.67	1.26	-56.3	-53.0	-54.3	-52.5

the high velocity section of the downstream riffle at VP-9, and the variations in depth along the reach are essentially ignored.

While the foregoing analysis does not totally answer the question of how many transects are required, it does indicate that if the predominate habitat types (as related to depth and velocity) are included, reasonable results can be expected. Further, as more accurate and reliable hydraulic information is needed to describe the aquatic habitat, a thorough set of measurements will be needed that clearly represent all changes in the stream reach of interest.

Summary

In assessing the primary hydraulic characteristics associated with incremental streamflow reductions, we found that the geometric elements (section factor, area, wetted perimeter, mean depth and top width) changed as expected for trapezoidal and parabolic shaped cross sections. That is, all geometric factors changed more rapidly in the trapezoidal cross sections than they did in the parabolic cross sections.

Velocity was found to decrease at a more constant rate through the range of flow reductions in the deeper sections of our channel. In the shallower sections, rate of change in velocity increased as flows were reduced.

Manning's roughness coefficient (n), in general, increased with decreasing streamflow. The degree of change was found to be dependent upon the size and number of roughness elements and the depth. The roughness coefficient changed least with reduced streamflow in shallower, boulder-free stream sections.

The energy slope (gradient) was found to vary from flow to flow as well as from transect to transect. No reliable means of predicting how much of a change or where the change would occur was found.

The velocity distribution coefficient (α) was found to have no overall effect on computation of the energy slope. However, it did increase the total energy head at all discharges, especially the larger flows. Velocity distribution coefficients generally increased in value as flows decreased. Directly affecting the value of the velocity distribution coefficient were the size and number of roughness elements. As the size and number of boulders increased, so did the velocity distribution coefficients. When flow was decreased, a greater portion of it was directly affected by large roughness elements which also resulted in large coefficient values. Velocity distribution coefficients were found to be greater than generally reported.

In our evaluation of hydraulic simulation models, we found that they generally do a good job in predicting the hydraulic parameters they were designed for. There were certain limitations in accuracy of predictions as the range of extrapolation of flows increased or decreased from the calibration flows. Generally, the WSP and IFG-1 (using stage-discharge option) allowed for a greater range of flow simulation from the calibration case than did the IFG-4 model or IFG-1 model using the Manning equation option. No actual ranges of extrapolation were determined in this study. We recommend that ranges of extrapolation suggested by Bovee and Milhous (1978) be followed during initial investigations and familiarization with the various hydraulic simulation models.

IFG-1 and IFG-4 models using the stage-discharge equation predicted depth (stage) and discharge better than the Water Surface Profile (WSP) and IFG-1 models using the Manning's equation option. Accurate determination of stage of zero flow appeared to be the most critical factor in calibration of the stage-discharge option followed by the WSP model and IFG-1 (Manning's equation option) model respectively. IFG-4 model does not directly predict average cross section velocities. The IFG-1 model, Manning's equation option, could be greatly improved in regard to velocity predictions by incorporating a means of modifying roughness coefficients.

Average segment velocities were predicted best by the WSP model employing Manning's equation and using modified n values for alternate flows. The WSP model was also most accurate over a wider range of flows, especially in the decreasing direction from the calibration flow. The IFG-4 model gave excellent average segment velocity predictions in the center of the channel, but predictions were often poor near the banks. Both models provide good segment depth predictions, with the IFG-4 model being slightly better.

Of the three hydraulic simulation models evaluated, the IFG-4 was the easiest to calibrate and use, followed by the IFG-1 model (stage-discharge option was more readily calibrated than Manning's equation option) with the WSP model the most difficult. Model output is more complete and easier to control in the IFG-4 model than either the WSP or IFG-1 models. More control over accuracy of velocity predictions is possible with the WSP (through roughness coefficient modifications) than the IFG-4 model. However, a good deal of skill and knowledge of Manning's n values and how they vary with changing flows is required.

From our investigation of reducing the number of transects used to define the hydraulics of a stream reach, the placement of transects is far more important than number of transects used. It appears that as long as major hydraulic types (i.e., riffle, run, pool) are sampled at least once, the small amount of information gained by adding more transects is not cost effective considering the required increases in labor.

CHAPTER 7
GENERAL DISCUSSION

Our research on the effects of reduced discharge on fish and fish-food organisms was a first step in answering the questions of 1) How much water is required to maintain a particular stream fishery? and 2) What is lost in terms of fish numbers or biomass at increments of reduced discharge? Since fish depend upon adequate physical habitat, suitable water quality and food for survival, we examined the response of juvenile rainbow-steelhead trout to flow-related changes in these parameters. We also examined the utility of various hydraulic models in predicting changes in physical characteristics of streams.

Responses of fish and fish-food organisms to reduction in discharge in large, near-natural stream channels included: 1) decreased abundance and biomass of juvenile rainbow-steelhead trout, 2) increased behavioral drift of aquatic insects at night immediately following flow reductions and 3) decreased aquatic insect drift rates during reduced flow periods.

Increased behavioral drift of aquatic insects following each discharge reduction would appear to be a negative effect of reduced flows. One could hypothesize that insects were abandoning the channel because of flow-related habitat changes. Although no large decreases in wetted perimeter occurred, changes in physical habitat do appear to be the most likely explanation for the observed insect movement. Our benthic data, however, suggest that rather than abandonment of the channels, the response is a mechanism by which aquatic insects redistribute themselves into suitable habitat within the stream; we observed no corresponding decreases in benthic density with reduced discharge although some individual taxa were reduced. Hafele (1978) reported similar findings.

Although density of benthic insects was not reduced in our short-term flow tests, we found a large decrease in drift rate (numbers of insects drifting past a point per unit time) at the low discharges tested. Aquatic insect drift rate is the most important measure of fish-food availability. Decreases in drift rate could result in decreased numbers and/or biomass of fish since territorial behavior of salmonids is largely based upon the food resource (Slaney and Northcote 1974; Chapman 1966; Symons 1971). Therefore, with reduced availability of food, territory size would increase and fewer fish could inhabit the stream.

Although food may become limiting at low discharge, the size-related emigration pattern of our experimental fish suggests that wild juvenile rainbow-steelhead trout were limited by habitat changes before food supply became limiting. If experimental trout had been limited primarily by food, we would expect that larger fish would have the advantage in successfully defending territories and therefore fish leaving the channels would be the smaller individuals. In our studies, however, we found the reverse of this situation. During constant high flows, small fish made up the bulk of emigrants while larger fish emigrated at a higher rate as flow was reduced. This suggests that fish were responding primarily to changes in physical habitat parameters rather than to a decrease in food availability.

Other supporting evidence for the habitat-limiting hypothesis is the insect drift rate-fish migration relationship. Although drift rate initially increased following each flow reduction tested, drift rate generally returned to near control levels except during severe low flow. Juvenile rainbow-steelhead trout, however, responded to each flow reduction (fall 1978) in an approximate linear fashion, with no flow tested producing a more severe effect than another. The form of this relationship could have been influenced by the short duration of test flows but the overall patterns would probably not have changed.

Increased emigration of larger fish in response to reduced flow suggests that physical habitat changes associated with low flow favored smaller test fish to the detriment of larger ones. Assuming this interpretation is correct, the question becomes, what physical change or changes in habitat account for the response of the fish population?

During our study we closely monitored changes in primary hydraulic parameters (depths, velocity, wetted perimeter, top width) associated with reductions in discharge. We also attempted to document cover utilization. By examining flow related changes in these parameters, we hoped to determine their order of importance to juvenile rainbow-steelhead trout and also to test the predictive accuracy of select hydraulic models.

Of the hydraulic parameters we examined in relation to the response of experimental fish, velocity was the parameter most affected by reduced flow, followed by depth, surface area and wetted perimeter. Our analysis of the emigration of juvenile rainbow-steelhead trout related to change in these parameters provided no conclusive evidence regarding their order of importance.

In an attempt to relate the response of test fish populations to physical habitat characteristics, and to validate the predictive accuracy of the Instream Flow Group Incremental Methodology, we calculated changes in weighted useable area (WUA) for the flows tested using habitat preference curves for juvenile steelhead trout developed by Bovee and Cochnauer (1977). These habitat preference curves were derived from data collected from small-stream populations of summer steelhead and are considered good quality curves. Our analyses indicated that WUA (based on depth and velocity) for juvenile steelhead actually increased in our test channel when discharge was reduced from 0.57 m^3/s (20 ft^3/s) to 0.28 m^3/s (10 ft^3/s (Figure 73). If the WUA curve we developed was accurate in predicting the response of the fish population, we would expect no difference in emigration of the fish from the test and control channels with flow reduction from 0.57 m^3/s (20 ft^3/s) to 0.28 m^3/s) (10ft^3/s), but a substantial decrease in fish abundance as flow was decreased below 0.14 m^3/s (5 ft^3/s).

In our fall 1978 test (Figure 73), reducing the flow to 0.28 m^3/s (10 ft^3/s) resulted in a larger percentage of wild juvenile steelhead-rainbow trout leaving the test channel than the control, indicating that factors other than depth and velocity were operating to bring about the response, since calculated WUA actually increased at this flow. Other discharge reductions tested resulted in fish emigrating in a pattern somewhat similar to the shape of the WUA curve but not decreasing as sharply as predicted.

In the summer 1979 test when base discharge was 0.28 m^3/s (10 ft^3/s), wild fish responded somewhat more intensely than predicted when flows were reduced to 0.14 m^3/s (5 ft^3/s). That is, with an approximate 8% reduction in WUA, there was about a 20% reduction in the wild fish population below the number that emigrated from the control channel. From our observations, it appears that depth and velocity

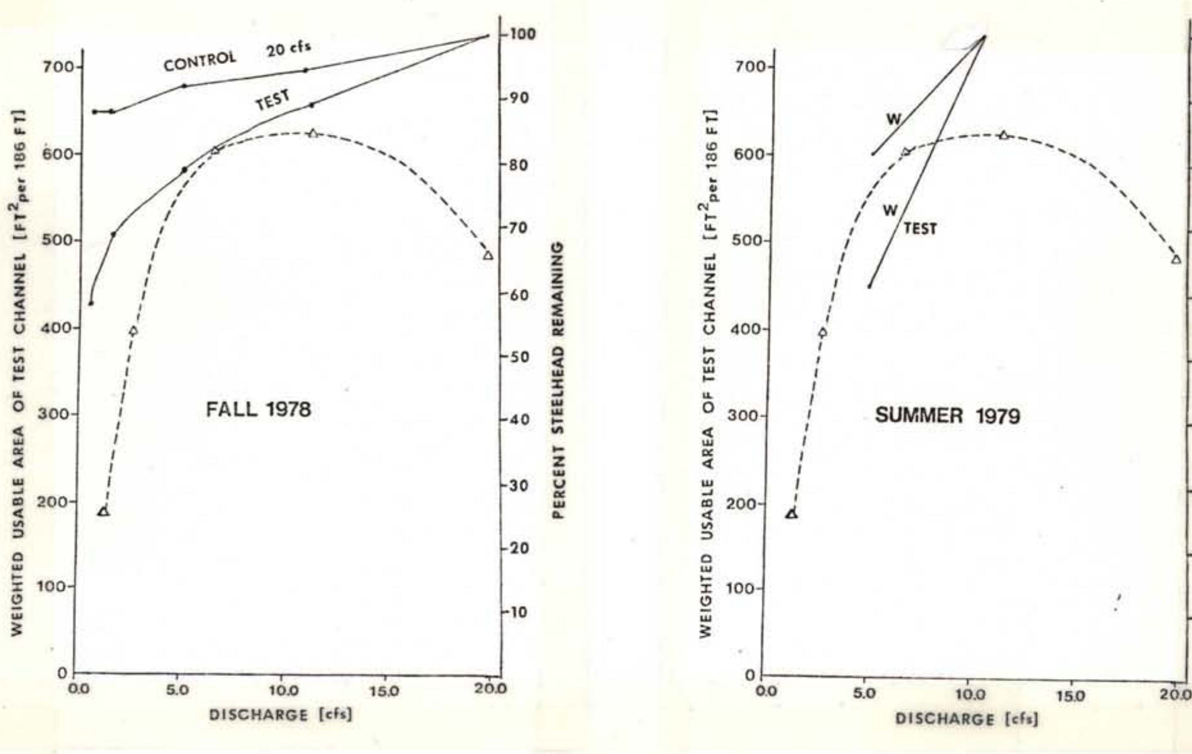


Figure 73. Comparison of weighted useable area (dashed line) and response of juvenile rainbow-steelhead trout populations to discharge in test and control channels, Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, fall 1978, and summer 1979.

preferences alone are not adequate for predicting the response of juvenile rainbow-steelhead trout.

From visual observations (overhead and underwater) of juvenile rainbow-steelhead trout in fall and summer tests, we noted that in the test channel, fish were primarily located in the run sections and closely associated with cover rocks during reduced flow tests. At the same time, fish in the control channel were observed to be in open sections of the stream. This indicates that as flow was decreased, cover in the form of depth and/or surface turbulance was reduced, resulting in fish associating more closely with structural cover elements. Although these data are limited, cover appears to be of prime importance in explaining the observed response of juvenile rainbow-steelhead trout to reduced flow. Nickelson and Hafele (1978) reported that "cover appears to be the most important factor determining standing crop of juvenile steelhead (coefficient of determination of 0.67)."

The overall effect of reduced flow on juvenile rainbow-steelhead trout is still in the hypothesis testing phase. No one hydraulic parameter could consistently be related to the response of test fish and our data on importance of cover are insufficient. It is reasonable to assume that cover and hydraulic parameters interact to bring about the overall response of fish to flow reductions. Further, habitat requirements of trout are known to vary seasonally, and therefore the importance of any one or combination of habitat variables may take precedence on a seasonal basis.

Water temperature was not significantly influenced in the test channel by reduced flow and therefore had no influence on the response of experimental fish. In natural streams, however, where large sections are dewatered, increases in water temperature could become an overriding influence.

The hydraulic simulation models we tested generally predicted accurately the parameters they were designed for. We found that some models predicted changes in a particular parameter better than others. Also models differed in the difficulty of calibration and application. The IFG-4 model was the easiest to calibrate and use, followed by the IFG-1 model, with the WSP model the most difficult. We also found certain limitations in accuracy of predictions as the range of extrapolation of flow increased or decreased from the calibration flow. Generally, the IFG-1 and WSP models (stage-discharge option) allowed for a greater range of flow simulation from the calibration case than did the IFG-4 model or the IFG-1 model using the Manning equation option. Since it was not our objective to determine actual limits on range of extrapolation of models tested, we recommend that ranges suggested by Bovee and Milhous (1978) be followed during initial investigations and familiarization of models used. Selection of a particular model for use in instream flow needs evaluations will depend upon the amount of time and money available, and the objective of the study.

We found that placement of transects for predicting changes in hydraulic parameters (depth and velocity) at reduced discharges in our run-riffle simulated stream reach was more important than the number of transects used. Our data indicated that as long as major hydraulic types (i.e. riffles, runs, pools) were sampled at least once, the small amount of information gained by adding more transects would not be cost effective. In our channels, flow recommendations based upon the WUA concept would be the same using four transects or 38 transects although the total amount of WUA would differ (Figure 72). Our findings may not apply well to channels with more habitat diversity.

Since hydraulic models tested adequately predicted flow-related changes in hydraulic parameters, the problem which remains is validation and further development of techniques which can be used to interface hydraulic predictions with response of fish populations in natural systems. The major gap in our knowledge is an adequate understanding and description of flow-related habitat requirements of fish species. Further, if hydraulic models are to provide an adequate description of changes in preferred velocities, we must determine if velocity preferences of fish are correlated with the 0.6 depth velocity predicted by the models.

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APPENDIX A

LIST OF MACROINVERTEBRATES

Table 32. Macroinvertebrate taxa collected in Hess and drift sample during the reduced stream discharge experiments at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, 1978-1979.

Class/Order	Family	Genus/Species
Acarina		
	Hydrachnidae	*Hydracarina* sp.
Plesiopora		
	Tubificidae	
Nematoda		
Gastropoda		
Decopoda	Astacidae	*Pacifastacus* sp.
Collembola		
	Poduridae	
Lepidoptera		
	Pyralidae	*Paragyractus* sp.
Plecoptera		
	Taeniopterygidae	*Taenionema pacificum*
	Nemouridae	*Zapata cinctipes*
		Prostoia sp.
	Pteronarcyidae	*Pteronarcys californica*
		Pteronarcella badia
	Chloroperlidae	*Alloperla severa*
		Sweltsa borealis
	Perlodidae	*Isogenoides elongatus*
		Isoperla fusca
		Skwala parallela
		Cultus tostonus
	Perlidae	*Hesperoperla pacifica*
		Calineuria californica
		Claassenia sabulosa
Trichoptera		
	Glossosomatidae	*Glossosoma* sp.
	Hydropsychidae	*Cheumatopsyche* sp.
		Hydropsyche sp.
		Arctopsyche sp.
	Limnephilidae	*Dicosmoecus* sp.
	Hydroptilidae	Unknown Hydroptilidae
	Polycentropodidae	*Polycentropus* sp.
	Brachycentridae	*Brachycentrus* sp.
		Amiocentrus aspilus
	Leptoceridae	*Oecetis* sp.
		Ceraclea sp.
	Psychomyiidae	*Psychomyia* sp.
	Lepidostomatidae	*Lepidostoma* sp.
	Helicopsychidae	*Helicopsyche* sp.

Table 32. Continued.

Class/Order	Family	Genus/Species
Ephemeroptera	Polymitarcyidae	*Ephoron album*
	Tricorythidae	*Tricorythodes minutus*
	Heptageniidae	*Rhithrogena hageni*
		R. morrisoni
		Heptagenia criddlei
		H. solitaria
		H. elegantula
		Epeorus albertae
		E. longimanus
	Ephemerellidae	*Ephemerella hecuba*
		E. heterocaudata
		E. inermis-infrequens
		E. flavilinea
		E. tibialis
	Baetidae	*Baetis bicaudatus*
		B. tricaudatus
		B. parvus
		Centroptilum sp.
		Callibaetis sp.
	Leptophlebiidae	*Paraleptophlebia debilus*
		P. bicornuta
		P. heteronea
	Siphlonuridae	*Ameletus* sp.
Diptera	Blephariceridae	
	Ceratopogonidae	*Culicoides* sp.
		Forcipomyia sp.
	Chironomidae	
	Deuterophlebiidae	*Deuterophlebia* sp.
	Empididae	
	Muscidae	*Limnophora* sp.
	Rhagionidae	*Atherix variegata*
	Simulidae	*Simulium* sp.
	Tipulidae	*Antocha* sp.
		Hexatoma sp.
Coleoptera	Elmidae	*Optioservus* sp.
		Heterlimnius sp.
		Lara sp.
	Dytiscidae	*Oreodytes* sp.
	Haliplidae	*Haliplus* sp.
	Dryopidae	*Helichus* sp.
Odonata	Gomphidae	*Ophiogomphus* sp.
Hemiptera	Belostomatidae	*Lethocerus americanus*
	Corixidae	

APPENDIX B

INSECT DRIFT - FALL 1978

Table 33. Insect drift densities (no/m^3) and rates (no/hr) in parentheses, during the fall, 1978 (22 August-4 October) reduced streamflow test at Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Baseflow = 0.57 m^3/s, 1st reduction period = 0.28 m^3/s, 2nd reduction period = 0.17 m^3/s, 3rd reduction period = 0.03 m^3/s, 4th reduction period = 0.03 m^3/s. Control flow = 0.57 m^3/s. Downstream station.

			Base Flow Period		1st Reduction Period				2nd Reduction	
Organism	Channel	Time	247-248[a]	248-249	249-250	250-251	254-255	255-256	256-257	257-258
Cheumatopsyche	Control	Dusk	.08 (10)	.08 (10)	0 (0)	.03 (5)	.02 (3)	0 (0)	.03 (5)	.06 (8)
		Midnight	.12 (15)	0 (0)	NT	0 (0)	0 (0)	.02 (3)	.03 (5)	0 (0)
		Dawn	0 (0)	.04 (5)	0 (0)	0 (0)	.02 (3)	0 (0)	0 (0)	0 (0)
	Test	Dusk	.06 (12)	.05 (10)	.03 (5)	.03 (5)	.09 (13)	.05 (8)	.33 (33)	.03 (3)
		Midnight	.04 (8)	.07 (15)	NT	.06 (8)	.03 (5)	.04 (5)	.05 (5)	.04 (4)
		Dawn	.02 (3)	.04 (8)	0 (0)	.02 (3)	0 (0)	0 (0)	.02 (2)	0 (0)
Hydropsyche	Control	Dusk	.06 (8)	.14 (18)	.05 (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Midnight	.02 (3)	.06 (8)	NT	0 (0)	0 (0)	0 (0)	.02 (3)	.01 (1)
		Dawn	.02 (3)	.02 (3)	.05 (8)	0 (0)	.02 (3)	0 (0)	.02 (3)	0 (0)
	Test	Dusk	.05 (9)	.03 (5)	.12 (18)	.03 (5)	.03 (5)	.13 (20)	.13 (13)	.06 (5)
		Midnight	.20 (38)	.02 (5)	NT	0 (0)	.02 (3)	.06 (8)	.08 (8)	.05 (4)
		Dawn	.02 (3)	.03 (5)	.02 (3)	.04 (5)	0 (0)	0 (0)	.02 (2)	.03 (3)
Oecetis	Control	Dusk	0 (0)	0 (0)	0 (0)	.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)
		Midnight	0 (0)	.02 (3)	NT	0 (0)	.02 (3)	.02 (3)	0 (0)	0 (0)
		Dawn	0 (0)	0 (0)	0 (0)	0 (0)	.02 (3)	.06 (8)	.02 (3)	0 (0)
	Test	Dusk	.02 (3)	.04 (8)	0 (0)	.02 (3)	0 (0)	.02 (3)	.03 (3)	.11 (10)
		Midnight	.02 (3)	.01 (3)	NT	.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)
		Dawn	.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)	.02 (3)	.01 (1)	0 (0)
Rhithrogena	Control	Dusk	0 (0)	0 (0)	0 (0)	.02 (3)	0 (0)	.05 (8)	0 (0)	.02 (3)
		Midnight	.04 (5)	.04 (5)	NT	.02 (3)	.03 (5)	0 (0)	0 (0)	0 (0)
		Dawn	0 (0)	0 (0)	0 (0)	0 (0)	.03 (5)	0 (0)	0 (0)	.02 (3)
	Test	Dusk	.01 (1)	.02 (3)	0 (0)	0 (0)	.02 (3)	.05 (8)	0 (0)	0 (0)
		Midnight	.02 (3)	.01 (3)	NT	.06 (8)	.05 (8)	0 (0)	0 (0)	.02 (2)
		Dawn	0 (0)	.02 (3)	0 (0)	0 (0)	.02 (3)	0 (0)	.02 (2)	0 (0)

[a] Julian date.

Table 33. Continued.

Organism	Channel	Time	Period 261-262	262-263	3rd Reduction Period 263-264	264-265	268-269	269-270	4th Reduction Period 270-271	271-272	275-276	286-277
Cheumatopsyche	Control	Dusk	.02 (3)	.06 (8)	.02 (3)	.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)	.02 (3)	.04 (5)
		Midnight	.03 (5)	0 (0)	0 (0)	0 (0)	.01 (1)	0 (0)	0 (0)	.02 (3)	.04 (6)	.02 (3)
		Dawn	0 (0)	0 (0)	0 (0)	.02 (3)	0 (0)	.03 (5)	0 (0)	0 (0)	.02 (3)	0 (0)
	Test	Dusk	0 (0)	.10 (10)	.19 (8)	.47 (20)	0 (0)	.30 (13)	.54 (10)	.33 (6)	.18 (4)	1.04 (19)
		Midnight	.03 (3)	.06 (6)	0 (0)	.03 (1)	.03 (1)	.06 (3)	.65 (12)	.23 (5)	.17 (4)	.11 (2)
		Dawn	0 (0)	0 (0)	.02 (1)	0 (0)	0 (0)	0 (0)	0 (0)	.09 (2)	0 (0)	.05 (1)
Hydropsyche	Control	Dusk	0 (0)	.02 (3)	0 (0)	0 (0)	.03 (5)	0 (0)	.02 (3)	0 (0)	0 (0)	.02 (3)
		Midnight	0 (0)	0 (0)	0 (0)	0 (0)	.01 (2)	0 (0)	0 (0)	.02 (3)	0 (0)	0 (0)
		Dawn	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)
	Test	Dusk	.05 (5)	.08 (8)	.07 (3)	.02 (1)	.02 (1)	.42 (18)	.22 (4)	.11 (2)	.14 (3)	.44 (8)
		Midnight	0 (0)	.01 (1)	.14 (6)	.14 (6)	.04 (2)	.13 (6)	.98 (18)	.36 (8)	.10 (2)	.27 (5)
		Dawn	0 (0)	0 (0)	.02 (1)	.07 (3)	.02 (1)	0 (0)	.23 (5)	.14 (3)	0 (0)	.05 (1)
Oecetis	Control	Dusk	0 (0)	.02 (3)	.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.02 (3)
		Midnight	0 (0)	0 (0)	0 (0)	0 (0)	.01 (2)	0 (0)	0 (0)	.04 (5)	0 (0)	.02 (3)
		Dawn	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.02 (3)	0 (0)	.02 (3)	0 (0)	.01 (2)
	Test	Dusk	0 (0)	.05 (5)	.05 (2)	0 (0)	.28 (12)	.47 (20)	.44 (8)	.44 (8)	.59 (13)	.60 (11)
		Midnight	0 (0)	0 (0)	0 (0)	.05 (2)	.08 (4)	.19 (9)	.54 (10)	.82 (18)	.34 (8)	.16 (3)
		Dawn	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.02 (1)	.18 (4)	.18 (4)	.09 (2)	.14 (3)
Rhithrogena	Control	Dusk	0 (0)	.06 (8)	0 (0)	.02 (3)	.07 (10)	0 (0)	.04 (5)	.04 (5)	.02 (3)	0 (0)
		Midnight	.02 (3)	.03 (5)	.02 (3)	.07 (10)	.02 (3)	.02 (3)	.07 (10)	.09 (13)	.04 (6)	.02 (3)
		Dawn	.03 (5)	0 (0)	.02 (3)	0 (0)	.02 (3)	0 (0)	.02 (3)	0 (0)	.05 (8)	.01 (1)
		Dusk	.03 (3)	.23 (23)	.68 (29)	.23 (10)	0 (0)	.42 (18)	.38 (7)	.38 (7)	.82 (18)	.54 (10)
		Midnight	.03 (3)	.04 (4)	.16 (7)	.09 (4)	.21 (10)	.30 (14)	.27 (5)	.27 (6)	.20 (5)	.05 (1)
		Dawn	.03 (3)	0 (0)	.05 (2)	9 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 33. Continued.

Organism	Channel	Time	Base Flow		1st Reduction Period			
			247-248 [a]	248-249	249-250	250-251	254-255	255-256
Ephemerella	Control	Dusk	.57 (73)	.43 (55)	.53 (78)	.61 (93)	.28 (43)	.36 (53)
		Midnight	.10 (13)	.27 (38)	NT	.28 (43)	.27 (40)	.20 (30)
		Dawn	.27 (35)	.21 (28)	.16 (25)	.10 (15)	.12 (18)	.20 (28)
	Test	Dusk	.26 (50)	.21 (40)	.39 (60)	.27 (40)	.46 (70)	.52 (80)
		Midnight	.18 (35)	.21 (43)	NT	.16 (23)	.31 (45)	.16 (23)
		Dawn	.11 (20)	.13 (25)	.12 (18)	.13 (18)	.23 (35)	.15 (23)
Baetis	Control	Dusk	3.57 (459)	3.11 (400)	3.73 (548)	2.52 (385)	.94 (143)	2.06 (303)
		Midnight	4.54 (583)	3.40 (478)	NT	2.18 (333)	.89 (130)	1.08 (158)
		Dawn	1.11 (143)	1.45 (195)	1.75 (268)	1.11 (170)	.78 (115)	.32 (45)
	Test	Dusk	3.88 (736)	3.69 (700)	4.47 (683)	2.72 (400)	1.49 (228)	1.60 (245)
		Midnight	5.84 (1108)	3.17 (640)	NT	2.30 (323)	1.60 (235)	1.30 (183)
		Dawn	.82 (150)	1.57 (298)	1.46 (215)	1.24 (175)	.77 (118)	.09 (13)
Simulium	Control	Dusk	1.18 (152)	.26 (30)	.19 (28)	.18 (28)	.25 (38)	.16 (23)
		Midnight	.12 (15)	.14 (20)	NT	.07 (10)	.09 (13)	.05 (8)
		Dawn	.08 (10)	.11 (15)	.10 (15)	.09 (13)	.03 (5)	.04 (5)
	Test	Dusk	1.22 (231)	.57 (108)	1.50 (230)	.63 (93)	.25 (38)	.52 (80)
		Midnight	.32 (60)	.27 (55)	NT	.18 (25)	.12 (18)	.11 (15)
		Dawn	.15 (28)	.11 (20)	.20 (30)	.04 (5)	.05 (8)	.05 (8)
Other	Control	Dusk	.23 (29)	.33 (42)	.31 (46)	.37 (56)	.17 (26)	.15 (22)
		Midnight	.26 (34)	.26 (37)	NT	.17 (27)	.11 (16)	.05 (8)
		Dawn	.18 (23)	.16 (22)	.04 (6)	.13 (20)	.09 (14)	.06 (8)
	Test	Dusk	.24 (46)	.10 (19)	.37 (56)	.20 (29)	.21 (32)	.25 (39)
		Midnight	.36 (69)	.24 (49)	NT	.15 (21)	.23 (34)	.20 (28)
		Dawn	.04 (8)	.06 (11)	.09 (14)	.11 (16)	.12 (18)	.08 (13)
Total	Control	Dusk	5.69 (731)	4.34 (558)	4.82 (708)	3.75 (573)	1.65 (253)	2.79 (409)
		Midnight	5.20 (668)	4.19 (589)	NT	2.72 (416)	1.41 (207)	1.43 (210)
		Dawn	1.67 (214)	1.99 (268)	2.11 (322)	1.43 (218)	1.13 (166)	.67 (94)
	Test	Dusk	5.74 (1088)	4.71 (893)	6.88 (1052)	3.92 (575)	2.54 (389)	3.16 (483)
		Midnight	6.98 (1324)	4.03 (813)	NT	2.92 (411)	2.37 (348)	1.86 (262)
		Dawn	1.17 (215)	1.95 (370)	1.91 (280)	1.58 (222)	1.19 (182)	.39 (60)

Table 33. Continued.

Organism	Channel	Time	2nd Reduction Period 256-257	257-258	261-262	262-263
Ephemerella	Control	Dusk	.16 (23)	.36 (50)	.33 (45)	.36 (48)
		Midnight	.09 (13)	.15 (21)	.07 (10)	.24 (35)
		Dawn	.14 (20)	.20 (30)	.14 (20)	.17 (25)
	Test	Dusk	.40 (40)	.45 (40)	.50 (50)	.43 (43)
		Midnight	.10 (10)	.24 (23)	.18 (18)	.30 (30)
		Dawn	.26 (26)	.20 (20)	.15 (15)	.28 (28)
Baetis	Control	Dusk	.67 (98)	.84 (118)	1.99 (268)	1.66 (223)
		Midnight	.65 (95)	.74 (108)	.84 (125)	.85 (125)
		Dawn	.24 (35)	.91 (133)	.33 (48)	.27 (40)
	Test	Dusk	2.67 (265)	1.85 (163)	2.93 (290)	3.38 (335)
		Midnight	1.39 (133)	1.52 (142)	.84 (83)	.88 (87)
		Dawn	.48 (48)	.91 (90)	.45 (45)	.23 (23)
Simulium	Control	Dusk	.07 (10)	.16 (23)	.25 (33)	.11 (15)
		Midnight	.05 (8)	.06 (9)	.03 (5)	.03 (5)
		Dawn	.03 (5)	0 (0)	.03 (5)	.02 (3)
	Test	Dusk	1.36 (135)	.77 (68)	.03 (3)	.23 (23)
		Midnight	.40 (40)	.09 (9)	.05 (5)	.10 (10)
		Dawn	.05 (5)	.15 (15)	.05 (5)	.03 (3)
Other	Control	Dusk	.26 (38)	.10 (14)	.19 (26)	.46 (62)
		Midnight	.09 (14)	.16 (23)	.13 (19)	.07 (11)
		Dawn	.02 (3)	.16 (24)	.09 (14)	.09 (14)
	Test	Dusk	.16 (16)	.33 (29)	.37 (37)	.26 (26)
		Midnight	.16 (16)	.15 (14)	.29 (29)	.11 (11)
		Dawn	.14 (14)	.06 (6)	.06 (6)	.19 (19)
Total	Control	Dusk	1.19 (174)	1.54 (216)	2.79 (375)	2.75 (370)
		Midnight	.94 (138)	1.11 (163)	1.14 (167)	1.23 (181)
		Dawn	.47 (69)	1.29 (190)	.63 (92)	.56 (82)
	Test	Dusk	5.10 (505)	3.61 (318)	3.92 (388)	4.77 (473)
		Midnight	2.19 (217)	2.11 (197)	1.42 (141)	1.50 (149)
		Dawn	1.01 (100)	1.35 (134)	.75 (74)	.74 (73)

Table 33. Continued.

Organism	Channel	Time	3rd Reduction Period				4th Reduction Period			
			263-264	264-265	268-269	269-270	270-271	271-272	275-276	276-277
Ephemerella	Control	Dusk	.24 (35)	.40 (58)	.14 (20)	.50 (73)	.63 (88)	.91 (128)	.47 (63)	.43 (60)
		Midnight	.17 (25)	.10 (15)	.40 (54)	.43 (60)	.50 (70)	.66 (93)	.25 (36)	.23 (33)
		Dawn	.10 (13)	.12 (18)	.16 (23)	.16 (23)	.14 (20)	.39 (55)	.19 (28)	.26 (37)
	Test	Dusk	.19 (8)	.37 (16)	1.05 (45)	3.27 (140)	.87 (16)	1.31 (24)	.82 (18)	1.31 (24)
		Midnight	.21 (9)	.26 (11)	.86 (40)	1.32 (62)	.71 (13)	.86 (19)	.65 (14)	.44 (8)
		Dawn	.09 (4)	.05 (2)	.23 (10)	.21 (9)	.18 (4)	.32 (7)	0 (0)	.23 (5)
Baetis	Control	Dusk	1.40 (205)	1.60 (235)	.67 (98)	1.14 (168)	.80 (113)	.53 (75)	.41 (55)	.55 (78)
		Midnight	1.29 (190)	1.19 (175)	1.32 (178)	1.19 (168)	1.03 (145)	1.31 (185)	.37 (55)	.46 (65)
		Dawn	.37 (50)	.37 (55)	.50 (73)	.33 (48)	.07 (10)	.20 (28)	.16 (23)	.10 (14)
	Test	Dusk	12.82 (549)	7.75 (332)	1.26 (54)	2.13 (91)	1.74 (32)	1.04 (19)	.32 (7)	.27 (5)
		Midnight	4.30 (184)	2.29 (98)	1.33 (63)	1.19 (56)	3.32 (61)	.91 (20)	.24 (6)	.22 (4)
		Dawn	.63 (27)	.42 (18)	.16 (7)	.12 (5)	0 (0)	.14 (3)	0 (0)	.05 (1)
Simulium	Control	Dusk	.12 (18)	.14 (20)	.07 (10)	.20 (30)	.04 (5)	.07 (10)	.02 (3)	.11 (15)
		Midnight	.09 (13)	.05 (8)	.06 (8)	.04 (5)	.09 (13)	.02 (3)	.03 (4)	0 (0)
		Dawn	.02 (3)	.02 (3)	.02 (3)	.09 (13)	.03 (5)	.04 (5)	.02 (3)	.02 (3)
	Test	Dusk	1.35 (58)	.75 (32)	.05 (2)	.16 (7)	.27 (5)	0 (0)	0 (0)	.05 (1)
		Midnight	1.05 (45)	.05 (2)	0 (0)	.02 (1)	.05 (1)	0 (0)	0 (0)	.05 (1)
		Dawn	.07 (3)	.02 (1)	.09 (4)	.07 (3)	.05 (1)	0 (0)	0 (0)	0 (0)
Other	Control	Dusk	.13 (19)	.20 (29)	.14 (21)	.32 (47)	.25 (35)	.28 (39)	.10 (14)	.17 (24)
		Midnight	.12 (17)	.12 (18)	.24 (32)	.25 (35)	.39 (55)	.21 (30)	.25 (36)	.09 (13)
		Dawn	.04 (6)	.12 (18)	.13 (19)	.05 (8)	.09 (13)	.06 (9)	.04 (6)	.03 (5)
	Test	Dusk	.37 (16)	.35 (15)	.28 (12)	.75 (32)	.65 (12)	.65 (12)	.36 (8)	1.30 (24)
		Midnight	.12 (5)	.30 (13)	.23 (11)	.40 (19)	.27 (5)	.64 (14)	.48 (11)	.21 (4)
		Dawn	.19 (8)	.12 (5)	.05 (2)	.12 (5)	.14 (3)	.23 (5)	.09 (2)	.04 (1)
Total	Control	Dusk	1.93 (283)	2.37 (348)	1.12 (164)	2.17 (318)	1.77 (249)	1.83 (257)	1.05 (141)	1.34 (188)
		Midnight	1.69 (248)	1.54 (226)	2.07 (279)	1.93 (271)	2.08 (293)	2.38 (335)	.98 (143)	.84 (120)
		Dawn	.56 (75)	.66 (97)	.82 (121)	.70 (103)	.35 (51)	.71 (100)	.48 (71)	.44 (62)
	Test	Dusk	15.72 (673)	9.95 (426)	2.94 (126)	7.92 (339)	5.12 (94)	4.25 (78)	3.22 (71)	5.56 (102)
		Midnight	5.98 (256)	3.34 (143)	2.77 (130)	3.61 (170)	6.81 (125)	4.09 (90)	2.19 (48)	1.53 (28)
		Dawn	1.07 (46)	.7 (30)	.56 (24)	.54 (23)	.77 (17)	1.09 (24)	.18 (4)	.54 (12)

[a] Julian date.

NT = No sample taken.

APPENDIX C

INSECT DRIFT - SPRING 1979

Table 34. Insect drift densities (no/m^3) and rates (no/hr), in parentheses, during the spring, 1979 (22 March-27 April) reduced streamflow test at the Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Control and base flow = 0.28 m^3/s, reduction flow = 0.03 m^3/s. Downstream station.

Organism	Channel	Time	Base Flow Period		Reduction Period			
			88-89[a]	95-96	96-97	99-100	102-103	109-110
Baetis	Control	Noon	.10 (18)	.04 (8)	.07 (12)	.02 (3)	.03 (5)	.03 (5)
		Dusk	1.16 (210)	.17 (30)	.46 (83)	.46 (80)	.75 (125)	1.14 (200)
		Midnight	.54 (100)	.25 (45)	.46 (88)	.19 (33)	.33 (58)	1.07 (193)
		Dawn	.87 (155)	.41 (78)	.40 (73)	.69 (123)	.37 (70)	.52 (95)
	Test	Noon	.05 (8)	.10 (15)	.05 (1)	0 (0)	.05 (1)	.21 (4)
		Dusk	.52 (78)	.41 (60)	3.81 (58)	2.38 (57)	1.86 (42)	1.85 (41)
		Midnight	.85 (132)	.26 (40)	2.68 (36)	.91 (21)	.38 (8)	.59 (13)
		Dawn	1.49 (233)	.75 (113)	2.44 (36)	1.71 (31)	.27 (6)	.41 (8)
Rhithrogena	Control	Noon	0 (0)	0 (0)	.01 (2)	0 (0)	0 (0)	0 (0)
		Dusk	.11 (20)	0 (0)	.02 (3)	.05 (8)	.02 (3)	.09 (15)
		Midnight	.11 (20)	.02 (3)	0 (0)	.03 (5)	.03 (5)	.02 (3)
		Dawn	0 (0)	.04 (8)	0 (0)	.03 (5)	0 (0)	0 (0)
	Test	Noon	.03 (5)	.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)
		Dusk	.13 (20)	.03 (5)	0 (0)	0 (0)	0 (0)	0 (0)
		Midnight	.18 (28)	.03 (5)	0 (0)	0 (0)	0 (0)	0 (0)
		Dawn	.03 (5)	0 (0)	.07 (1)	0 (0)	0 (0)	0 (0)
Ephemerella	Control	Noon	.05 (10)	.02 (3)	.02 (4)	.03 (5)	.02 (3)	0 (0)
		Dusk	.75 (135)	.10 (18)	.14 (25)	.20 (35)	.15 (25)	.20 (35)
		Midnight	.67 (123)	.08 (15)	.07 (13)	.14 (25)	.13 (23)	.14 (25)
		Dawn	.14 (25)	.08 (15)	.13 (23)	.11 (20)	.03 (5)	.08 (15)
	Test	Noon	.02 (3)	.05 (8)	0 (0)	.06 (1)	.05 (1)	0 (0)
		Dusk	.56 (83)	.16 (23)	.07 (1)	.04 (1)	0 (0)	.27 (6)
		Midnight	.35 (55)	.12 (18)	0 (0)	0 (0)	0 (0)	.05 (1)
		Dawn	.12 (18)	.15 (23)	.07 (1)	0 (0)	0 (0)	0 (0)
Simulium	Control	Noon	.05 (10)	.05 (10)	.03 (5)	0 (0)	0 (0)	0 (0)
		Dusk	.08 (15)	.07 (13)	.13 (23)	.05 (8)	.11 (18)	.11 (20)
		Midnight	.03 (5)	.04 (8)	.07 (13)	.04 (8)	.03 (5)	.14 (25)
		Dawn	.02 (3)	.13 (25)	.05 (10)	0 (0)	.02 (3)	.03 (5)
	Test	Noon	.06 (3)	.06 (10)	.09 (2)	.06 (1)	0 (0)	0 (0)
		Dawn	.13 (20)	.16 (23)	.20 (3)	.04 (1)	0 (0)	0 (0)
		Midnight	.05 (8)	.10 (15)	0 (0)	0 (0)	0 (0)	0 (0)
		Dusk	.06 (10)	.03 (5)	.07 (1)	0 (0)	0 (0)	0 (0)

Table 34. Continued.

Organism	Channel	Time	Base Flow Period 88-89	95-96	Reduction Period 96-97	99-100	102-103	109-110
Other	Control	Noon	.03 (6)	0 (0)	.03 (5)	.02 (3)	0 (0)	.03 (6)
		Dusk	.19 (34)	.06 (11)	.09 (17)	.05 (8)	.10 (17)	.14 (25)
		Midnight	.09 (17)	.03 (6)	.03 (6)	.11 (20)	.08 (14)	.08 (14)
		Dawn	.07 (12)	.02 (3)	.03 (6)	.02 (3)	.06 (11)	.03 (6)
	Test	Noon	.09 (14)	.07 (11)	0 (0)	0 (0)	0 (0)	.16 (3)
		Dusk	.17 (25)	.09 (14)	.06 (1)	.08 (2)	.04 (1)	.22 (5)
		Midnight	.15 (24)	.14 (22)	.15 (2)	0 (0)	.05 (1)	.09 (2)
		Dawn	.13 (21)	.02 (3)	.07 (1)	.05 (1)	0 (0)	.15 (3)
Total	Control	Noon	.24 (44)	.11 (21)	.15 (28)	.06 (11)	.05 (8)	.06 (11)
		Dusk	2.29 (414)	.41 (72)	.84 (151)	.80 (139)	1.13 (188)	1.67 (295)
		Midnight	1.44 (265)	.42 (77)	.62 (120)	.51 (91)	.60 (105)	1.44 (260)
		Dawn	1.10 (195)	.68 (129)	.62 (112)	.84 (151)	.47 (89)	.66 (121)
	Test	Noon	.21 (33)	.30 (47)	.14 (3)	.12 (2)	.09 (2)	.37 (7)
		Dusk	1.52 (226	.85 (125)	4.13 (63)	2.55 (61)	1.91 (43)	2.34 (52)
		Midnight	1.59 (247)	.65 (100)	2.82 (38)	.91 (21)	.43 (9)	.72 (16)
		Dawn	1.84 (287)	.96 (144)	2.71 (40)	1.76 (32)	.27 (6)	.57 (11)

[a] Julian date.

APPENDIX D

INSECT DRIFT - SUMMER 1979

Table 35. Insect drift densities (no./m^3) and rates (no./hr), in parentheses, during the summer, 1979 (12 June-4 August) reduced streamflow test at Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon. Baseflow = 0.28 m^3/s, 2nd reduction = 0.06 m^3/s after fourth day of period. Control flow = 0.28 m^3/s 0.01 m^3/s after fourth day of final flow period. Downstream station.

Organism	Channel	Time	Base Flow Period		1st Reduction Period				2nd Reduction Period			
			180-181[a]	186-187	187-188	190-191	194-195	200-201	201-202	204-205	210-211	215-216
Cheumatopsyche	Control	Noon	ND	0 (0)	.02 (3)	ND	ND	.02 (3)	.02 (3)	.11 (6)	0 (0)	0 (0)
		Dusk	0 (0)	.04 (5)	0 (0)	.02 (3)	.03 (3)	.04 (5)	.10 (13)	1.27 (42)	0 (0)	0 (0)
		Midnight	.06 (8)	.14 (18)	0 (0)	.02 (3)	.10 (13)	.04 (5)	.02 (3)	.44 (15)	0 (0)	.26 (1)
		Dawn	.04 (5)	.02 (3)	.02 (3)	.04 (5)	0 (0)	.02 (3)	.13 (18)	.16 (5)	0 (0)	0 (0)
	Test	Noon	ND	.02 (3)	0 (0)	ND	ND	0 (0)	.04 (1)	0 (0)	0 (0)	0 (0)
		Dusk	0 (0)	0 (0)	.19 (13)	.04 (3)	.07 (5)	.18 (13)	1.30 (43)	.09 (3)	0 (0)	0 (0)
		Midnight	0 (0)	.05 (8)	.16 (10)	0 (0)	.04 (3)	0 (0)	.14 (5)	.26 (10)	0 (0)	.22 (1)
		Dawn	0 (0)	.24 (35)	.05 (3)	.08 (5)	0 (0)	.04 (3)	.11 (4)	.05 (2)	0 (0)	0 (0)
Hydropsyche	Control	Noon	ND	0 (0)	0 (0)	ND	ND	.07 (10)	.02 (3)	0 (0)	0 (0)	0 (0)
		Dusk	0 (0)	.02 (3)	0 (0)	.02 (3)	.04 (5)	.34 (45)	.27 (35)	1.15 (38)	0 (0)	.29 (1)
		Midnight	.10 (13)	.10 (13)	.02 (3)	.04 (5)	.22 (30)	.56 (80)	.68 (93)	.94 (32)	.26 (2)	0 (0)
		Dawn	0 (0)	0 (0)	0 (0)	0 (0)	.06 (8)	.41 (60)	.31 (43)	.16 (5)	0 (0)	0 (0)
	Test	Noon	ND	0 (0)	0 (0)	ND	ND	0 (0)	.33 (9)	.07 (2)	.11 (1)	0 (0)
		Dusk	0 (0)	0 (0)	0 (0)	0 (0)	.14 (10)	.05 (4)	.33 (11)	0 (0)	0 (0)	0 (0)
		Midnight	.11 (15)	.03 (5)	.08 (5)	.20 (13)	.22 (15)	.42 (28)	.63 (22)	.39 (15)	.11 (1)	.65 (3)
		Dawn	0 (0)	.06 (8)	0 (0)	.08 (5)	.04 (3)	.32 (23)	.20 (7)	.08 (3)	0 (0)	0 (0)
Rhithrogena	Control	Noon	ND	0 (0)	0 (0)	ND	ND	0 (0)	0 (0)	.02 (1)	0 (0)	0 (0)
		Dusk	.04 (5)	.04 (5)	0 (0)	.19 (25)	.16 (18)	.06 (8)	.24 (30)	.81 (27)	0 (0)	0 (0)
		Midnight	1.24 (165)	.31 (45)	.19 (25)	.34 (45)	.56 (75)	1.46 (208)	2.00 (275)	3.81 (130)	0 (0)	0 (0)
		Dawn	0 (0)	.02 (3)	0 (0)	0 (0)	.02 (3)	.03 (5)	0 (0)	0 (0)	0 (0)	0 (0)
	Test	Noon	ND	0 (0)	0 (0)	ND	ND	0 (0)	0 (0)	.04 (1)	0 (0)	0 (0)
		Dusk	.04 (5)	0 (0)	.07 (5)	.32 (23)	.11 (8)	.04 (3)	.72 (24)	.03 (1)	.19 (1)	0 (0)
		Midnight	1.21 (168)	.26 (40)	.70 (43)	.30 (20)	.15 (10)	1.13 (75)	3.06 (107)	1.60 (61)	0 (0)	.22 (1)
		Dawn	.06 (8)	.02 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.05 (2)	0 (0)	0 (0)
Ephemerella	Control	Noon	ND	.02 (3)	.04 (5)	ND	ND	.02 (3)	.01 (1)	0 (0)	.34 (4)	.11 (1)
		Dusk	0 (0)	.27 (33)	0 (0)	.17 (23)	.29 (33)	.15 (20)	.12 (15)	.42 (14)	0 (0)	0 (0)
		Midnight	.38 (50)	.27 (35)	.32 (43)	.21 (28)	.48 (65)	.35 (50)	1.08 (148)	6.41 (219)	.65 (5)	.26 (1)
		Dawn	.04 (5)	.07 (10)	0 (0)	.03 (3)	.06 (8)	.12 (18)	.13 (18)	.10 (3)	.18 (2)	.20 (1)
	Test	Noon	ND	.03 (5)	.04 (3)	ND	ND	0 (0)	0 (0)	.04 (1)	.33 (3)	0 (0)
		Dusk	0 (0)	.10 (15)	.15 (10)	.27 (20)	.04 (3)	.23 (17)	1.36 (45)	.24 (8)	.38 (2)	0 (0)
		Midnight	.43 (60)	.22 (33)	.78 (48)	.23 (15)	.33 (23)	.72 (48)	2.43 (85)	1.10 (42)	.53 (5)	0 (0)
		Dawn	.04 (5)	.09 (13)	0 (0)	.08 (5)	.07 (5)	.21 (15)	.03 (1)	.10 (4)	0 (0)	0 (0)

Table 35 . Continued.

Organism	Channel	Time	Base Flow Period		1st Reduction Period				2nd Reduction Period			
			180-181	186-187	187-188	190-191	194-195	200-201	201-202	204-205	210-211	215-216
Baetis	Control	Noon	ND	.75 (100)	.40 (53)	ND	ND	.44 (63)	.25 (30)	.37 (20)	0 (0)	0 (0)
		Dusk	.57 (70)	11.85 (1450)	7.47 (990)	5.68 (753)	6.77 (780)	4.21 (558)	3.45 (440)	3.17 (105)	0 (0)	0 (0)
		Midnight	1.49 (198)	12.52 (1595)	8.16 (1082)	6.83 (905)	9.25 (1245)	6.47 (923)	6.05 (833)	4.27 (146)	0 (0)	0 (0)
		Dawn	1.77 (235)	4.19 (590)	3.52 (485)	3.44 (403)	2.70 (353)	2.54 (368)	2.24 (305)	.71 (22)	.09 (1)	0 (0)
	Test	Noon	ND	.89 (135)	1.20 (83)	ND	ND	.37 (28)	.33 (9)	.25 (7)	0 (0)	0 (0)
		Dusk	.98 (120)	10.41 (1528)	27.33 (1843)	10.06 (733)	6.50 (455)	3.30 (242)	5.55 (184)	1.09 (36)	0 (0)	0 (0)
		Midnight	1.08 (150)	13.23 (2003)	39.36 (2408)	14.68 (973)	7.04 (485)	7.01 (465)	7.49 (262)	1.39 (53)	0 (0)	.22 (1)
		Dawn	1.20 (165)	5.31 (770)	5.39 (330)	2.75 (168)	1.85 (133)	2.02 (144)	.77 (27)	.42 (16)	0 (0)	0 (0)
Simulium	Control	Noon	ND	.30 (40)	.02 (3)	ND	ND	.18 (25)	.16 (20)	.82 (44)	0 (0)	0 (0)
		Dusk	.31 (38)	.78 (95)	.19 (25)	.53 (70)	.63 (73)	.68 (90)	.47 (60)	4.29 (142)	0 (0)	0 (0)
		Midnight	.32 (43)	.30 (38)	.23 (30)	.17 (23)	.56 (75)	.27 (38)	.47 (65)	1.87 (64)	0 (0)	0 (0)
		Dawn	.19 (25)	.25 (35)	.13 (18)	.07 (8)	.21 (28)	.31 (45)	.29 (40)	.77 (24)	0 (0)	0 (0)
	Test	Noon	ND	.15 (23)	.33 (23)	ND	ND	.13 (10)	.76 (21)	.07 (2)	0 (0)	0 (0)
		Dusk	.47 (58)	.43 (63)	1.33 (90)	.82 (60)	.43 (30)	.40 (29)	2.35 (78)	.78 (26)	0 (0)	0 (0)
		Midnight	.25 (35)	.28 (43)	.49 (30)	.12 (8)	.36 (25)	.27 (18)	.71 (25)	.29 (11)	0 (0)	0 (0)
		Dawn	.04 (5)	.34 (50)	.25 (15)	.21 (13)	.11 (8)	.74 (53)	.34 (12)	.29 (11)	0 (0)	0 (0)
Other	Control	Noon	ND	1.03 (136)	.29 (38)	ND	ND	.16 (23)	.21 (26)	.52 (28)	.26 (3)	0 (0)
		Dusk	1.04 (127)	2.50 (306)	.56 (75)	1.67 (222)	.98 (113)	1.14 (152)	1.13 (144)	1.45 (48)	.38 (4)	.29 (1)
		Midnight	.74 (98)	2.12 (271)	.74 (98)	1.01 (134)	1.19 (160)	1.62 (231)	2.36 (325)	4.92 (168)	1.57 (12)	1.53 (6)
		Dawn	1.41 (187)	1.04 (147)	.31 (43)	.71 (83)	.35 (46)	.79 (115)	.55 (76)	.90 (28)	.18 (2)	.20 (1)
	Test	Noon	ND	1.27 (192)	1.20 (83)	ND	ND	.10 (8)	.44 (12)	.58 (16)	.33 (3)	.15 (1)
		Dusk	1.04 (127)	1.12 (165)	2.28 (154)	2.89 (211)	1.10 (77)	.84 (62)	1.87 (62)	.78 (26)	.19 (1)	0 (0)
		Midnight	1.09 (151)	1.50 (227)	1.99 (122)	1.54 (102)	1.06 (73)	1.54 (102)	4.40 (154)	2.07 (79)	.63 (6)	.22 (1)
		Dawn	.70 (96)	1.85 (269)	1.08 (66)	1.32 (81)	.50 (36)	.92 (66)	.29 (10)	.52 (20)	.19 (2)	.43 (2)
Total	Control	Noon	ND	2.11 (279)	.77 (102)	ND	ND	.89 (127)	.68 (83)	1.85 (99)	.60 (7)	.11 (1)
		Dusk	1.96 (240)	15.51 (1897)	8.22 (1090)	8.29 (1099)	8.90 (1025)	6.62 (878)	5.78 (737)	12.55 (416)	.38 (4)	.58 (2)
		Midnight	4.34 (575)	15.77 (2010)	9.66 (1281)	8.62 (1143)	12.36 (1663)	10.75 (1535)	12.66 (1742)	22.66 (774)	2.43 (19)	2.04 (8)
		Dawn	3.45 (457)	5.60 (788)	3.99 (549)	4.28 (502)	3.42 (446)	4.24 (614)	3.65 (503)	2.79 (87)	.46 (5)	.41 (2)
	Test	Noon	ND	2.36 (358)	2.77 (192)	ND	ND	.60 (46)	1.89 (52)	1.05 (29)	.77 (7)	.15 (1)
		Dusk	2.53 (310)	12.06 (1771)	31.36 (2115)	14.40 (1050)	8.40 (588)	5.04 (370)	13.89 (447)	3.02 (100)	.77 (4)	0 (0)
		Midnight	4.18 (579)	15.58 (2359)	43.58 (2666)	17.07 (1131)	9.20 (634)	11.09 (736)	18.87 (660)	7.09 (271)	1.27 (12)	1.74 (8)
		Dawn	2.03 (279)	7.92 (1148)	6.77 (414)	4.53 (277)	2.57 (185)	4.26 (304)	1.74 (61)	1.52 (58)	.20 (2)	.44 (2)

[a] Julian date.

ND = No data.

APPENDIX E

DIEL DRIFT - SUMMER 1978

Aquatic invertebrates exhibit a distinct periodicity in their drift (Chaston 1968; Waters 1969). The effects of water level fluctuations on drift may be compounded if the timing of the discharge alterations coincide with periods of low drift activity. In 1978, a sampling of the daily drift into the experimental channels was made during the months June through September. This sampling consisted of a one-hour sample during each three hour period of a 24-hour day, starting at noon. All sampling was conducted at the upstream station of the east channel. Discharge ranged from 0.28 to 0.57 m^3/s (10-20 ft^3/s) between the various months, but was held steady during each daily sampling.

Drift activity was greatest during July and August (Figure 74). The high drift rates in July may reflect the declining flow, and a resultant decrease in wetted perimeter, of the Grande Ronde River. Discharge of the Grande Ronde River declined 2.83 m^3/s (100 ft^3/s) per day during this sample period (U.S. Geological Survey 1978). Although stonefly drift rates are usually quite low (M.A. Brusven, personal communication), an extremely high drift rate of *Isogenoides* (1,345/hr) was measured at midnight of the July sampling.

A typical diurnal pattern of drift exists in the Grande Ronde River. Lowest drift activity usually occurred during the daylight hours between 0900 and 1500 hours. Drift increased sharply with the onset of darkness in all months except June when increased drift activity began several hours before dusk. Heavy rains and cloud cover just prior to the 1800 hour sampling probably initiated this late afternoon drift activity. In June and July drift increased to a peak at midnight then declined throughout the remainder of the night. In August and September a bigeminus pattern of drift, with a high peak shortly after dark and a second, lower peak later at night, was evident.

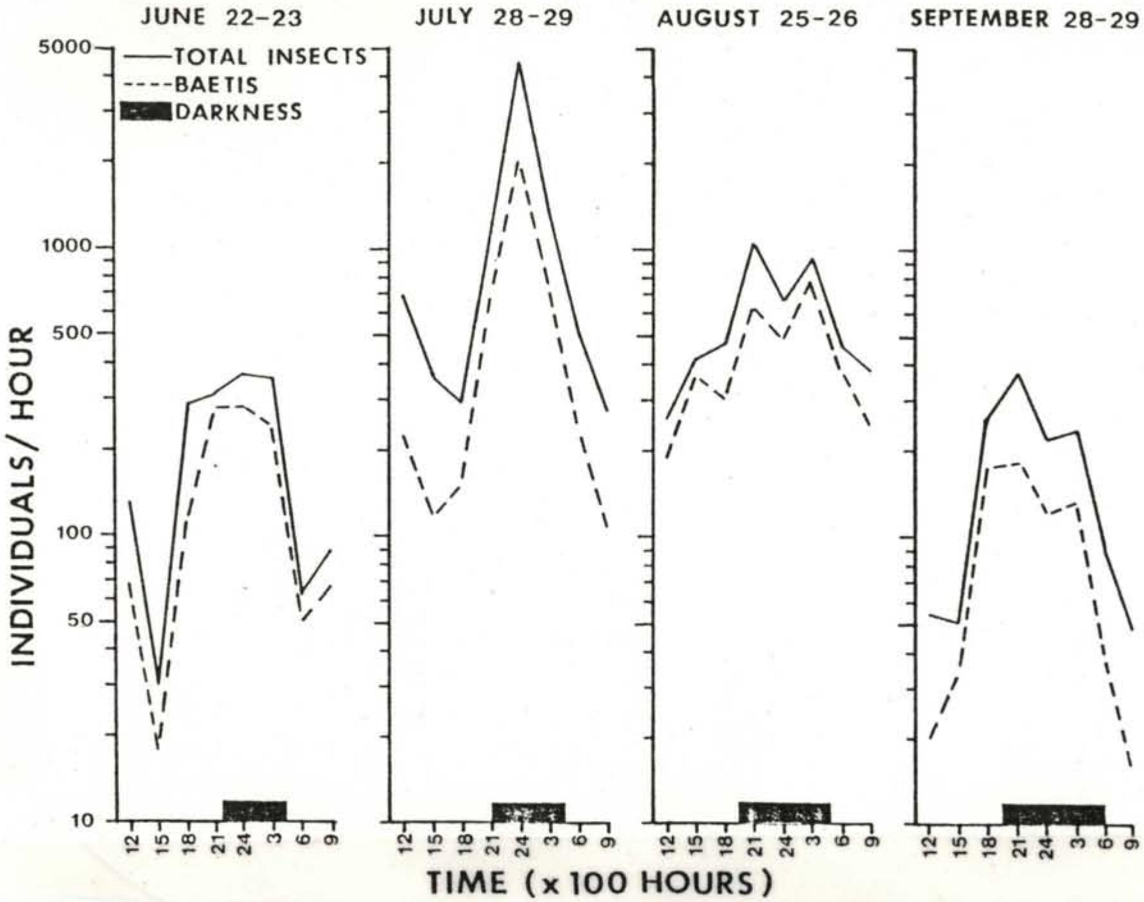

Figure 74. Diel drift (no/hr) of total insects, and the contribution of Baetis, entering the east channel, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, summer 1978.

The mayfly *Baetis* was the most common organism in the drift followed by the dipterans *Simulium* and Chironomidae (Table 36). *Baetis* drift resembled total drift in all months except August when *Baetis* displayed an alterans pattern (two peaks, second one highest). *Simulium* with a bigeminus pattern in June and August, but only one nighttime peak occurred in July and September. No clear patterns of drift were displayed by chironomid larvae. No other organisms were collected consistently enough to show drift patterns, though most were captured at night.

The most detrimental time to reduce streamflow, particularly in a stream where large changes in wetted perimeter would occur, would be in the mid-afternoon when drift activity is lowest. At that time invertebrates would most likely be stranded as water level declined. The best time to make flow reductions would be shortly after dusk or at night when drift activity is high. In our experiments, flow reductions were made during mid-morning hours when relatively few invertebrates were drifting. However, the likelihood of stranding was minimal in the channels.

Table 36. Diel drift (no/hr) of selected insects entering the experimental channels at Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon on June 22-23, July 28-29, August 25-26 and September 28-29, 1978.

		Time							
		1200	1500	1800	2100	2400	0300	0600	0900
Isogenoides	June					3	3		
	July				16	1345	58	1	
	August				3	15	10		
	September	1		3		3	2		
Chematopsyche	June								
	July	92	8	14	57		45	37	32
	August		3	1					
	September	1							1
Hydropsyche	June					3			3
	July					73	28	1	
	August				8	10	3	3	3
	September			3	2		3		
Rhithrogena	June					3			
	July	1			12	258	53		
	August					5	3		
	September	1		5	10	10	9		2
Heptagenia	June				3	3			
	July			1		33	13	1	
	August		3		10				3
	September			3	10	5	4	3	
Ephemerella	June	3				25		3	
	July				1	73	10		
	August			2					25
	September	18	15	38	148	60	68	35	13
Baetis	June	68	18	110	280	283	243	50	68
	July	225	118	154	712	2025	725	235	106
	August	188	353	299	615	485	768	380	248
	September	20	33	178	182	123	131	40	16
Paralepto-phlebia	June		3				10		
	July				2	35	13		1
	August				18	15	5		
	September				2	3		3	1
Simulium	June	8	5	20	13	10	15		8
	July	366	209	115	280	448	303	194	122
	August	65	55	159	368	130	145	60	95
	September	5	3	15	13	13	10	5	6
Chironomidae	June	50	3	138	15	10	48	10	8
	July	8	16	7	58	48	13	23	9
	August	5	5	7	5	5	3	20	3
	September	8		3	2		3	3	4
Total	June	132	29	281	311	365	354	63	90
	July	693	351	291	1144	4420	1292	492	270
	August	258	419	468	1045	668	937	463	380
	September	54	51	258	370	217	232	92	47

APPENDIX F

Table 37. Substrate codes used for hydraulic measurements and trout microhabitat studies during the reduced stream discharge experiments, Troy Instream Flow Research Facilities, Grande Ronde River, Wallowa County, Oregon, 1978-1979.

Code	Description	size range: inches	size range: mm
1	Plant detritus		
2	Mud		0 - 0.004
3	Silt		0.004 - 0.062
4	Sand	0.1	0.062 - 2.0
5	Gravel	0.1 - 1.5	2.0 - 64.0
6	Rubble	1.5 - 10.0	64.0 - 250.0
7	Boulder	10.0 - above	250.0 - above
8	Bedrock		

A mixture of two different (but adjacent) substrate types was described by the code. For example: if the substrate was 80% gravel (5) and 20% rubble (6), a value of 5.2 was used versus a value of 5.8 for a mixture of 20% gravel and 80% rubble.