Research Technical Completion Report

EFFECTS OF REDUCED STREAM DISCHARGE ON FISH AND AQUATIC MACROINVERTEBRATE POPULATIONS
PHASE II

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B-053-IDA

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U.S. Geological Survey
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TABLE OF CONTENTS

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ABSTRACT

Wild juvenile rainbow-steelhead trout responded to seasonal 95% reductions in discharge by emigrating from the test channel. An intermediate (50%) reduction in discharge during 1980 tests resulted in little change in number or biomass. Most emigration occurred during the first night following the 95% flow reduction and was predominantly upstream. Since aquatic insects drifted catastrophically during the 24 hours following flow reduction, habitat changes, rather than food limitation, are indicated as the causative factor.

Evaluation of changes in microhabit utilization by juvenile trout showed that mean fish depth increased slightly with flow but was similar between seasons. Mean facing velocity increased between the 0.03 m^3/s flow but was similar between the 0.28 m^3/s flow and the 0.57 m^3/s flow. Facing velocity was larger during the summer than the fall and may be related to increased standard metabolism and food demand at the slightly higher mean water temperature during this period. Juvenile rainbow-steelhead trout were closely associated with cover during summer and fall with the distance to cover decreasing with decreases in discharge. Evaluation of the relationship between cover density and trout abundance showed that greatest densities in the control channel (constant 0.57 m^3/s) were in the section with the highest cover density. When flows were reduced, however, the highest density shifted to the pool area which had no instream structural cover objects. This suggests that during reduced flow, pool depth was more important than the high density of structural objects in the run. These data point to the importance of habitat-component interactions.

We observed a poor relationship between facing velocity and the corresponding 0.6 depth velocity utilized in several predictive models. The 95% flow reduction resulted in no decrease in benthic insect density except during spring. However, numbers of *Baetis tricaudatus* were reduced in all experiments. Species diversity and insect functional groups showed little response to reduced flows. Moderate numbers of insects were stranded in the spring; most insects were stranded in the fall. Reduced flows had little effect on the hyporheic insect community.

In four of the five experiments the second flow reduction (0.28 to 0.03 m^3/s) caused catastrophic drift in the test channel with drift peaking at night. *Simulium* sp. and *Baetis tricaudatus* were the principle drift components. *Dicosmoecus* sp. migrated downstream in response to reduced stream discharge. Drift density two weeks following the 95% flow reduction was reduced.

An evaluation and critique of the 1978 version of the IFG4 model is provided.

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. However, a lack of reliable technical information for quantifying the flows required to protect instream values, and for predicting the biologic-hydrologic consequence of particular instream flow regimes remains a stumbling block to the accommodation process. Consequently, biologists must 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 physical and biological factors. Giger (1973) presented an extensive review of research dealing with the relationship between stream flow and aquatic life.

Several investigators have found correlations between physical habitat parameters and fish abundance and biomass in streams. 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. Verification of Wesche's cover rating systems as an indicator of standing crop trout [brown (*Salmo trutta*), brook (*Salvelinus fontinalis*), and rainbow (*Salmo gairdneri*)] was made by comparing biomass estimates and cover ratings in 11 study areas. 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. 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. These models were developed from data collected on streams in which fish populations were believed to be 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.

In the first phase of the present study, White et al. (1981) examined the response of juvenile rainbow-steelhead trout to flow related changes in habitat during spring, summer and fall. All flow reduction tests resulted in decreased numbers and biomass of juvenile rainbow-steelhead trout. Since availability of food organisms in the drift was not decreased substantially, except at the lowest discharges tested, juvenile rainbow-steelhead trout apparently responded to changes in physical habitat parameters rather than decreased food availability. Although the relationship between hydraulic parameters and response of experimental fish was examined, no single hydraulic parameter could consistently be related to the response of test fish. Changes in cover with decreased flow appeared to have a dominant influence on juvenile rainbow-steelhead trout habitat utilization.

Nelson (1980) found a good correlation between annual variation in the standing crop of adult trout and annual flow variation in reaches of the Madison, Beaverhead, Gallatin and Bighole rivers. For example, higher estimates of trout numbers and biomass were associated with years of higher daily average flow.

Verification of the habitat-standing crop relationship is particularly important for validation of currently used instream flow methodologies. This study was an unsuccessful attempt at this validation.

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.

An unregulated stream manifests a "continuum" of orderly physical and chemical changes. Headwaters typically have a high gradient, fast current and large rocky substrate. In the middle and lower reaches the gradient is reduced, current velocity is slower and mean substrate size is smaller. Typically, headwater reaches are cool, lower reaches warmer. Factors such as temperature, flow, depth, substrate, vegetation, dissolved substances, food and biotic interactions influence aquatic macroinvertebrate distribution and abundance (Hynes, 1970 and Ward and Stanford, 1979b). The "river continuum", however, may be disrupted by regulated downstream flow (Stanford and Ward, 1979).

Insect community changes as a result of controlled flows have been documented by numerous workers. Brusven et al. (1974) found that reduced flows and a subsequent dewatering of the Hell's Canyon reach of the Snake River caused exposure and death of aquatic invertebrates. They suggested that prolonged dewatering reduced primary production causing a lag in recolonization when conditions again became favorable. Kroger (1973) examined the Snake River below Jackson Lake, Wyoming and noted that rapid fluctuations left many insects stranded and dead. Trotsky and Gregory (1974) reported that extreme water level fluctuations on the Upper Kennebec River in Maine are limiting to most benthic invertebrates. Fisher and LaVoy (1972) reported that benthic invertebrate communities in exposed areas are lower in density and diversity than those areas which are continously flooded.

Spence and Hynes (1971) found large changes in the benthic community downstream from an impoundment. The number of species decreased; however, the density of some species increased while others were replaced by closely related ones. Changes in community composition were attributed to lower summer temperatures, a super abundance of epilithic algae and large numbers of plankton released from the reservoir.

In Colorado, Ward (1976) found low standing crops of aquatic insects but high diversity at unregulated stream sites. High standing crop at regulated sites was attributed to the presence of epilithic algae, angiosperms, hard water, high dissolved salts, low turbidity, reduced erosion and warm winter water temperature. In a similar study, Williams and Winget (1979) found that diversity remained constant, but the community composition changed from detrital feeders and shredders to algal scrapers, filter feeders and low-flow tolerant species. On the Green River in Wyoming, Pearson et al. (1968) found that insect diversity increased and density decreased progressively downstream from Flaming Gorge Dam.

Hynes (1970) stated that the more complex the substrate, the greater the invertebrate diversity and that certain insects have specific substrate preferences. Minshall and Minshall (1977) found that organisms in riffles were generally reduced or absent from pools. Williams (1980) noted increased diversity with increased substrate diversification. Cummins and Lauff (1969) examined 10 species of benthic invertebrates and found primary and secondary habitat selection on the basis of substrate particle size. Current velocity alters substrate composition, the associated insect community and invertebrate drift.

Drift is a daily occurrence in the life of many benthic invertebrates in streams. Current velocity is a major factor affecting diel periodicites (Waters 1969). Bailey (1966), Anderson and Lehmkull (1968) and Ciborowski et al. (1977) found that generally higher drift is associated with higher velocity. Pearson and Franklin (1968) reported that reduced discharge may have a devastating effect on insects, causing them to migrate toward the center of the stream. Minshall and Winger (1968) examined insect drift in response to reduced stream flow and noted marked increases; the stream width remained constant therefore drift must be triggered by reduced depth and/or velocity. Often, when conditions become so severe, invertebrates must retreat or die.

The hyporheic zone acts as a refuge from undesirable currents and temperatures (Hynes 1970) and provides a home for early instars (Ward and Stanford, 1979a). Hynes (1974), Williams and Hynes (1976), Williams (1977) and Brusven et al. (1979) demonstrated the ecological importance of the hyporheic zone as a reservoir for recolonization. Trotsky and Gregory (1974) found that insects suited to the hyporheic zone were much more abundant below a dam than above it. Poole and Stewart (1976) reported insect density was reduced on the streambed surface but more numerous in the hyporheic zone after a spate than before. Coleman and Hynes (1970) reported strikingly fewer organisms on the substrate surface than found in the same approximate area below the surface. Because of the importance of aquatic insects as food for fish, a better understanding of how these populations respond to reduction 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 second phase of this research effort by the Idaho Cooperative Fishery Research Unit to study the effects of reduced flows on fish and macroinvertebrate populations started in 1980.

The objectives of this study were:

1. To develop habit-standing crop functions for select fish and aquatic macroinvertebrate species by relating changes in distribution and abundance to flow associated changes in habitat (e.g. cover, depth, velocity, wetted perimeter, temperature and food).

2. To examine cover utilization by select fish species as related to water depth and velocity.

3. To establish relationships among the hydraulic parameters (e.g. discharge, velocities, depths, wetted perimeter, top width, etc.) for the existing channel configuration at the Troy facility for various discharges ranging from minimum flows up to discharges at which significant sediment movement is imminent.

4. To verify habitat-standing crop functions by using the hydraulic relationships and habitat functions developed during the study to design and construct a new channel configuration for which habitat changes will be maximum for given incremental changes in discharge.

5. To integrate habitat-standing crop functions into a predictive model incorporating both the independent and interactive effects of cover, depth, velocity, wetted perimeter, substrate, temperature, and food.

Although all objectives were addressed, a combination of technical difficulties and limitations of experimental channels resulted in our inability to adequately develop habitat-standing crop functions for rainbow-steelhead trout and aquatic insects. Without these functions we were also unable to develop the predictive model.

STUDY AREA

The Troy Experimental channels are located on the Grande Ronde River approximately 10 km southwest of Troy, Wallowa County, Oregon (Figure 1). The Grande Ronde River originates in Oregon's Blue Mountains, follows a northeasterly course and empties into the Snake River. The river valley is of volcanic origin and is underlain by Columbia River basalt (Laird 1964). [Water chemistry 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).] Summers are hot and dry while most of the 30 cm of annual precipitation falls in the spring and winter (Laird, 1964). Elevation at the experimental channels is 520 m above sea level.

Tests were conducted in two nearly identical channels, 62.3 m in length and 6 m in width (Figure 2). The channels were partially filled with river gravel and shaped to simulate a natural stream with a run-riffle configuratin. Each channel originally consisted of two 9.14 m riffles, two 12.2 m runs and was rectangular in cross section. The bottom width of the riffles was 3.0 m, and the runs 2.4 m. Cobbles (2.5 to 7.6 cm) formed the riffle substrate whereas the runs consisted of similar cobble and small (0.3m) boulders. The runs, however, soon became covered with fine particulate organic matter. Boulders (>0.3 m) were placed in runs to provide cover and resting areas for fish.

During the winter of 1980-81 the channels were reconstructed to maximize changes in wetted perimeter with each flow reduction (Figure 2).

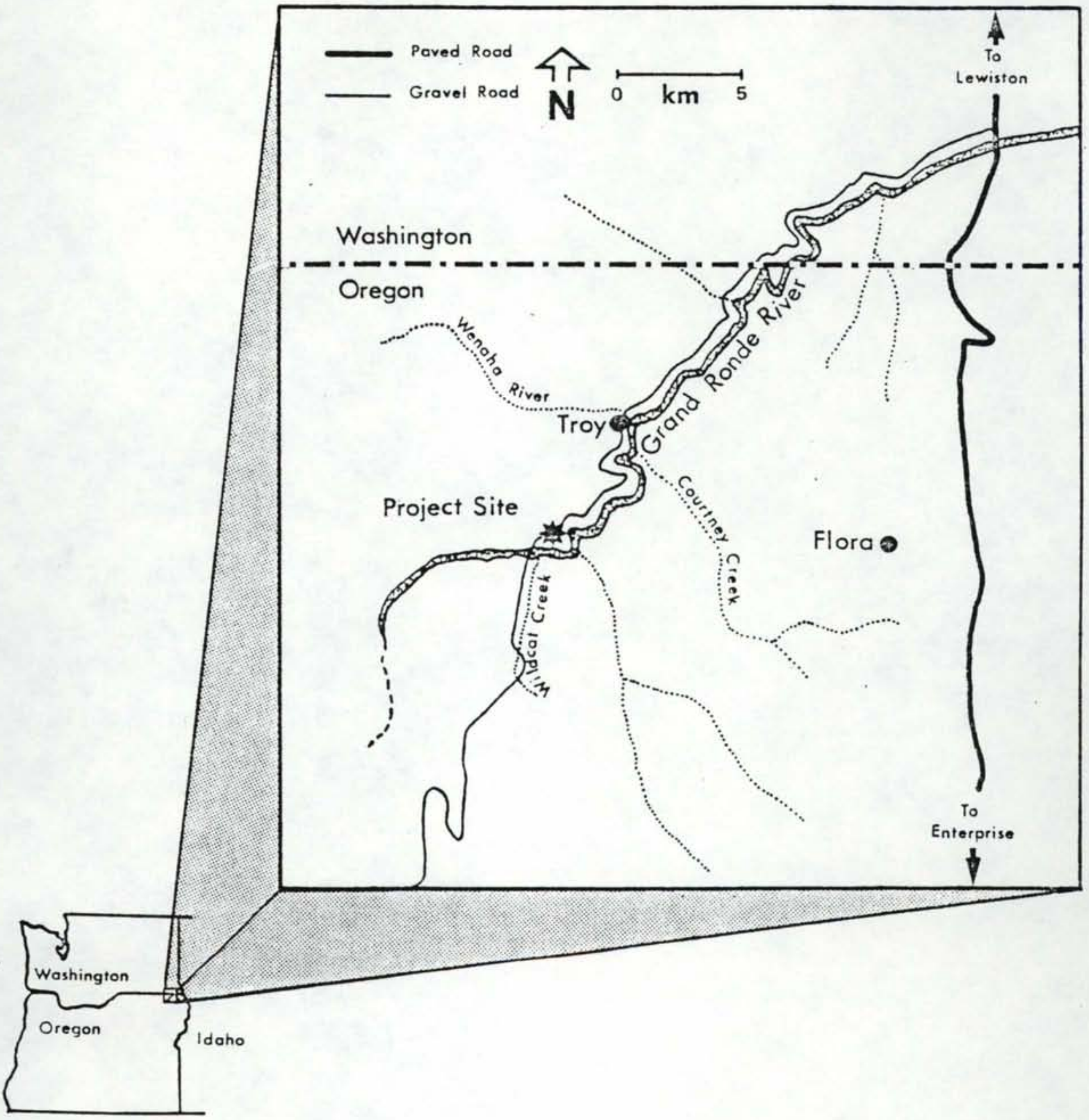

Figure 1. Location of the study area on the Grande Ronde River Troy, Oregon.

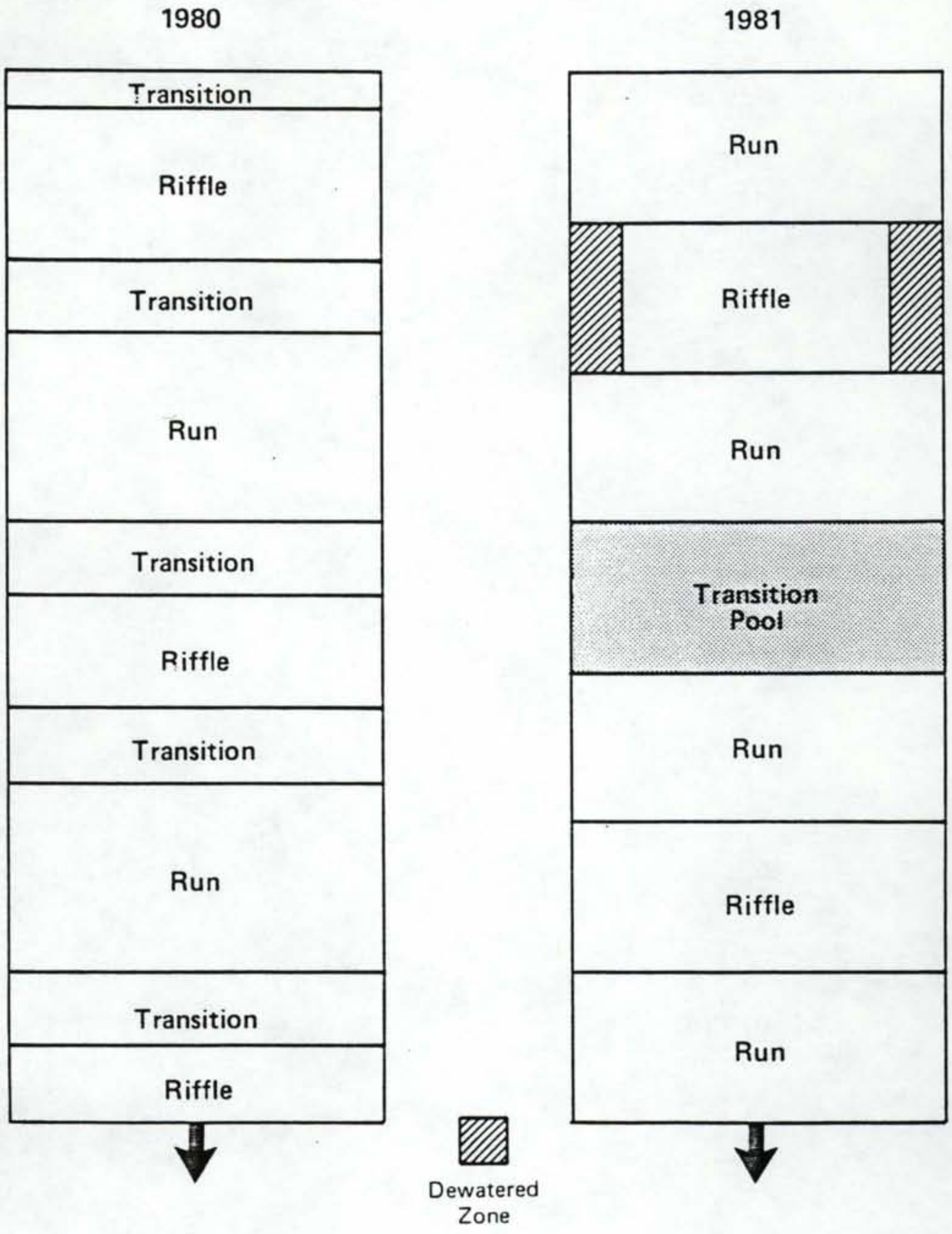

Figure 2. Configuration of Troy experimental channels, Troy, Oregon, 1980 and 1981.

This was accomplished by forming a v-shaped stream cross section. Within each channel two identical run-riffle-run reaches were built, the two separated by a transition pool (Figure 2). Each run and riffle was 10 m long. Weirs and fish traps were located at the upstream and downstream ends of the channels to monitor fish emigration.

Grande Ronde River water, diverted through a diked side channel, provided for up to 0.57 m^3/s flow in each test channel. 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.

METHODS

Six experiments were conducted during this study: spring 1980 8 April - 18 May), summer 1980 (3 June - 17 July), fall 1980 (16 August - 28 September), spring 1982 (9 April - 18 May), summer 1982 (12 June - 21 July) and fall 1982 (19 August - 15 September) as detailed in Table 1.

A base flow of 9.57 m^3/s was diverted into the test and control channels and juvenile rainbow - steelhead trout (Salmo gairdneri) were stocked. Fish used for stocking (Table 2) were obtained from Courtney Creek, Wildcat Creek or Mud Creek, all tributaries of the Grande Ronde River, (Figure 1) except in spring 1980 when juvenile steelhead from Dworshak NFH were used. Two to 4 days were required to collect experimental fish by electrofishing with a backpack electroshocker. Wild fish were transported to the channels in 30 gallon plastic containers, anesthetized with MS 222, fin clipped (adipose), measured (mm), weighed (g), allowed to recover from the anesthetic and stocked in the channels. Equal numbers of fish were placed at random in the test and control channels (Table 2). A record of daily discharge (cfs) from a gauging station on the Grande Ronde River at Troy, Oregon was obtained from the U.S. Geological Survey in Portland (Figure 3). Both high and low flows created technical difficulties.

Upstream and downstream traps were checked twice daily and emigrant fish were weighed and measured. Condition of trout was recorded as healthy, injured, diseased or dead. During the acclimation period, which lasted from 4 to 27 days (Table 1), emigrant trout were restocked. Following the acclimation period there was a stabilization period of 6

Table 1. Dates and flows from six experiments at the Troy channels, Troy, Oregon, 1980 and 1982.

Experiment	Flow Period	Dates	Control Channel Flow (m^3/s)	Test Channel Flow (m^3/s)	Percent Decrease
Spring 1980	Acclimation	8 Apr - 12 Apr	0.57	0.57	0
	Stabilization	13 Apr - 20 Apr	0.57	0.57	0
	Test	20 Apr - 18 May	0.57	0.03	95
Summer 1980	Acclimation	3 June - 11 June	0.57	0.57	0
	Stabilization	12 June - 18 June	0.57	0.57	0
	Test	19 June - 3 July	0.57	0.28	50
	Test	3 July - 17 July	0.57	0.03	95
Fall 1980	Acclimation	16 Aug - 24 Aug	0.57	0.57	0
	Stabilization	24 Aug - 31 Aug	0.57	0.57	0
	Test	31 Aug - 14 Sep	0.57	0.28	50
	Test	14 Sep - 28 Sep	0.57	0.03	95
Spring 1982	Acclimation	9 Apr - 19 Apr	0.57	0.57	0
	Stabilization	20 Apr - 3 May	0.57	0.57	0
	Test	4 May - 18 May	0.57	0.03	95
Summer 1982	Acclimation	12 June - 8 July	0.57	0.57	0
	Stabilization	9 July - 15 July	0.57	0.57	0
	Test	16 July - 21 July	0.57	0.03	95
Fall 1982	Acclimation	19 Aug - 24 Aug	0.57	0.57	0
	Stabilization	25 Aug - 31 Aug	0.57	0.57	0
	Test	1 Sep - 15 Sep	0.57	0.03	95

Table 2. Number of experimental fish (*Salmo gairdneri*) stocked, known mortalities (%) and number accountable in the test and control channels from the spring, summer and fall 1980 and 1982 experiments, Troy channels, Troy, Oregon.

	Number Fish Stocked	Known Mortalities (%)	Number Accountable (%)
Spring 1980			
Test	350	40 (11.4)	240 (69)
Control	350	32 (9.1)	296 (85)
Summer 1980			
Test	135	9 (6.7)	111 (82)
Control	135	8 (5.9)	105 (78)
Fall 1980			
Test	141	9 (6.4)	118 (84)
Control	141	6 (4.3)	104 (74)
Spring 1982			
Test	147	5 (3.4)	80 (54)
Control	146	5 (3.4)	62 (42)
Summer 1982			
Test	150	15 (10.0)	105 (70)
Control	150	2 (1.3)	136 (91)
Fall 1982			
Test	150	8 (5.3)	133 (89)
Control	151	35 (23.2)	126 (84)

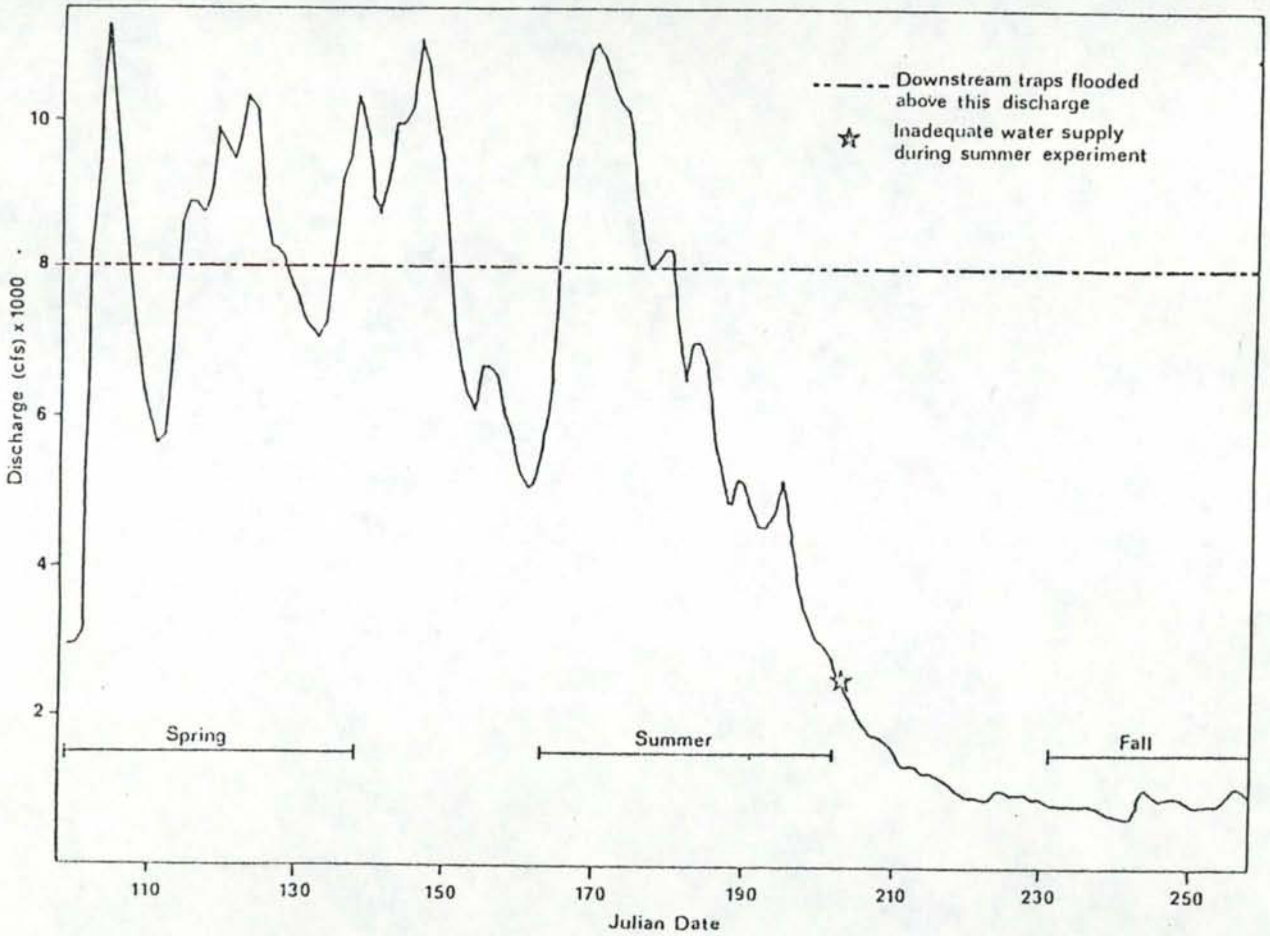

Figure 3. Daily discharge (cfs) from the Grande Ronde River at Troy, Oregon, 1982. Also shown are flow limitations during the spring and summer experiments.

to 14 days. Stabilization was followed by a test period of 7 to 28 days. At the onset of the test period, flows in the test channel were reduced from 0.57 m^3/s to 0.28 m^3/s in equal increments over a 3 hour period. During the stabilization and test period, all emigrant trout were removed from their respective channels and returned to the stream of origin. Upon completion of each, we electroshocked the channels to determine number of fish remaining and, in 1982, to determine habitat utilization. Immigration of non-stocked fish was prevented from a downstream direction by the trap structures; non-stocked fish could enter the channel from the upstream end.

In an attempt to develop habitat-standing crop functions for juvenile rainbow-steelhead trout we related changes in distribution and abundance to flow associated changes in habitat. Snorkeling observations were made to evaluate habitat utilization during summer and fall 1980 at discharges of 0.57 m^3/s, 0.28 m^3/s, and 0.03 m^3/s. This technique was also utilized during fall 1979 to observe a natural population of juvenile rainbow-steelhead trout in Wildcat Creek at flows between 0.09 and 0.12 m^3/s. Fish locations were characterized by measuring the distance the fish was above the substrate and total depth at this location, distance to nearest cover object, distance to nearest conspecific within view, surface turbulence above fish (0 = no turbulence, 1 = intermediate turbulence and 3 = foamy water), associated substrate and habitat type (riffle, run, pool, transition). Surface, bottom, 0.6 depth, and facing velocity associated with the observed fish were recorded. Velocity at fish locations was also measured at 0.03 m increments for total depths less than or equal to 0.34 m or every 0.06 m for total depths greater than 0.34 m.

To assess the relationship between fish density and instream cover, we placed artificial cover blocks in the channels during the 1982 experiments. Cover blocks were placed only in the runs (Figure 4). Two densities of cover blocks were used, 7 cover blocks in two runs (low density) and 28 cover blocks (high density) in each of the remaining two runs. Placement of cover densities was stratified so that high and low cover densities were represented both below a riffle and below a pool. High density cover in run (C) was below riffle (B) and low density cover in run (G) was below riffle (F). High density cover in run (E) was below the central pool (D) and low density cover in run (A) was below the pool of water that supplied the channels. Cover blocks were arranged to maximize visual isolation of experimental fish from each other (Figure 4). Artificial cover objects placed in the channels were concrete cinder blocks (20 cm x 20 cm x 40 cm) whose openings were filled with "sac-crete", a commercial ready mix concrete. Prior to filling the cinder block openings with "sac-crete", a metal rebar handle was placed in the openings. The handle allowed for easy movement and placement of the cover blocks.

To facilitate the capture of experimental fish in each of the habitat types (riffles, runs and central pool), block nets were constructed. Block nets were installed at the downstream end of habitat sections A-G (Figure 4). Rectangular wooden boxes, open at the top, were imbedded in the channels, flush with the gravel/cobble substrate and perpendicular to the current. The dimensions of the boxes were approximately 10 cm wide by 20 cm high by 6 m long. On the downstream edge of each box, a 6 mm mesh seine (1.3 m x 6 m) was secured. The seine was secured to the box by placing a strip of plastic molding over

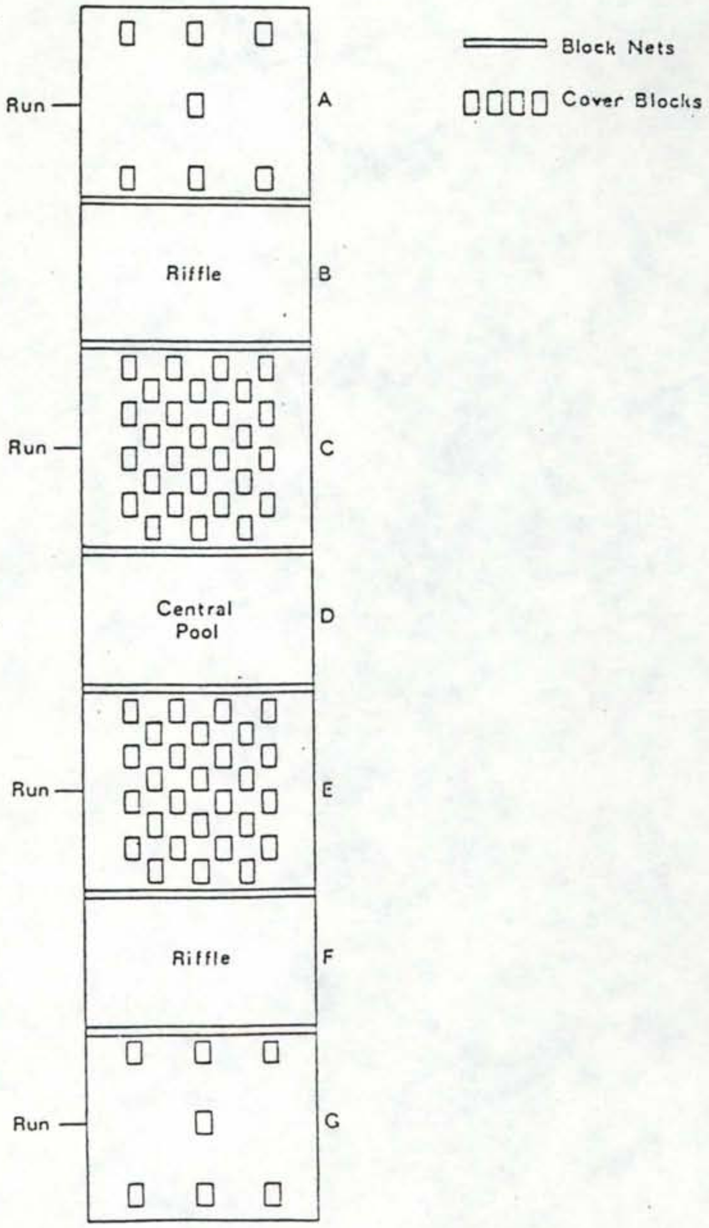

Figure 4. Schematic diagram of an experimental channel showing cover blocks, block nets, habitat types (run, riffle and pool) and sections A-G at the Troy channels, Troy, Oregon.

the edge of the seine and tacking it to the box. The net was then accordionpleated in the wooden box with a rope attached to each of the two top corners of the net. The ropes were secured directly above the nets, outside the channel. Prior to electrofishing, the nets were lifted from outside the channels to avoid spooking the fish. The remaining fish were then electroshocked from habitat sections A-G, weighed, measured and returned to either Courtney creek or Wildcat Creek.

Spring 1980 Experiment

Juvenile hatchery steelhead trout were used in the spring 1980 experiment (Table 1). A total of 350 juvenile steelhead were stocked in each channel on the first day of the experiment. Experimental fish ranged in length from 70 to 159 mm, but most were between 90 and 112 mm (Figure 5). The base flow level of 0.57 m^3/s was maintained in both channels for 12 days, of which the first 4.5 days comprised the acclimation period followed by a 7.5 day stabilization period (Table 3). One reduced flow level was tested (0.03 m^3/s) over a four week period.

Summer 1980 Experiment

The summer 1980 experiment was conducted during June and July (Table 1). One hundred thirty-five rainbow-steelhead trout from Wildcat Creek were stocked in each channel during the first four days of the experiment. Experimental fish ranged in length from 80 to 280 mm, but most were between 113 and 144 mm (Figure 6). Total biomass stocked was slightly larger in the control channel (Table 3). The base flow level used for this experiment was 0.57 m^3/s (Table 1). This flow was maintained in both channels for 16 days, of which the first 8 days comprised the acclimation period followed by an 8 day stabilization

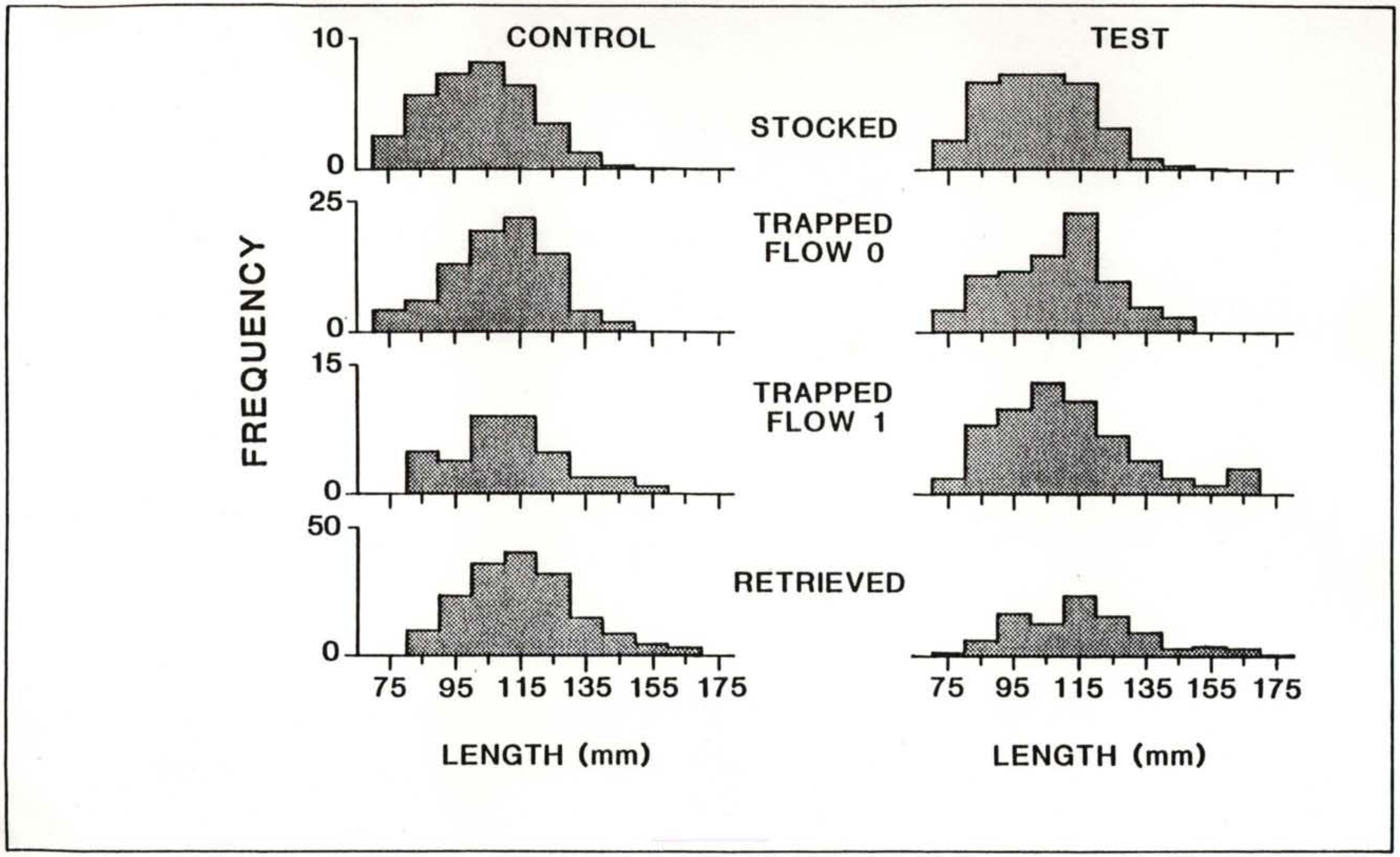

Figure 5. Length frequency histograms of stocked, trapped, and retrieved steelhead trout (*Salmo gairdneri*) during the spring 1980 reduced stream discharge experiment, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

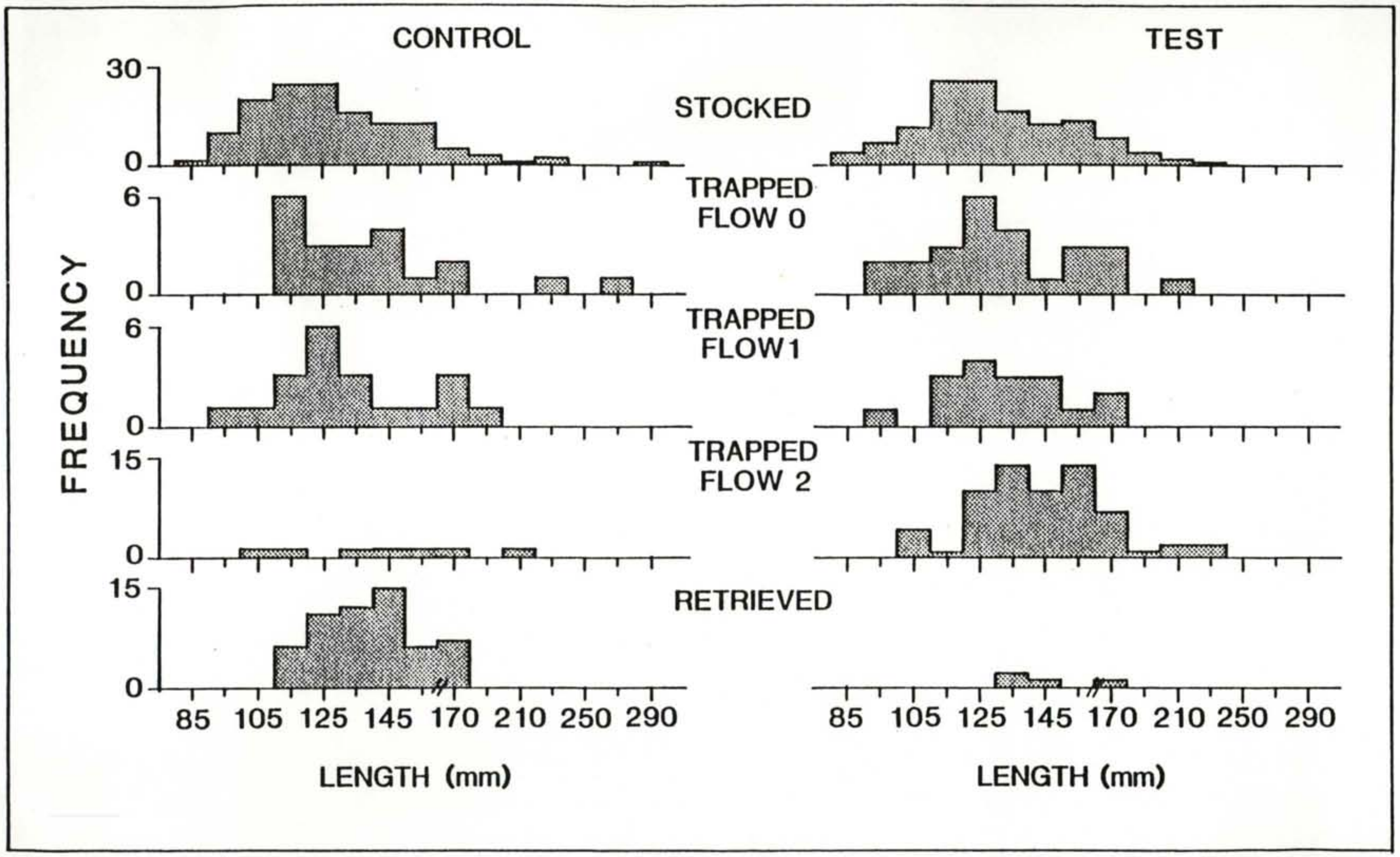

Figure 6. Length frequency histograms of stocked, trapped, and retrieved rainbow-steelhead trout (*Salmo gairdneri*) during the summer 1980 reduced stream discharge experiment, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

period. Two reduced flow levels were tested (0.28 m^3/s and 0.03 m^3/s). Each reduced flow period lasted 2 weeks.

Fall 1980 Experiment

The fall 1980 experiment was conducted during August and September (Table 1). Rainbow-steelhead trout from Mud Creek, a nearby tributary of the Grande Ronde River (Figure 1), were stocked during the first 2 days of the experiment (Table 1). A total of 141 trout were stocked in each channel. Experimental fish ranged in size from 71 to 264 mm but most were between 117 and 168 mm (Figure 7). A larger biomass of trout was stocked in the test channel during this experiment (Table 3) A base flow of 0.57 m^3/s was maintained in both channels for 15 days. The first eight days comprised the acclimation period followed by a seven day stabilization period (Table 1). Two, two-week reduced flow tests (0.28 m^3/s and 0.03 m^3/s) were conducted during the experiment.

Spring 1982 Experiment

The spring 1982 experiment was conducted during April - May (Table 1) and experimental fish were obtained from Courtney Creek. From 5-8 April, we stocked 147 and 146 fish in the test and control channels, respectively (Table 2). Size range of fish was 76 - 194 mm but most were from 80 - 120 mm (Figure 8). Mean length of experimental fish in the test and control channel was 110.3 mm and 106.7 mm, respectively (Table 4). Total biomass of stocked fish was similar in both channels with slightly more biomass in the test channels (Table 3).

Extreme water levels in the Grande Ronde River created a series of technical problems. At the onset of the spring experiment minimum flows in the Grande Ronde River prevented maintenance of the desired base flow of 0.57 m^3/s. On 12 April, three days into the experiment, a

Table 3. Total biomass (g) of rainbow-steelhead trout (*Salmo gairdneri*) stocked, trapped, and retrieved during the spring, summer and fall 1980 and 1982 experiments, Troy channels, Troy, Oregon.

	Fish Biomass					
	Spring		Summer		Fall	
	Test	Control	Test	Control	Test	Control
1980						
Stocked	3834	3836	3054	3066	4636	4400
Trapped						
$0.57m^3/s$	1010	1045	615	724	873	534
$0.18m^3/s$	--	--	392	483	591	43
$0.03m^3/s$	816	469	2086	216	1350	160
Retrieved	1447	2632	127	1453	1274	2737
1982						
Stocked	2172	1947	1282	2659	2543	2596
Trapped						
$0.57\ m^3/s$	321	43	195	134	357	340
$0.03\ m^3/s$	1124	198	1043	68	1190	186
Retrieved	122	922	318	2576	711	1479

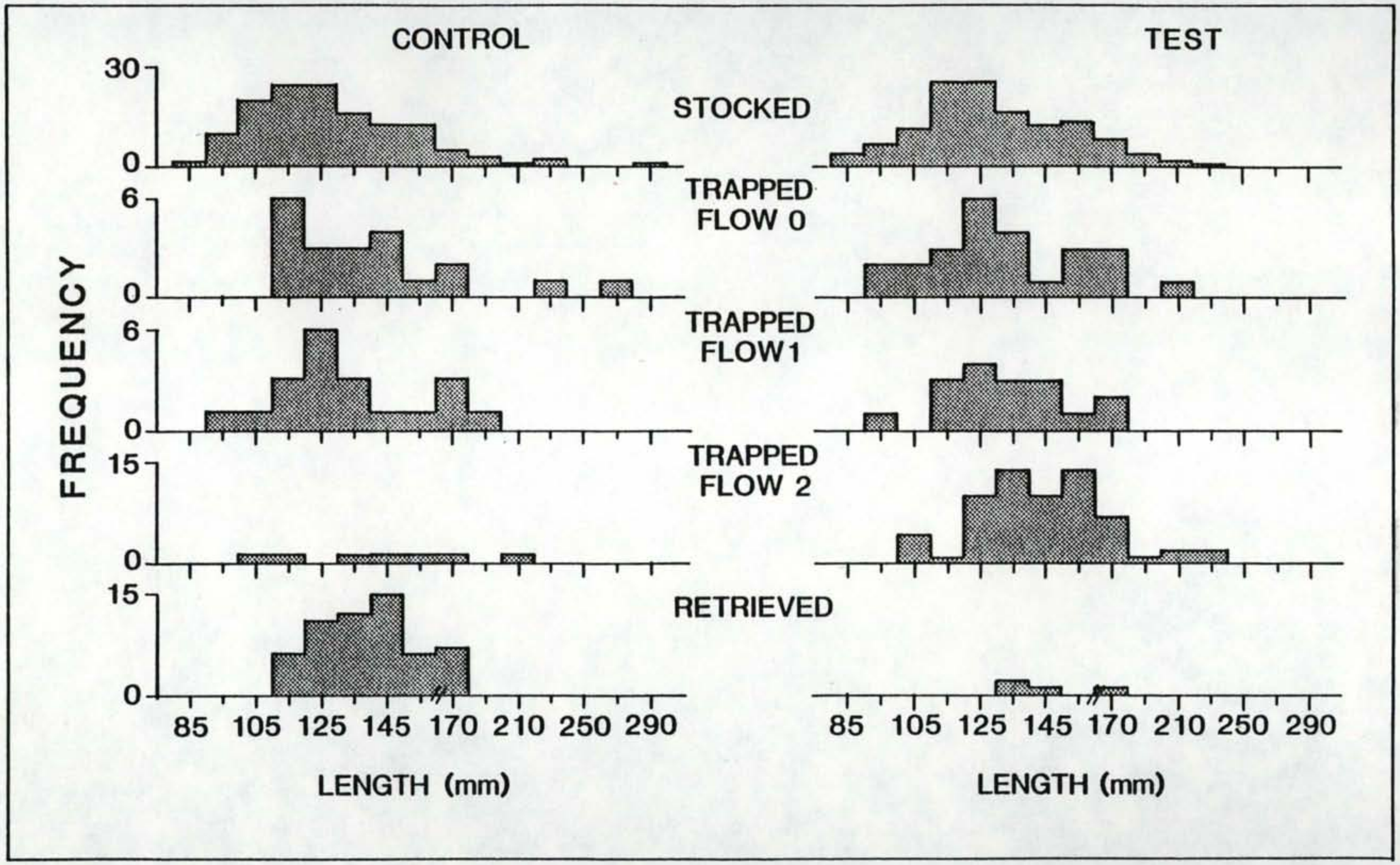

Figure 7. Length frequency histograms of stocked, trapped, and retrieved rainbow-steelhead trout (*Salmo gairdneri*) during the summer 1980 reduced stream discharge experiment, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

hard rain caused the Grande Ronde River to rise overnight from 3200 cfs to 8300 cfs. Discharge greater than 8,000 cfs caused the Grande Ronde to backflow into the channels, disrupt the desired hydraulic properties and create, in effect, a large pond. In addition, flows greater than 8,000 cfs flooded the downstream traps such that they could not be checked (Figure 3). The storm of 12 April flushed large amounts of organic debris into the channels and caused tremendous pressure to build up on the downstream traps. To relieve this pressure, it was necessary to reduce flows into the channels from 0.57 m^3/s to 0.28 m^3/s. Discharge greater than 8000 cfs persisted until 17 April when lower, cleaner flows allowed the checking of the downstream traps and re-establishing a base flow of 0.57 m^3/s. This discharge extended the acclimation period to 19 April at which point a scheduled seven day stabilization period began. On 24 April, discharge in the Grande Ronde River again exceeded 8000 cfs, backflowed into the channels and prevented the checking of the downstream traps (Figure 3). High flows persisted and on 3 May it was decided to reduce flows in the test channel rather than abort the experiment. First, however, it was necessary to remove any fish from the downstream traps which were still submerged. To accomplish this the downstream traps were sealed with block nets and electrofishing was done in and around the traps. Extreme turbidity and subsequent low visibility (0.3 m) caused the questioning of success of this endeavor. On 3 May flows were reduced and a two week test period began. During the test period the only time the downstream traps could be checked was 9-14 May (Figure 3). Electrofishing the downstream trap was difficult due to high turbidity and almost zero visibility. On 15 May, Grande Ronde River discharge was 8100 cfs and increased throughout the remainder of the spring experiment. On 18 May the block nets were pulled and the remaining fish were electroshocked. Each habitat section was shocked until three consecutive unsuccessful passes were made, however, backflows and low visibility again hampered our efforts.

Summer 1982 Experiment

The second experiment was conducted during June-July (Table 1). Experimental fish were obtained from Wildcat Creek. During 9-11 June 150 fish were stocked in both the test and control channel (Table 2). Experimental fish ranged in size from 76-168 mm but most were from 85-125 mm (Figure 3). Mean length of stocked fish in the test and control channel was 110.6 mm and 114.2 mm, respectively (Table 4). Total biomass of stocked fish was similar in both channels with slightly more biomass in the control channel (Table 3). There was a moderate increase in mean water temperature throughout the experiment but differences between the test and control channel were insignificant.

Three days after stocking was completed, Grande Ronde River discharge exceeded 8,000 cfs and remained this way until 28 June. This sudden and unexpected rise in discharge was caused by unseasonably hot weather which melted the remaining snowpack rapidly. Since it was not possible to check the downstream traps during the high flow period, the scheduled seven day acclimation period was extended to 8 July. The stabilization period lasted seven days, as scheduled. However, the scheduled two week test period lasted only six days (Table 1) because of reduced discharge in the Grande Ronde River which proved inadequate to maintain flows into the channels (Figure 3).

Fall 1982 Experiment

The diversion channel was dredged between the summer and fall experiments to provide the experimental channels with an adequate supply of water. The fall experiment was conducted during August - September and fish were obtained from Wildcat Creek. On 17 and 18 August 150 and 151 fish were stocked in the test and control channels, respectively (Table 2). Fish ranged in size from 80-192 mm but most were from 95-125 mm (Figure 8). Mean length of stocked fish was 120.4 mm and 122.7 mm in the test and control channels, respectively (Table 4). Total biomass of stocked fish was nearly identical in the test and control channels (Table 3). Mean water temperature decreased throughout the fall experiment.

The fall experiment was not hampered by high or low flows in the Grande Ronde River and went according to schedule. The seven day acclimation period was followed by the seven day stabilization period which was in turn followed by the two week test period (Table 1).

Numerical Analysis

Due to a lack of experimental replicates, data analysis was astatistical. Length frequency, mean length, mean weight and numbers of stocked fish were examined for each of the experiments. Total and cumulative number of fish emigrating and number of fish trapped upstream and downstream were examined also. Length frequency, mean length, total biomass and number of fish remaining at the end of the experiment was also counted. Habitat utilization was evaluated which involved the relationship between fish density and mean depth (m), mean velocity (cm/s) and cover for each of the habitat sections A - G in the test and control channels.

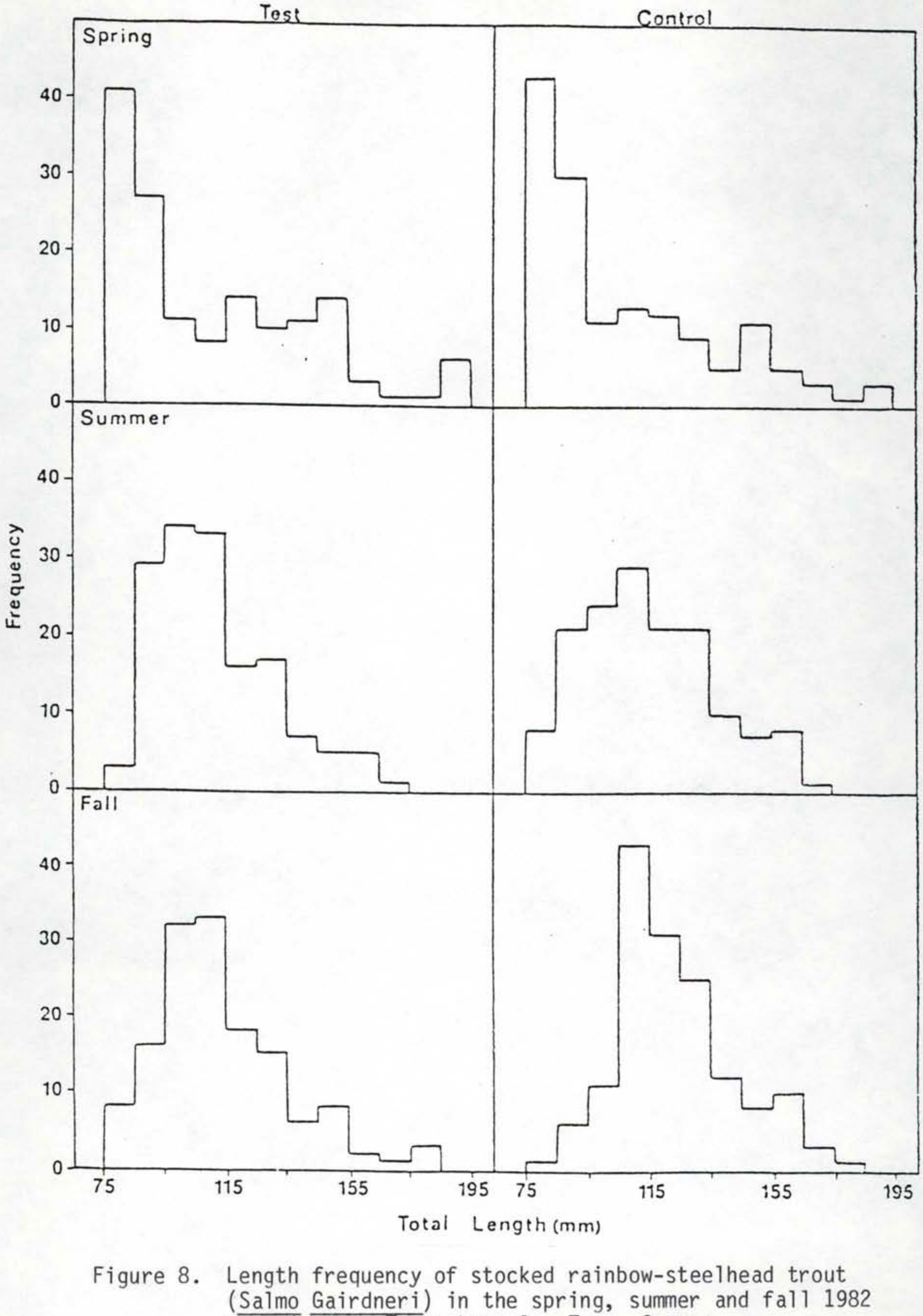

Figure 8. Length frequency of stocked rainbow-steelhead trout (Salmo Gairdneri) in the spring, summer and fall 1982 experiments, Troy channels, Troy, Oregon.

Table 4. Mean length (mm) and weight (g) of rainbow steelhead trout (*Salmo gairdneri*) stocked, trapped and retrieved during the spring, summer and fall 1982 experiments, Troy channels, Troy, Oregon.

	Mean Length (mm)					
	Spring		Summer		Fall	
	Test	Control	Test	Control	Test	Control
Stocked	110.3	106.7	110.6	114.2	120.4	122.7
Trapped						
$0.57 m^3/s$	126.9	105.8	128.4	132.0	122.1	131.3
$0.03 m^3/s$	124.6	152.5	120.7	122.5	122.2	132.3
Retrieved	121.0	122.3	118.7	124.6	123.4	126.8

	Mean Weight (g)					
	Spring		Summer		Fall	
	Test	Control	Test	Control	Test	Control
Stocked	14.8	13.3	15.9	17.7	17.0	17.2
Trapped						
$0.57 m^3/s$	22.9	10.7	19.5	22.4	17.0	21.3
$0.03 m^3/s$	20.8	33.0	17.4	17.1	18.0	23.2
Retrieved	20.3	20.5	15.9	20.8	18.7	22.1

RESULTS

Spring 1980 Experiment

Although more hatchery trout emigrated from the test channel during the single reduced flow period (0.57 m^3/s to 0.03 m^3/s) than from the control channel (Figure 9) the overall response to test conditions was small. Most of the trout which emigrated from the test channel did so during the last 4-5 days of the experiment. Prior to that time the number emigrating from each channel was approximately equal.

Total biomass of trout emigrating from each channel exhibited patterns similar to individual emigration (Table 3). However, the biomass which emigrated from the test channel appeared to be proportionally larger than from the control channel when compared to individual numbers (Table 3, Figure 10). This difference was probably due to a greater proportion of larger trout (150+ mm) emigrating out of the test channel than the control channel during the reduced flow period (Figure 5).

The total number of trout retrieved was 174 and 96 from the control and test channels, respectively. Biomass of trout remaining in the control channel was 1.7 times larger than the biomass of trout in the test channel (Table 3). The total number of trout accounted for (trapped and retrieved) was 240 and 296 or 69% and 85% of the original number stocked in the control and test channels, respectively (Table 2).

During the reduced flow period more healthy trout migrated in the upstream direction in both channels. There was an apparent effect of flow reduction on the direction of emigration when comparing the two channels, as the test channel trout appeared to move more in the upstream direction as compared to the control channel.

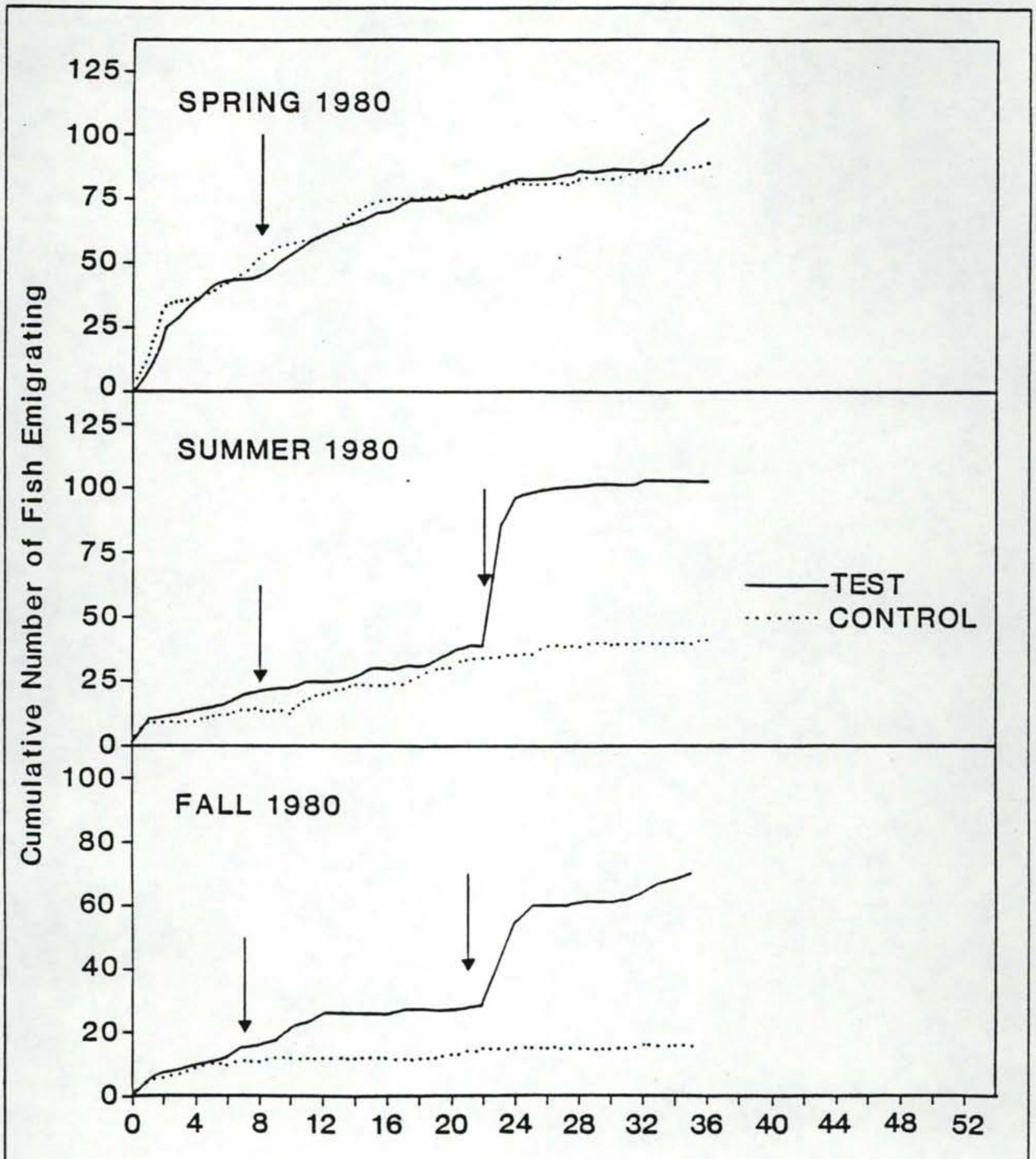

Figure 9. Cumulative number of stocked rainbow-steelhead trout (Salmo gairdneri) trapped by day in the test and control channels during the 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. Vertical arrows indicate flow reduction(s) in the test channel. Day 0 is the start of the stabilization period.

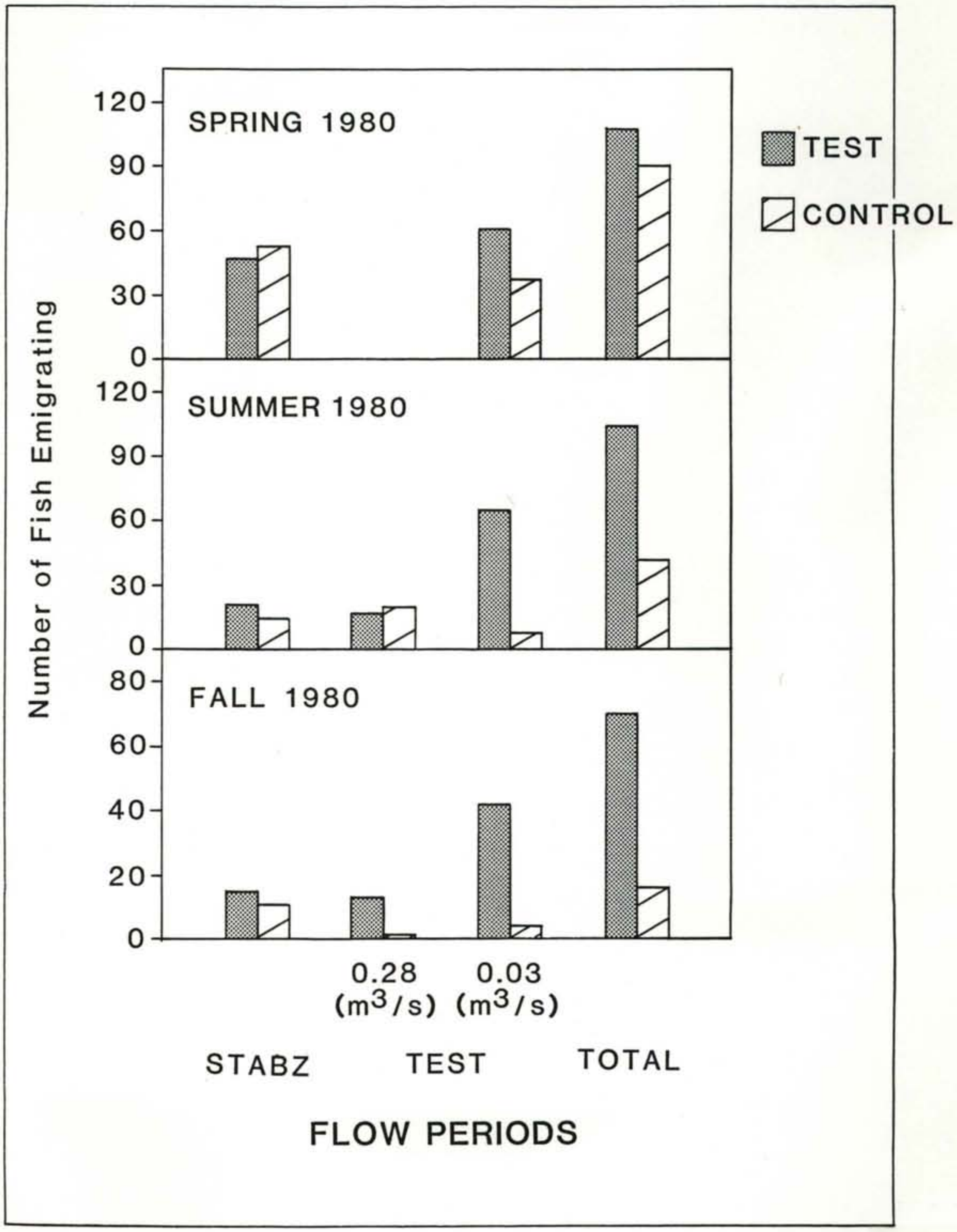

Figure 10. Number of stocked rainbow-steelhead trout (Salmo gairdneri) emigrating from the test and control channels during the stabilization (STABZ), test, and total flow periods, 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

Summer 1980 Experiment

More stocked wild trout emigrated from the test channel than the control channel during the second reduced flow period (0.03 m^3/s) (Figure 10). A large proportion of emigrating trout left the test channel during the 24 hour period immediately following the flow reduction (Figure 9). There was no detectable emigration response to the first flow reduction (0.57 m^3/s to 0.28 m^3/s) (Figures 9 and 10).

Total biomass of trout migrating from each channel exhibited patterns similar to individual emigration (Table 3). The total number of trout retrieved was 57 and 4 from the control test channels, respectively. Biomass of trout remaining in the control channel was 11.4 times as great as the biomass of trout in the test channel (Table 3). The total number of trout accounted for (trapped and retrieved) was 111 and 105 or 82% and 78% of the original number stocked in the control and test channels, respectively (Table 2).

Migration of stocked trout was predominately in the upstream direction in both channels throughout the experiment, with an apparent increase in the proportion of upstream migrants in the test channel as flow was reduced.

Fall 1980 Experiment

More juvenile rainbow-steelhead trout emigrated from the test channel during both reduced flow periods (0.57 m^3/s to 0.28 m^3/s, then to 0.03 m^3/s) than from the control channel (Figure 9). The response of trout to flow reduction was greater for the second reduced flow period (0.03 m^3/s) as compared to the first flow reduction (to 0.28 m^3/s). As in the summer 1980 experiment, a large proportion of the trout which emigrated from the test channel during the second reduced flow period did so during the 24 hour period immediately following the flow reduction (Figure 9). The total biomass of trout migrating out of each channel exhibited patterns similar to individual emigration (Table 3).

The number of trout retrieved was 82 and 35 from the control and test channels, respectively. Biomass of trout remaining in the control channel was 2.1 times larger than biomass of trout in the test channel (Table 3). The total number of trout accounted for (trapped and retrieved) was 118 and 104 or 84% and 74% of the original number stocked in the control and test channels, respectively (Table 2). Migration was predominately in the upstream direction in both channels throughout the experiment.

Spring 1982 Experiment

Reduced stream flows in the spring experiment (Table 1) resulted in more fish emigrating from the test channel than from the unregulated control channel (Figure 11). Following the flow reduction, the rate of emigration was quite sudden (Figure 12). Eleven fish emigrated the afternoon of the reduction and 20 fish moved that night. Thereafter, the rate of emigration was slow but uniform. Most emigrant fish in the test channel moved in an upstream direction (Figure 13). Total biomass of emigrating fish in the test period was 1124 g and 198 g in the test and control channels, respectively (Table 3). Mean length and weight of fish emigrating during the low flow period was considerably greater in the control channel. Numbers of emigrating fish, dead fish and fish retrieved at the end of the experiment accounted for 54% and 42% of fish originally stocked in the test and control channels, respectively

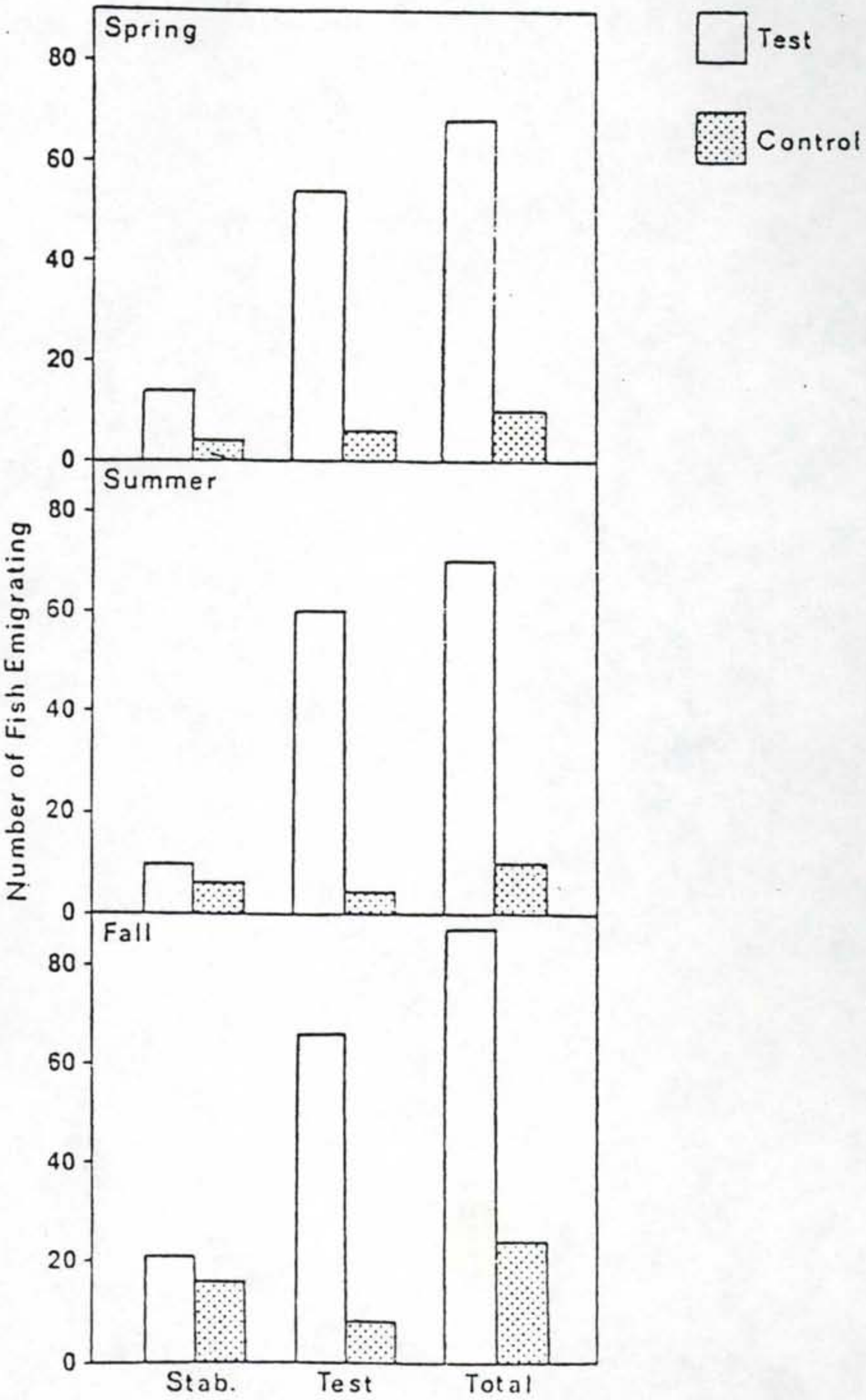

Figure 11. Numbers of stocked rainbow-steelhead trout (Salmo gairdneri) emigrating from the test and control channels during the stabilization (stab.) and test periods. Spring, summer and fall 1982 experiments, Troy channels, Troy, Oregon.

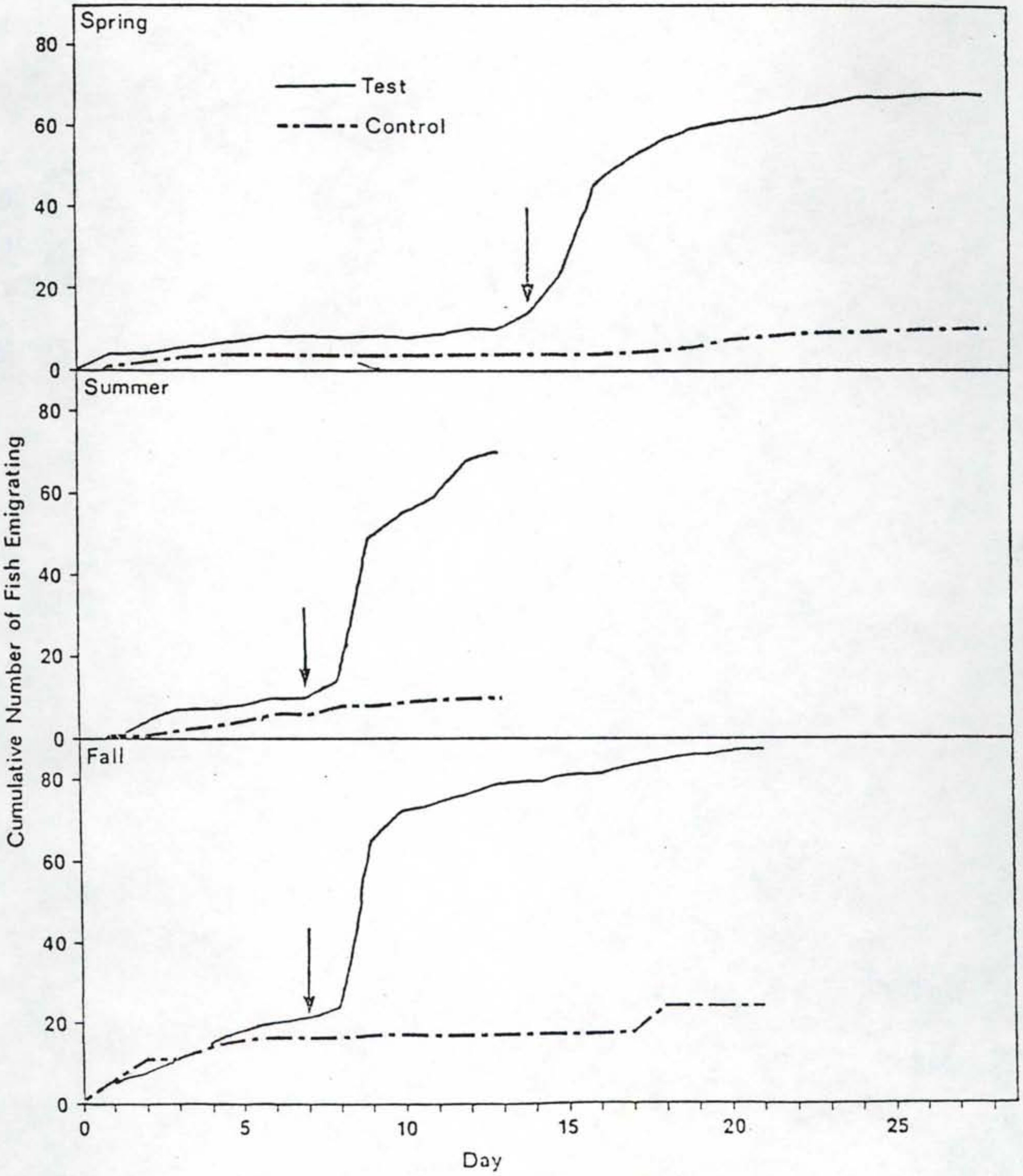

Figure 12. Cumulative number of stocked rainbow-steelhead trout (Salmo gairdneri) trapped by day in the test and control channels during the spring, summer and fall 1982 experiments, Troy channels, Troy, Oregon. Vertical arrows indicate flow reductions and start of the test period. Day 0 is the start of the stabilization period.

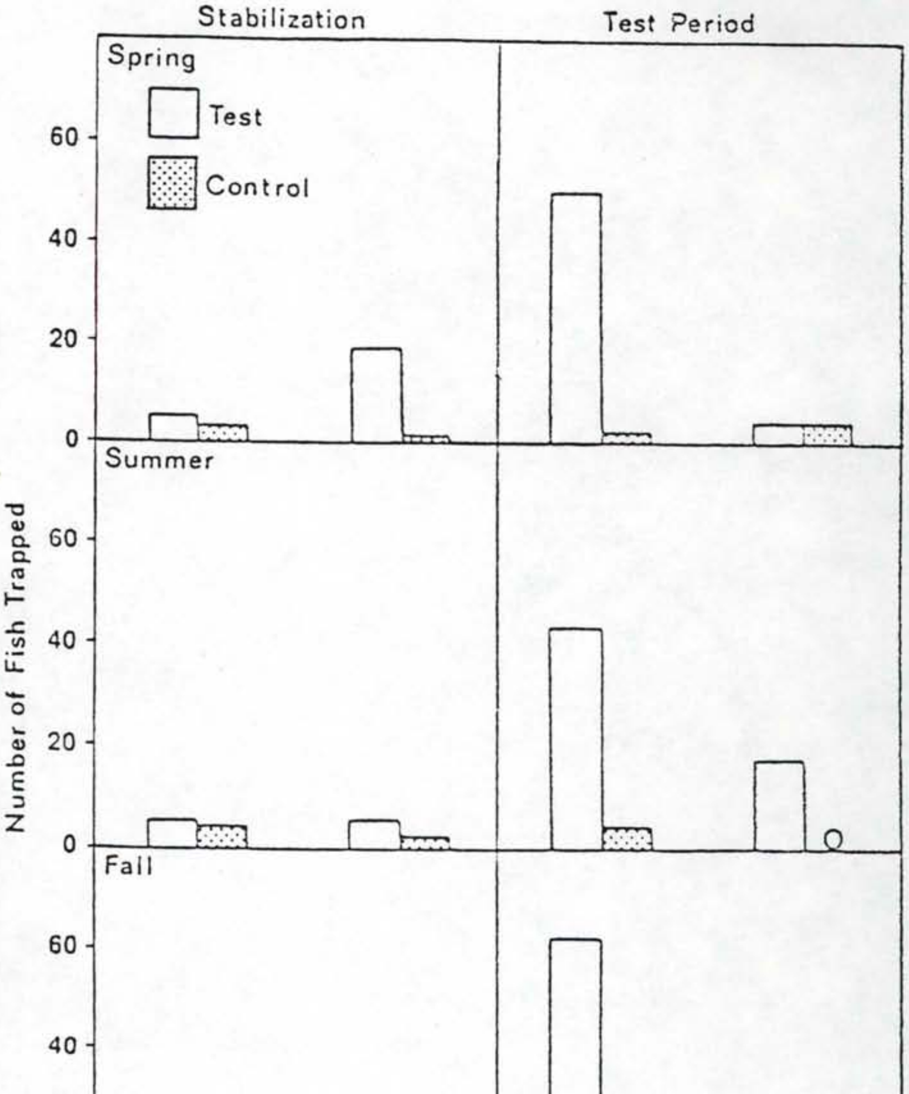

Figure 13. Number of stocked steelhead-trout (Salmo gairdneri) trapped in the upstream traps (UST) and downstream traps (DST) during the spring, summer and fall 1982 experiments, Troy channels, Troy, Oregon.

(Table 2). We were unable to account for approximately one-half of the stocked fish. Five stocked fish were found dead in each of the test and control channels.

Few stocked fish were captured when the test channel was electrofished at the conclusion of the spring experiment but 45 fish were found in the control channel (Table 5). One-third of those 45 experimental fish were found in Run A; the remaining fish were fairly evenly distributed in habitat sections B through F. Run G had only one fish. The longest and heaviest fish in the control channel were found in the central pool. The smallest fish were found in the riffles (Table 5). The greatest density of experimental fish in the control channel was in Run A which also had the lowest cover density (Table 6). Relatively moderate fish densities were observed in Run C and the central pool. Run C had the highest cover density in the control channel while the central pool had no cover blocks.

Summer 1982 Experiment

During the summer experiment, 60 fish were observed emigrating from the low flow test channel while only 4 fish emigrated from the unregulated control channel (Figure 11). Following the flow reduction, we observed a delayed rate of emigration from the test channel (Figure 12). Only four fish emigrated from the test channel during the afternoon of the flow reduction, however, 29 fish emigrated that night and were present in the traps the next morning. Emigration continued at a moderate rate for several days at which time insufficient flows forced termination of the summer experiment. Emigration in the unregulated control channel was minimal. Directional movement of emigrating fish in the test channel was upstream/downstream 2.5:1 (Figure 13). Total

Table 5. Total number, mean length (mm) and mean weight (g) of stocked rainbow-steelhead trout (*Salmo gairdneri*) retrieved by electrofishing the various habitats in the test and control channels at the end of the spring, summer and fall 1982 experiments, Troy channels, Troy, Oregon

Habitat (Section)	No. Fish		$\bar{x}$Length (mm)		$\bar{x}$Weight (g)	
	T	C	T	C	T	C
Spring						
Run (A)	3	16	136.7	130.6	28.0	24.2
Riffle (B)	0	5	--	96.0	--	9.3
Run (C)	0	7	--	106.8	--	13.2
Pool (D)	1	6	122.0	154.2	19.9	34.0
Run (E)	1	5	92.0	134.0	7.5	27.1
Riffle (F)	0	5	--	99.4	--	9.9
Run (G)	1	1	102.0	92.0	10.2	6.7
Total	6	45	121.0	122.3	20.3	20.5
Summer						
Run (A)	10	19	118.7	129.9	15.1	23.4
Riffle (B)	0	8	--	117.2	--	17.6
Run (C)	1	39	111.0	121.5	13.4	19.0
Pool (D)	8	20	122.5	130.8	18.1	24.6
Run (E)	0	9	--	132.0	--	25.7
Riffle (F)	0	10	--	122.7	--	19.0
Run (G)	1	19	96.0	120.0	8.6	17.7
Total	20	124	118.7	124.6	15.9	20.8
Fall						
Run (A)	0	18	--	129.8	--	23.5
Riffle (B)	0	2	--	115.0	--	19.0
Run (C)	7	21	1181.3	132.3	16.7	25.3
Pool (D)	23	8	127.5	126.9	20.4	20.7
Run (E)	1	5	117.0	112.4	14.1	14.7
Riffle (F)	0	3	--	130.0	--	23.0
Run (G)	7	10	115.8	118.6	16.0	17.7
Total	38	67	123.4	126.8	18.7	22.1

Table 6. Mean depth (m), velocity (cm/s), % cover (area) and fish/m^2 in each habitat section from the test (T) and control (C) channels. Habitat sections A and G had low cover density and sections C and E had high cover density. Test flow = 0.03 m^3/s and control flow = 0.57 m^2/s. Spring, Summer, fall 1982 experiments at Troy channels, Troy, Oregon.

Habitat	$\bar{x}$ Depth (m)		$\bar{x}$ Velocity		% Cover		Spring Fish/m^2		Summer Fish/m^2		Fall Fish/m^2	
	T	C	T	C	T	C	T	C	T	C	T	C
Run (A)	0.18	0.36	1.83	26.82	1.83	1.2	0.10	0.34	0.32	0.41	0.00	0.39
Riffle (B)	0.06	0.20	7.01	75.60	----	---	0.00	0.02	0.00	0.21	0.00	0.05
Run (C)	0.12	0.30	2.44	42.37	7.1	5.8	0.00	0.17	0.03	9.95	0.21	0.51
Pool (D)	0.39	0.64	0.61	13.41	---	---	0.03	0.17	0.24	0.58	0.70	0.23
Run (E)	0.19	0.38	1.83	24.99	6.7	5.0	0.03	0.10	0.00	0.19	0.30	0.10
Riffle (F)	0.05	0.20	12.50	81.69	---	---	0.00	0.13	0.00	0.27	0.00	0.08
Run (G)	0.15	0.34	2.44	37.19	1.7	1.2	0.03	0.02	0.03	0.40	0.20	0.21

biomass of fish emigrating from the test channel during the low flow period was much greater than was observed for the unregulated control channel (Table 3). Mean length and mean weight of emigrating fish during the test period was similar in the test and control channels (Table 4). It was possible to account for 70% and 91% of fish stocked in the test and control channels, respectively (Table 2). Included were fish that died, emigrated and those fish remaining at the end of the experiment.

Nearly all of the stocked fish were still residing in the control channel at the end of the summer experiment (Table 5). The greatest density (and number) of fish in the control channel was observed in Run C where cover density was also greatest (Table 6). The central pool had the next highest density of fish ($0.58/m^2$). Run A and run G, both low cover density areas, had relatively moderate fish densities of $0.41/m^2$ and $0.40/m^2$, respectively. The lowest fish densities in the control channel were observed in both riffles and in Run E. Run E, a high cover density area, had become inundated with silt, partially burying some of the blocks while completely burying others. This phenomena occurred in the test and control channels and was caused by the deposition of silt in the central pool. Fish that remained in the test channel were concentrated in two areas, Run A and the central pool, neither of which contained high density cover.

Fall 1982 Experiment

During the reduced flow period we observed 66 and 8 fish emigrating from the test and control channels, respectively (Figure 11). Following the flow reduction a delayed rate of emigration was noted. Only 3 fish emigrated the afternoon of the flow reduction, however, 36 stocked fish emigrated that night (Figure 12). The rate of emigration quickly tapered off and was slow but steady for the remainder of the experiment. Emigration in the unregulated control channel was minimal. Directional movement of fish emigrating from the test channel during the low flow period was almost exclusively upstream (Figure 13). Total biomass of fish emigrating from the test channel during the low flow period was greater than that observed in the unregulated control channel (Table 3). Mean length and mean weight of fish emigrating during the test period were slightly larger in the control channel (Table 4). Eighty-nine percent and 84% of fish stocked were accounted for in the test and control channels, respectively (Table 2). Fish mortality was notable during the stabilization period when 5.3% and 23.2% of experimental fish died in the test and control channels, respectively.

Almost one-half of the fish originally stocked in the control channel remained at the end of the fall experiment (Table 5). The greatest density of fish remaining in the control channel was found in Run C. Run C also had the greatest density of cover (Table 6). Run A, low in cover density, had the next highest fish density ($0.39/m^2$). The central pool, which had no cover blocks, contained a relatively moderate density of stocked fish ($0.23/m^2$). In the test channel, fish density was greatest in the central pool where 60% of the remaining fish were observed. Run C, high density cover, and Run G, low density cover, held moderate fish densities.

Determinants of Response of Trout to Reduced Flow

Habitat data collected were not adequate to develop habitat standing crop functions as originally planned. Only a summary of the findings is presented here. An in-depth evaluation of these and other related data is forthcoming in a Ph.D. Dissertation by Allen E. Bingham. All data presented were collected in 1980 when test channels had a run-riffle configuration.

Depth

Mean depth occupied by wild rainbow-steelhead juveniles during summer and fall 1980 increased slightly with flow and was similar between the two seasons (Figure 14). Mean depth at fish locations during summer 1980 was 0.33, 0.38 and 0.46 m at 0.03, 0.28, and 0.57 m^3/s flow, respectively. Mean depth occupied during fall 1980 was 0.36, 0.41 and 0.52 m at the same three flows. Range of depths utilized also increased with increased discharge.

Velocity

Facing velocities occupied by juvenile rainbow-steelhead trout at the 0.03 m^3/s flow were always less than 0.10 m/s during summer and fall 1980 (Figure 15). Mean facing velocity observed during fall 1980 sampling was 0.02 m/s (Figure 16). At the two higher discharges (0.28 m^3/s and 0.57 m^3/s), mean facing velocity in fall increased to about 0.2 m/s. Range of facing velocities utilized during the two higher flows, was also larger (0.0 - 0.55 m/s) during both summer and fall than at the 0.03 m^3/s test flow (Figures 17 and 18). Possible seasonal differences were observed during the 0.57 m^3/s) flow tests (Figure 18); in general, facing velocities during summer were higher than during fall. Variation in facing velocity, however, was largest during fall.

Surface Turbulence

Surface turbulence associated with location of juvenile rainbow-steelhead trout within experimental channels was used very nearly in proportion to mean availability (Figures 19 and 20). There were no

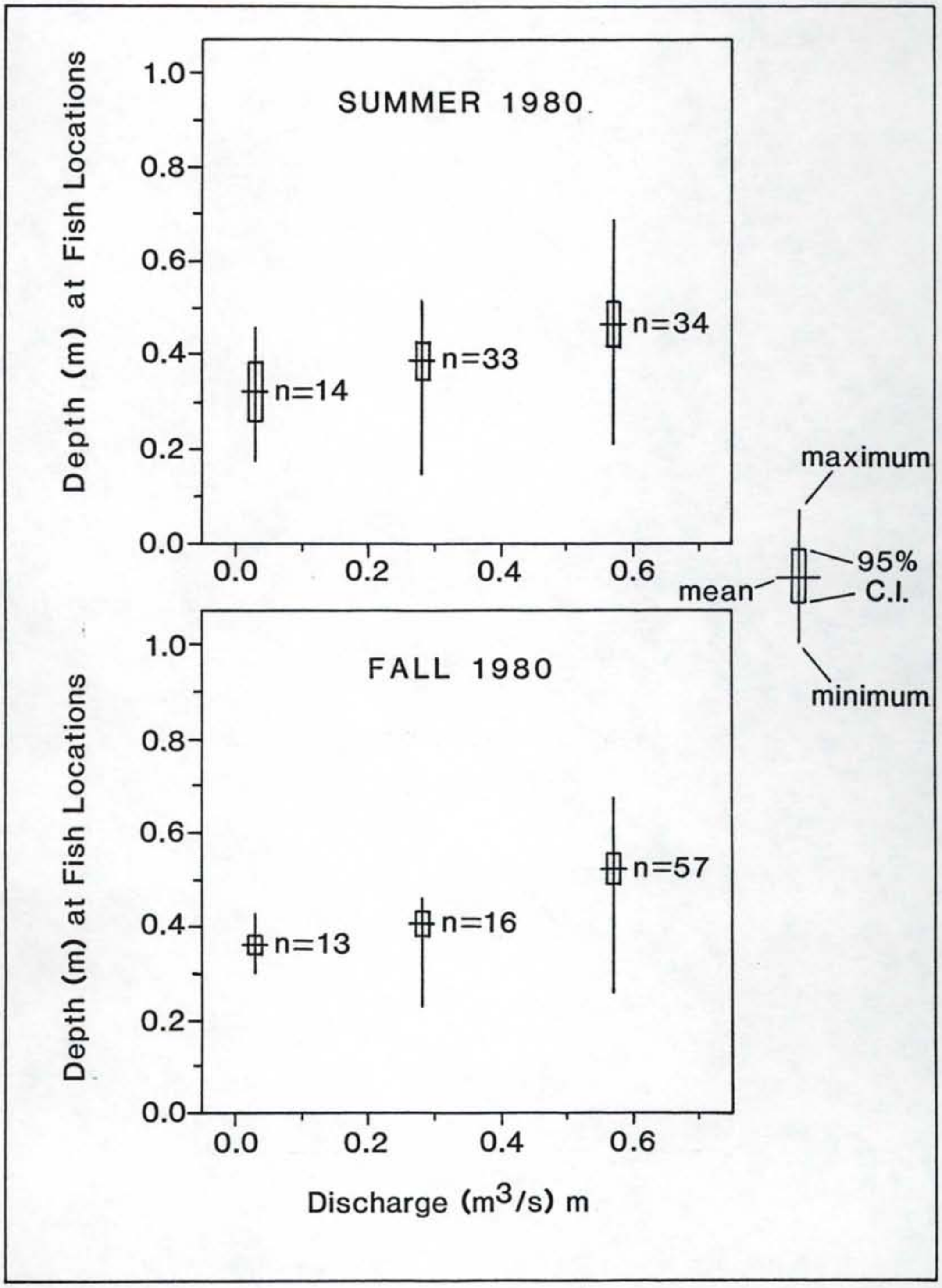

Figure 14. Depths at fish locations measured while snorkeling versus discharge during the summer and fall 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

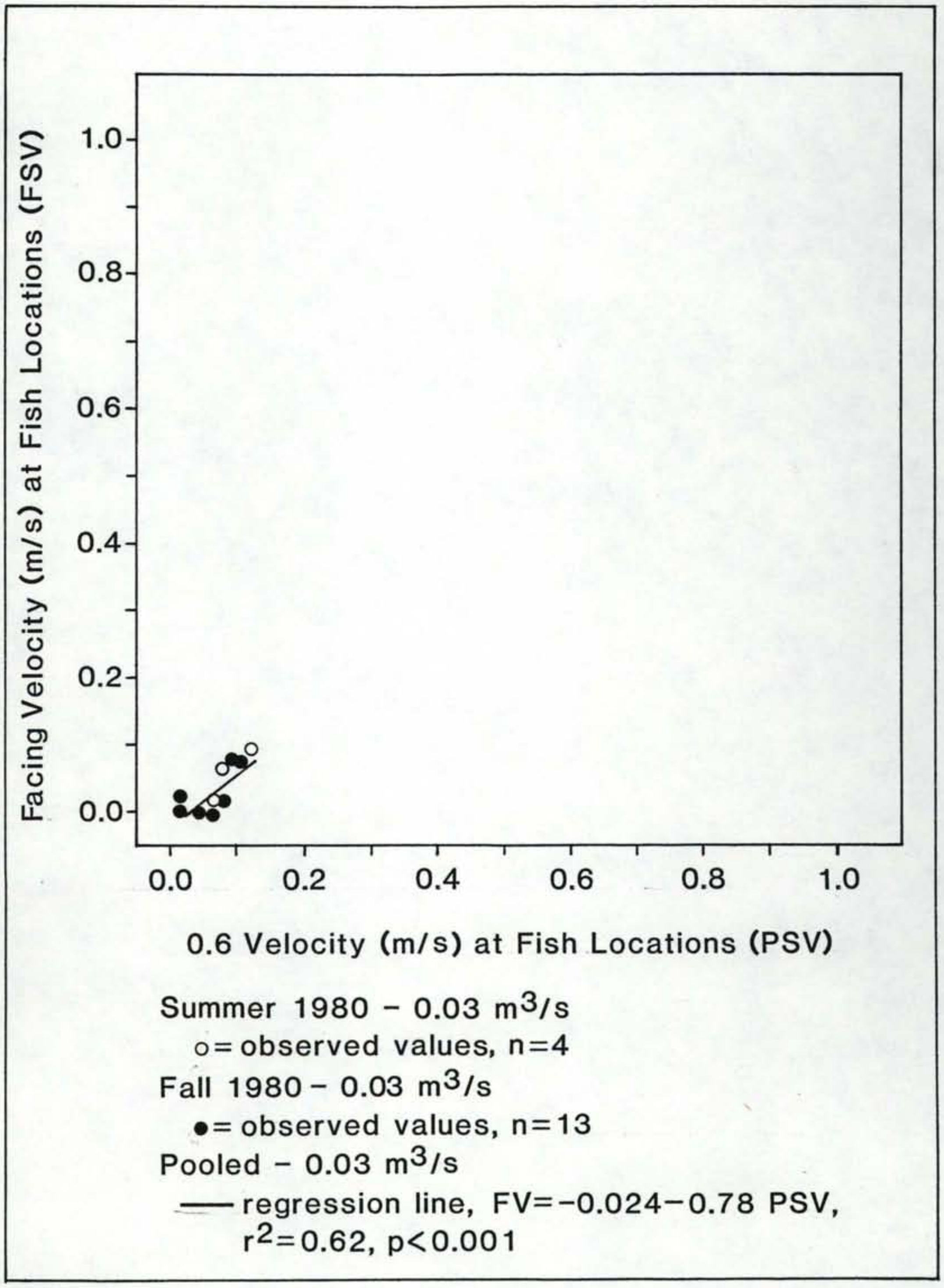

Figure 15. Facing velocity (FV) versus 0.6 velocity (PSV) at fish locations measured while snorkeling at the 0.03 m^3/s flow level during the summer and fall 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

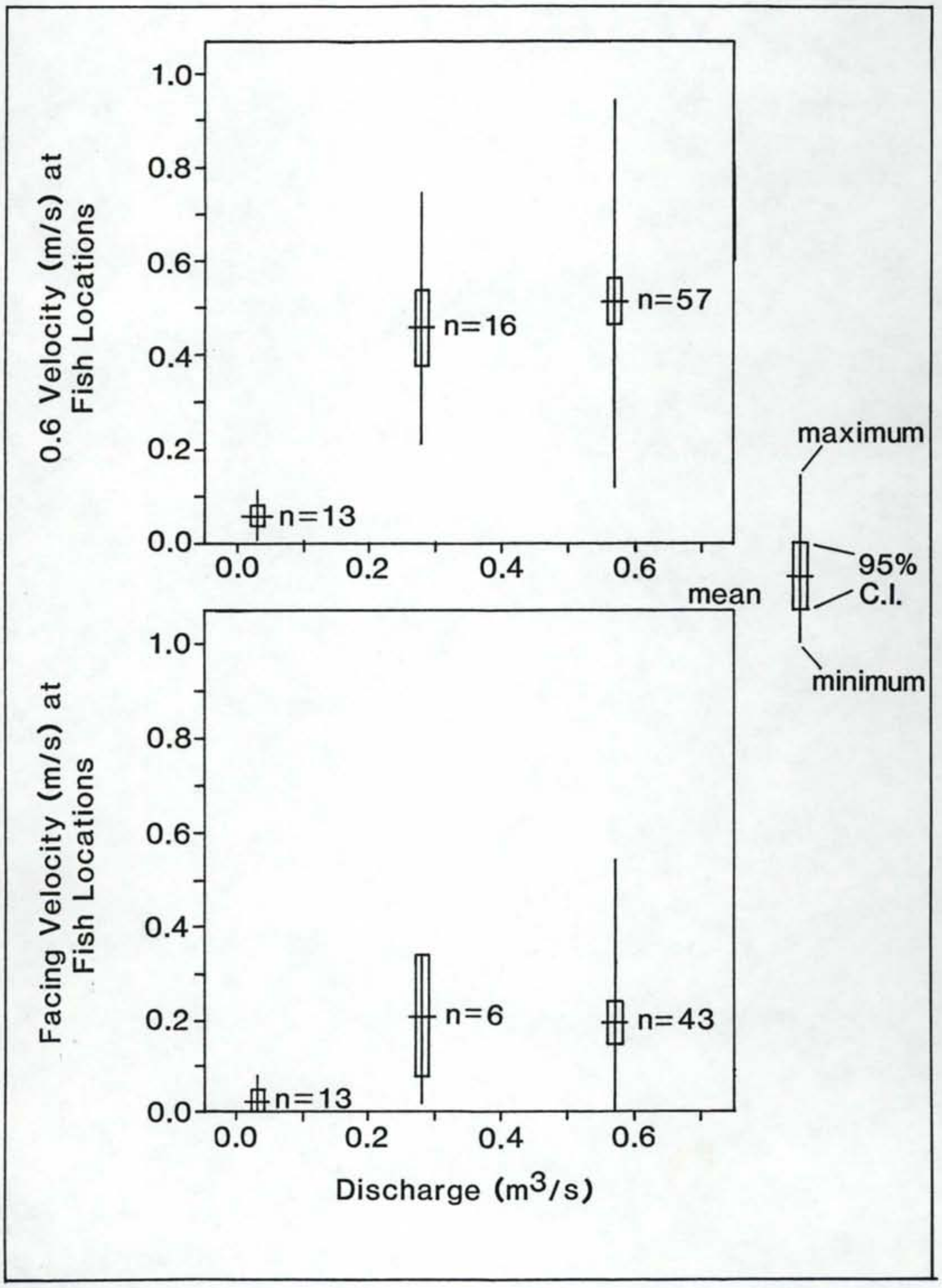

Figure 16. Velocities at fish locations versus discharge measured while snorkeling during the fall 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. Facing velocity is velocity at the depth where fish was located; 0.6 velocity is velocity observed at 0.6 times total depth from the surface at fish locations.

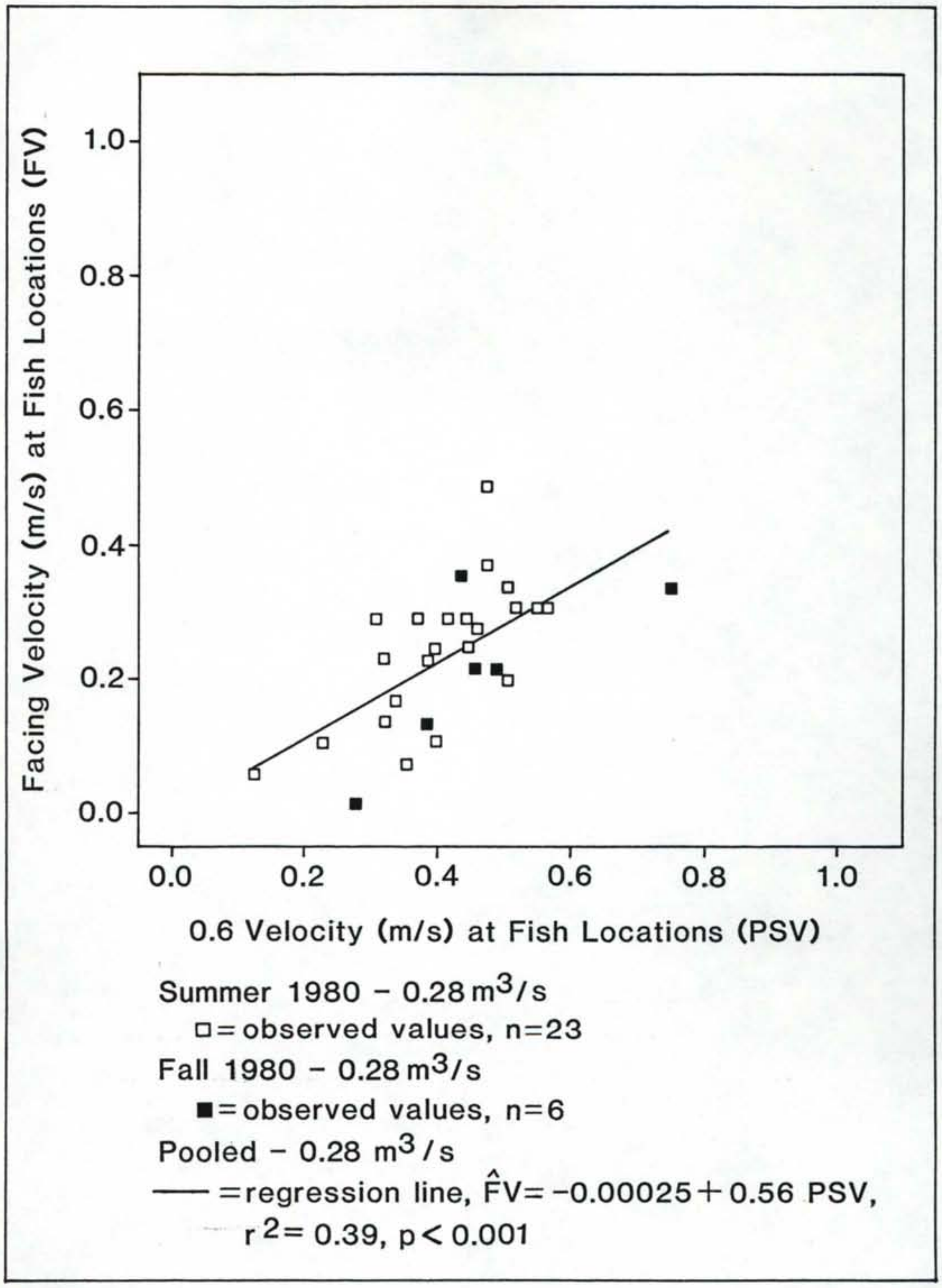

Figure 17. Facing velocity (FV) versus 0.6 velocity (PSV) at fish locations measured while snorkeling at the 0.28 m^3/s flow level during the summer and fall 1980 reduces stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

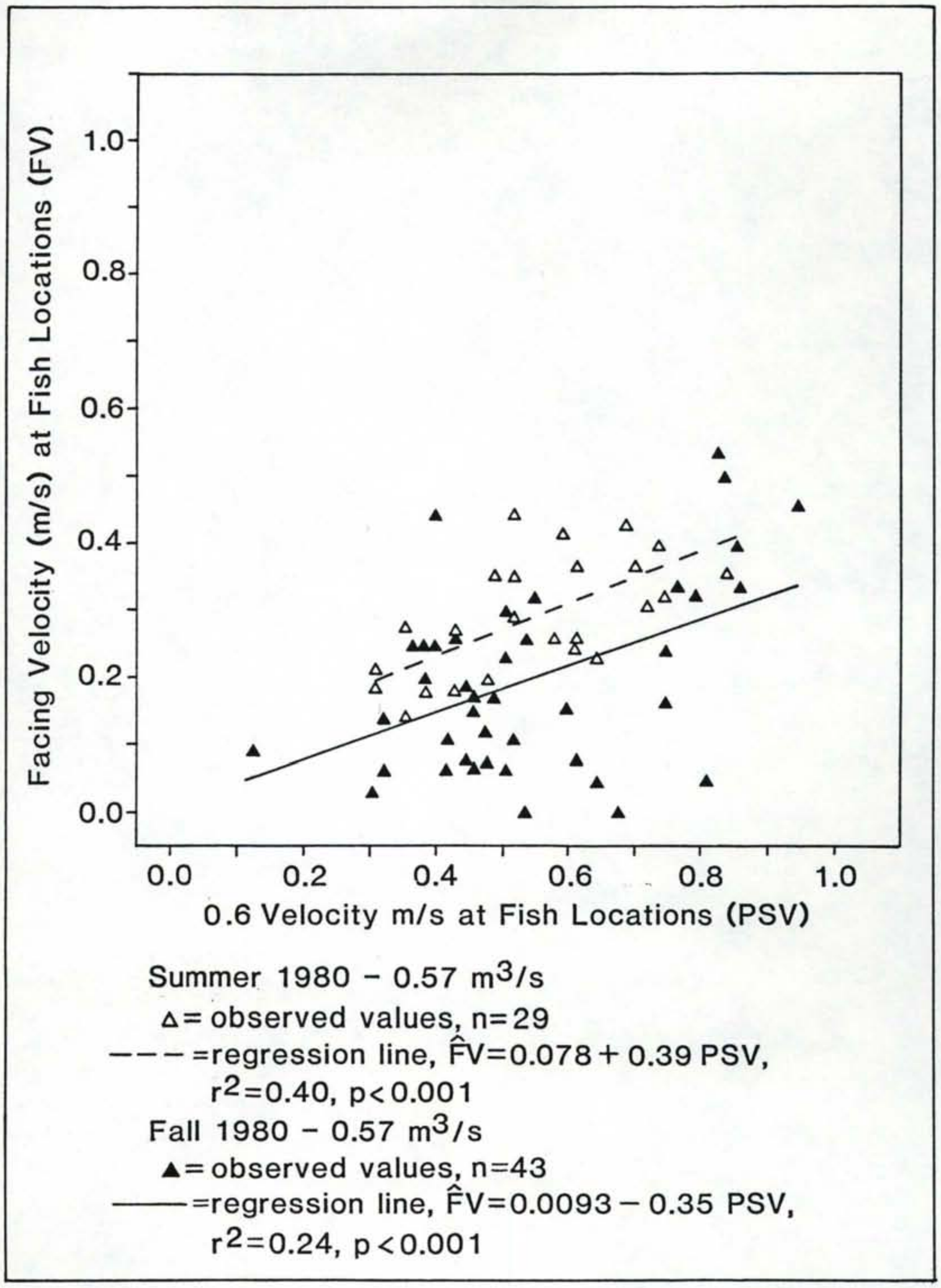

Figure 18. Facing velocity (FV) versus 0.6 velocity (PSV) at fish locations measured while snorkeling at the 0.57 m^3/s flow level during the summer and fall 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

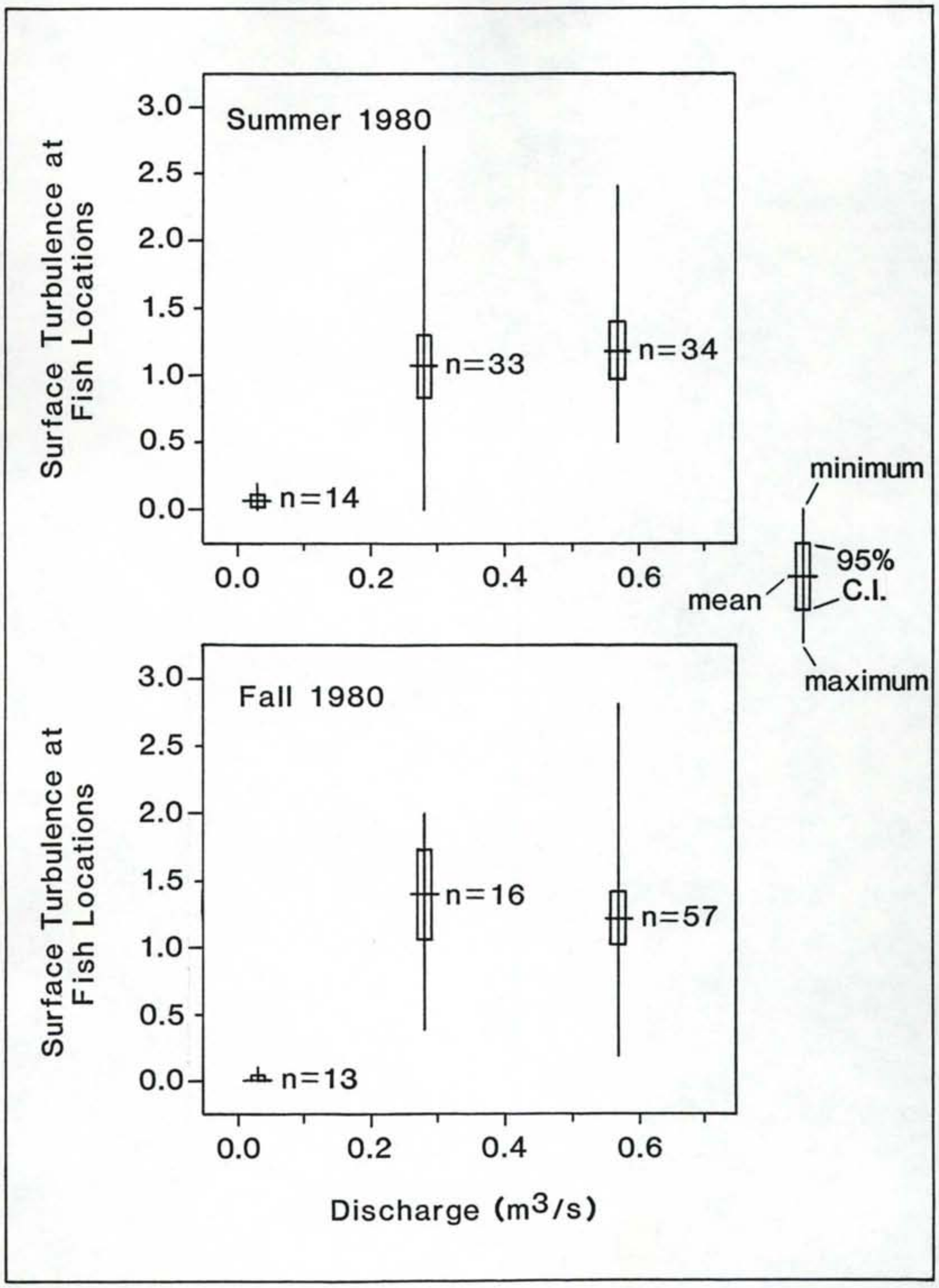

Figure 19. Surface turbulence at fish locations versus discharge measured while snorkeling during the summer and fall 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. Surface turbulence was rated subjectively from a scale of 0 (no turbulence) to 3 (high turbulence = foamy water).

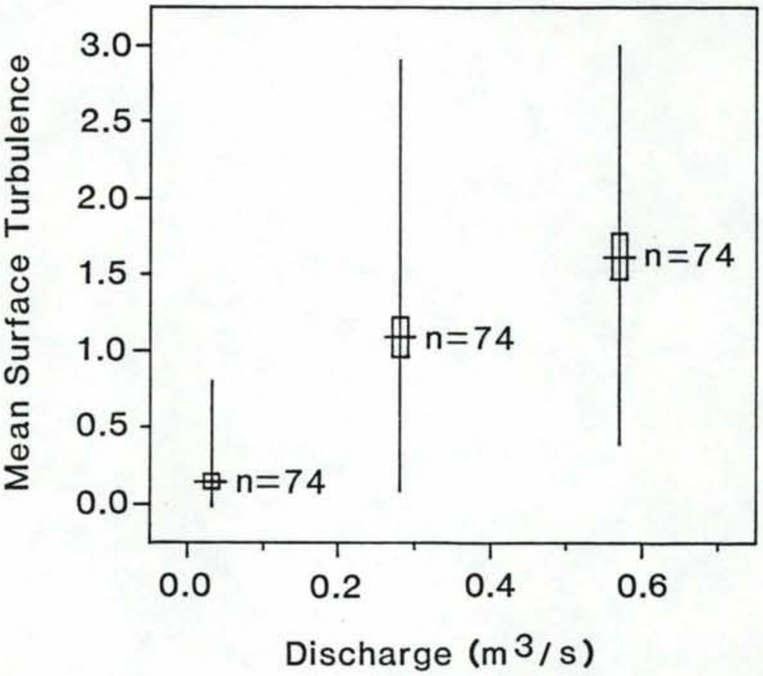

Figure 20. Mean "available" surface turbulence in stream channel sections (both channels) versus discharge levels, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. Surface turbulence was rated subjectively from a scale of 0 (no turbulence) to 3 (high turbulence = foamy water).

large differences in turbulence association between summer and fall observations.

Distance to Cover

During summer and fall flow tests, juvenile rainbow-steelhead trout were closely associated with cover items (Figure 21). The closest association was observed during the 0.03 m^3/s test, where all fish observed during fall 1980 were 0.0 m from cover items. At the two higher flows tested, the range of distance of fish from cover increased but the mean distance was always less than 0.3 m. The maximum observed distance of any one fish to cover was about 0.9 m.

Minimal Distance to Conspecific

Minimal distance of juvenile rainbow-steelhead trout to conspecifics decreased with decreases in flow but, on the average, this distance was not large even at the highest flow (0.57 m^3/s) (Figure 22). No seasonal differences were detected. Mean distance to the closest neighbor ranged from 0.03 m at 0.03 m^3/s discharge to 0.18 m during the 0.57 m^3/s flow.

Relationship Between Facing Velocity and 0.6 Depth Velocity

A poor relationship was observed between juvenile rainbow-steelhead trout facing velocity and the associated 0.6 depth velocity except at the lowest flow tested (0.03 m^3/s) (Figures 15, 16, 17 and 18). Although there was a general linear relationship between facing velocity and 0.6 depth velocity, the range in variability was large at the two higher flows (0.28 m^3/s and 0.57 m^3/s) resulting in low correlations. The best relationship observed was for the 0.03 m^3/s flow where the r^2 value was 0.62. A similar relationship was observed

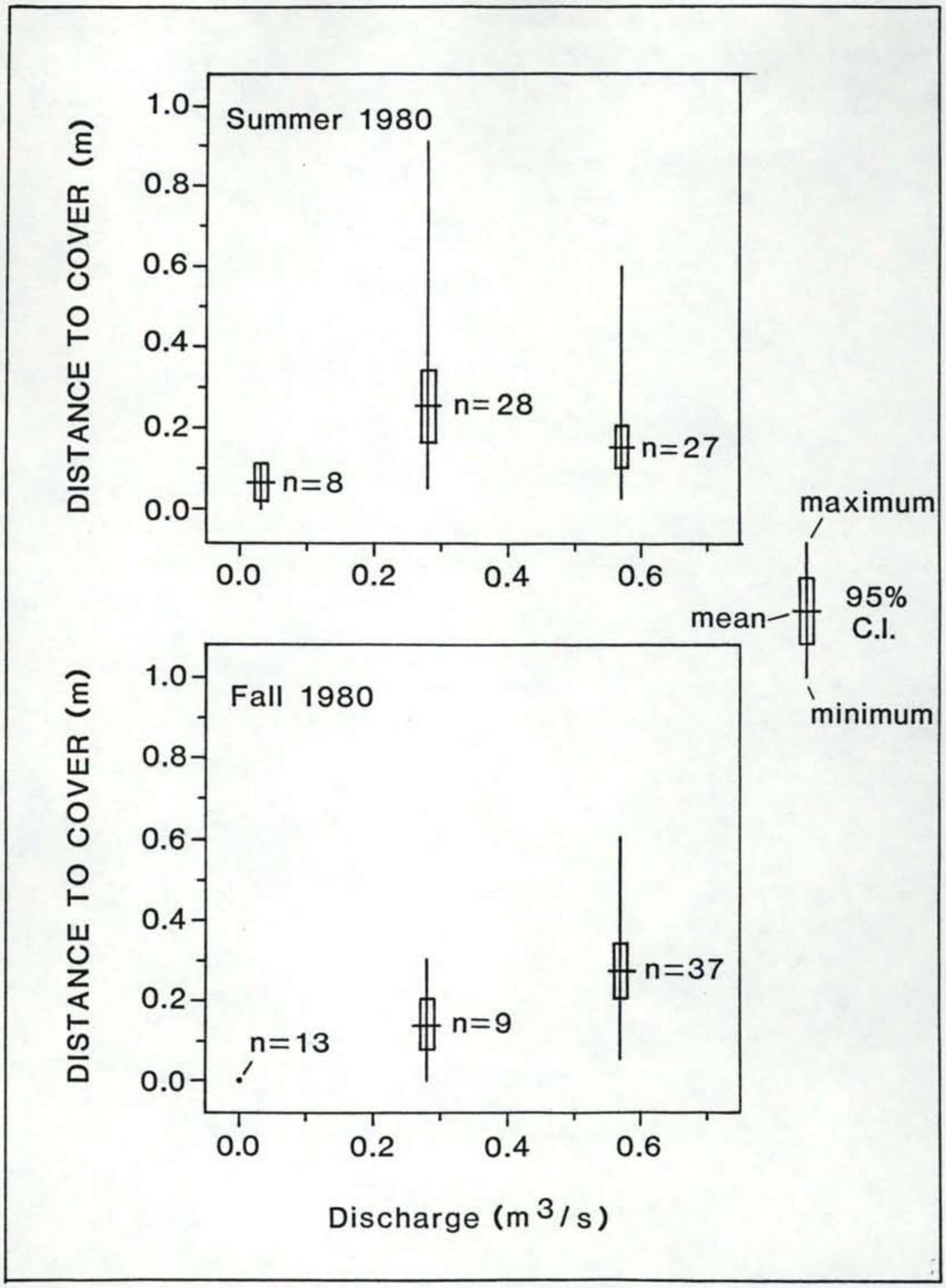

Figure 21. Distance from fish to nearest cover item versus discharge observed by snorkeling during the summer and fall 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. Observations comprised of only those fish which appeared to be associated with cover items.

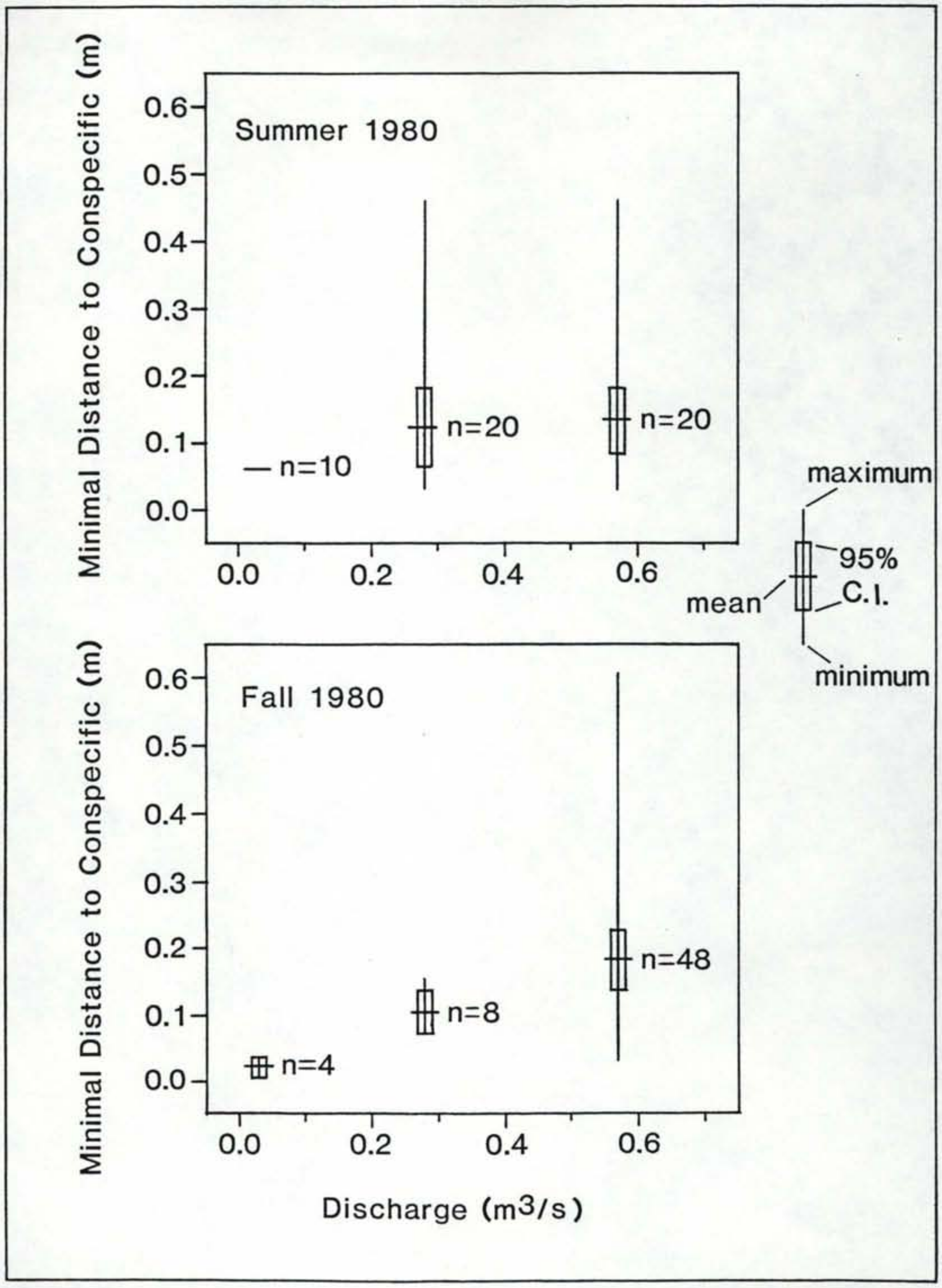

Figure 22. Minimal distance to conspecifics versus discharge observed during snorkeling during the summer and fall 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon. Observations comprised of only those fish which were "in view" of conspecifics.

(r^2 = 0.68) for juvenile rainbow-steelhead in Wildcat Creek during fall 1979 when flows ranged between 0.09 and 0.12 m^3/s (Figure 23).

Water Temperature

Water temperature patterns were similar during 1980 and 1982 seasonal tests (Figures 24 and 25). Mean minimum and maximum temperatures during test periods were usually slightly lower in the control than the test channel but this difference was always less than 1°C and usually less than 0.5°C (Table 7). The warmest water temperatures occurred during fall experiments.

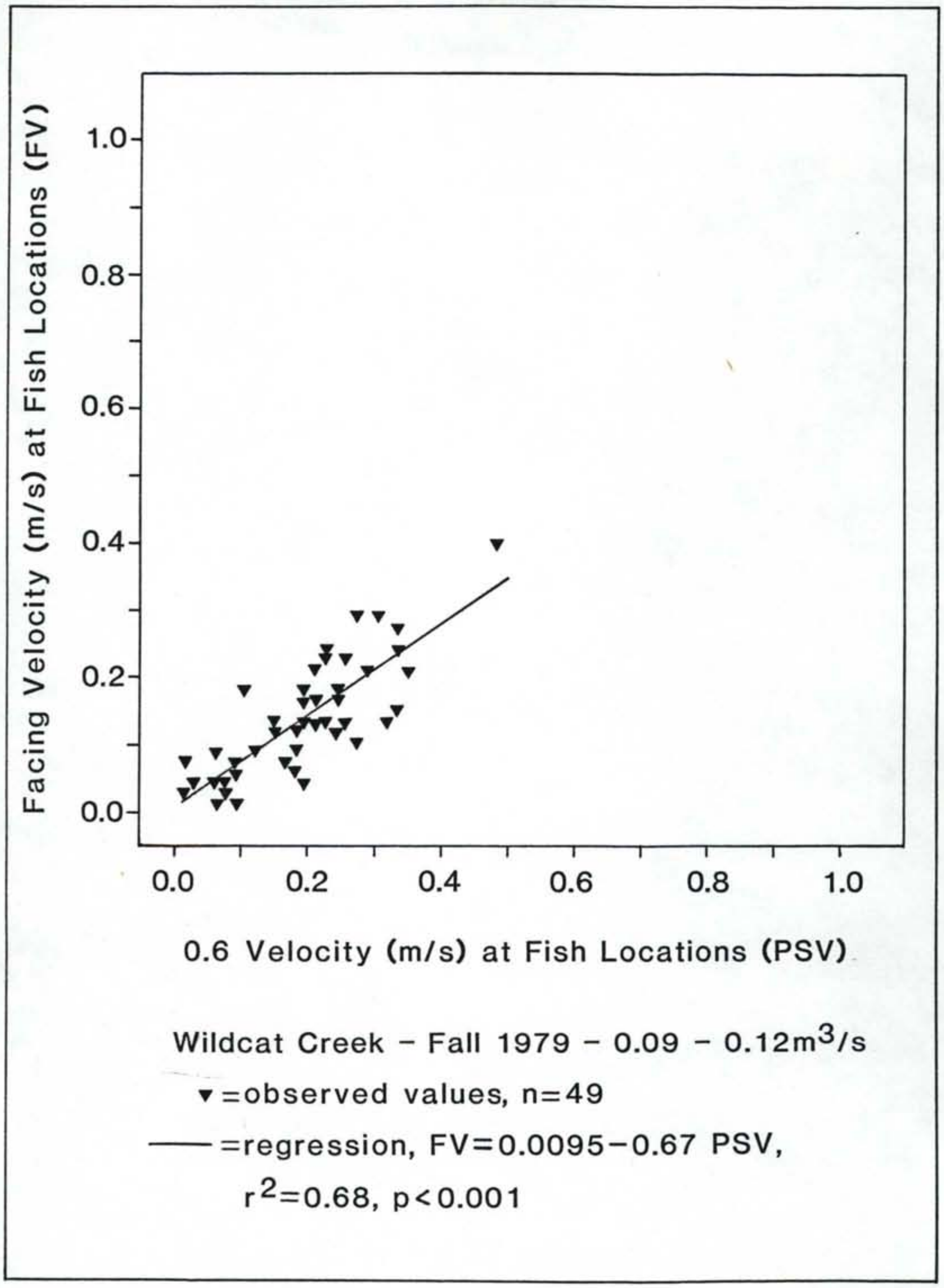

Figure 23. Facing velocity (FV) versus 0.6 velocity (PSV) at fish locations measured during snorkeling Wildcat Creek at flow levels of 0.09 to 0.12 m^3/s, during the fall, 1979, near Troy, Oregon.

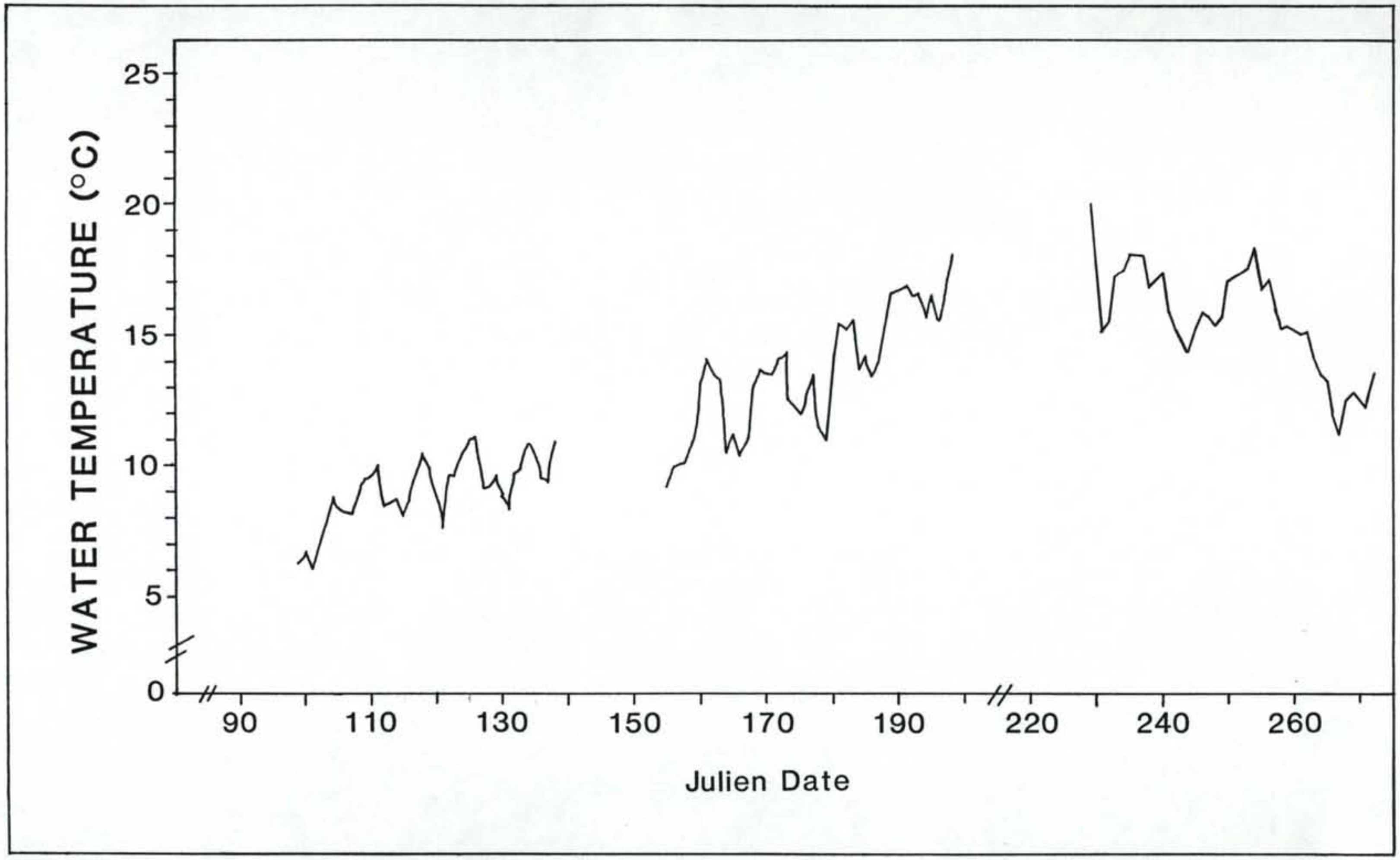

Figure 24. Mean daily water temperatures for the 1980 reduced stream discharge experiments, Instream Flow Research Facilities, Grande Ronde River, near Troy, Oregon.

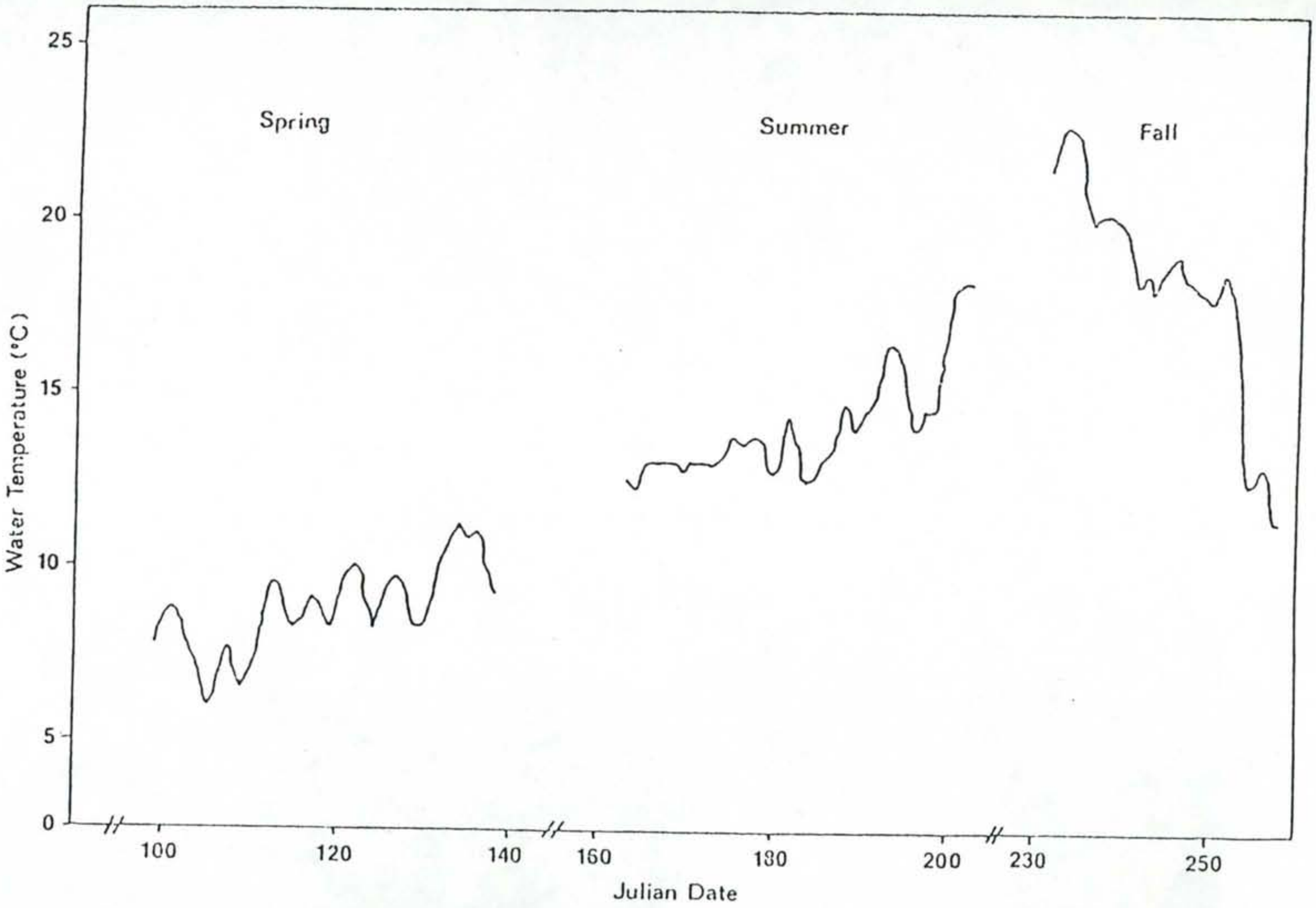

Figure 25. Mean daily water temperature for the spring, summer and fall 1982 experiments Troy channels, Troy, Oregon.

Table 7. Water temperature statistics for the spring, summer and fall 1982 experiments, Troy channels, Troy, Oregon.

	Water Temperature (^{o}C)					
	Test			Control		
	Mean	Min.	Max.	Mean	Min.	Max.
Spring 1980						
Acclimation) Stabilization)	8.0	5.1	10.4	7.9	5.0	10.2
Test	9.8	8.3	11.6	9.5	7.2	12.0
Summer 1980						
Acclimation) Stabilization)	11.7	8.2	14.5	11.7	8.3	14.5
Test 1	13.4	10.0	16.4	13.3	10.0	16.3
Test 2	16.0	12.7	20.0	15.8	12.7	19.6
Fall 1980						
Acclimation) Stabilization)	16.7	11.7	22.1	16.7	11.5	22.3
Test 1	16.4	12.4	19.9	16.3	12.3	20.0
Test 2	13.3	9.4	16.9	13.3	10.6	17.1
Spring 1982						
Acclimation	7.3	6.6	8.0	7.2	6.5	8.0
Stabilization	8.8	7.7	9.8	8.9	7.7	10.0
Test Period	10.2	9.4	10.9	9.6	8.8	10.5
Summer 1982						
Acclimation	12.6	12.4	13.0	13.2	12.6	13.9
Stabilization	14.9	14.5	15.5	15.3	14.5	16.1
Test Period	17.0	16.0	18.1	16.6	15.3	17.7
Fall 1982						
Acclimation	22.4	20.0	24.5	21.7	19.2	24.2
Stabilization	19.9	17.8	21.2	19.2	16.9	21.5
Test Period	16.7	15.0	18.3	16.1	14.0	18.1

DISCUSSION

As observed in the first phase of this study (White et al. 1981) wild juvenile rainbow-steelhead trout responded to seasonal 95% reduction in discharge by emigrating from test channels (Figures 9, 10, 12 and 13). An intermediate decrease in discharge (0.28 m^3/s) during 1980 experiments resulted in little change in abundance between test and control channels (Figure 9). Randolph and White (1984) observed decreases in abundance in rainbow trout number and biomass with decreases in flow in three sections of a natural stream with different levels of flow reduction related to irrigation diversion. Other researchers have reported similar results (Kraft 1968, 1972; Krueger 1979).

The largest pulse of juvenile rainbow-steelhead trout emigration in response to the 95% decrease in discharge occurred during the night following the change in flow. Similar observations were reported by White et al. (1981). In an experiment with juvenile chinook salmon (Oncorhynchus tshawytscha) Kruger (1979) reported minimal emigration 24 hours after a 66% flow reduction. Edmundson et al. (1968) found that steelhead trout were inactive at night and associated with low velocity areas on the stream bottom. Corrarino (1982) and White et al. (1981) reported that incremental flow reductions caused drifting aquatic insects to respond in a delayed catastrophic fashion with peak drift density at night. Since stream dwelling salmonids are opportunistic feeders, our experimental fish may have responded first to a superabundance of food and then emigrated from the channels. Nighttime emigration could also be an adaptation to avoid predators.

Movement of fish responding to reduced flows was almost exclusively upstream during both 1980 and 1982. White et al. (1981), Randolph and White (1984), Kraft (1972) and Easterbrooks (1981) also reported that reduced flows resulted in upstream emigration of trout. Easterbrooks (1981) speculated that upstream emigration may be triggered by an instinct to search for cool tributaries or springs, thereby increasing the chance of survival during periods of low flow and high water temperature in downstream, mainstem stream reaches. Another possible explanation would be that trout move upstream to seek preferred habitat above fish and social dominance.

White et al. (1981) reported a lack of a breaking point in relative abundance of wild trout, even at the 95% reduction level in fall, the only test conducted with multiple flow levels. In the present study, however, the 95% flow reduction during summer and fall 1980 and during all seasons in 1982 resulted in a large increase in the rate of emigration. The only known difference between the two directly comparable tests (Fall 1978 and Fall 1980; channel configuration run-riffle; wild rainbow-steelhead only) was stocking density. In fall 1978, 282 wild juvenile rainbow-steelhead were stocked in the test channel (White et al. 1981), while only one-half this number (141) were used in the 1982 test. Perhaps the larger density in 1978 resulted in greater social tolerance and thus less response to crowding associated with reduced discharge. Wesche (1973) concluded that a breaking point in rate of habitat change occurs between a 75% and 87.5% reduction from ADF. Kraft (1972) reported that a 90% flow reduction had more impact than a 75% flow reduction. In summer 1980 no detectable response was observed with a 50% flow reduction; a small increase in rate of emigration was observed during 50% flow reduction in fall but this was much less than at the 95% reduction level. During the 1982 tests we had only a single 95% flow reduction and thus we were unable to be more precise in describing a breaking point. Although we attempted to maximize the difference in channel configuration between 1980 and 1982 tests, the general response of test fish to flow reduction remained unchanged.

In an attempt to develop habitat-standing crop functions, microhabitat utilization was evaluated in 1980 by snorkeling during summer and fall. Mean depth occupied by juvenile rainbow-steelhead increased slightly with flow but was similar between seasons. Facing velocity increased between the 0.03 m^3/s flow and 0.28 m^3/s. Mean facing velocities did not increase further when flow was increased to 0.57 m^3/s but range of facing velocities observed increased. In general facing velocities were high during summer at the 0.57 m^3/s flow than during fall. Smith and Li (1983) found that increased facing velocities of juvenile steelhead trout were related to higher water temperatures. They suggest that higher temperatures should increase standard metabolism and food demand, resulting in fish seeking faster water where food is more abundant. This may explain the increased velocity utilized by our test fish in summer, although mean temperature differences were only slightly larger (Table 7).

During summer and fall 1980 observations juvenile rainbow-steelhead were closely associated with cover, with fish moving closer to cover as flow decreased. From visual observations of juvenile rainbow-steelhead trout in fall and summer (White et al. (1981)) 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 were limited, cover appeared 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)."

Instream cover allows sight feeding fish to expend little energy while waiting to prey on food items that may be drifting nearby (Kalleberg 1958; Waters 1969). A reduction in stream flow could cause an increase in foraging, an unnecessary expenditure of energy, more space to acquire food and a subsequent reduction in carrying capacity. Conversely, fish densities may be measurably increased by a rise in current velocity and a subsequent increase in use of substrate as cover (Giger 1973). Hartman (1963) found that the degree of association with artificial structures increased with increasing water velocity which also resulted in modified agressive behavior. Instream cover may increase fish density by increasing visual isolation of fish (Stewart 1970). Wesche (1974) defined trout cover as rubble-boulders or overhanging bank areas in association with a water depth of at least 0.15m. Thus a reduction in stream discharge could result in the loss of available habitat and an increase in competition, both due to a reduction in cover, current velocity and water depth.

The 1982 tests were designed to better evaluate the importance of instream cover to juvenile rainbow-steelhead in relation to flow. In our spring experiment, it was difficult to evaluate the relationship between fish density (number/m^2) and instream cover. Back flowing water into the channels was extremely turbid thus electrofishing efficiency was questionable. In the control channel we found 4 squawfish (Ptchocheilus oregonensis) and 1 bull trout (Salvelinus confluenstus) ranging from 300-500 mm in length. One of the squawfish had an experimental trout in its stomach, identified by our marking procedure. It is impossible to estimate how many test trout were eaten by these predators but the number could be large.

In the summer and fall experiments, the greatest density of fish in the constant high flow control channel was in Run C. Run C also had the highest density of cover and ws located below the food producing riffle. When flows were reduced, however, Run C no longer provided optimal habitat despite a relatively larger area of cover. Mean water depth in Run C was reduced below what Wesche (1974) recommended as minimum depth and our cover blocks became partially exposed. Run E had high density cover but low fish densities were frequently noted in the test and control channel. Low fish densities in Run E may have been due to heavy siltration which filled the spaces in and around the cover blocks, resulting in less suitable trout habitat. Food availability may have also affected fish densities in Run E as many of the drifting invertebrates may have settled out of the water column in Pool D.

In all three experiments, Run A (low cover density) contained moderately high densities of fish in the control channel. During the summer experiment, Run A in the test channel had the greatest fish density. Run A was located at the head of the channels where the water surface elevation dropped approximately 0.50 m as diverted water entered the channels. This drop in water surface elevation created a long stretch of surface turbulence which appeared to provide adequate fish cover. In 1980, we found that fish utilized areas of surface turbulence in proportion to availability in both channels. In addition, the area where the fish entered the upstream trap in Run A was gouged out and contained several large boulders to stabilize the structure. These boulders provided interstitial spaces that were excellent fish habitat. Fish densities in Run G, the downstream run with low cover density, were inconsistent throughout the study and results were difficult to interpret.

In the control channel, Pool D, which had no cover blocks, had moderately high densities of fish throughout the study. Pool D fish densities were among the highest in the test channel during the summer and fall experiment. Apparently, those fish which remained in the test channel following the flow reduction concentrated in Pool D. The central pool also contained the largest fish while the smallest fish were found in the riffles. Kraft (1972) found that when flows were reduced, tagged fish moved from runs to pools and that the number and weight of trout in pools increased. As flows were reduced, the pool became relatively deeper and provided fish cover in the form of water depth. Stewart (1970) showed that deep water areas can function as fright cover. Gibson (1978) found that Atlantic salmon (*Salmo fontinalis*) showed a preference for a deep tank with no cover versus a shallow tank with shade cover.

It was difficult to establish a strong relationship between fish density and depth and/or current velocity during 1982 tests. Although mean depth and velocity were often quite similar in the two corresponding upstream and downstream habitat sections, fish density was often different and could be attributed to differing cover densities. Current velocities in the test riffle were similar to current velocities in the control pool but fish were rarely found in the riffle yet were abundant in the pool. Mean water depths in the test Run A and control Riffle B were similar but differences in fish densities were notable. We may have been able to better understand the relationship between depth and velocity and fish density during 1982 tests if we had point depths and velocities. Unfortunately, turbid water in the spring and fall made underwater observation impossible. In the summer, when the water was clearer, we ran out of water.

Our data point to the importance of the interaction between cover, depth and velocity in determining habitat preference of fish. As observed in previous tests (White, et al. 1981), the emigration of juvenile rainbow-steelhead trout associated with reductions in discharge was apparently due to changes in habitat rather than to decreased food supply. Although drift rate was less in the test channel than in the control channel following two weeks of exposure to the lowest flows tested, the largest amount of emigration occurred within the first 24 hours following the flow reduction. Over the long term, however, reduced drift rates associated with low flow conditions could result in a food-limited response.

We observed a poor relationship between facing velocity of juvenile rainbow-steelhead trout and the corresponding mean velocity of the water column at the fish location. This suggests that the accuracy of models which use 0.6 depth velocity calculations in predicting the response of fish to changes in discharge is probably poor. However, since the observed relationship had a general linear form, the models may be adequate in predicting relative changes in habitat conditions. More research is needed to better evaluate this relationship.

RESPONSE OF FISH FOOD ORGANISMS TO REDUCTIONS IN STREAM DISCHARGE

METHODS AND MATERIALS

Flow Regime

Five experiments were conducted during the entomological study: spring 1980 (21 March - 15 May); summer 1980 (21 May - 16 July); fall 1980 (2 August - 26 September); spring 1981 (9 March - 2 May) and fall 1981 (9 August - 3 October) as detailed in Appendix A.

Both channels were maintained at a base flow of 0.57 m^3/s four weeks prior to the initial flow reductions which allowed for invertebrate colonization. Coleman and Hynes (1970), Williams and Hynes (1976) and Brusven and Trihey (1978) reported that four weeks was sufficient time for natural colonization to occur. Gersich and Brusven (1980) reported at least 47 days for carrying capacity to be reached on autoclaved rocks in an unregulated reach of a river. Shaw and Minshall (1980) found that 64 days were required to establish a stable macroinvertebrate community. In a colonization study of air dried rocks at the Troy experimental channels, Ruediger (1980) reported that six weeks were required for adequate colonization during summer months. With one exception, both test and control channels maintained at least a trickle of water between experiments which allowed a residual insect community to survive. The one exception, however, was during the winter of 1980-81 when the channels were reconstructed (Figure 2). Since the reconstruction required total removal of the substrate, overwintering insects were killed and no periphytic food base existed. Brusven and Trihey (1978) reported that three to six weeks were required for the estabishment of filamentous algae. Consequently, more than four weeks for colonization would have been desirable prior to the spring 1981 experiment. However, due to the interdisciplinary nature of the experiment, a compromise was made and only four weeks were allowed for invertebrate colonization.

Upon completion of the four week colonization period, the randomly selected test channel discharge was reduced from 0.57 m^3/s to 0.28 m^3/s. All flows were reduced in equal increments every 30 minutes over a three hour period and monitored by using a predetermined stage discharge relationship. Two weeks following the initial flow reduction, flows were reduced from 0.28 m^3/s to 0.03 m^3/s. Flows remained at this level for two weeks after which time the experiments were terminated (Appendix A). The control channel maintained a base flow of 0.57 m^3/s throughout each experiment. This schedule was adhered to in four of the five experiments; the one exception was during the spring 1980 experiment. At that time, excessive runoff potentially threatened to back flow from the Grande Ronde River into the channels. Rather than abort the test, we hastened the schedule and bypassed the intermediate flow of 0.28 m^3/s. Following the initial colonization period, flows in the test channel were dropped from 0.57 m^3/s to 0.03 m^3/s. Since the river did not back up into the channels, the low flow was maintained for four weeks (Appendix A).

Wetted Perimeter

Engineers took standard hydrological measurements in both channels to determine physical changes occurring with each successive flow reduction. Since most macroinvertebrate production occurs in riffles (Hynes, 1970) information on population and community characteristics from that habitat type was used in benthic macroinvertebrate analysis (Figure 26).

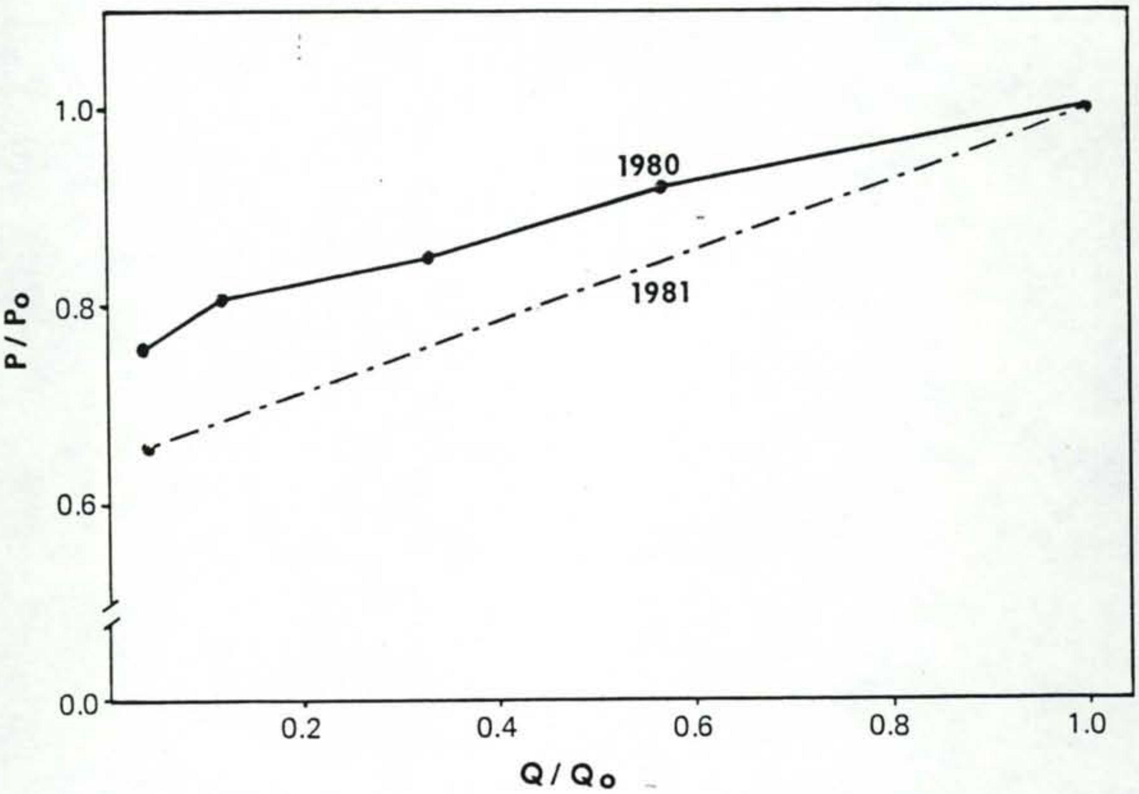

Figure 26. Relative change in wetted perimeter (P/P_0) vs. relative change in discharge (Q/Q_0) for a typical riffle from Troy channels, Troy, Oregon, 1980 and 1981. $Q_0 = 0.57$ m^3/s. Five data values for 1980 and two for 1981.

Surface Benthos and Drift Sampling Schedule: 1980

Benthic macroinvertebrates were collected using a 0.093 m^2 modified Hess sampler (Waters and Knapp, 1961) with a 750 micron mesh net. Water depth (cm), current velocity (0.6 depth) and substrate were measured at each sampling location. The substrate was visually ranked using a surface sediment classification (Table 8 and 9) similar to that described by Brusven and Meehan (1979). This system employed the descriptors of: 1) size of dominant material, 2) degree of embeddedness of cobbles and 3) size of material surrounding cobbles.

Benthic samples were taken at the end of the colonization period on the day before the first flow reduction, (0.57 m^3/s to 0.28 m^3/s); two weeks later just prior to the second flow reduction (0.28 m^3/s to 0.03 m^3/s), and, finally, two weeks later when each experiment was terminated. The intermediate flow and its subsequent sampling period were omitted during the spring 1980 experiment. At each sampling period four random samples were taken from each of three habitat types: riffle, transition and run in both test and control channels.

To assess any changes in the diel periodicity of drifting organisms, two 30 cm square drift nets set in tandem, with mesh diameters of 750 and 250 microns, respectively, were placed at the downstream end of each channel. The 250 micron net was placed approximately 30 cm downstream from, and partially overlapping the 750 micron net. This was done to facilitate the capture of early instars and/or small insects that may have passed through the larger pore-size net.

Thirty minute drift samples were taken 24 hours prior to, during and 24 hours after each flow reduction (Table 10). During the 24-hour period prior to each flow reduction, drift was taken at 1200, sunset,

Table 8. Surface sediment rank classification of dominant material and surrounding particle size. (From Brusven and Meehan, 1979).

Class	Description
1	particulate organic matter -- detritus
2	less than 1.5 mm in diameter (1/16 in) -- sand
3	1.5 - 6.4 mm in diameter (1/16 - 1/4 in) -- pea gravel
4	6.4 - 25.4 mm in diameter (1/4 - 1 in) -- small pebble
5	25.4 - 63.5 mm in diameter (1 - 2 1/2 in) -- large pebble
6	63.5 - 127.0 mm in diameter (2 1/2 - 5 in) -- small cobble
7	127.0 - 254.0 mm in diameter (6 - 10 in) -- large cobble
8	greater than 254.0 mm in diameter (10 in) -- boulder

Table 9. Cobble imbeddedness rank classification. (From Brusven and Meehan, 1979).

Class	Description
1	nearly 100% imbedded (heavy)
2	75% imbedded (moderate)
3	50% imbedded (intermediate)
4	25% imbedded (light)
5	unimbedded

2400 and 30 minutes before sunrise. Sunrise and sunset were determined using a table prepared by the United States Naval Observatory for Lewiston, Idaho.

Current velocity (cm/s) and stream depth (cm) were taken immediately in front of the drift nets while they were in place. Current velocity was measured with a Marsh-McBirney direct readout current meter at 0.6 stream depth. Both drift rate and density were calculated.

Table 10. Drift sampling schedule before, during and after each flow reduction at the Troy channels near Troy, Oregon, 1980 - 1981.

Before	During	After
Noon	Prereduction	Noon
Dusk	Reduction	Dusk
Midnight		Midnight
Dawn		Dawn

Surface Benthos and Drift Sampling Schedule: 1981

All invertebrate work was conducted in the upstream run-riffle-run section in both test and control channels (Figure 2). This was done to avoid any influence the transition pool may have had on the downstream section.

To assess possible changes in the macroinvertebrate community, four Hess samples were randomly taken from each of three habitat types during five sampling periods (Table 11). The three habitat types were run, riffle and the dewatered zone. The dewatered zone was designated as that area in the riffle, adjacent to the shoreline, which was exposed following each flow reduction (Figure 2). This region is of particular importance because of the potential for insects to be stranded and killed as a result of flow reductions (Kroger, 1973; Brusven et al. 1974).

The first sampling period (day 1) was on the day preceeding the initial flow reduction from 0.57 m^3/s to 0.28 m^3/s.

Table 11. Benthic sampling schedule for spring and fall 1981 experiments at the Troy channels, Troy Oregon. Flows at time 1=0.57 m^3/s (day 1); 2=0.28 m^3/s (day 2); 3=0.28 m^3/s (day 14); 4=0.03 m^3/s (day 15) and 5=0.03 m^3/s (day 28). X=Four Hess samples taken from both test and control channels. Control flow = 0.57 m^3/s.

Habitat	Time Period				
	1	2	3	4	5
Run	x	x	x	x	x
Riffle	x	x	x	x	x
Dewatered Zone	x	x	x	x	

Samples were taken from the run, riffle and the dewatered zone. The second sampling period began the following day (day 2), several hours after the initial flow reduction was complete. A Hess sampler was placed on the dewatered substrate and insects were flushed into the net using water under pressure from a submersible pump. Samples were then taken from the run and riffle, ending the second sampling period.

Two weeks later, test flows were again reduced (0.28 m^3/s to 0.03 m^3/s), and the third (day 14) and fourth (day 15) sampling periods were conducted exactly as the first and second sampling period.

Two weeks after the second flow reduction (0.28 m^3/s to 0.03 m^3/s), the fifth (day 28) sampling period was conducted. Samples were taken in the run and riffle only since no more dewatering occurred.

Throughout each experiment, samples were taken in the control channel (0.57 m^3/s) in the exact manner as described for the test channel.

Drift samples were collected at the lower end of each riffle using a schedule similar to that employed in the 1980 experiments. In addition to the 1980 schedule, drift samples were taken at the termination of the spring and fall experiments at 1200, sunset, 2400 and 30 minutes before sunrise.

Vertical Distribution

One month prior to the fall 1981 experiment, eight canister samples, as described by Gilpin and Brusven (1976) were filled with 1-2 cm pebbles. Each canister was marked with surveyors tape and embedded flush with the substrate. The canisters were divided by plates into three equal (10 cm) sections. Both the canisters and the plates were perforated with 1.24 cm holes to allow vertical and horizontal movement of insects.

Four canisters were placed in the riffle thalweg and four in the riffle margin. Canisters were placed in the test channel only. As shown in Figure 26, relatively little dewatering occurred when discharge was reduced from 0.57 m^3/s to 0.28 m^3/s. Maximum exposure, both horizontally and vertically, occurred when flows were reduced from 0.28 m^3/s to 0.03 m^3/s. Consequently, canisters placed in the riffle margin were located at the waters edge when flows were at 0.28 m^3/s. This placement would allow for maximum change in horizontal and vertical water levels when discharge was reduced from 0.28 m^3/s to 0.03 m^3/s. Vertical water levels were monitored with an aluminum standpipe placed in a line with those canisters to be dewatered. This permitted the determination of which vertical section(s) of the canister would be most affected.

Immediately preceeding the flow reduction from 0.28 m^3/s to 0.03 m^3/s, two canisters were removed from both the riffle margin and the riffle thalweg. Two weeks later, the water level in the standpipe was checked and the remaining canisters were removed.

Preservation and Identification of Samples

Drift and benthic samples were placed in pint jars and preserved with 70% ethyl alcohol. Samples were sorted and identified using keys by Usinger (1956), Jensen (1966), Wiggins (1977), Baumann et al. (1977), Merritt and Cummins (1978) and Szczytho and Stewart (1979). Chironomids were identified only to family due to taxonomic uncertainties at the species level. All other insects were identified to species when possible and assigned one of three age classes based on body size and/or wing pad development.

Benthic Insect Analyses

Benthic insect analyses for all experiments were conducted at the population and community level. Mean insect densities/0.093 m^2 (± std. error), species diversity, evenness and biomass were determined for each of the three habitat types in both test and control channels. The Brillouin diversity index (H), species richness and evenness were calculated after Pielou (1966). Chironomids were excluded from these calculations.

Insect biomass (dry weight), was determined by placing insects in weighed crucibles and drying them in a convection oven for one hour at 105° C. Crucibles were then placed in a vacuum oven for an additional hour at 105° C. Biomass was then weighed to the nearest 0.0001 g.

RESULTS

Benthos: Spring, Summer and Fall Experiments

Density. Reduced stream discharge caused a variety of seasonal impacts on insect density. Six orders, 37 families and 67 species of aquatic insects were identified throughout the study (Appendix B). Since the riffle and transition habitats were so similiar, they were treated as one habitat (Riffle). Insect densities in the run habitat remained unaltered in all five experiments.

Throughout both spring experiments, insect densities in the test riffle declined in relation to the control (Figures 27 and 28) especially at low flows. Most of this decrease was caused by the mayflies *Baetis tricaudatus*, *Ephemerella inermis* and *Rhithrogena hageni* (Tables 12 and 13).

Only one summer experiment (1980) was conducted. This was due to an insufficient supply of water in 1981. At the onset of the summer experiment, insect densities in the test riffle were considerably greater than those in the control riffle (Figure 27). Although some species contributed more than others, nearly all "key" species were more abundant in the test riffle than in the control riffle (Table 14). This anomoly was not encountered in any other experiment. Throughout the remainder of the summer experiment, total insect densities in the test and control riffles (Figure 27) were comparable. Two mayflies, *Baetis tricaudatus* and *Epeorus albertae* were, however, adversely affected by reduced flows in the summer experiment (Table 14).

Throughout both fall experiments, total insect densities in the test and control riffles increased comparably (Figures 27 and 28). Much of this increase was a result of the mayflies *Ephemerella margarita*,

Table 12. Number/0.37 m^2 of "key" species collected from the test and control riffle at two test flows (0.57 and 0.03 m^3/s) during the spring 1980 experiment. Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon.

	Test		Control	
	0.57	0.03	0.57	0.57
Baetis tricaudatus	948	22	1028	244
Ephemerella inermis	276	100	324	564
Heptagenia spp.	0	56	20	64
Rhithrogena hageni	60	16	96	368
Hydropsychidae	36	15	28	160
Chironomidae	3288	252	2220	436
Simulium sp.	132	0	56	4

Table 13. Number/0.37 m^2 of "key" species collected from the test and control riffle at three test flows (0.57, 0.28 and 0.03 m^3/s) during the spring 1981 experiment. Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon.

	Test			Control		
	0.57	0.28	0.03	0.57	0.57	0.57
Baetis tricaudatus	156	408	18	166	640	456
Ephemerella inermis	43	33	54	26	60	276
Heptagenia spp.	0	0	0	4	2	0
Rhithrogena hageni	254	222	19	273	426	578
Hydropsychidae	5	16	3	0	12	84
Chironomidae	12	120	387	6	62	352
Simulium sp.	57	585	2	26	78	42

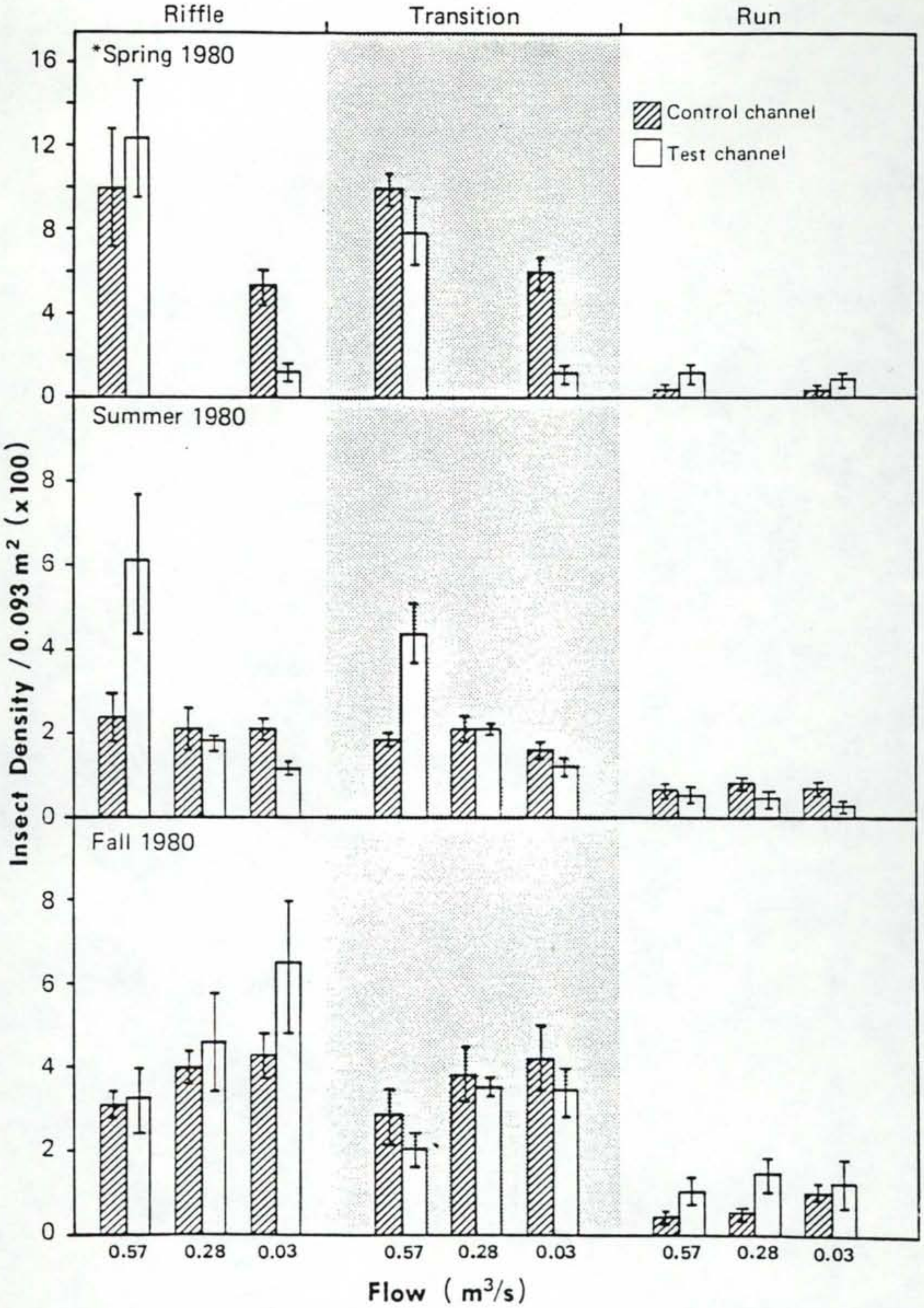

Figure 27. Mean insect densities /0.093 m^2 ($\pm$ std. error) from three experiments (spring, summer, and fall 1980), three habitats (riffle, transition and run) and three test flows (0.57, 0.28 and 0.03 m^3/s). Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon. *Spring 1980 experiment had only two test flows, 0.57 and 0.28 m^3/s.

Table 14. Number/0.37 m^2 of "key" species collected from the test and control riffle at three test flows (0.57, 0.28 and 0.03 m^3/s) during the summer 1980 experiment. Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon.

	Test			Control		
	0.57	0.28	0.03	0.57	0.57	0.57
Baetis tricaudatus	530	228	31	216	361	241
Epeorus albertae	84	58	12	75	107	108
Ephemerella inermis	154	12	1	81	17	5
Heptagenia spp.	76	163	113	100	71	52
Rhithrogena hageni	174	8	0	84	53	1
Hydropsychidae	54	16	23	18	53	131
Chironomidae	866	111	215	200	75	139
Simulium sp.	256	8	1	102	17	24

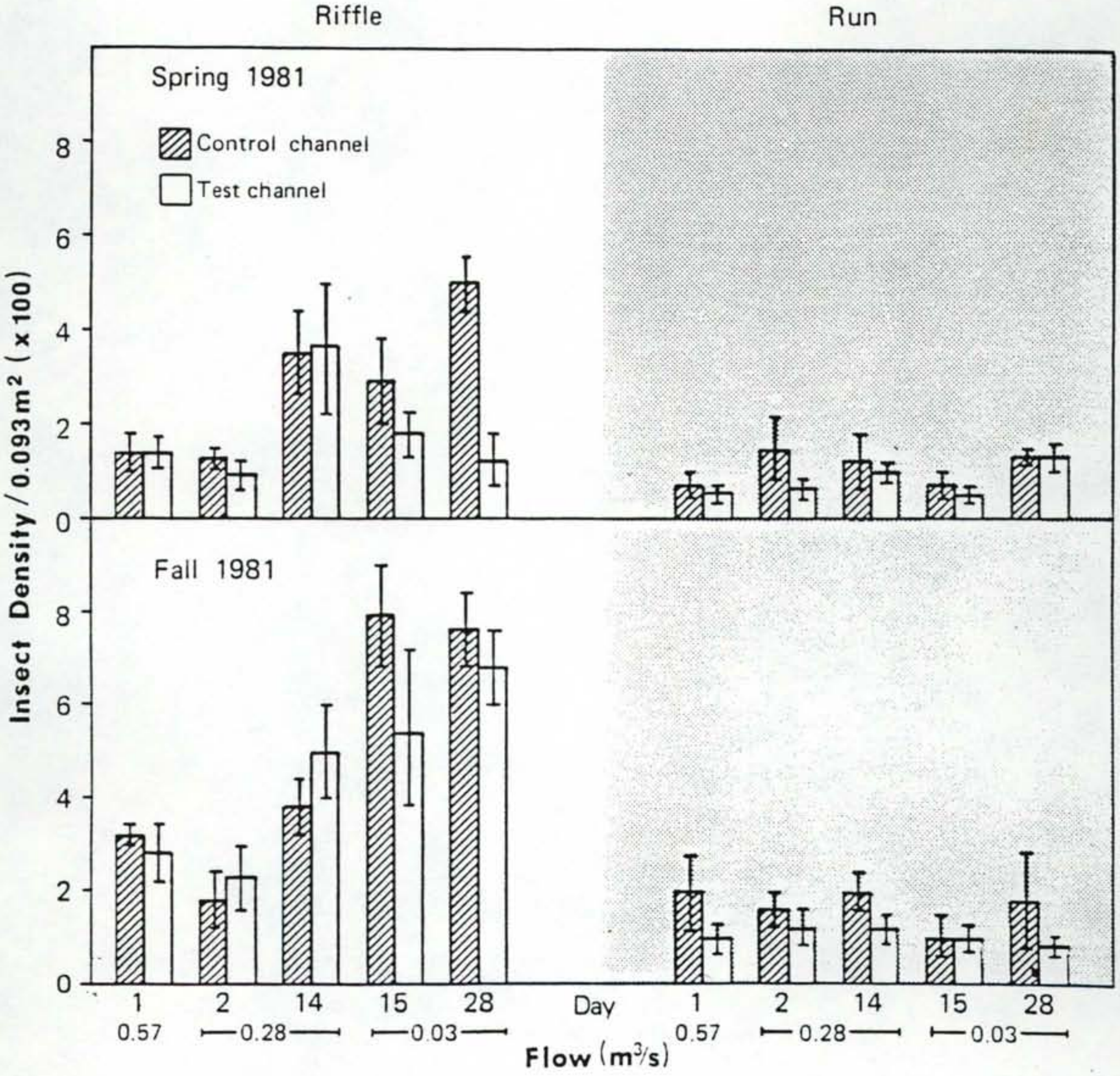

Figure 28. Mean insect densities /0.093 m^2 ($\underline{+}$ std. error) from two experiments (spring and fall 1981), two habitats (riffle and run) five time periods (day 1, 2, 14, 15 and 28) and three test flows (0.57, 0.28, and 0.03 m^3/s). Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon.

Paraleptophlebia bicornuta, and *Rhithrogena hageni*, and the caddisfly Hydropsychidae (Tables 15 and 16). Hydropsychidae were comprised of two genera, *Hydropsyche* and *Cheumatopsyche*, each approximately equal in abundance. Only the mayfly *Baetis tricaudatus* was adversely affected by reduced flows in the fall.

Biomass. During both spring experiments time trends in insect biomass were relatively similiar to insect densities. A reduction in test flows, particularly the lowest flow (0.03 m^3/s), caused a large reduction in insect biomass (Figures 29 and 30) in the test riffle.

In the summer experiment, insect biomass was greater in the test riffle than in the control riffle at the onset of the experiment (Figure 29). At the intermediate flow (0.28 m^3/s), the test and control biomass was comparable but less than at the former flow. At the low flow (0.03 m^3/s), biomass increased slightly in the test riffle (Figure 29).

Insect biomass in both fall experiments was varied. Biomass during the fall 1980 experiment was comparable between the test and control riffle (Figure 29) and changed little during the period of the test. In the fall 1981 experiment, insect biomass in the control riffle increased while in the test riffle it was approximately similar on the starting and concluding dates of the experiment, although intermediate sampling dates showed an increase (Figure 30). Much variation was noted in test riffle biomass during the experiment.

Diversity. The Brillouin diversity index, evenness and number of species were computed for the test and control riffle at each flow (Table 17). At no time, for any given flow, did diversity or evenness differ appreciably (0.39 and 0.10 respectively) between the test and

Table 15. Number/0.37 m^2 of "key" species collected from the test and control riffle at three test flows (0.57, 0.28 and 0.03 m^3/s) during the fall 1980 experiment. Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon.

	Test			Control		
	0.57	0.28	0.03	0.57	0.57	0.57
Baetis tricaudatus	79	54	12	156	94	128
Ephemerella margarita	4	16	233	10	22	104
Heptagenia spp.	17	66	43	51	74	340
Paraleptophlebia bicornuta	0	48	451	0	34	44
Rhithrogena hageni	406	438	749	176	364	340
Hydropsychidae	462	926	807	498	764	860
Chironomidae	168	44	31	128	66	76
Simulium sp.	4	0	0	56	2	0

Table 16. Number/0.37 m^2 of "key" species collected from the test and control riffle at three test flows (0.57, 0.28 and 0.03 m^3/s) during the fall 1981 experiment. Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon.

	Test			Control		
	0.57	0.28	0.03	0.57	0.57	0.57
Baetis tricaudatus	113	88	24	146	142	436
Ephemerella margarita	0	10	160	0	14	72
Heptagenia spp.	6	16	4	10	8	0
Paraleptophlebia bicornuta	2	20	116	0	4	24
Rhithrogena hageni	87	188	372	98	212	144
Hydropsychidae	593	1326	1640	655	850	1972
Chironomidae	202	164	200	180	150	262
Simulium sp.	35	0	0	147	4	0

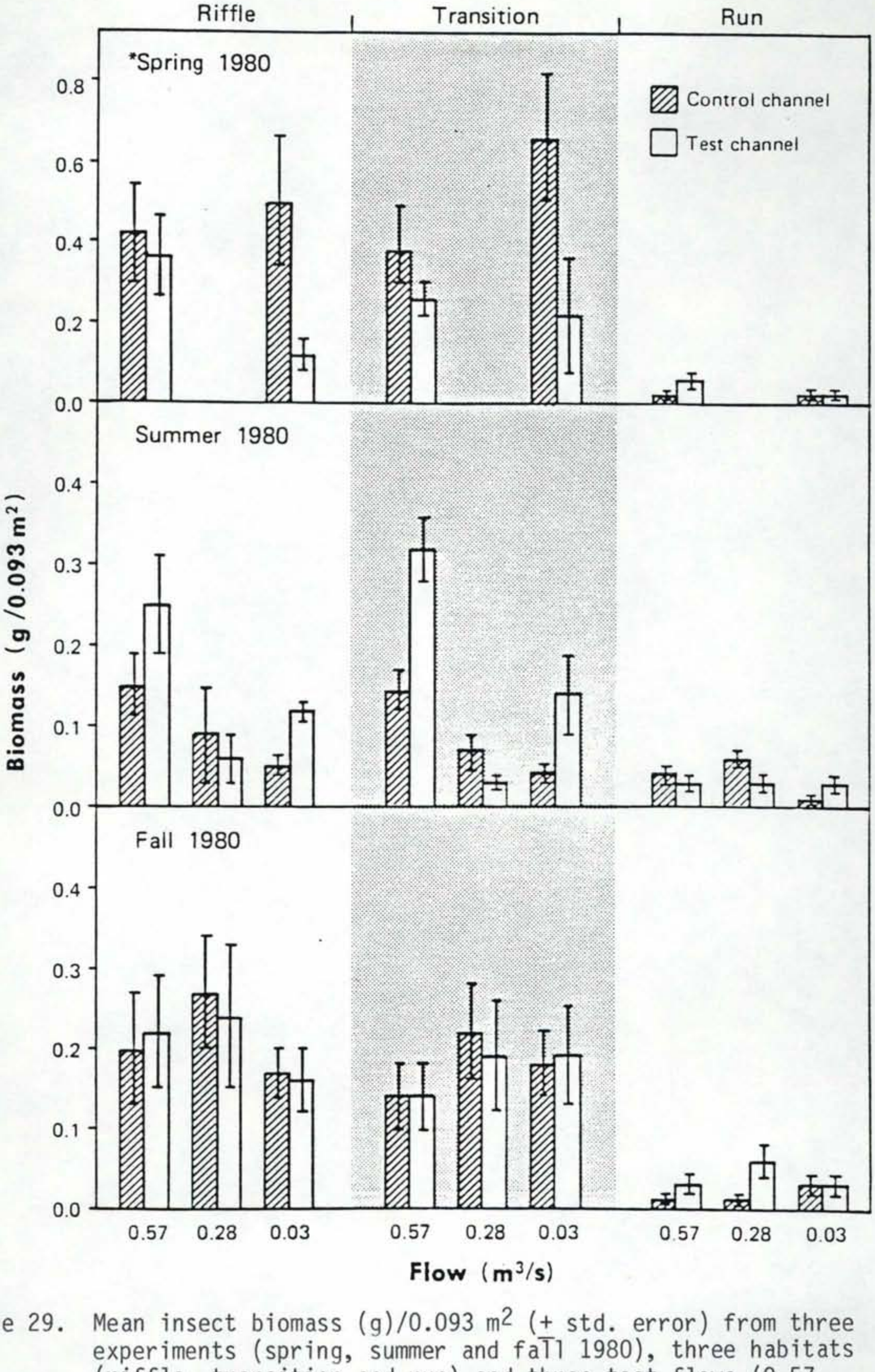

Figure 29. Mean insect biomass (g)/0.093 m^2 (+ std. error) from three experiments (spring, summer and fall 1980), three habitats (riffle, transition and run) and three test flows (0.57, 0.28 and 0.03 m^3/s). Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon. *Spring 1980 experiment had only two test flows, 0.57 and 0.03 m^3/s.

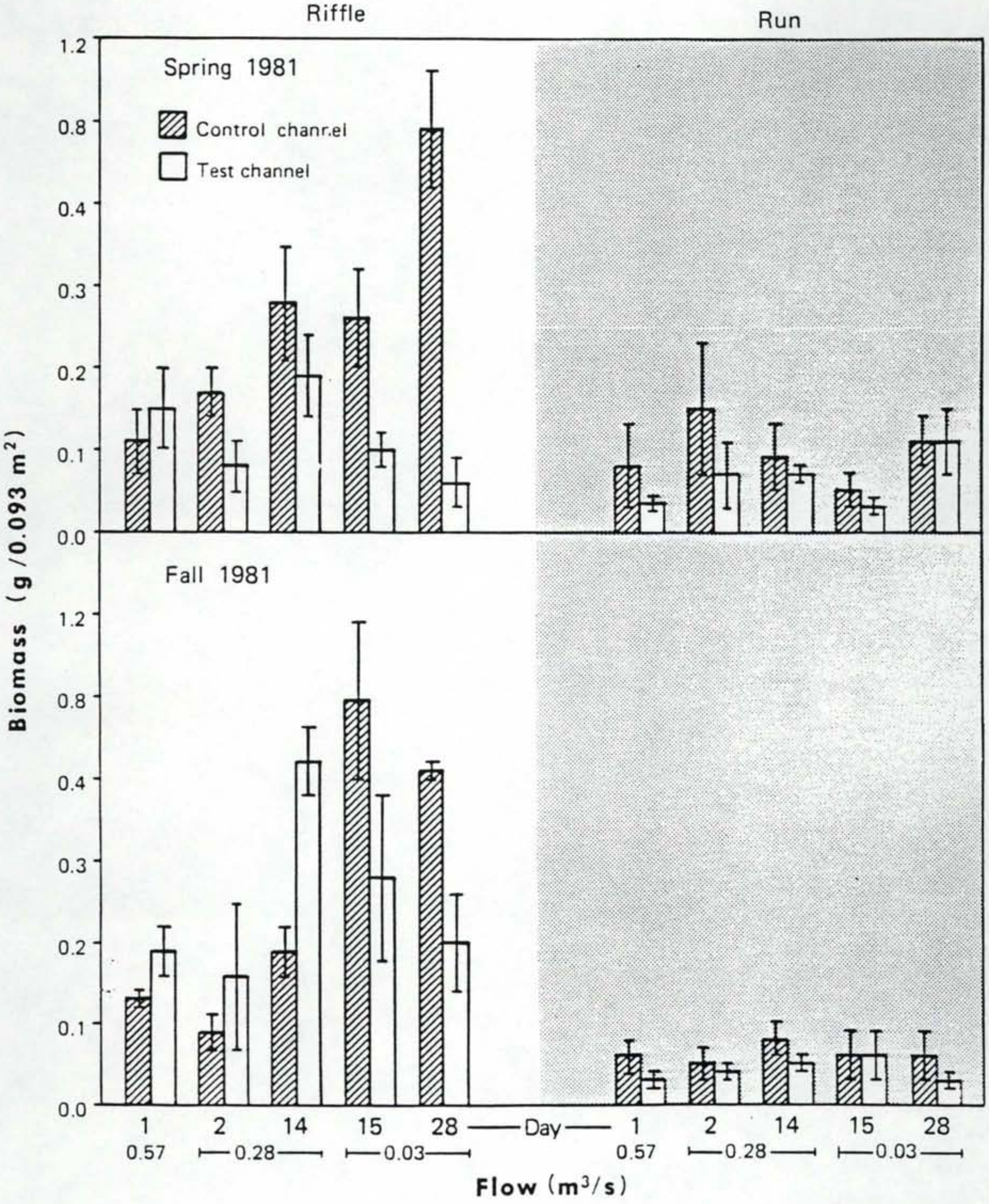

Figure 30. Mean insect biomass (g)/0.093 m^2 ($\pm$ std. error) from two experiments (spring and fall 1981), two habitats (riffle and run), five time periods (day 1, 2, 14, 15 and 28) and three test flows (0.57, 0.28 and 0.03 m^3/s. Troy channels, Troy, Oregon.

Table 17. Species diversity, evenness, number of species and density (no/0.093 m^2) from test (T) and control (C) riffles at three test flows (0.57, 0.28 and 0.03 m^3/s). Control flow = 0.57 m^3/s. Chironomidae was excluded from diversity, evenness and number of species but included in density. Spring, summer and fall 1980 and 1981 experiments, Troy channels, Troy Oregon. *Spring 1980 experiment had only two test flows, 0.57 and 0.03 m^3/s.

	FLOW (m^3/s)					
	0.57		0.28		0.03	
	T	C	T	C	T	C
*SPRING 1980						
Diversity	2.16	2.06			2.85	3.05
Evenness	0.55	0.51			0.72	0.64
No. of Species	16	17			16	27
Density (no/0.093 m^2)	1238	986			133	534
SUMMER 1980						
Diversity	3.11	3.01	2.44	2.69	2.63	2.95
Evenness	0.68	0.68	0.58	0.66	0.68	0.66
No. of Species	24	21	19	18	15	14
Density (no/0.093 m^2)	614	239	182	208	119	209
FALL 1980						
Diversity	2.62	3.01	2.75	2.82	2.87	2.79
Evenness	0.59	0.69	0.61	0.65	0.67	0.68
No. of Species	22	21	23	21	20	17
Density (no/0.093 m^2)	326	308	458	406	655	434
SPRING 1981						
Diversity	2.43	2.14	2.07	2.10	2.44	2.71
Evenness	0.61	0.54	0.51	0.51	0.68	0.61
No. of Species	17	15	17	17	13	22
Density (no/0.093 m^2)	151	146	364	353	128	506
FALL 1981						
Diversity	2.32	2.47	2.32	2.40	2.12	2.22
Evenness	0.53	0.58	0.56	0.61	0.51	0.53
No. of Species	22	20	18	15	18	18
Density (no/0.093 m^2)	282	326	493	371	677	760

control riffle. The number of insect species present in the test and control riffles differed only at the end of both spring experiments (Table 17). During the summer and fall experiments the number of species were similar.

Functional Groups. Most insect functional groups in the Troy channels were collector-gatherers and collector-filterers (Table 18). Chironomids were excluded from these calculations since they were not identified beyond the family level. The majority of the collector-gatherers were the Ephemeroptera. The collector-filterers, especially Hydropsychidae, became increasingly dominant throughout the year; in the fall they comprised 73% of the insect community (Table 18). Most of the engulfers were Plecoptera and represented less than 15% of the insect community. None of the above functional groups were affected by reduced stream discharge. Conversely, low flow conditions favored scrapers in the summer experiment (Table 18). Most scrapers were represented by the mayfly Heptagenia spp.

Hyporheic Insect Distribution. Hyporheic insect studies were conducted in the fall 1981 experiment only. Immediately prior to the second flow reduction (0.28 to 0.03 m^3/s), half of the canisters were removed from the riffle margin and riffle thalweg. In each, (riffle margin and riffle thalweg) the principle insects were the caddisfly Hydropsychidae, chironomids and "other" insects (Figure 31). Chironomidae were most abundant in the riffle margin while Hydrophychidae were most abundant in the riffle thalweg. Most insects were found in the upper 10 cm of all canisters (>65%).

Two weeks after flow reductions (0.28 to 0.03 m^3/s) the remaining canisters were removed from the riffle margin and riffle thalweg.

Table 18. Per cent composition of functional groups in test (T) and control (c) riffle, at three flows (0.57, 0.28 and 0.03 m^3/s) from five experiments. Chironomidae was excluded. Control flow = 0.57 m^3/s. Troy channels, Troy, Oregon. *Spring 1980 experiment had only two test flows, 0.57 and 0.03 m^3/s.

Functional Group	FLOW (m^3/s)					
	0.57		0.28		0.03	
	T	C	T	C	T	C
*SPRING 1980						
Collector - gatherer	85	89			67	79
Collector - filterer	10	5			5	11
Engulfer	2	2			4	5
Scraper	3	4			24	5
SUMMER 1980						
Collector - gatherer	73	68	64	77	44	56
Collector - filterer	21	16	5	11	9	25
Engulfer	1	2	4	1	3	5
Scraper	5	14	27	11	44	14
FALL 1980						
Collector - gatherer	47	36	31	34	58	38
Collector - filterer	42	50	52	49	31	52
Engulfer	8	5	7	9	7	5
Scraper	3	8	10	7	4	5
SPRING 1981						
Collector - gatherer	79	86	52	89	81	85
Collector - filterer	10	5	45	7	4	8
Engulfer	8	8	3	4	15	7
Scraper	3	1	0	0	0	0
FALL 1981						
Collector - gatherer	23	23	29	19	26	28
Collector - filterer	71	68	64	73	71	65
Engulfer	3	7	3	5	2	6
Scraper	3	2	4	3	1	1

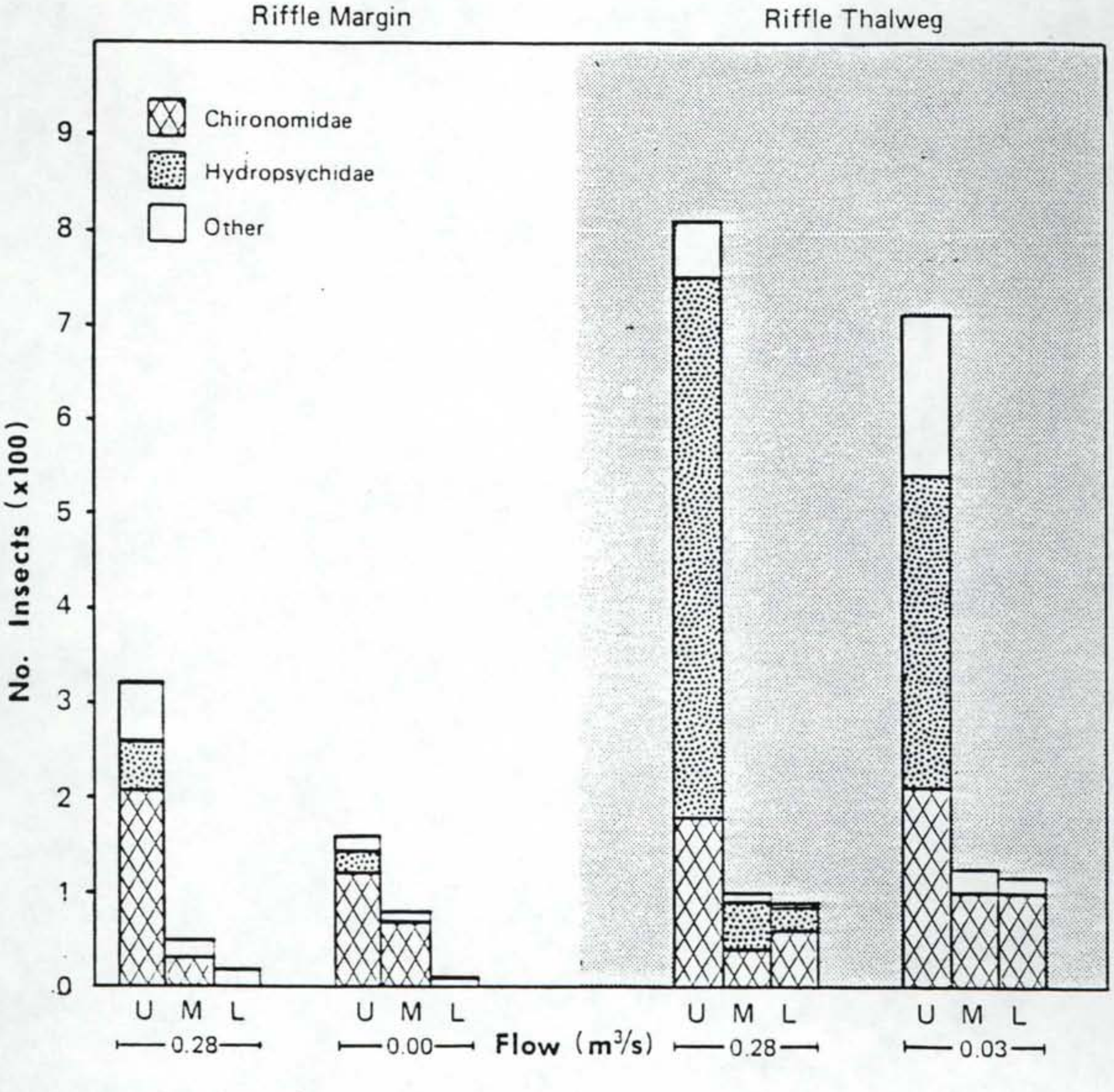

Figure 31. Mean number of insects in upper (U), 0-10 cm; middle (M), 10-20 cm; and lower (L), 20-30 cm of 30-cm canisters placed in the thalweg and margin of the test riffle. Riffle thalweg flows were 0.28 and 0.03 m^3/s; riffle margin flows were 0.28 and 0.00 m^3/s as canisters were dewatered for two weeks. Troy channels, Troy, Oregon, fall 1981 experiment.

The canisters in the riffle margin had been dewatered for two weeks. The water level in the riffle margin after the flow reductions was 10 cm below the substrate surface. Insect densities in the upper 10 cm of riffle margin canisters were reduced to approximately half that of the densities at the previous flow (Figure 31). The hyporheic insect composition was relatively constant during the same time period.

Drift. In four of the five experiments conducted (spring, summer and fall 1980 and spring 1981), reduced stream discharge clearly caused a catastrophic increase in insect drift density (Figure 32). The initial flow reduction (0.57 to 0.28 m^3/s) triggered a minor pulse at midnight, especially during the summer 1980 experiment. Increased drift density was most evident, however, following the second flow reduction from 0.28 to 0.03 m^3/s.

A variety of drift responses were noted following the second flow reduction. An immediate response to flow reduction was seen in the spring 1981 experiment (Figure 32). During the spring, summer and fall 1980 experiments, the first major pulse occurred at noon, one hour after incremental flow reductions were complete. In all of the experiments, however, the greatest drift pulse occurred under the cover of darkness and generally at midnight.

Although a plethora of insects drifted, two species were particularly important, the mayfly, Baetis tricaudatus Dodds, and the dipteran Simulium sp. In the unregulated control channel, B. tricaudatus displayed a high propensity to drift at night (Figure 33). In the test channel, when flows were reduced from 0.28 to 0.03 m^3/s, B. tricaudatus displayed a delayed catastrophic response at midnight

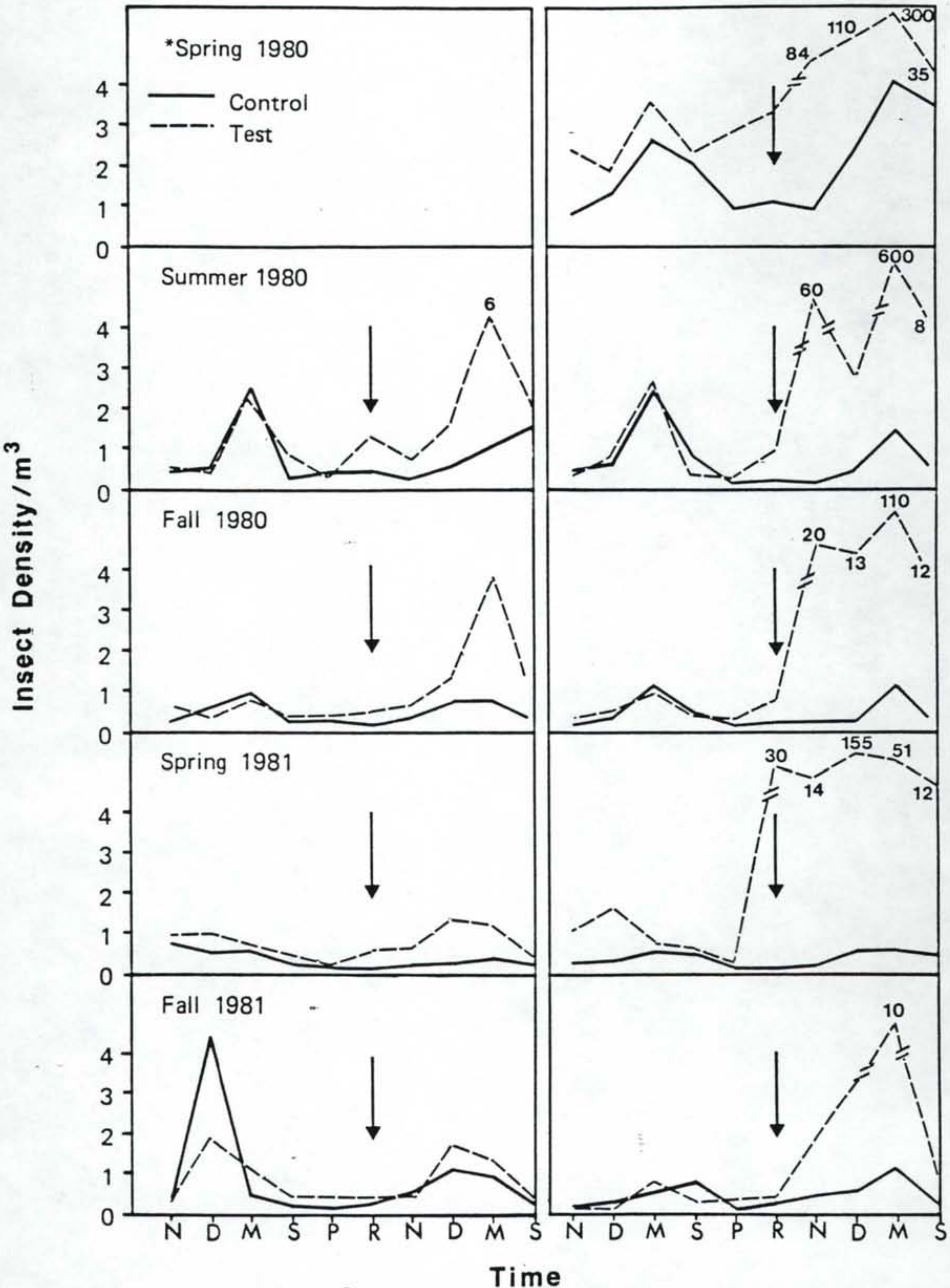

Figure 32. Insect density /m^3 from five experiments. Left arrow indicates reduction from 0.57 to 0.28 m^3/s; right arrow from 0.28 to 0.03 m^3/s. Control volume = 0.57 m^3/s. Double vertical lines denote a two week lapse. N = noon; D = dusk; M = midnight; S = sunrise; P = prereduction and R = reduction. *Spring 1980 had only one reduction from 0.57 to 0.03 m^3/s.

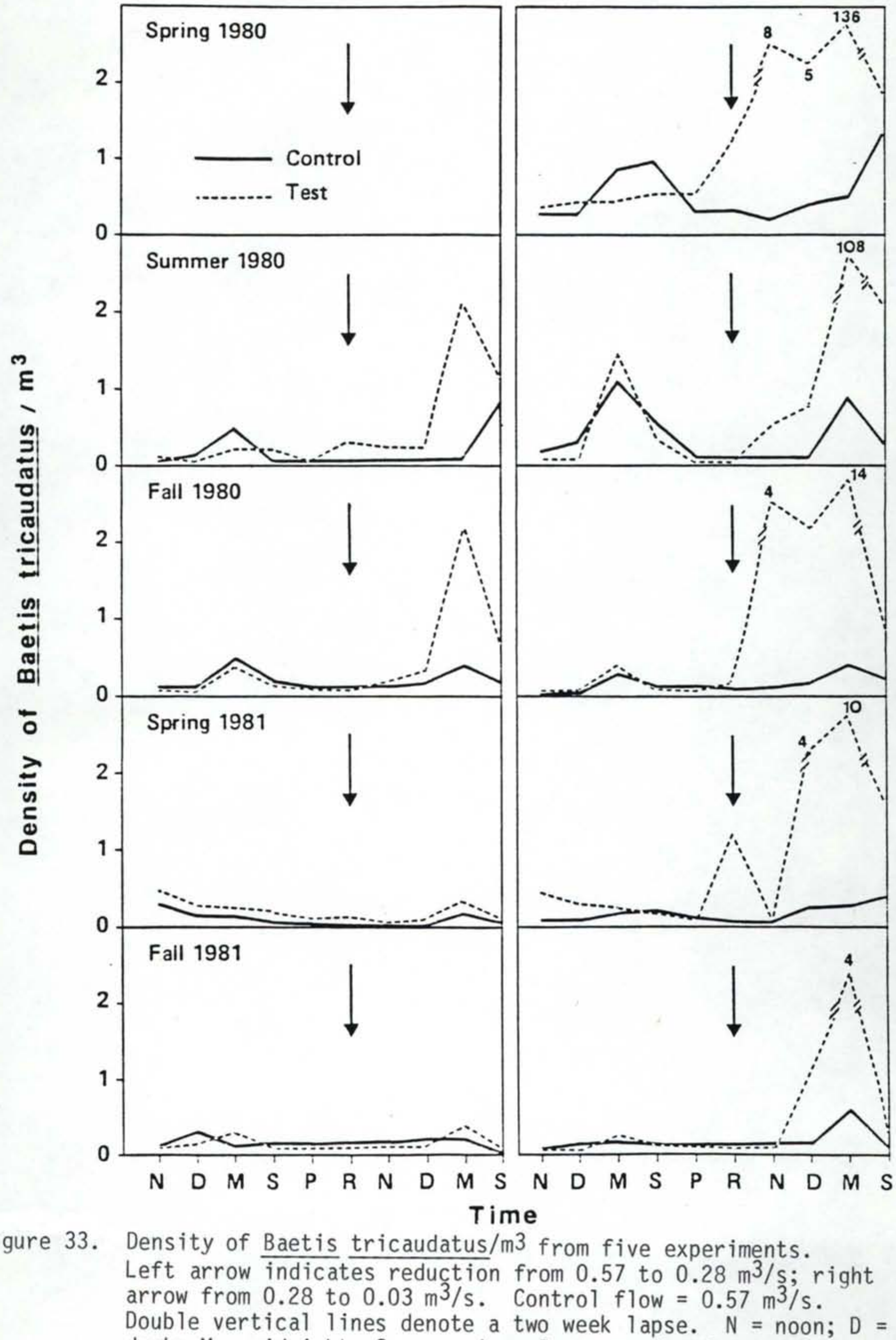

Figure 33. Density of Baetis tricaudatus/m3 from five experiments. Left arrow indicates reduction from 0.57 to 0.28 m3/s; right arrow from 0.28 to 0.03 m3/s. Control flow = 0.57 m3/s. Double vertical lines denote a two week lapse. N = noon; D = dusk; M = midnight; S = sunrise; P = prereduction and R = reduction. *Spring 1980 had only one reduction from 0.57 to 0.03 m3/s.

the flow reduction. Simulium sp. showed no consistent drift trend in the unregulated control channel, but responded catastrophically to the second flow reduction (0.28 to 0.03 m^3/s) in the test channel. Simulium sp. entered the drift by noon, only one hour after the completion of incremental flow reductions (Figure 34).

Insect Stranding. Reduced stream discharge caused peripheral areas of the test riffle to become dewatered and resulted in stranding of benthic insects. Following the initial flow reduction (0.57 to 0.28 m^3/s) in the spring experiment, only a few insects were stranded (Figure 35). The second, and more drastic flow reduction (0.28 to 0.03 m^3/s) resulted in considerably more insects being stranded. However, greater than half of the insects still managed to reach the refuge of running water (Figure 35). The principle insect that avoided stranding was the mayfly B. tricaudatus (Table 19). "Key" species stranded were the mayfly, Rhithrogena hageni Eaton, and the dipterans Chironomidae and Simulium sp. Insect density in the control channel dewatered zone remained relatively unchanged throughout both flow reductions (Figure 35).

Stranding of insects due to reduced stream discharge was much more apparent in the fall 1981 experiment. Both flow reductions (0.57 to 0.28 m^3/s and 0.28 to 0.03 m^3/s) resulted in many "key" species becoming stranded, particularly the hydropsychid caddisflies (Hydropsyche and Cheumatopsyche) and Chironomidae (Table 20). As in the spring experiment, B. tricaudatus avoided stranding.

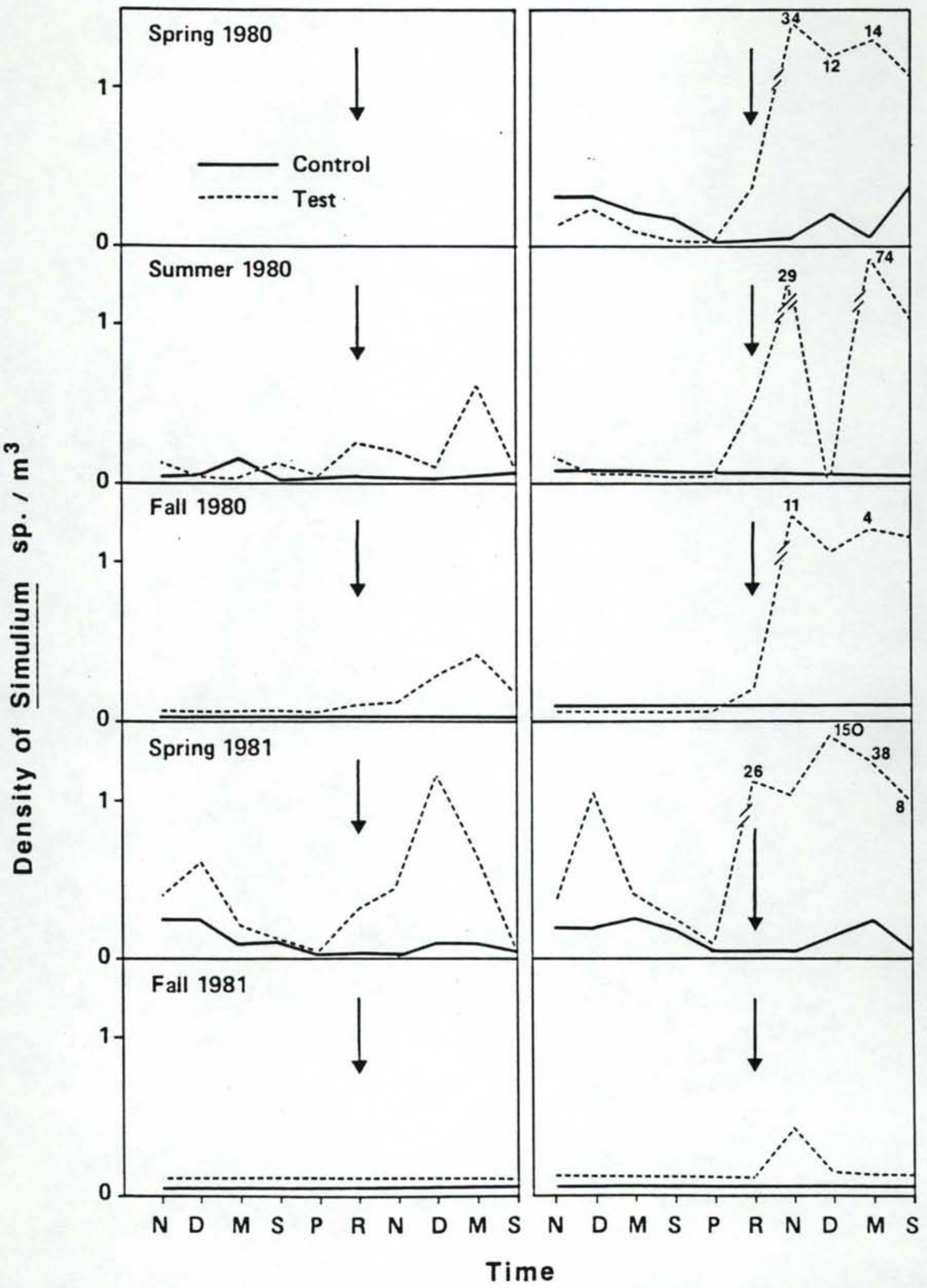

Figure 34. Density of Simulium sp. /m^3 from five experiments. Left arrow indicates reduction from 0.57 to 0.28 m^3/s; right arrow from 0.28 to 0.03 m^3/s. Control flow = 0.57 m^3/s. Double vertical lines denote a two week lapse. N = noon; D = dusk; M = midnight; S = sunrise; P = prereduction and R = reduction. *Spring 1980 had only one reduction from 0.57 to 0.03 m^3/s.

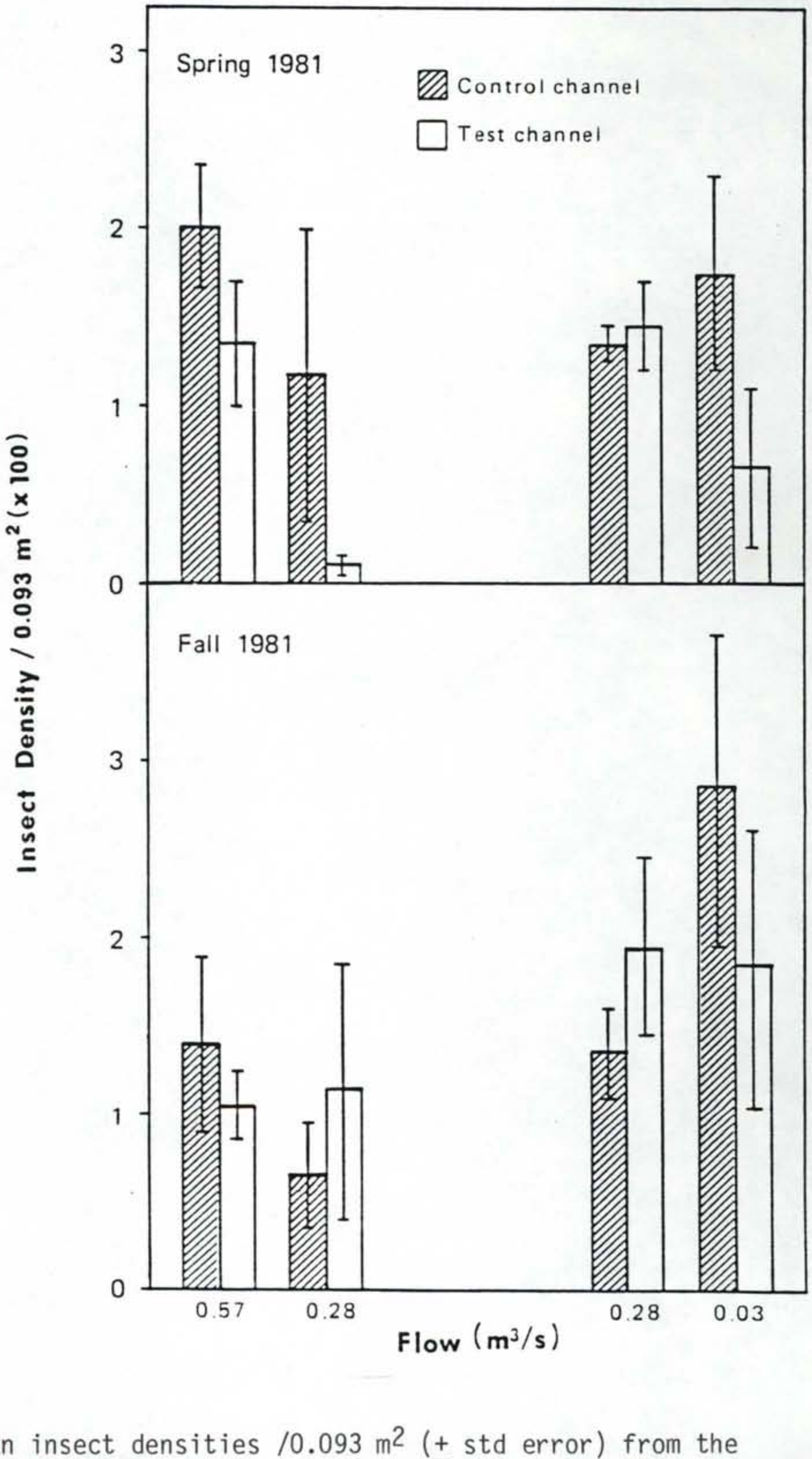

Figure 35. Mean insect densities /0.093 m^2 ($\pm$ std error) from the dewatered zone when test flows were reduced from 0.57 to 0.28 m^3/s and from 0.28 to 0.03 m^3s. Control flow = 0.57 m^3/s. Spring and fall 1981, Troy channels, Troy, Oregon.

Table 19. Number/0.37 m^2 of "key" species found in the test and control dewatered zone before and after each flow reduction. Flow reductions were from 0.57 to 0.28 m^3/s and from 0.28 to 0.03 m^3/s. Control flow = 0.57 m^3/s. Spring 1981 experiment, Troy channels, Troy, Oregon.

	Flow Reductions (m^3/s)			
	0.57	0.28	0.28	0.03
TEST				
Baetis tricaudatus	366	14	282	28
Ephemerella inermis	27	1	21	10
Heptegenia spp.	0	0	1	0
Rhithrogena hageni	53	6	52	38
Hydropsychidae	3	0	1	7
Chironomidae	31	5	188	110
Simulium sp.	2	1	8	51
Total	482	27	453	244
CONTROL				
Baetis tricaudatus	457	312	326	282
Ephemerella inermis	17	9	2	11
Heptagenia spp.	0	0	1	0
Rhithrogena hageni	123	57	37	45
Hydropsychidae	5	0	0	0
Chironomidae	43	46	79	250
Simulium sp.	47	2	13	57
Total	685	426	457	645

Table 20. Number/0.37 m^2 of "key" species found in the test and control dewatered zone before and after each flow reduction. Flow reductions were from 0.57 to 0.28 m^3/s and from 0.28 to 0.03 m^3/s. Control flow = 0.57 m^3/s. Fall 1981 experiment, Troy channels, Troy, Oregon.

	Flow Reductions (m^3/s)			
	0.57	0.28	0.28	0.03
TEST				
Baetis tricaudatus	55	11	68	10
Ephemerella inermis	1	1	12	18
Heptegenia spp.	4	6	6	3
Rhithrogena hageni	23	5	95	28
Hydropsychidae	122	144	440	562
Chironomidae	145	266	78	60
Simulium sp.	20	3	0	0
Total	370	436	759	681
CONTROL				
Baetis tricaudatus	77	41	64	71
Ephemerella inermis	8	3	5	17
Heptagenia spp.	25	8	5	4
Rhithrogena hageni	19	14	49	115
Hydropsychidae	177	23	255	541
Chironomidae	204	131	115	255
Simulium sp.	4	0	0	0
Total	514	210	493	905

DISCUSSION

Benthic Insect Response to Flow Reductions

Reduced stream discharge caused seasonally different responses to riffle insects. Because riffles traditionally support the greatest insect densities and diversities they are especially useful in detecting cause-effect relationships from incrementally reduced flows.

Spring was the only season during which total insect density, biomass and number of species were adversely affected by reduced flows. In temperate regions, many aquatic insects are late instars in the spring, ready to emerge as adults (Hynes, 1970). We believe spring flow reductions caused crowding which resulted in a density dependent response (i.e. emigration). In a similar spring study at the Troy channels, Ruediger (1980) found no significant difference between test and control insect densities following flow reductions. This discrepancy may have been in part due to more intensive sampling in our study. We took four Hess samples from each habitat at each flow increment while Ruediger (1980) collected two to three samples.

At the onset of the summer experiment, insect density and biomass were much greater in the test riffle than they were in the control riffle. The test channel during the 1980 summer experiment was the control channel in the recently completed spring experiment. This condition was because of the alternating nature of control and test channels in our experimental design. Thus, high flows had been maintained in the summer test channel for the past 12 weeks compared to only four weeks in the control. Even though this four-week colonization period was justified earlier, more time may have been required to attain carrying capacity.

At the end of the summer experiment, insect density and biomass were comparable in test and control riffles. These findings agree with Ruediger's (1980) summer test results. McClay (1968) and Hafele (1978) also found no invertebrate response to reduced flows in the summer.

Throughout both fall experiments, insect densities increased comparably in test and control riffles. Most insects found in the fall were early instars. Hynes (1970) discusses the seasonal fluctuations of stream invertebrates and notes that fall recruitment via egg eclosion was considerable. Since low flows typically occur in the fall, it appears that, given normal seasonal conditions, surface and hyporheic insects have become genetically entrained to cope with these conditions, if the insects are not stranded.

Different "key" species showed a variety of responses to reduced stream discharge. Chironomids did not respond to reduced stream discharge in any consistent fashion. More information might have become available if chironomid taxomony were more resolute.

Several mayflies were affected by reduced stream discharge. *Emphemerella inermis* and *Rhithrogena hageni*, both rheophilic organisms, declined appreciably in the spring due to reduced flows. Both species are dorsoventrally flattened and highly adapted to running water. This flattening allows these insects to avoid direct current (Hynes, 1970) and exist in the boundary layer. Nearby current provides a rapid replacement of water, ensuring a continual supply of dissolved oxygen. Current also prevents silting, allowing periphyton to flourish. A combination of crowding, respiratory and feeding problems probably caused displacement and subsequent emigration of *E. inermis* and *R. hageni* from the test riffle in the spring. *E. inermis* was found only in the spring and early summer as a late instar. *R. hageni* occurred as a late instar in the spring and as an early instar in the fall experiments. Throughout the fall experiments, *R. hageni* densities increased in both the test and control riffle but increased to a much greater degree in the test riffle. Since low flows occur naturally in the fall, early instar *R. hageni* is probably better suited to low flow conditions than its late instar counterpart.

Baetis tricaudatus, without exception, were adversely affected as a result of reduced flows. *B. tricaudatus* are strong swimmers with fusiform bodies and are highly adapted to running waters (Merritt and Cummins, 1978). They are rarely stranded and showed a high propensity to drift. Thus, it was not surprising to observe their emigrating tendencies. Ruediger (1980) also reported a reduction of *Baetis* due to low flows.

One might expect insect density and biomass to fluctuate in unison but this was not always the case. Insect biomass was more variable than insect density because of occassional large insects, usually stoneflies, found in the bottom samples.

Insect Drift and Stranding of Near Shore Insects

Waters (1972), in his review on drift of stream insects, identified three types of drift: catastrophic, behavioral and constant. All three types were observed during this study, however, catastrophic drift was especially apparent because of its role in destabilizing the system and potentially altering trophic dynamic processes.

Generally, a diel periodicity was observed in the control channel with a single peak at midnight. Much work has been conducted showing that most insects are night active (Waters 1972) and that drift is triggered by light intensity (Anderson 1966; Chaston 1968). Other peaks may have occurred during the night, but because of the sampling schedule these were not apparent. The initial flow reduction (0.57 to 0.28 m^3/s) caused ca. 8% loss in wetted perimeter and may be the reason that a large surge in insect drift was not observed. However, catastrophic drift was evident following the second flow reduction (0.28 to 0.03 m^3/s), at which time ca. 31% of the dewatered zone was exposed. Corning (1969) found that as wetted perimeter decreased, insect density increased. Although data are not available to verify this, we believe that the second flow reduction (0.28 to 0.03 m^3/s) likely caused a short term increase in insect densities because of species and density "packing" in the more restricted habitat. A temporary "packing" condition would theoretically cause increased density dependent responses, hence, increased drift.

In most of the experiments, insect drift increased before noon following the second flow reduction (0.28 to 0.03 m^3/s). Minshall and Winger (1968) also noted an increase in daytime drift due to flow reductions. Most of the increase in daytime drift was attributable to *Simulium* sp. Hynes (1970) reported *Simulium* having a very narrow tolerance range to current velocities (80-90 cm/s). Since *Simulium* is a filter feeder, it congregates in places where the water flow is laminar. Because *Simulium* sp. has specific current velocity requirements, sudden flow reductions would likely cause immediate drifting.

The greatest drift pulse following the second flow reduction occurred under the cover of darkness, usually at midnight. Brusven et al. (1974) also observed a delayed catastrophic response to changing stream discharge. We believe that most insects delayed drifting because of the strong overriding influence of light as a triggering mechanisms causing behavioral drift (Anderson 1966; Chaston 1968; Elliot 1965; Muller 1963; Waters 1972). *Baetis tricaudatus* was the most abundant drift component throughout the study. Peters (1973); Radford and Hartland-Rowe (1971) and Ruediger (1980) also reported *Baetis* having a high propensity to drift, especially in response to reduced flows. Without exception, *B. tricaudatus* showed a delayed catastrophic response at midnight following the second flow reduction (0.28 to 0.03 m^3/s).

After each incremental flow reduction, a substantial amount of riffle was dewatered. This condition was especially evident in 1981 when the riffle was more V shaped than the trapezoidal cross-section used in 1980. Most insects stranded in the spring experiment were *Rhithrogena hageni*, Chironomidae and *Simulium* sp. Pearson and Franklin (1968) also found *Simulium* readily stranded. In the fall, Chironomidae and the hydropsychid caddisflies were the most abundant insects stranded. Brusven et al. (1974) reported taxonomically similar insects stranded during the flow reduction studies on the Snake River, Idaho.

In the spring, relatively cool air and water temperatures permitted some near-shore insects to survive dewatering. Greater survivability was at least partially attributed to their larger size and greater mobility at this time of the year. In the fall, however, warm air and water temperatures caused rapid drying of the exposed mineral substrate and attached algae mats. Consequently, fall dewatering caused nearly 100% stranding of near-shore insects. At this time, only *B. tricaudatus* effectively avoided stranding. Its greater mobility apparently allowed it to maintain contact with the water column, and contributed to its high drift rate. Pearson and Franklin (1968) observed Baetis sp. moving towards deeper water, usually crawling, but occasionally swimming, when subjected to reduced flows.

Insect drift was consistent in its response to reduced stream discharge to all except the fall 1981 experiment. Reasons for the lack of a pronounced behavioral or catastrophic drift during the later experiment are speculative. Walker (1972) found drift to be lowest in the fall on the Clearwater River, Idaho. Many of the insects found in the Troy Channels during the fall were quite small. We believe that small, early instar nymphs were not as mobile as their larger and older counterparts. As a consequence, they were more readily stranded. Since most of the insects in the dewatered zone were stranded in the fall 1981 experiment, they were not available to drift. One might ask, why the disproportionately large drift in the fall 1980 experiment? Due to the trapezoidal shape of the original channels, dewatering was not a major problem with respect to large changes in wetted perimeter, therefore, insects were not likely to be stranded and were able to drift.

Our results clearly show that seasonally reduced stream discharge has a variety of impacts on benthic invertebrates. Season-specific responses to flows are important for proper management of regulated lotic systems. Fortunately, manipulated flow reductions are not common in the spring since ample water is available from winter snowpacks in most streams. We feel that summer and fall are the most critical times for stream insects subjected to flow reductions. Warm air and water temperatures combined with the inability of many early instars and/or small insects to reach the refuge of running water could result in high rates of mortality for many insects. The least damaging time of day to reduce flows would be at night since most insects are night drifters. Cooler nighttime air and water temperatures would retard evaporation and allow more time for insects to escape or to be rewatered if the system were subjected to daily fluctuations. Other management considerations should include species present, geographic location and sight feeding fish dependent upon benthic insects as a food source.

SUMMARY

Aquatic insects were sampled seasonally in the Troy channels to determine the effects of reduced stream discharge on: 1) the distribution and abundance of the surface and hyporheic insect community, 2) insect drift and 3) stranding of insects due to dewatering.

Benthic insect densities displayed a seasonal response to reduced stream discharge (0.57 to 0.28 m^3/s and 0.28 to 0.03 m^3/s). In the spring, total insect densities were reduced in the test channel. The mayflies *Baetis tricaudatus*, *Ephemerella inermis* and *Rhithrogena hageni* were affected most by reduced flows. In the summer and fall, no apparent reduction in total insect density was noted. Numbers of *Baetis tricaudatus* were, however, reduced in all experiments.

No major changes were noted in the hyporheic insect community in the riffle thalweg when subjected to reduced stream flows. Only a minor impact to the hyporheic community was noted along the riffle margin.

We observed catastrophic insect drift following the second flow reduction (0.28 to 0.03 m^3/s) in four of the five experiments. No catastrophic drift occurred in the fall 1981 experiment. Total drift responses to reduced flows varied from immediate in the spring to delayed in the summer experiment. *Simulium* sp. drifted during or shortly after flow reductions (daylight), whereas *Baetis tricaudatus* waited until midnight to respond to reduced stream discharge.

Some insect stranding occurred in the spring but relatively larger body size allowed appreciable numbers of insects to avoid stranding. In the fall, almost all insects in the dewatered zone were stranded.

This stranding was due to the immobility of early instars. *Baetis tricaudatus* were able to avoid stranding in the spring and fall experiments.

From the results of these experiments, flow reductions in the summer and fall would cause the most damage to the aquatic insect community. We propose that nighttime flow reductions would be less harmful to the insect community than flow reductions during the daylight hours because 1) genetically entrained behavioral drift occurs most prominently at night in most stream insects, 2) of less probability of stranding insects and 3) of less mortality because of more favorable temperatures if stranded.

PREDICTIVE MODEL EVALUATION
METHODOLOGY FOR DATA COLLECTION AND ANALYSIS

The Instream Flow Experimental Facility is located on the Grande Ronde River, six miles south of Troy, Oregon. The facility has two large flumes, each measuring 250 ft (76.2 m) in length and 19.7 ft (6 m) in width. Near identical stream channel configurations were constructed in each flume, using river gravel. Each stream channel was 200 ft (61 m) in length and contained two 30 ft (9.1 m) riffles and two 40 ft (12.2 m) runs (Figures 36 and 37).

Grande Ronde River water, diverted through a diked side channel provided for up to 20.5 cubic feet per second (0.57 m^3/s) flow in each test channel. 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. These channels are referred to hereafter as the East Channel and West Channel. All cross-sections were parabolic in shape. There were two data collection periods for both channels - March, 1982 (winter) and August, 1982 (summer). In each of the data collection periods a March-McBirney electronic velocity meter (model 201) was used.

Data Collection Procedure

In each of the data collection periods, velocity readings in several vertical sections were taken at each cross-section in each channel. Velocities were recorded at various depths in each vertical, and one reading was taken at 0.6 of the maximum depth of each vertical. The location of the data collection points is shown in Figure 38. One set of velocity measurements was taken for each of three

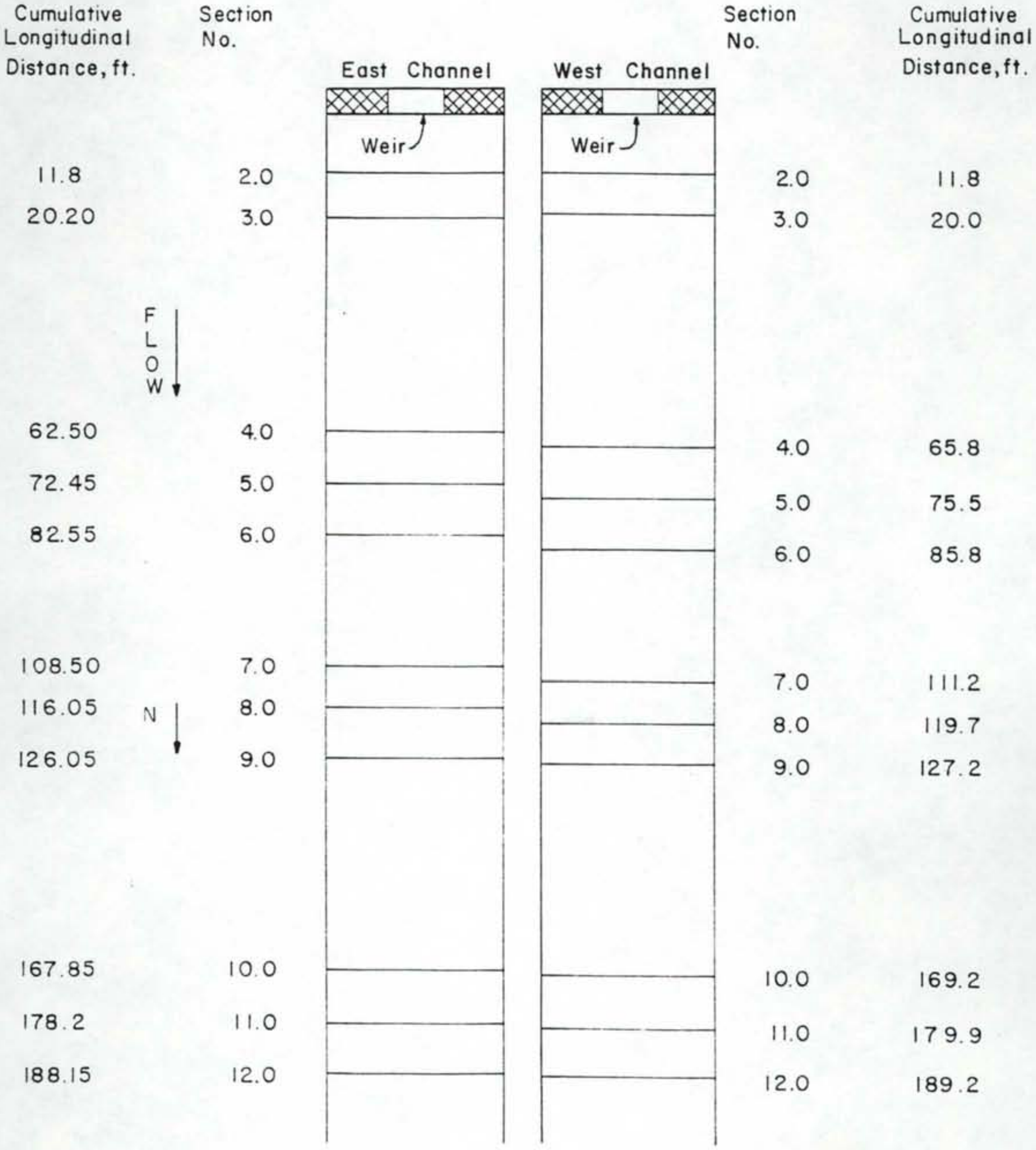

Figure 36. Plan view of the Troy channels cross-section layout for the winter data collection.

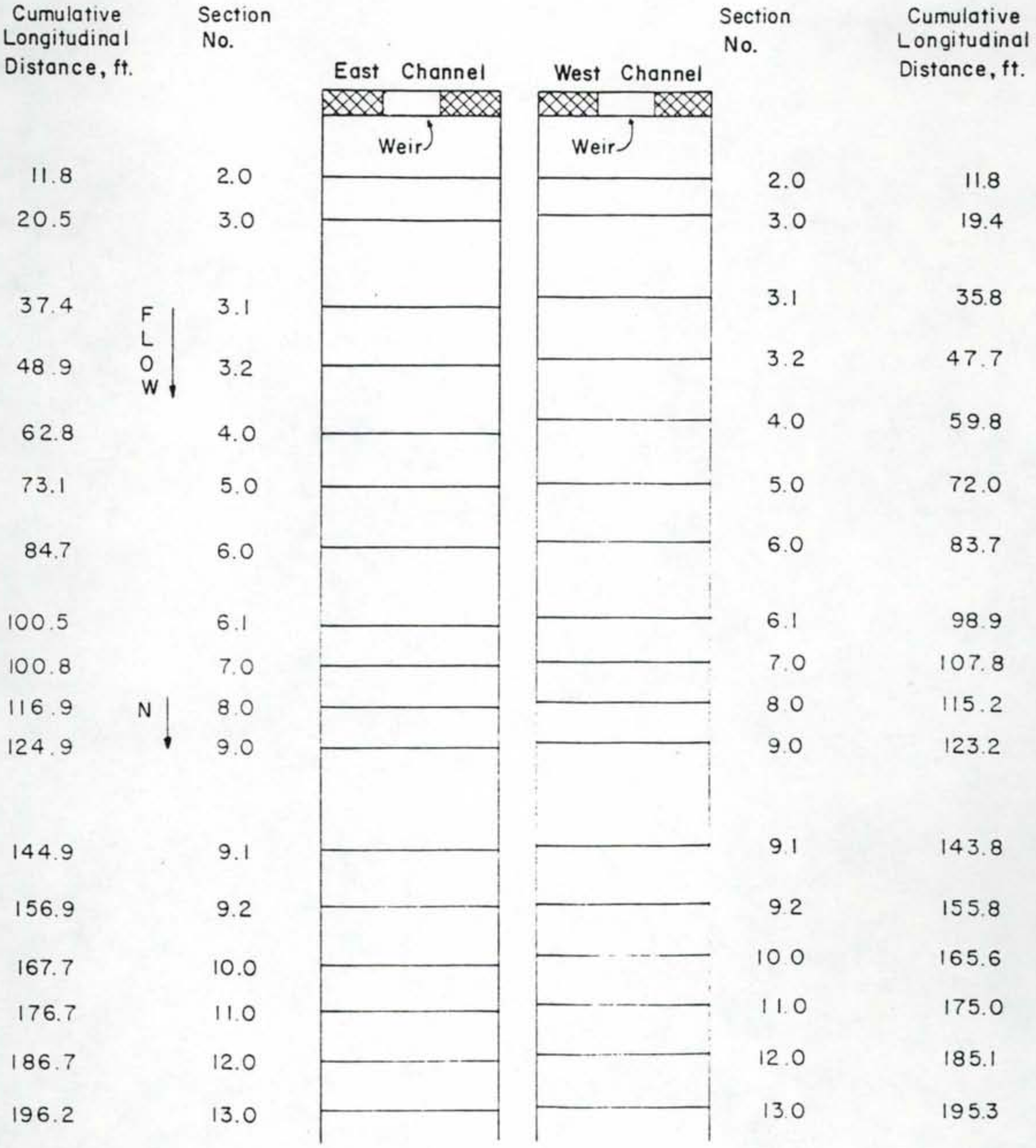

Figure 37. Plan view of the Troy channels cross-section layout for the summer data collection period.

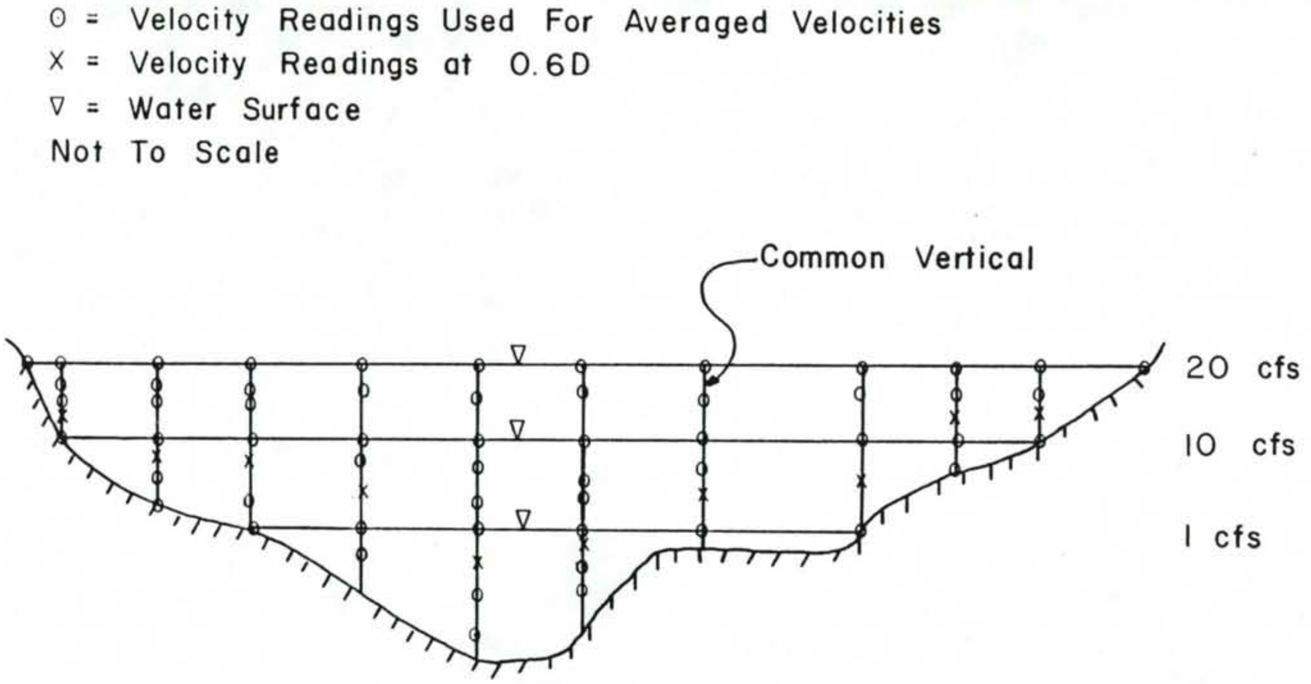

Figure 38. Schematic cross-section illustrating velocity data collection points.

different flow rates: 1 cfs, 10 cfs, and 20 cfs. The flow rates were set by controlling the opening in the head gate of each channel. A constant headwater depth was maintained for each flow rate. The 20 cfs velocity measurement set was taken first, the 10 cfs set second and the 1 cfs set last.

The position of each velocity measurement in a given cross-section can be located using an x, y coordinate system, where x is the horizontal distance from the channel wall and y is the vertical distance from a point slightly below the lowest point in the cross section. For each cross-section, the x coordinates of the velocity measurement points were constant regardless of the flow rate ensuring that velocities were a function of discharge only. This criterion was essential for the proper operation of the IFG4 model and will be discussed later. The raw data were hand-recorded and later entered into a comprehensive data base on an IBM/370 computer.

Data Analysis Methodology

There were three phases of the data analysis each of which used a specially written data processing program (HYDSUM and TROYSTAT) or the IFG4 model. Each of these three phases will be explained separately in order of execution and will discuss the operation of each program and its input requirements and output information. All computer operations were done on the IBM/4341 computer.

Phase I-HYDSUM

This phase of the analysis used the HYDSUM program which processed the raw hydraulic data to produce weighted average column velocities and velocities taken at 0.6 of the maximum depth of each vertical. A complete set of these velocities was produced for each of the three flow rates (1, 10 and 20 cfs). Additional output data from HYDSUM were:

- top width
- wetted perimeter
- cross-sectional area
- ground profile coordinates (x, y representation of the cross-section bottom)
- water surface elevation
- measured flow rate for each of the two types of velocities

The IFG4 model requires that one velocity be associated with each vertical in a cross-section for a given flow rate. Because the raw data have many velocity vs. depth measurements in each vertical, a weighted average was computed using depth vs. the weighting variable for each vertical. Following is an example of this process.

TABLE 21. Raw Data for Weighted Average Velocity

i	Horizontal Distance from Flume Wall, ft. (x_i)	Distance below Water Surface, ft. (d_i)	Velocity, fps (V_i)
1	19.50	0.00	2.00
2	19.50	0.10	3.30
3	19.50	0.20	4.50
4	19.50	0.30	4.20
5	19.50	0.40	3.80
6	19.50	0.50	3.50
7	19.50	0.60	3.10
8	19.50	0.70	2.50
9	19.50	0.80	0.00

The general equation for weighted average velocity is:

$$V_{avg} = \frac{\sum_{i=1}^{n-1} (V_i + V_{i+1})/2*(d_{i+1} - d_i)}{d_n}$$

Expanding:

$$[\frac{(2.0 + 3.3)}{2}*(0.1 - 0.0) + \frac{(3.3 + 4.5)}{2}*(0.2 - 0.1) + \frac{(4.5 + 4.2)}{2}*(0.3 - 0.2) + \frac{(4.2 + 3.8)}{2}*(0.4 - 0.3) + \frac{(3.8 + 3.5)}{2}*(0.5 - 0.4) + \frac{(3.5 + 3.1)}{2}*(0.6 - 0.5) + \frac{(3.1 + 2.5)}{2}*(0.7 - 0.6) + (2.5 + 0.0)*(0.8 - 0.7)]/0.8 = 3.24 \text{ fps}$$

This kind of a velocity will be referred to in the remainder of this report as an "averaged velocity." The velocity reading taken at six-tenths of the maximum depth of each vertical will be referred to as "velocity at 0.6D."

Phase II-IFG4

In this phase of the analysis, the IFG4 model was used to predict cell velocities (see below) and water surface elevation for each of the cross-sections for each of the three flow rates. The IFG4 model uses predicted versus desired flow rate as the criterion for adjusting either the predicted velocities or water surface elevation. Adjustment of velocity or water surface elevation is a model user option which was decided upon at run time. Both types of adjustment were used in the analysis on both kinds of velocity measurements (averaged and 9.6D).

Calibration

The IFG4 model first computes cell velocities for each cross-section. A cell velocity is merely an average of two contiguous column velocities. Hence, if there are twenty column velocities for a given cross-section, then nineteen cell velocities are computed and used in the analysis. Based on these input velocities, a "given" flow rate is computed. This process is repeated for the number of velocity sets (one for each flow rate). Each of these flow rates is then fitted with the corresponding velocities to a power function (one for each cell in a cross-section) with velocity as the dependent variable. The equation is:

$$V = aQ^b$$

where V = velocity for a cell, fps

Q = flow rate, cfs

a, b = regression constants

A log-log transformation is used for the linear regression. If any negative cell velocities are encountered, then a semi-log transformation is used. The same kind of curve fitting procedure is then done for the flow rate and water stage input data for each cross-section. An additional term, stage at zero flow is added to the flow rate versus stage equation. State is the dependent variable. If any of the cells have less than two velocity vs. flow rate pairs, then a Manning's "n" is computed which is used later to generate a predicted velocity for that cell.

Prediction

Using the previously described calibration equation, the IFG4 model predicts cell velocities and a water surface elevation (stage) for each cross-section based on a desired flow rate. Based on whether velocity adjustment or water surface elevation adjustment is selected as the method used by IFG4 to force agreement of the predicted and desired flow rates, one of two routes of computation is followed.

General Computations

1. From the calibration equation, water surface elevation is predicted from the desired flow rate.
2. Using either the flow rate versus velocity calibration equations or, when necessary, Manning's equation, a predicted velocity is computed for each cell in a cross-section.
3. Based on the predicted water surface elevation, the depth of water and subsequent cross-sectional area for each cell is computed. These cell areas are multiplied by the predicted velocities to yield the predicted flow rate. From this a ratio of desired flow rate to predicted flow rate is calculated (FACTOR).

The above three steps are common to either method of adjustment. If velocity adjustment is effected, then the computations continue as follows:

4. Each cell velocity is multiplied by FACTOR to give the final predicted velocities. Because of the rules of algebra, the final predicted flow rate will be exactly equal to the desired flow rate yielding a final flow rate.

If water surface elevation adjustment is used and $1.1 > \text{FACTOR} > 0.9$, the computations follow step 4 above. If $\text{FACTOR} > 1.1$ or <0.9 the computations continue as follows:

4. An initial water surface elevation adjustment of one foot is added or subtracted depending on whether the difference between the predicted flow rate and the desired flow rate is negative or positive, respectively.

5. With the new water surface elevation, the depth and subsequent cross-sectional area of each cell is re-calculated. The initial predicted cell velocities are then multiplied by these new cell areas to yield a new predicted flow rate.
6. The previous adjustment is then halved, and depending on whether the difference between the new predicted flow rate and the desired flow rate is positive or negative, subtracted or added, respectively, to the previous adjustment which yields a cumulative water surface elevation adjustment.
7. Steps 5 and 6 are repeated until the incremental adjustment is less than 0.005 ft (about eight iterations), which yields a final water surface elevation adjustment. Note that with water surface elevation adjustment, the initial velocity predictions are <u>not</u> modified.

The above procedures are, in effect, a summary description of the "guts" of the IFG4 model.

Phase III-TROYSTAT

The TROYSTAT computer program presents tabular summaries of the measured and predicted cell velocities. The most important aspect of the TROYSTAT program is the chi-square analysis which statistically evaluated the effectiveness of the IFG4 model. Following is a discussion of the strategy of the chi-square analysis.

The random variable of interest is the difference between any pair of predicted and measured cell velocities, D, and is assumed to be normally distributed with a mean μ and a variance σ^2. It is desired that D lie within $\pm$ e units of μ with a probability, α . Hence the confidence interval is as follows:

$$\text{upper bound} = \mu + z$$

$$\text{lower bound} = \mu - z$$

where z is the value of the standard normal deviate corresponding to a probability level, α. Hence,

$$e = \text{upper bound} - \mu = z \ .$$

In this analysis, e is the maximum tolerable difference between any predicted measured cell velocity pair and has been assigned a value of 0.5 fps. Thus solving for α,

$$\sigma = \frac{e}{z} => \sigma^2 = \frac{e^2}{z^2}.$$

It is also known that $\frac{D - \mu}{\sigma}$ is normally distributed with a mean of zero and a variance of one. From this we know that

$$\sum_{i=1}^{n} \left(\frac{D-\mu}{\sigma}\right)^2 => \sum_{i=1}^{n} \frac{D^2}{\sigma^2}$$

approximates a chi-square distribution with n degrees of freedom. This equation computes the chi-square test statistic which is compared to a corresponding tabular chi-square value with n degrees of freedom. In this analysis, n represents the number of velocity pairs for a given flow rate. If the computed chi-square test statistic is greater than the corresponding tabular chi-square value, then the computed variance is larger than the desired variance $(\frac{e^2}{z^2})$ and, hence, the IFG4 model does not provide the desired level of accuracy. An identical analysis was done on the measured and predicted water surface elevations.

RESULTS AND DISCUSSION

The analysis of the results of the IFG4 simulation are discussed here. The objectives of the analysis are to:

1. Evaluate the ability of a previously developed hydraulic simulation model for instream flow studies (IFG4) to describe the changes in the depths and distribution of velocities across a cross-section as a function of discharge.
2. Review and evaluate the assumptions upon which the IFG4 model was developed and recommend any appropriate modifications.

Evaluation of the IFG4 Model

In this section, reference will be made to three sets of velocities and water surface elevations - one set of each for each of the three flow rates (1, 10, and 20 cfs). A set will be identified by its flow rate. During the data analysis it was discovered that the actual measured flow rates were less than 1, 10, and 20 cfs. The discrepancy between the design and measured flow rates can be attributed to problems in maintaining an adequate supply of water to the channels and thus in maintaining an adequate supply of water to the channels and thus in maintaining a constant head. The measured column velocities were multiplied by their corresponding cross-sectional areas for each cross-section to yield a measured flow rate at the cross-section. These flow rates were then averaged to give a representative channel flow rate. Tables 22 and 23 summarize this information.

For each of the two types of input (measured) cell velocities, averaged and 0.6D, and the measured water surface elevation the IFG4 model generated two predicted velocities and two water surface

TABLE 22

MEASURED FLOW RATES (cfs) FOR THE WINTER DATA COLLECTION PERIOD

	WEST CHANNEL						EAST CHANNEL					
	Averaged Velocities			Velocities at 0.6D			Averaged Velocities			Velocities at 0.6D		
Section	1 cfs	10 cfs	20 cfs	1 cfs	10 cfs	20 cfs	1 cfs	10 cfs	20 cfs	1 cfs	10 cfs	20 cfs
2	0.34	9.80	18.45	0.30	9.51	17.00	0.65	9.42	18.03	0.75	9.39	17.86
3	0.49	9.65	17.78	0.53	9.43	14.98	0.77	8.47	19.88	0.85	7.85	20.58
4	0.21	7.17	17.38	0.21	9.83	20.96	0.57	8.29	20.88	0.76	9.63	24.39
5	0.55	8.66	18.93	0.55	8.42	17.52	0.48	8.29	21.19	0.48	6.55	18.66
6	0.44	10.03	18.91	0.48	9.83	17.36	0.49	9.16	19.35	0.55	9.35	17.84
7	0.42	9.24	16.95	0.43	7.20	17.98	0.46	7.22	15.45	0.58	7.60	15.21
8	0.16	7.97	16.99	0.06	8.31	17.74	0.38	7.75	17.21	0.45	7.58	18.24
9	0.11	8.84	19.08	0.10	8.22	19.22	0.48	8.47	18.23	0.43	7.93	18.30
10	0.52	8.86	20.69	0.71	9.75	23.29	0.39	8.47	18.10	0.59	8.46	18.68
11	0.74	10.22	18.41	0.81	9.53	15.29	0.52	8.12	19.81	0.54	6.77	21.26
12	0.43	8.91	19.28	0.53	7.02	18.99	0.48	8.45	17.26	0.45	8.51	17.33
MEAN	0.40	9.03	18.44	0.43	8.82	18.21	0.52	8.37	18.67	0.58	8.15	18.94
σ	0.19	0.91	1.12	0.24	1.04	2.39	0.11	0.60	1.73	0.14	1.03	2.40

TABLE 23

MEASURED FLOW RATES (cfs) FOR THE SUMMER DATA COLLECTION PERIOD

	WEST CHANNEL						EAST CHANNEL					
	Averaged Velocities			Velocities at 0.6D			Averaged Velocities			Velocities at 0.6D		
Section	1 cfs	10 cfs	20 cfs	1 cfs	10 cfs	20 cfs	1 cfs	10 cfs	20 cfs	1 cfs	10 cfs	20 cfs
2	0.26	8.37	18.06	0.30	8.43	17.87	0.42	7.65	18.80	0.58	8.01	18.71
3	0.36	8.43	18.11	0.39	8.52	19.03	0.45	6.95	18.35	0.35	6.88	18.14
3.1	0.73	9.22	17.98	0.73	11.37	20.13	0.68	8.51	18.60	0.68	10.16	22.16
3.2	0.80	9.48	22.14	0.80	11.52	23.90	0.67	9.17	18.35	0.67	11.36	20.30
4	0.45	8.38	18.60	0.54	11.02	20.78	1.06	7.53	18.02	1.06	9.47	22.34
5	0.45	8.32	22.04	0.48	8.10	19.02	0.28	7.43	19.35	0.13	7.20	13.47
6	0.44	8.70	18.22	0.58	8.98	16.46	0.56	4.37	20.14	0.75	4.59	19.88
6.1	-0.24*	10.09	16.22	-5.64*	8.20	7.18	-0.04*	6.97	12.75	-0.54*	-10.70*	3.40
7	-0.89*	5.87	16.56	-0.74*	5.73	13.86	0.11	7.02	14.71	0.15	8.39	12.62
8	0.34	7.12	17.22	0.28	8.11	18.14	0.47	7.90	17.16	0.49	8.24	17.79
9	0.47	8.05	16.78	0.28	8.12	17.79	0.28	7.55	16.92	0.33	7.30	17.32
9.1	0.78	8.54	18.88	0.88	9.84	21.36	0.51	8.79	17.60	0.51	10.46	20.12
9.2	0.74	8.22	20.35	0.93	10.80	22.32	0.46	7.97	18.84	0.46	9.19	20.91
10	0.21	8.87	20.58	0.21	9.55	19.61	0.59	8.55	18.29	0.59	11.09	18.54
11	0.59	7.52	20.97	0.82	5.97	16.77	0.57	8.05	17.61	0.36	5.91	15.78
12	0.22	7.86	18.88	0.18	5.81	14.80	0.42	7.90	18.70	0.34	7.21	14.95
13	0.40	8.04	17.49	0.68	8.49	17.10	0.38	6.60	17.34	0.50	6.34	17.37
MEAN	0.48	8.30	18.76	0.54	8.72	18.01	0.49	7.54	17.74	0.50	8.24	17.28
σ	0.20	0.94	1.84	0.26	1.82	3.80	0.21	1.08	1.75	0.23	1.94	4.53

*These cross-sections were not included in the mean. Their negative value is a result of substantial eddy flow.

elevations: one for velocity adjustment and one for water surface elevation adjustment. This was repeated three times, once for each of the three flow rates. The first run used the measured hydraulic data from the 10 and 20 cfs flow rates to predict velocities and water surface elevations for 1 cfs. The second run used the measured hydraulic data from the 1 and 20 cfs flow rates to predict velocities and water surface elevations for 10 cfs. The final run used the measured hydraulic data from the 1 and 10 cfs flow rates to predict velocities and water surface elevations for 20 cfs.

Velocity Prediction

The evaluation of the ability of the IFG4 model to predict velocities is based on the chi-square statistical test. There are four different sets of data to be discussed, each of which will be treated separately. After the fourth set has been analyzed, a composite summary will be given. Following is a list of the four data sets:

A. Winter data collection period, West Channel, both velocity types, and both adjustment procedures.
B. Winter data collection period, East Channel, both velocity types, and both adjustment procedures.
C. Summer data collection period, West Channel, both velocity types, and both adjustment procedures.
D. Summer data collection period, East Channel, both velocity types, and both adjustment procedures.

Within each of these analysis sets, the same types of analyses will be done. They are:

1. Computed versus tabular chi-square statistics for the channel and each channel cross-section for each of the three flow rates.

2. Graphical analysis of predicted versus given velocities for every combination of velocity type and adjustment procedure. In this analysis, no velocities which exceeded 5 fps were plotted. This was done to limit the size of each plot. Very few points were ultimately excluded.
3. A summary of the results of the analyses done by the preceding two steps.

Extensive reference will be made to appropriate portions of Figure 39. This figure is composed of plus (+) and minus (-) signs (the difference between the tabular and computed chi-square values) and rows and columns of subtotals and totals of the number of plus and minus signs. A plus sign indicates that the IFG4 model adequately predicted cell velocities for a specified cross-section or channel within the specified maximum allowable difference of ±0.5 fps, i.e., the model "passed" the chi-squre test. An important point to remember is that for a chi-square test of any cross-section, the computed chi-square value (Figures 40-43) is composed of a velocity pair (measured and predicted) for every cell in that cross-section. Thus a "failure" of the chi-square test for a cross-section (or for a channel) means that one or more, but not necessarily all, of the cell velocity differences was significantly large. Appendix A contains all of the measured and predicted cell velocities for the entire study period. The velocities in that Appendix were those used to calculate the computed chi-square values.

A. Winter Data Collection Period, West Channel

1 cfs

The desired flow rates were 0.40 and 0.43 cfs for the averaged velocities of 0.6D, respectively. Except for cross-section 5, a riffle

DATA COLLECTION PERIOD	CHANNEL	CROSS-SECTION NUMBER	1 cfs				Subtotal[2].		10 cfs				Subtotal		20 cfs				Subtotal		Total	
			VAVV[1].	VAVW	V6DV	V6DW	(+)	(-)	VAVV	VAVW	V6DV	V6DW	(+)	(-)	VAVV	VAVW	V6DV	V6DW	(+)	(-)	(+)	(-)
WINTER	WEST	2	N/A	N/A	N/A	N/A	0	0	-	-	-	-	0	4	-	-	-	-	0	4	0	8
		3	N/A	N/A	N/A	N/A	0	0	+	+	+	+	4	C	-	-	-	-	0	4	4	4
		5	-	-	-	-	0	4	-	-	-	-	0	4	-	-	-	-	0	4	0	12
		9	+	+	+	+	4	0	+	+	+	+	4	0	+	+	-	-	2	2	10	2
		11	+	+	-	-	2	2	+	+	+	+	4	0	-	-	-	-	0	4	6	6
		12	+	+	+	+	4	0	+	+	+	+	4	0	-	-	-	-	0	4	8	4
	Subtotal	+	3	3	2	2	10	6	4	4	4	4	16	8	1	1	0	0	2	22	28	36
		-	1	1	2	2	6	X	2	2	2	2	8	X	5	5	6	6	22	X	36	X
	CHANNEL		+	-	-	-	1	3	-	-	-	-	0	4	-	-	-	-	0	4	1	11
WINTER	EAST	5	N/A	N/A	N/A	N/A	0	0	-	-	-	-	0	4	-	-	-	-	0	4	0	8
		6	N/A	N/A	N/A	N/A	0	0	+	+	-	-	2	2	-	-	-	-	0	4	2	6
		7	+	+	+	+	4	0	+	+	+	+	4	0	-	-	-	-	0	4	8	4
		8	+	+	+	+	4	0	+	+	+	+	4	0	+	+	-	-	2	2	10	2
		9	+	+	+	+	4	0	+	+	+	+	4	0	+	+	-	+	3	1	11	1
	Subtotal	+	3	3	3	3	12	0	4	4	3	3	14	6	2	2	0	1	5	15	31	21
		-	0	0	0	0	0	X	1	1	2	2	6	X	3	3	5	4	15	X	21	X
	CHANNEL		+	+	+	+	4	0	-	-	+	-	1	3	-	-	-	-	0	4	5	7
SUMMER	WEST	2	+	+	+	+	4	0	+	+	+	+	4	0	-	-	-	-	4	0	8	4
		3	+	+	+	+	4	0	+	+	+	+	4	0	-	-	-	-	0	4	8	4
		3.1	+	+	+	+	4	0	+	+	+	+	4	0	-	-	-	-	0	4	8	4
		3.2	+	+	+	+	4	0	-	-	-	-	0	4	-	-	-	-	0	4	4	8
		7	N/A	N/A	N/A	N/A	0	0	-	-	-	-	0	4	-	-	-	-	0	4	0	8
		9	+	+	+	+	4	0	+	+	-	-	3	1	-	-	+	+	2	2	9	3
		13	+	+	-	-	2	2	+	+	-	-	2	2	-	-	-	-	0	4	4	8
	Subtotal	+	6	6	5	5	22	2	5	5	3	4	17	11	0	0	1	1	2	26	41	39
		-	0	0	1	1	2	X	2	2	4	3	11	X	7	7	6	6	26	X	39	X
	CHANNEL		+	+	+	-	3	1	-	-	-	-	0	4	-	-	-	-	0	4	3	9
SUMMER	EAST	2	+	+	+	+	4	0	+	+	+	+	4	0	-	-	-	-	0	4	8	4
		4	-	-	-	-	0	4	-	+	-	-	3	1	-	-	-	-	0	4	1	11
		7	N/A	N/A	N/A	N/A	0	0	+	+	+	+	4	0	-	-	-	-	0	4	4	4
		8	+	+	+	+	4	0	+	+	+	+	4	0	+	+	+	+	4	0	12	0
		9	+	+	+	+	4	0	+	+	+	+	4	0	+	+	-	-	2	2	10	2
		9.1	+	+	-	-	2	2	-	-	-	-	0	4	-	-	-	-	0	4	2	10
		9.2	+	+	-	-	2	2	-	-	-	-	0	4	-	-	-	-	0	4	2	10
	Subtotal	+	5	5	3	3	16	8	4	5	4	4	17	11	2	2	1	1	6	22	39	41
		-	1	1	3	3	8	X	3	2	3	3	11	X	5	5	6	6	22	X	41	X
	CHANNEL		-	+	-	-	1	3	+	+	-	-	2	2	-	-	-	-	0	4	3	9
	Section[3]. Total	+	17	17	13	13	60	16	17	18	14	15	64	26	5	5	2	3	15	85	139	137
		-	2	2	6	6	16	X	8	7	11	10	36	X	20	20	23	22	85	X	137	X
	Channel	+	3	3	2	1	9	7	1	1	1	0	3	13	0	0	0	0	0	16	12	36
		-	1	1	2	3	7	X	3	3	3	4	13	X	4	4	4	4	16	X	36	X

1. VAVW = Averaged velocities with velocity adjustment
   VAVW = Averaged velocities with water surface elevation adjustment
   V6DV = Velocities of 0.60 with velocity adjustment
   V6DW = Velocities at 0.60 with water surface elevation adjustment

2. Subtotals are either horizontal or vertical summations of the number of plus and minus signs.

3. Totals are the sums of the subtotals.

Figure 39. Results based on chi-square tests of the ability of the IFG4 model to predict velocities.

	COMPUTED χ^2[1] 1 cfs										COMPUTED χ^2 10 cfs										COMPUTED χ^2 20 cfs									
		TABULAR								TABULAR									TABULAR											
SECTION	n[2]	χ^2[3]	VAVV[4]	VAVW	V6DV	V6DW	TW[5]	P[6]	n	χ^2	VAVV	VAVW	V6DV	V6DW	TW	P	n	χ^2	VAVV	VAVW	V6DV	V6DW	TW	P
2	18	28.87	0.95	1.33	1.96	2.60	13.20	13.44	18	28.87	7.04	5.76	9.09	8.03	16.40	16.82	18	28.87	32.88	36.94	46.36	46.36	17.50	18.17
4	12	21.03	68.44	49.07	78.72	78.72	9.90	9.92	12	21.03	23.07	19.53	58.99	36.72	12.30	12.50	12	21.03	167.55	128.93	102.27	102.27	15.50	15.74
7	-	-	-	-	-	-	-	-	13	22.36	1.58	2.85	8.12	9.27	19.60	19.69	13	22.36	75.21	75.21	91.59	79.30	19.60	19.63
8	13	22.36	2.01	7.29	0.93	1.27	13.90	14.23	13	22.36	4.99	4.99	4.65	3.20	18.00	18.47	13	22.36	11.61	11.61	12.35	9.61	18.80	19.31
9	17	27.59	13.75	13.88	0.53	0.53	12.80	13.07	17	27.59	5.44	5.44	6.51	6.51	15.20	15.75	17	27.59	24.37	24.37	36.22	53.04	16.50	17.22
9.1	11	19.68	7.43	7.43	20.03	59.00	6.50	6.56	11	19.68	28.11	28.11	87.31	87.31	9.10	9.39	11	19.68	187.58	138.30	283.34	283.34	10.50	10.93
9.2	10	18.31	16.38	16.38	19.79	19.79	5.80	5.85	10	18.31	40.37	40.37	56.17	56.17	8.40	8.58	10	18.31	107.09	107.09	101.80	101.80	9.90	10.30
CHANNEL	81	103.01	108.97	95.39	121.96	161.91	-	-	94	117.50	110.62	107.06	230.84	207.21	-	-	94	117.50	606.27	522.44	673.92	675.72	-	-

1. Computed $\chi^2 = \dfrac{\sum_{i=1}^{n} (V_p - V_G)^2}{\sigma^2}$, where: V_p = predicted velocity by IFG4, fps

V_G = given velocity (measured), fps

$\sigma^2 = E^2/Z^2$

E = maximum tolerable difference between V_p and V_G = 0.5 fps

Z = standard normal deviate for $\alpha = 0.05$ (two-tailed)

2. n = number of pairs of predicted and given velocities

3. Tabular χ^2 based on n degress of freedom and $\alpha = 0.05$

4. VAVV = Averaged velocities with velocity adjustment

VAVW = Averaged velocities with water surface elevation adjustment by IFG4

V6DV = Velocities at 0.6D with velocity adjustment

V6DW = Velocities at 0.6D with water surface elevation adjustment by IFG4

5. TW = Top width of cross-section, ft

6. P = wetted perimeter of cross-section, ft

Figure 40. Chi-square values for velocities for the east channel and the summer data collection period.

	COMPUTED χ^2[1] 1 cfs								COMPUTED χ^2 10 cfs								COMPUTED χ^2 20 cfs							
SECTION	n[2]	TABULAR χ^2[3]	VAVV[4]	VAVW	V6DV	V6DW	TW[5]	P[6]	n	TABULAR χ^2	VAVV	VAVW	V6DV	V6DW	TW	P	n	TABULAR χ^2	VAVV	VAVW	V6DV	V6DW	TW	P
2	20	31.41	0.88	3.71	2.22	6.03	14.70	14.88	20	31.41	11.89	13.64	20.74	15.91	17.00	17.49	20	31.41	51.39	53.18	46.46	48.89	19.20	19.88
3	18	28.89	0.90	1.66	1.02	1.65	12.20	12.43	18	28.89	11.35	10.50	13.29	13.08	14.70	15.18	18	28.89	50.70	44.11	46.63	43.50	16.80	17.38
3.1	12	21.03	5.24	5.24	9.71	9.71	6.00	6.06	12	21.03	14.84	14.84	18.83	18.83	9.60	9.81	12	21.03	108.46	108.46	117.30	117.30	10.70	10.93
3.2	11	19.68	19.01	13.69	12.07	10.73	7.30	7.32	11	19.68	32.78	32.78	43.40	43.40	9.70	9.88	11	19.68	111.39	111.39	103.23	103.23	10.70	10.94
7	-	-	-	-	-	-	-	-	11	19.68	508.87	242.73	94.76	126.29	19.60	20.70	11	19.68	3696.56	3696.56	9999.99	3591.96	19.60	19.63
9	14	23.68	0.34	0.34	1.09	0.89	14.70	14.90	14	23.68	3.08	3.08	73.56	19.46	16.80	17.31	14	23.68	30.88	30.88	11.94	15.80	18.70	19.26
13	11	19.68	12.45	12.45	45.84	36.10	7.90	8.04	11	19.68	3.54	3.54	38.28	32.79	11.70	12.23	11	19.68	30.06	30.06	39.05	39.05	14.20	14.56
CHANNEL	86	108.64	38.81	37.08	71.95	137.06	-	-	97	120.98	586.36	321.10	302.86	269.76	-	-	97	120.98	4079.44	4074.62	9999.99	3959.73	-	-

[1] Computed $\chi^2 = \dfrac{\sum_{i=1}^{n} (V_p - V_G)^2}{\sigma^2}$, where:

V_p = predicted velocity by IFG4, fps

V_G = given velocity (measured), fps

$\sigma^2 = E^2/Z^2$

E = maximum tolerable difference between V_p and V_G = 0.5 fps

Z = standard normal deviate for $\alpha = 0.05$ (two-tailed)

[2] n = number of pairs of predicted and given velocities

[3] Tabular χ^2 based on n degress of freedom and $\alpha = 0.05$

[4] VAVV = Averaged velocities with velocity adjustment

VAVW = Averaged velocities with water surface elevation adjustment by IFG4

V6DV = Velocities at 0.6D with velocity adjustment

V6DW = Velocities at 0.6D with water surface elevation adjustment by IFG4

[5] TW = Top width of cross-section, ft

[6] P = wetted perimeter of cross-section, ft

Figure 41. Chi-square values for velocities for the west channel and the summer data collection period.

	COMPUTED χ^2 [1] 1 cfs								COMPUTED χ^2 10 cfs								COMPUTED χ^2 20 cfs							
SECTION	n[2]	TABULAR χ^2 [3]	VAVV[4]	VAVW	V6DV	V6DW	TW[5]	P[6]	n	TABULAR χ^2	VAVV	VAVW	V6DV	V6DW	TW	P	n	TABULAR χ^2	VAVV	VAVW	V6DV	V6DW	TW	P
5	-	-	-	-	-	-	-	-	17	27.59	123.04	123.04	67.17	99.92	14.6	15.11	17	27.59	195.07	277.77	341.02	311.47	16.3	16.97
6	-	-	-	-	-	-	-	-	14	23.68	13.46	13.46	26.55	26.55	14.2	14.60	14	23.68	28.71	28.71	53.73	53.73	16.0	16.57
7	19	30.14	1.74	18.35	2.42	17.28	19.30	19.30	19	30.14	5.99	6.80	4.06	4.20	19.3	19.31	19	30.14	133.65	133.65	120.36	120.36	19.3	19.69
8	18	28.87	1.40	1.40	3.77	3.77	12.0	12.41	18	28.87	2.03	2.03	2.83	2.83	18.0	18.60	18	28.87	25.48	24.30	40.56	40.56	18.6	19.12
9	17	27.59	0.33	0.33	0.65	1.00	12.5	12.79	17	27.59	2.34	2.34	3.86	3.42	15.3	16.11	17	27.59	21.10	21.10	28.50	27.43	17.3	17.99
CHANNEL	54	72.14	3.46	22.08	6.83	22.05	-	-	85	107.51	146.86	147.67	104.47	136.92	-	-	85	107.51	404.01	485.53	584.16	553.55	-	-

[1] Computed $\chi^2 = \dfrac{\sum_{i=1}^{n} (V_p - V_G)^2}{\sigma^2}$, where: V_p = predicted velocity by IFG4, fps

V_G = given velocity (measured), fps

$\sigma^2 = E^2/Z^2$

E = maximum tolerable difference between V_p and V_G = 0.5 fps

Z = standard normal deviate for $\alpha = 0.05$ (two-tailed)

[2] n = number of pairs of predicted and given velocities

[3] Tabular χ^2 based on n degress of freedom and $\alpha = 0.05$

[4] VAVV = Averaged velocities with velocity adjustment

VAVW = Averaged velocities with water surface elevation adjustment by IFG4

V6DV = Velocities at 0.6D with velocity adjustment

V6DW = Velocities at 0.6D with water surface elevation adjustment by IFG4

[5] TW = Top width of cross-section, ft

[6] P = wetted perimeter of cross-section, ft

Figure 42. Chi-square values for velocities for the east channel and the winter data collection period.

	COMPUTED χ^2 [1.] 1 cfs								COMPUTED χ^2 10 cfs								COMPUTED χ^2 20 cfs							
SECTION	n [2.]	TABULAR χ^2 [3.]	VAVV [4.]	VAVW	V6DV	V6DW	TW [5.]	P [6.]	n	TABULAR χ^2	VAVV	VAVW	V6DV	V6DW	TW	P	n	TABULAR χ^2	VAVV	VAVW	V6DV	V6DW	TW	P
2	-	-	-	-	-	-	-	-	19	30.14	44.83	44.83	25.86	25.96	17.50	17.97	19	30.14	100.75	100.75	74.39	66.39	18.10	18.86
3	-	-	-	-	-	-	-	-	16	26.30	14.08	12.81	24.56	24.56	14.70	15.27	16	26.30	50.38	50.38	77.74	77.74	16.00	16.86
5	16	26.30	55.93	3578.17	50.64	582.63	10.50	10.68	16	26.30	38.96	51.39	46.44	63.58	13.50	13.92	16	26.30	185.49	185.49	246.29	256.07	14.50	15.23
9	19	30.14	0.43	0.43	1.29	2.27	14.80	15.14	19	30.14	2.57	2.57	16.90	13.68	17.60	18.18	19	30.14	14.53	14.53	31.53	40.59	19.20	20.00
11	15	25.00	5.60	9.08	77.08	198.67	12.30	13.07	15	25.00	13.93	13.93	16.93	16.93	14.60	15.24	15	25.00	34.69	34.69	34.11	34.11	17.10	17.86
12	17	27.59	0.24	0.24	0.50	0.69	12.20	12.50	17	27.59	2.06	2.06	18.66	18.66	14.50	15.17	17	27.59	37.09	37.09	62.11	62.11	16.60	17.46
CHANNEL	67	87.10	62.19	3587.92	129.52	784.26	-	-	101	103.94	116.43	127.58	149.35	163.35	-	-	101	103.94	422.93	422.93	526.16	537.01	-	-

1. Computed $\chi^2 = \dfrac{\sum_{i=1}^{n} (V_p - V_G)^2}{\sigma^2}$, where: V_p = predicted velocity by IFG4, fps

V_G = given velocity (measured), fps

$\sigma^2 = E^2/Z^2$

E = maximum tolerable difference between V_p and V_G = 0.5 fps

Z = standard normal deviate for α = 0.05 (two-tailed)

2. n = number of pairs of predicted and given velocities

3. Tabular χ^2 based on n degress of freedom and α = 0.05

4. VAVV = Averaged velocities with velocity adjustment

VAVW = Averaged velocities with water surface elevation adjustment by IFG4

V6DV = Velocities at 0.6D with velocity adjustment

V6DW = Velocities at 0.6D with water surface elevation adjustment by IFG4

5. TW = Top width of cross-section, ft

6. P = wetted perimeter of cross-section, ft

Figure 43. Chi-square values for velocities for the west channel and the winter data collection period.

section (see Figure 44), the IFG4 model did a respectable job of predicting section velocities regardless of the type of velocity or velocity adjustment. However, in only one instance did the model adequately predict velocities for the entire channel (see Figure 43).

10cfs

The desired flow rates were 9.03 cfs and 8.82 cfs for the averaged velocities and for the velocities at 0.6D, respectively. The IFG4 model failed the chi-square test in all cases for cross-sections 2 and 5 (run and riffle sections respectively) and passed the chi-square test for the remaining cases. Overall, in 16 of the 24 chi-square tests made on the cross-sections, the IFG4 model performed favorably. However, in no instance did the model adequately predict velocities for the entire channel (see Figure 39).

20 cfs

The desired flow rates were 18.44 and 18.21 cfs, respectively, for the averaged velocities and for the velocities at 0.6D. The IFG4 model performed very poorly here. In only 2 of the 24 chi-square tests performed on the cross-sections did the IFG4 model adequately predict cross-section velocities (see Figure 39). In no instance did the IFG4 model adequately predict velocities for the entire channel. It can be seen from Figures 45 through 48 that the velocities at 20 cfs deviate the most from the line of perfect agreement. This merely supports the chi-square analyses because the plotted data are the data from which the chi-square analyses were done.

The results of the winter data collection period in the West Channels are summarized as follows:

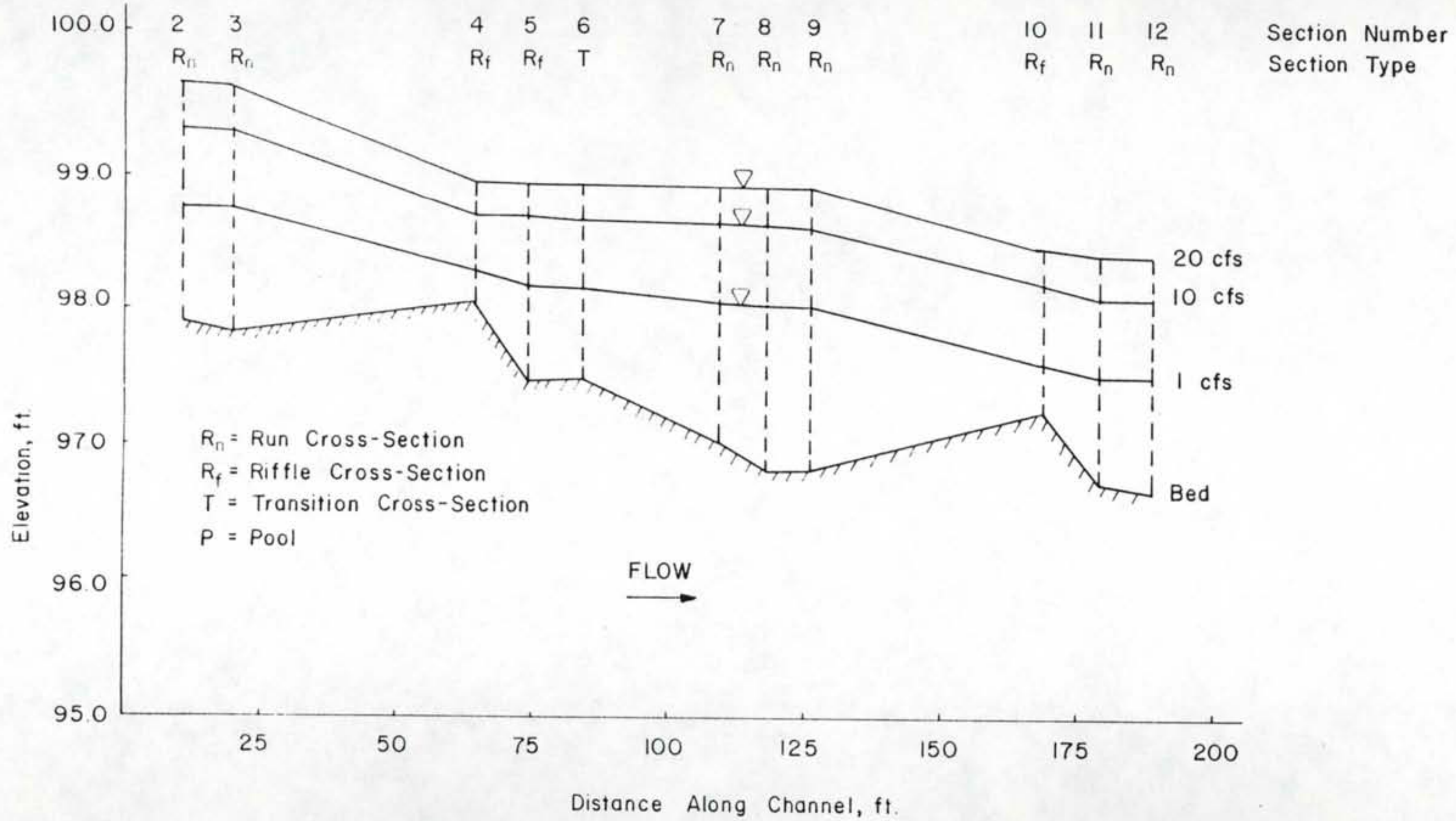

Figure 44. Measured water surface profile for the west channel and the winter data collection period.

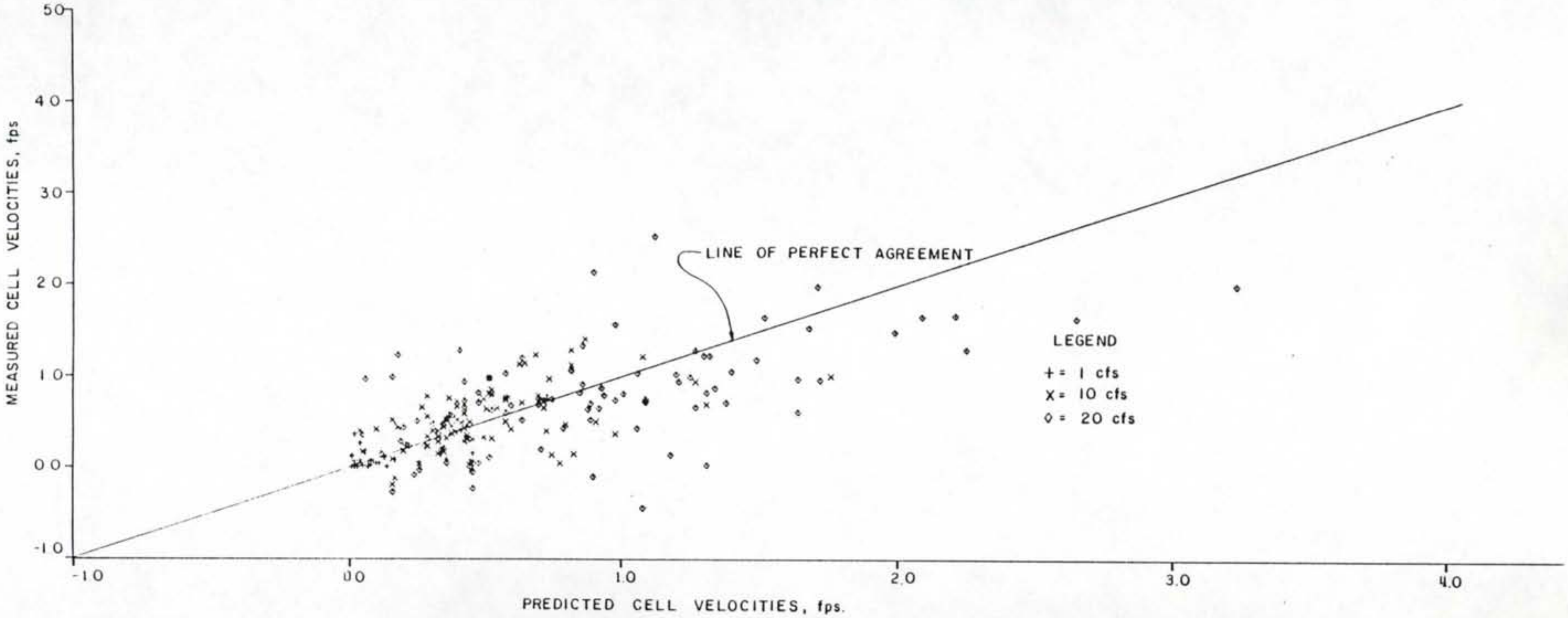

Figure 45. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the west channel for winter 1982. Velocities are averaged and velocity adjustment was used.

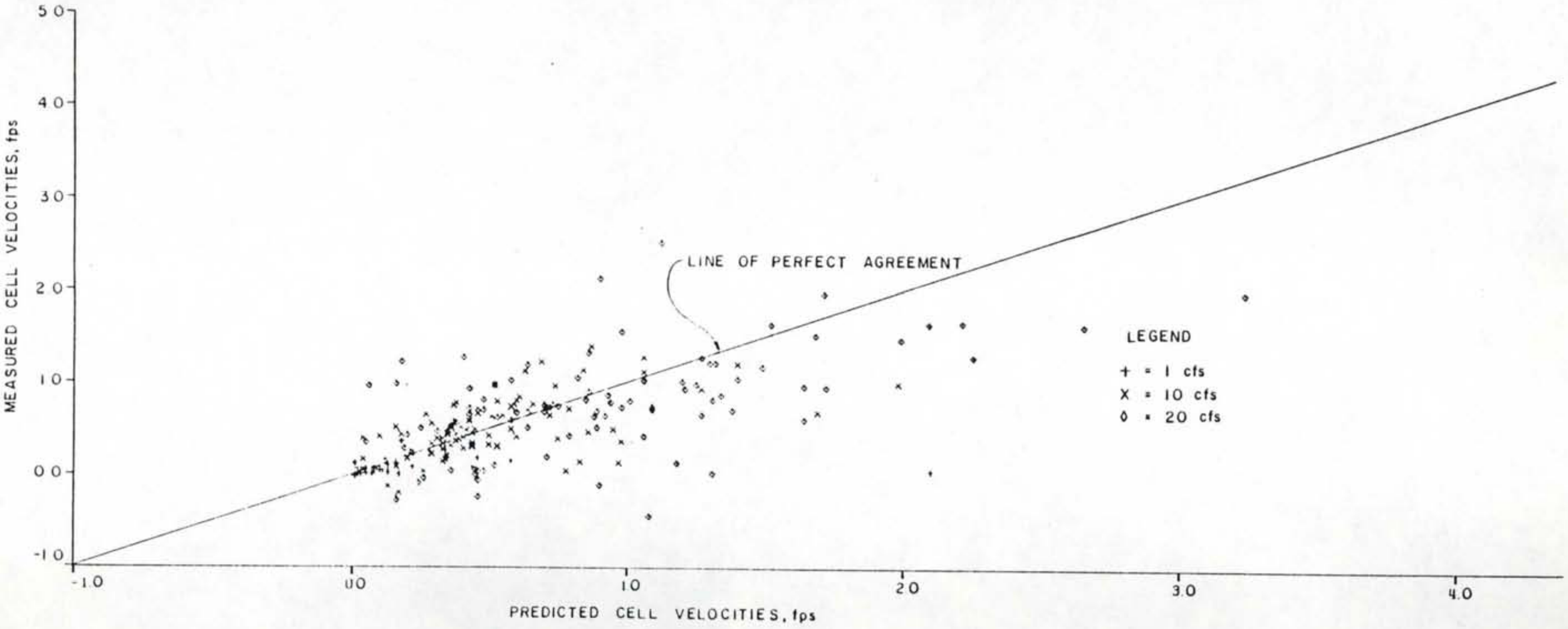

Figure 46. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the west channel for winter 1982. Velocities are averaged and water surface elevation adjustment was used.

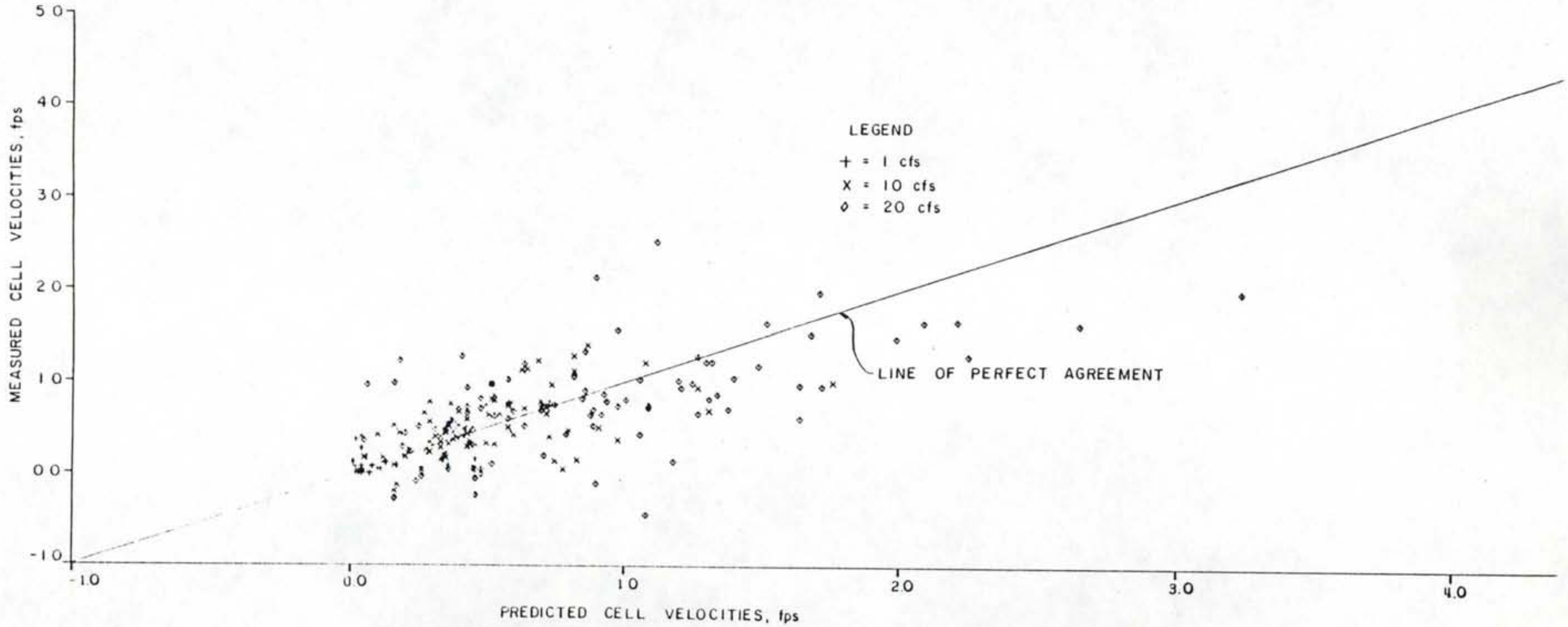

Figure 47. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the west channel for winter 1982. Velocities are at 0.6D and velocity adjustment was used.

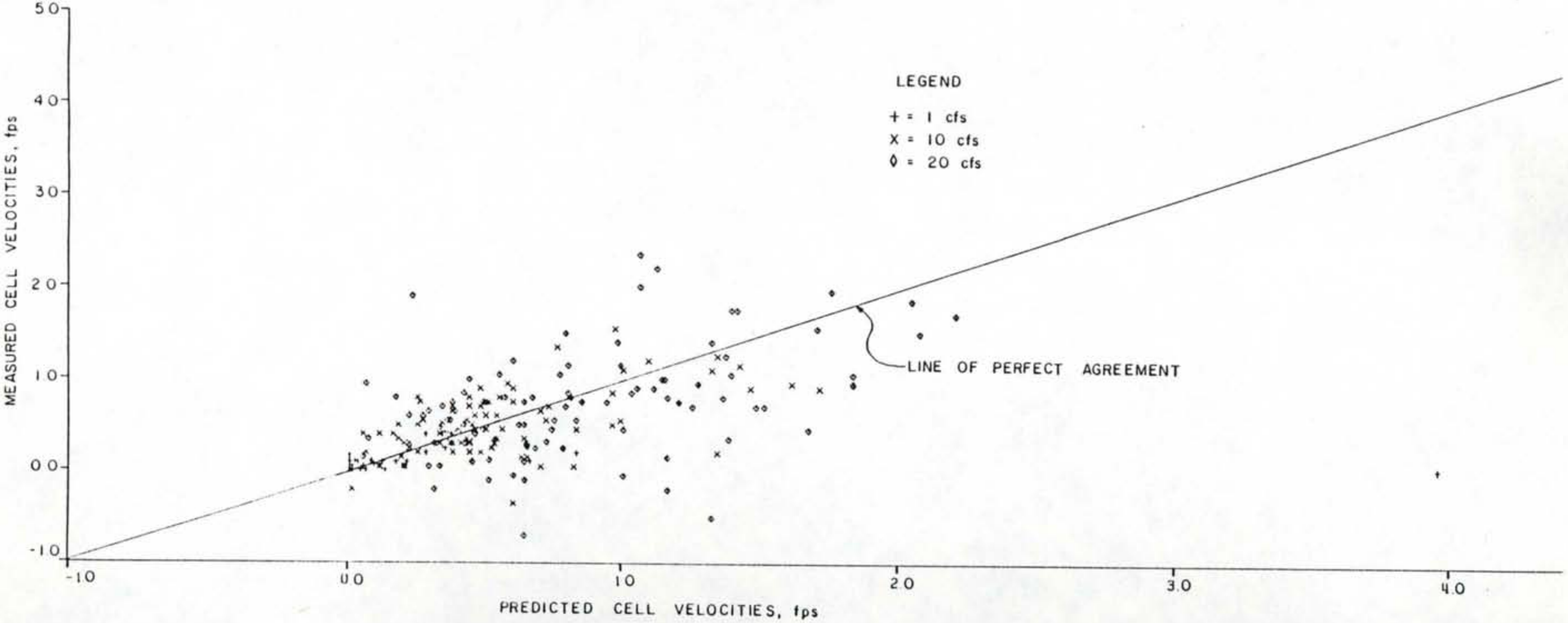

Figure 48. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the west channel for winter 1982. Velocities are at 0.6D and water surface elevation adjustment was used.

1. The averaged velocities yielded better velocity prediction than did the velocities at 0.6D, regardless of flow rate or type of adjustment.
2. Using measured velocities at 1 cfs and 20 cfs to predict velocities at 10 cfs provided the best results, while using the 1 cfs and 10 cfs measured velocities to predict velocities at 20 cfs yielded the worst results.
3. Neither velocity nor water surface elevation adjustment improved prediction results.
4. Overall the IFG4 model predictions passed the chi-square test on cross-sections in 28 of the 64 instances and in one of 11 instances for the entire channel.

B. Winter Data Collection Period, East Channel

The profile of the East Channel from which data were collected during the winter is shown in Figure 49. This channel is characterized as a riffle-run channel.

1cfs

The desired flow rates were 0.52 cfs and 0.58 cfs for the averaged velocities and for the velocities at 0.6D, respectively. The IFG4 model passed the chi-square test in all cases at the cross-section and channel level (see Figure 39).

10 cfs

The desired flow rates were 8.37 cfs and 8.15 cfs for the averaged velocities and for the velocities at 0.6D, respectively. The IFG4 model failed the chi-square test in all cases for cross-section five, a run section (see Figure 39). Overall, in 14 of the 20 chi-square tests made on the cross-sections, the IFG4 model adequately predicted velocities.

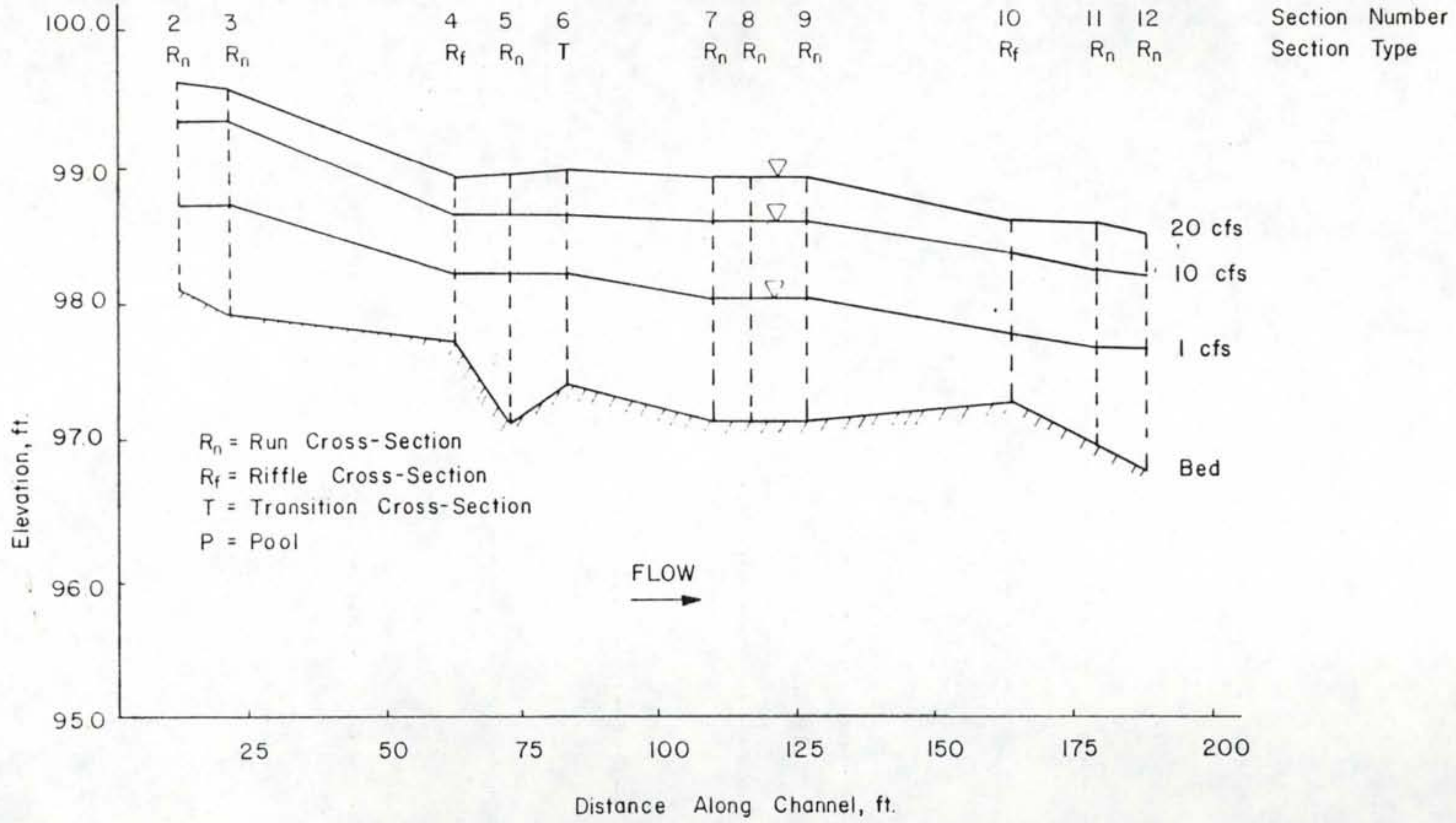

Figure 49. Measured water surface profile for the east channel and the winter data collection period.

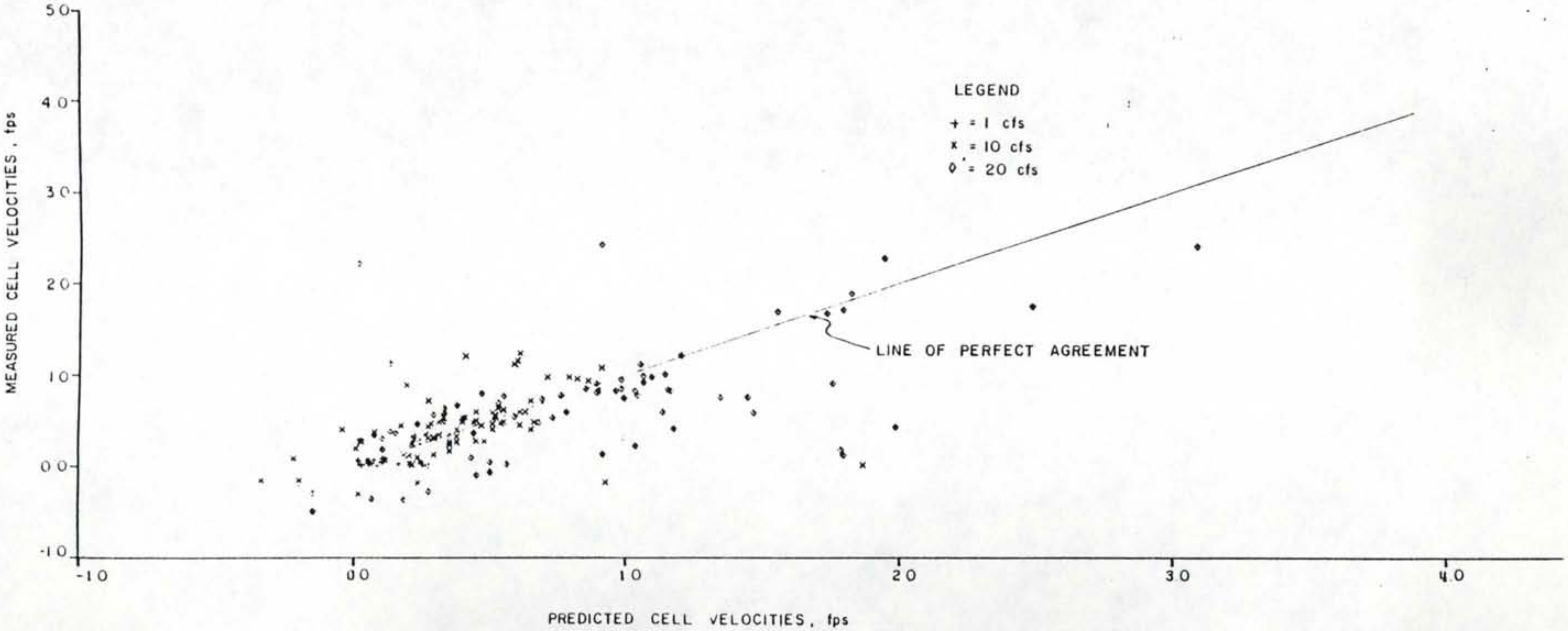

Figure 50. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the east channel for winter 1982. Velocities are averaged and velocity adjustment was used.

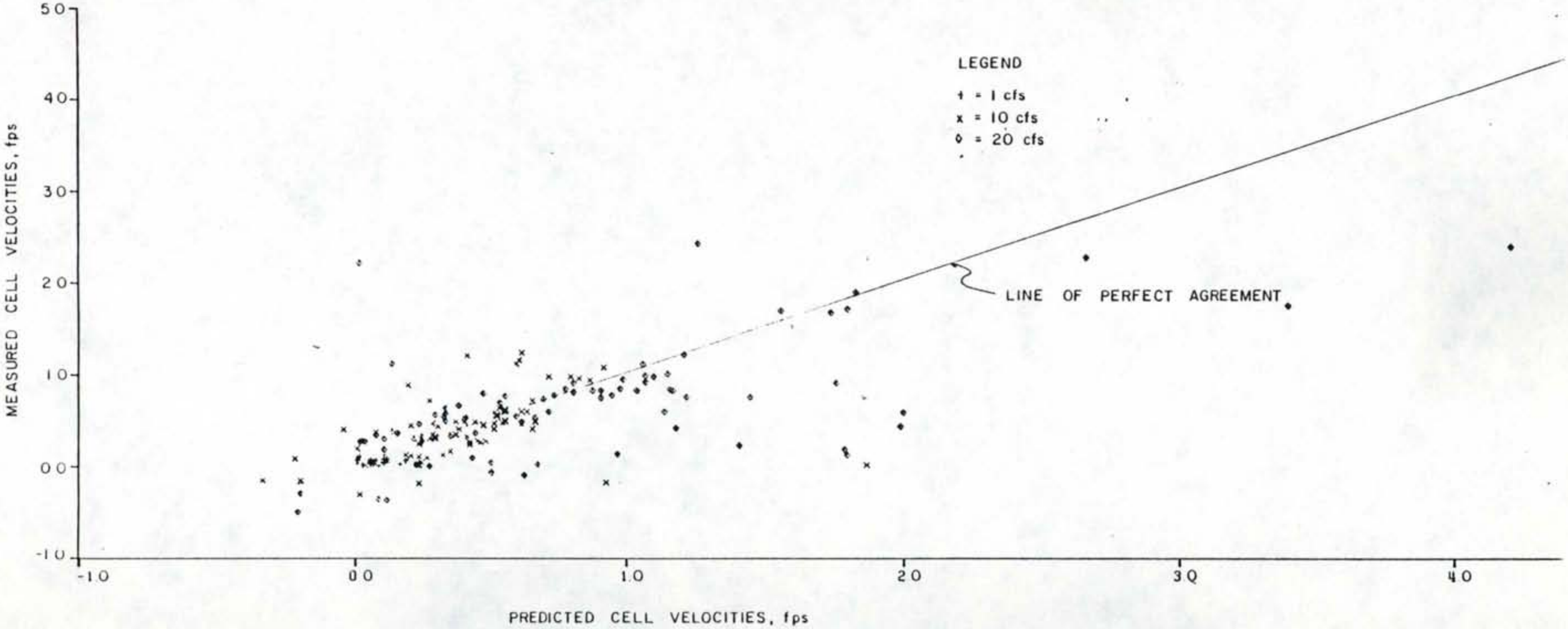

Figure 51. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the east channel for winter 1982. Velocities are averaged and water surface elevation adjustment was used.

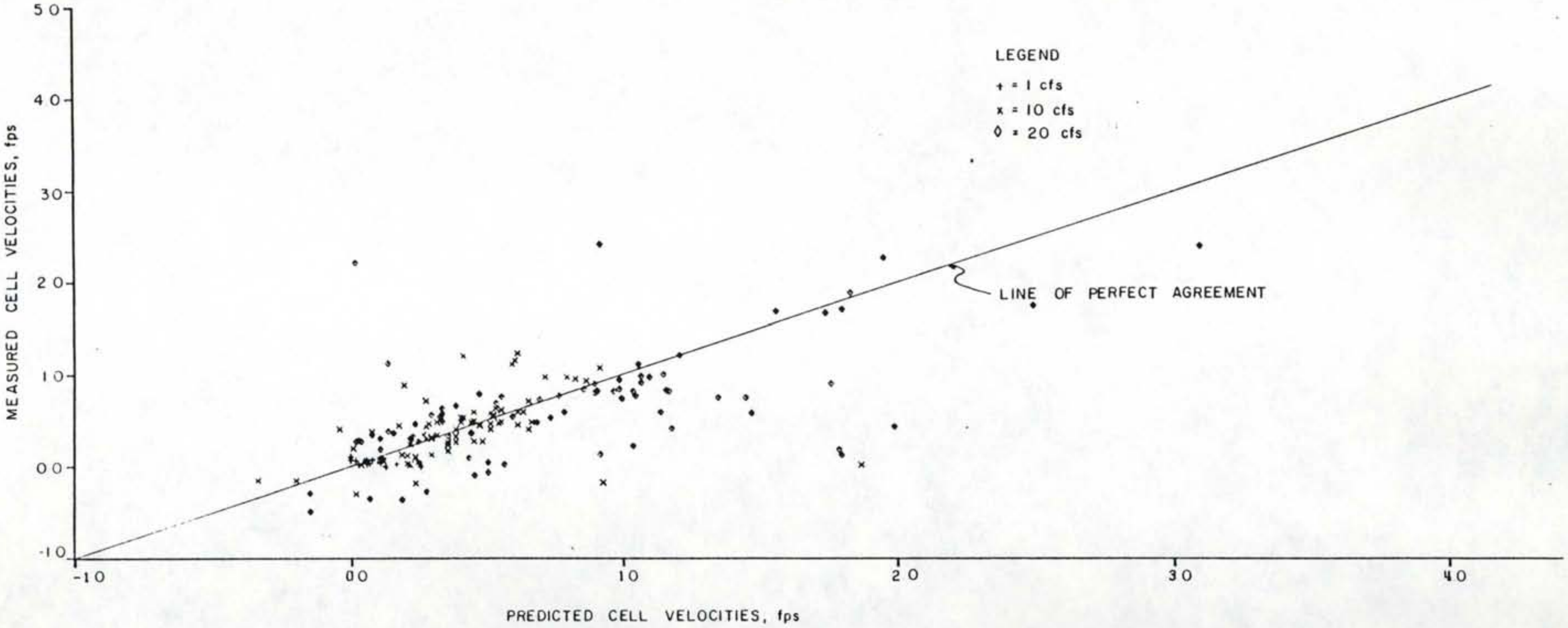

Figure 52. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the east channel for winter 1982. Velocities are at 0.6D and velocity adjustment was used.

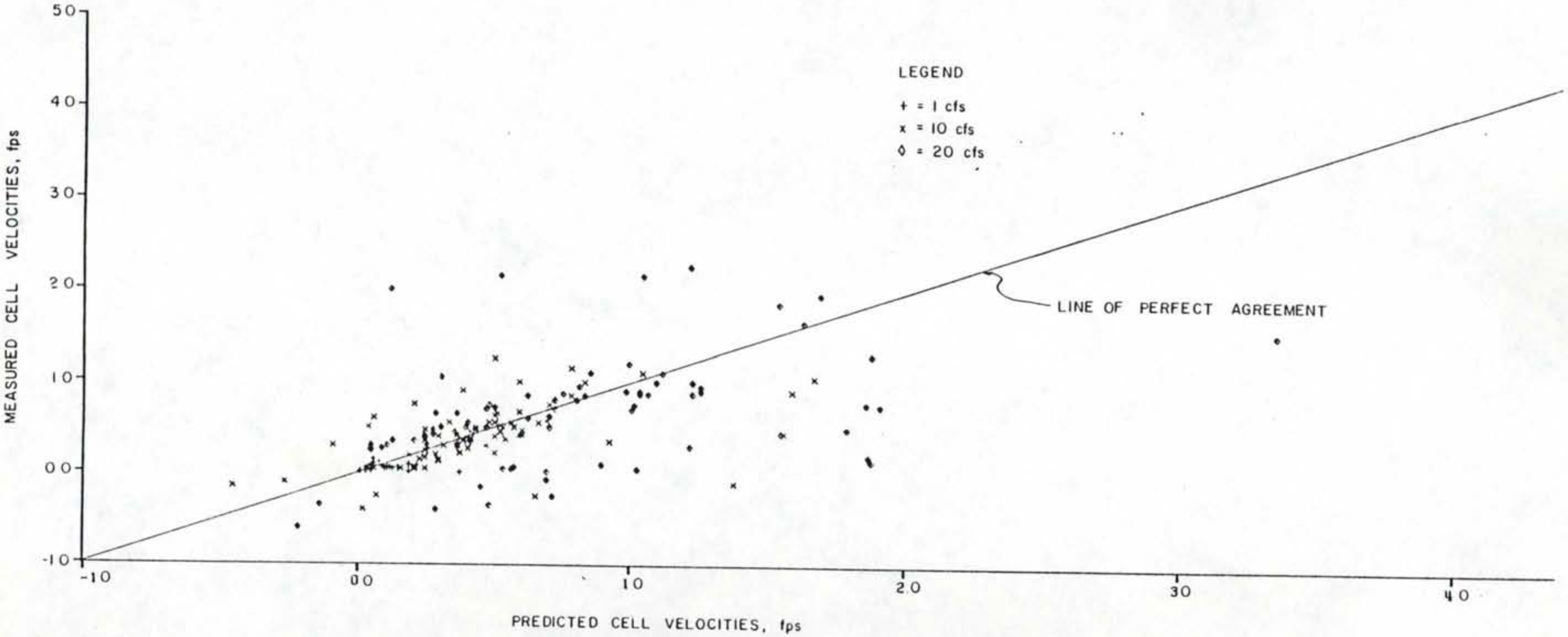

Figure 53. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the east channel for winter 1982. Velocities are at 0.6D and water surface elevation adjustment was used.

The combination of velocity at 0.6D with velocity adjustment was the only case where the model adequately predicted velocities for the entire channel.

20 cfs

The desired flow rates were 18.67 cfs and 18.94 cfs for the averaged velocities and for the velocities at 0.6D, respectively. In only five of the 20 chi-square tests made on the cross-sections, did the IFG4 model adequately predict velocities. The model failed the chi-square test in all instances of velocity prediction for the entire channel. See Figures 50 through 53 for a confirmation of the poor predictive ability of the IFG4 model when predicting velocities at 20 cfs.

The results of the winter data collection period and the East Channel are summarized as follows:

1. The averaged velocities yielded better velocity prediction than did the velocities at 0.6D, regardless of flow rate or type of adjustment.
2. Using velocities at 10 cfs and 20 cfs to predict velocities at 1 cfs provided the best results, while using velocities at 1 cfs and 10 cfs to predict velocities at 20 cfs yielded the worst results.
3. Neither velocity adjustment nor water surface elevation adjustment improved prediction results.
4. Overall, the IFG4 passed the chi-square test on cross-sections in 31 of the 52 instances and in five of seven instances on the entire channel.

C. Summer Data Collection Period, West Channel

The profile of the west channel from which data were collected during the summer is shown in Figure 54. This channel has a mix of riffles and runs with a single pool.

1 cfs

The desired flow rates were 0.48 cfs and 0.54 cfs for the averaged velocities and for the velocities at 0.6D, respectively. The IFG4 model failed the chi-square test in only two of the 24 tests made on the cross-sections (see Figure 39). The combination of velocity at 0.6D with water surface elevation adjustment was the only case in which the model failed to adequately predict velocities for the entire channel.

10 cfs

The desired flow rates were 8.30 cfs and 8.72 cfs for the averaged velocities and for the velocities at 0.6D, respectively. The IFG4 model failed the chi-square test in all cases for cross-sections 3.1 and 7, riffle and pool sections, respectively (see Figure 54). Overall in 17 of the 28 chi-square tests made on the cross-sections, the model adequately predicted velocities. The model failed the chi-square test in all instances of velocity prediction for the entire channel.

20 cfs

The desired flow rates were 18.76 cfs and 18.01 cfs for the averaged velocities and for the velocities at 0.6D, respectively. In only two of the 28 chi-square tests made on the cross-sections, did the IFG4 model adequately predict velocities. The model failed the chi-square test in all instances of velocity prediction for the entire channel. See Figures 55 through 58 for a graphical confirmation of the poor predictive ability of the IFG4 model when velocities at 1 cfs and

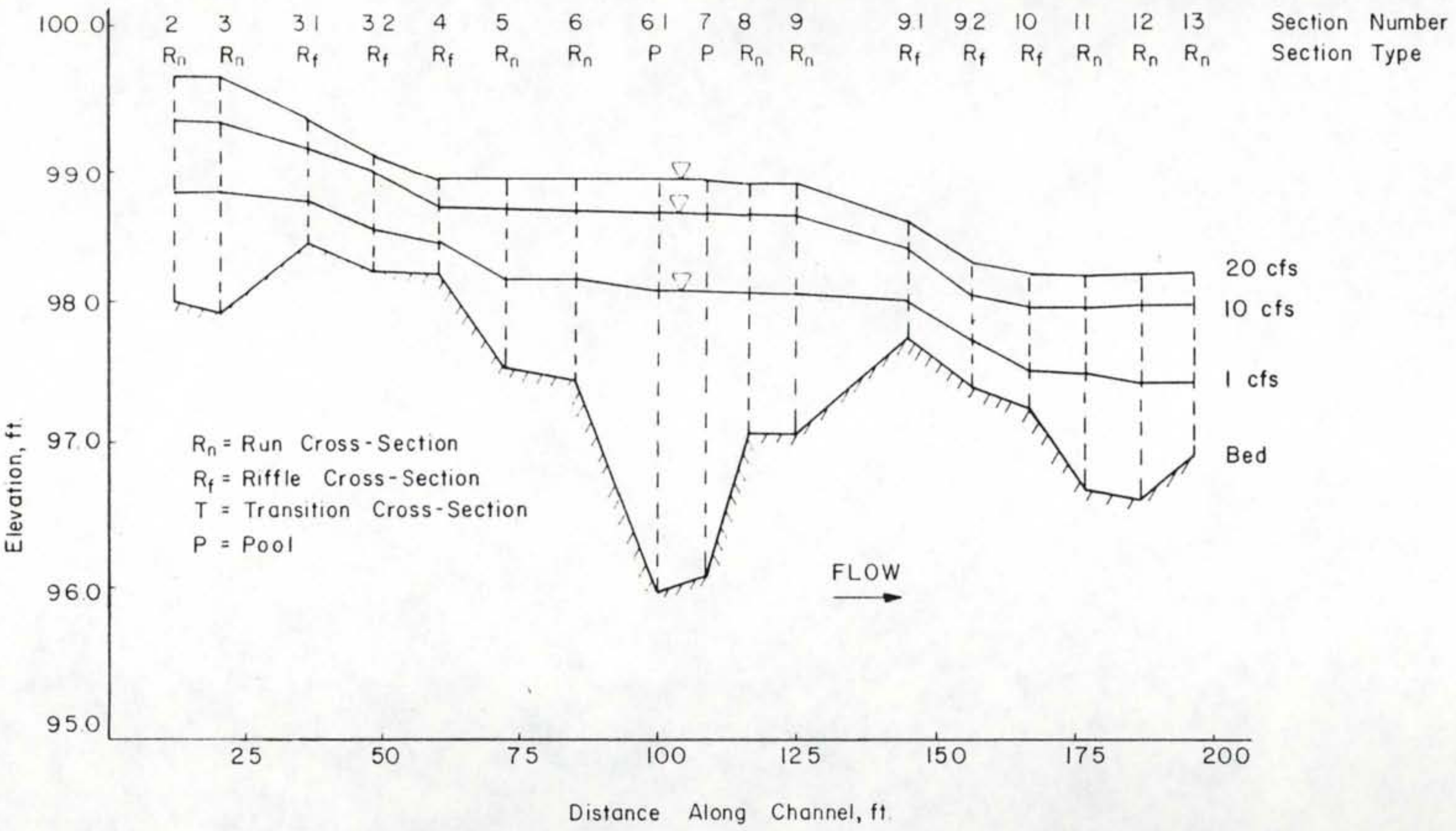

Figure 54. Measured water surface profile for the west channel and the summer data collection period.

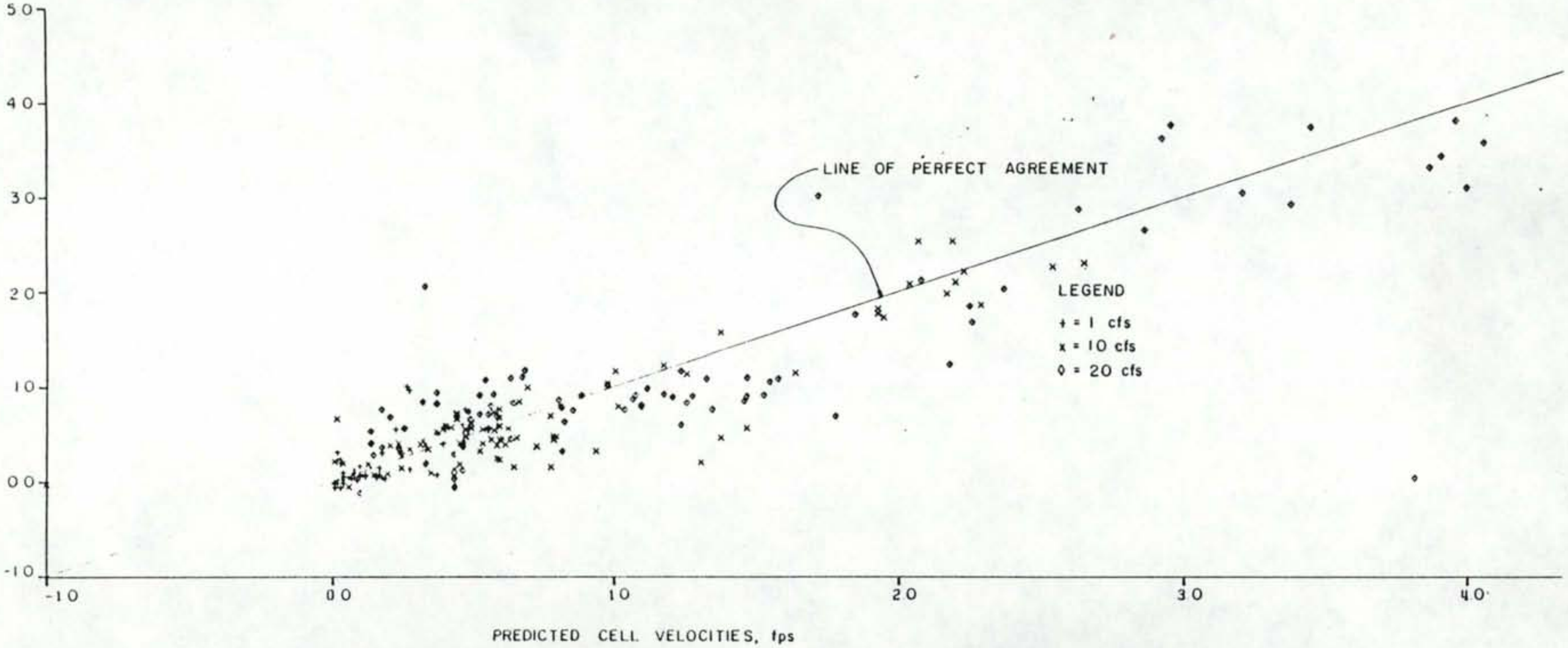

Figure 55. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the west channel for summer 1982. Velocities are averaged and velocity adjustment was used.

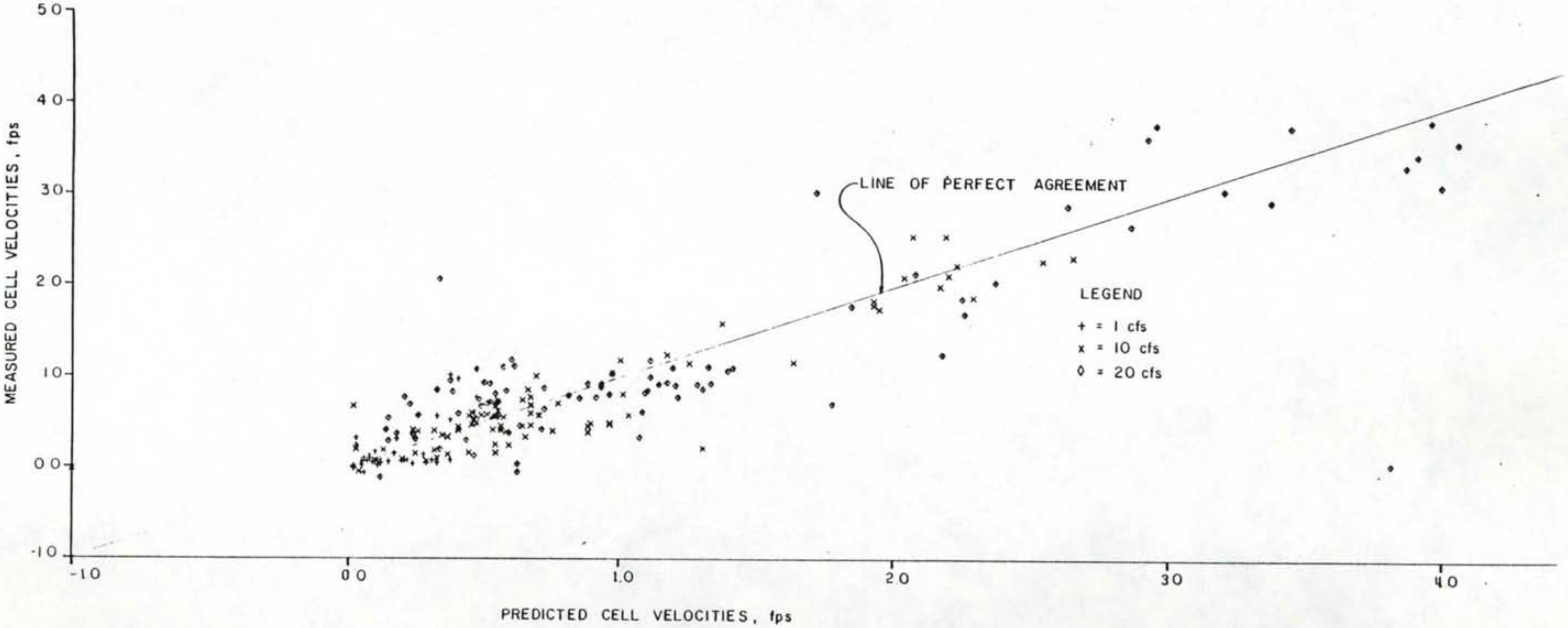

Figure 56. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the west channel for summer 1982. Velocities are averaged and water surface elevation adjustment was used.

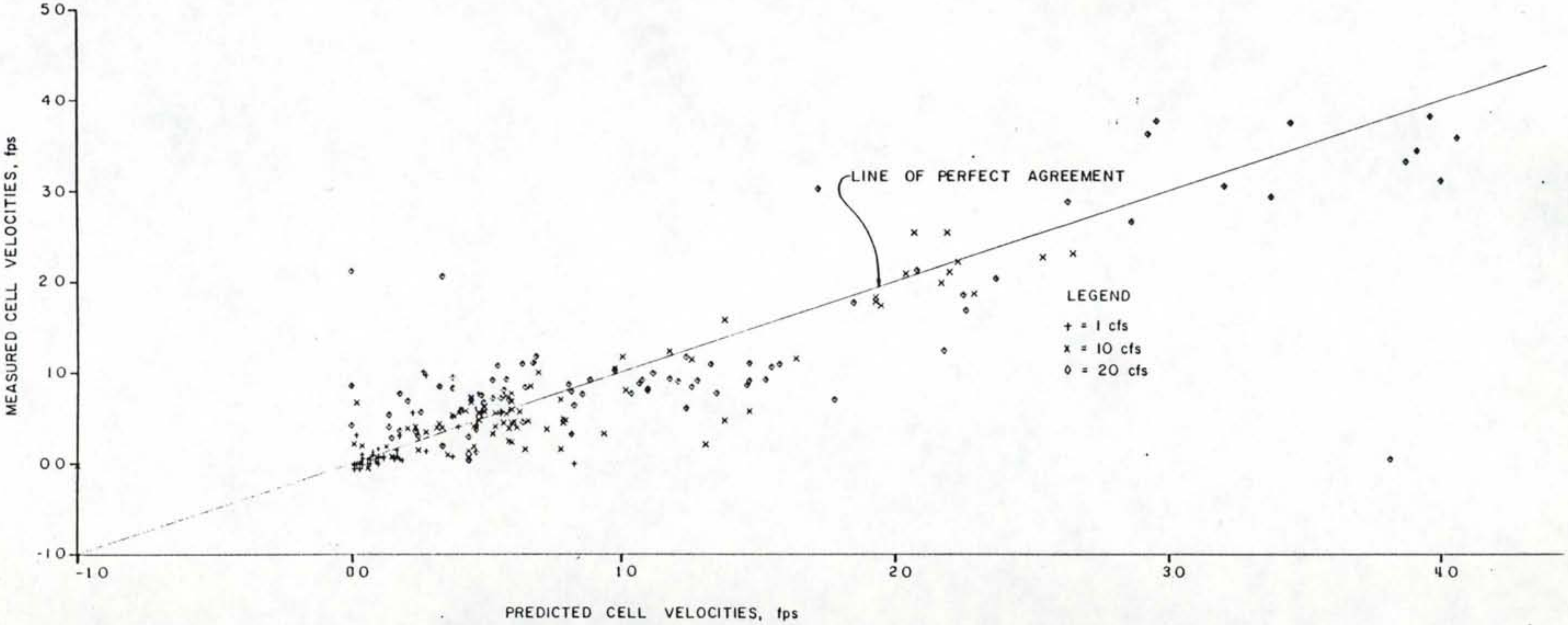

Figure 57. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the west channel for summer 1982. Velocities are at 0.6D and velocity adjustment was used.

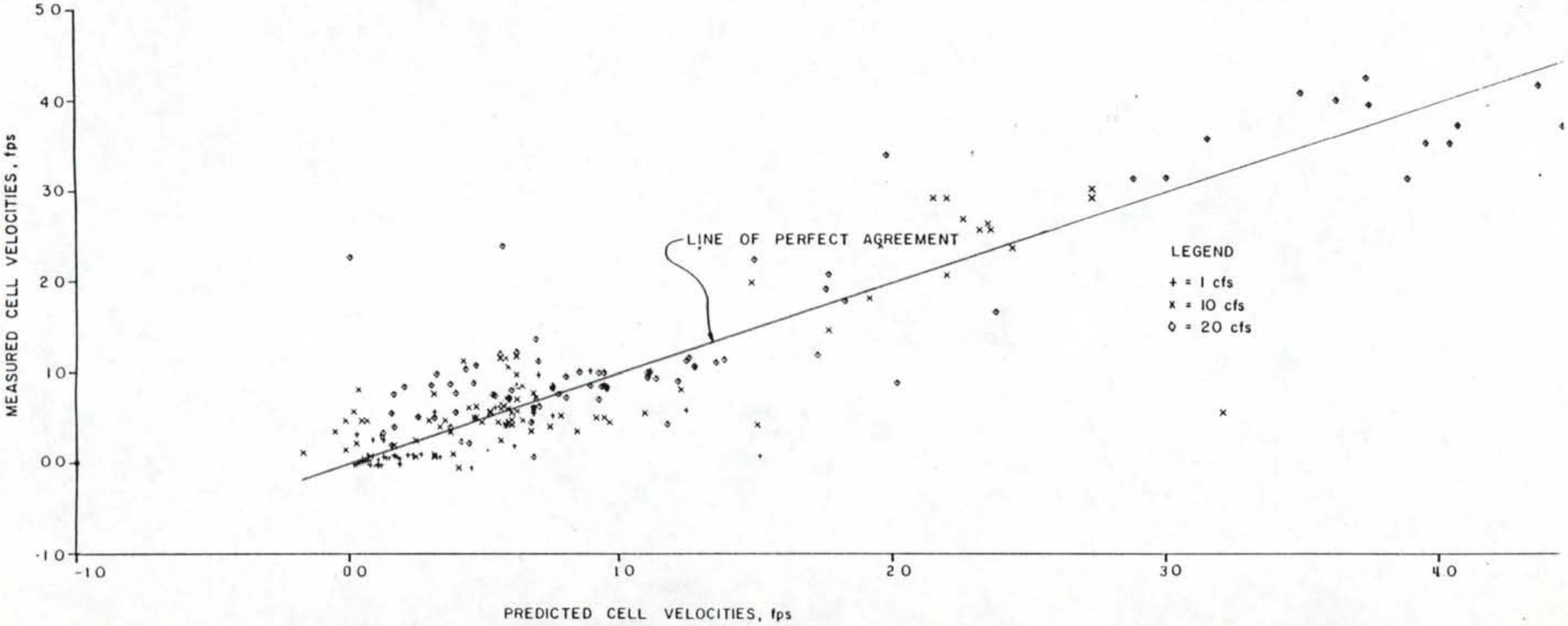

Figure 58. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the west channel for summer 1982. Velocities are at 0.6D and water surface elevation adjustment was used.

10 cfs were used to predict those at 20 cfs.

The results of the summer data collection in the West Channel are summarized as follows:

1. The averaged velocities yielded better velocity prediction than the velocities at 0.6D, regardless of flow rate or type of adjustment.
2. Using velocities at 10 cfs and 20 cfs to predict velocities at 1 cfs provided the best results, while using velocities at 1 cfs and 10 cfs to predict velocities at 20 cfs yielded the worst results.
3. Neither velocity adjustment nor water surface elevation adjustment gave better prediction results.
4. Overall, the IFG4 model passed the chi-square test on cross-sections in 41 of the 80 instances and in three instances on the entire channel.

D. Summer Data Collection Period, East Channel

1 cfs

The desired flow rates were 0.49 cfs and 0.50 cfs for the averaged velocities and for the velocities at 0.6D, respectively. The IFG4 model failed the chi-square test in all cases for cross-section 4, a riffle section. The model passed the chi-square test in 16 of the 24 tests made on the cross-sections (see Figure 39). The combination of averaged velocity with water surface elevation adjustment was the only case in which the model adequately predicted velocities for the entire channel.

10 cfs

The desired flow rates were 7.54 cfs and 7.80 cfs for the averaged velocities and for the velocities at 0.6D, respectively. The IFG4 model failed the chi-square test in all cases for cross-sections 9.1 and 9.2, riffle sections (see Figure 59). The model passed the chi-square test in 17 of the 28 tests made on the cross-sections. When averaged velocities are used, regardless of type of adjustment, the model adequately predicted velocities for the entire channel.

20 cfs

The desired flow rates were 17.74 cfs and 17.28 cfs for the average velocities and for the velocities at 0.6D, respectively. The IFG4 model passed the chi-square test in all cases for cross-section 8 only (a run section with converging flow). The model passed the chi-square test in only 6 of the 28 tests performed on the cross-sections and not once for the entire channel. See Figures 60 through 63 for a graphical confirmation of the poor predictive ability of the IFG4 model when velocities at 1 cfs and 10 cfs were used to predict those at 20 cfs.

The results of the summer data collection period in the East Channel are summarized as follows:

1. The averaged velocities yielded better velocity prediction than the velocities at 0.6D, regardless of flow rate or type of adjustment.
2. Using velocities at 10 cfs and 20 cfs to predict velocities at 1 cfs provided the best results, while using velocities at 1 cfs and 10 cfs to predict velocities at 20 cfs yielded the worst results.

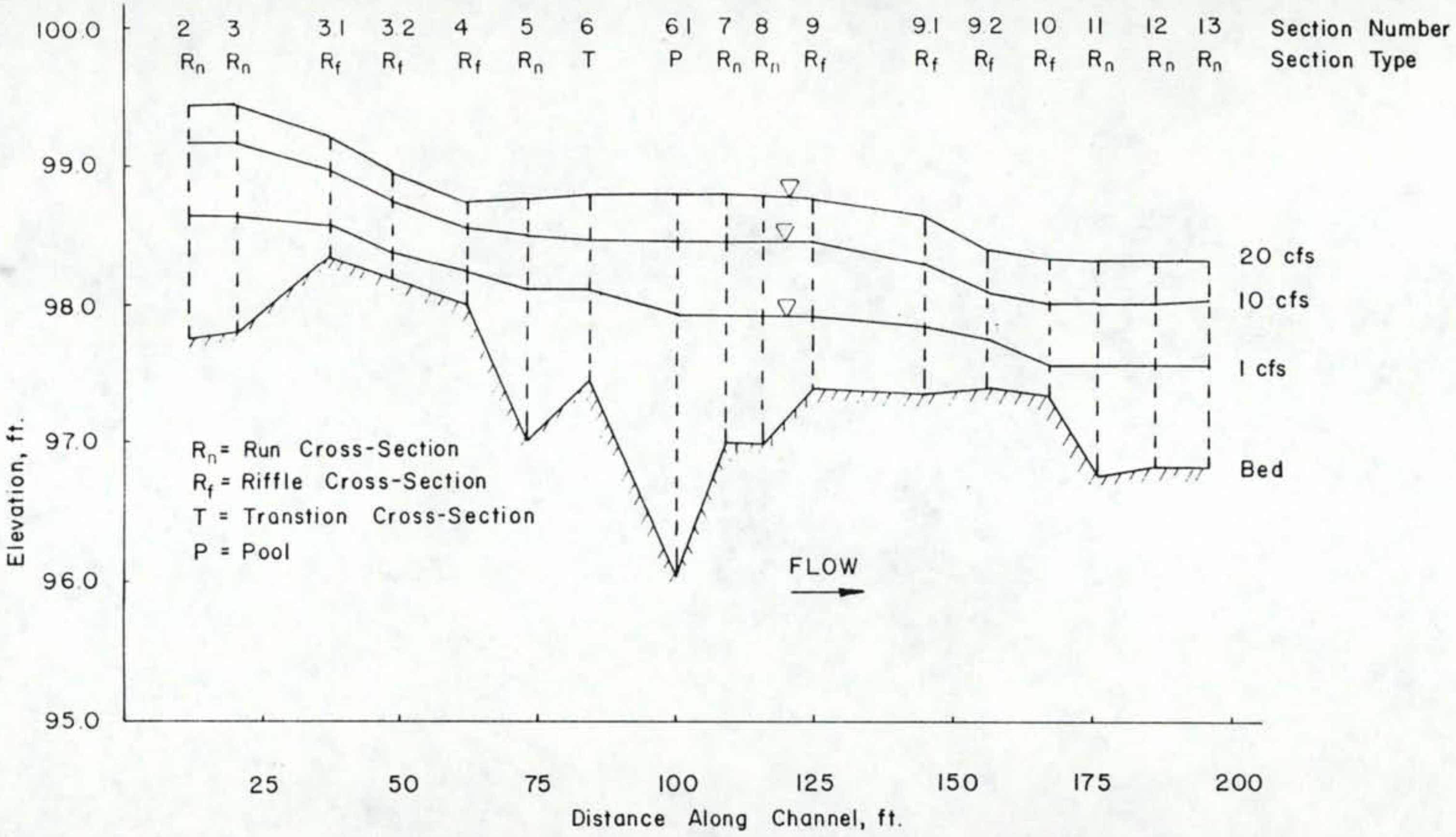

Figure 59. Measured water surface profile for the east channel and the summer data collection period.

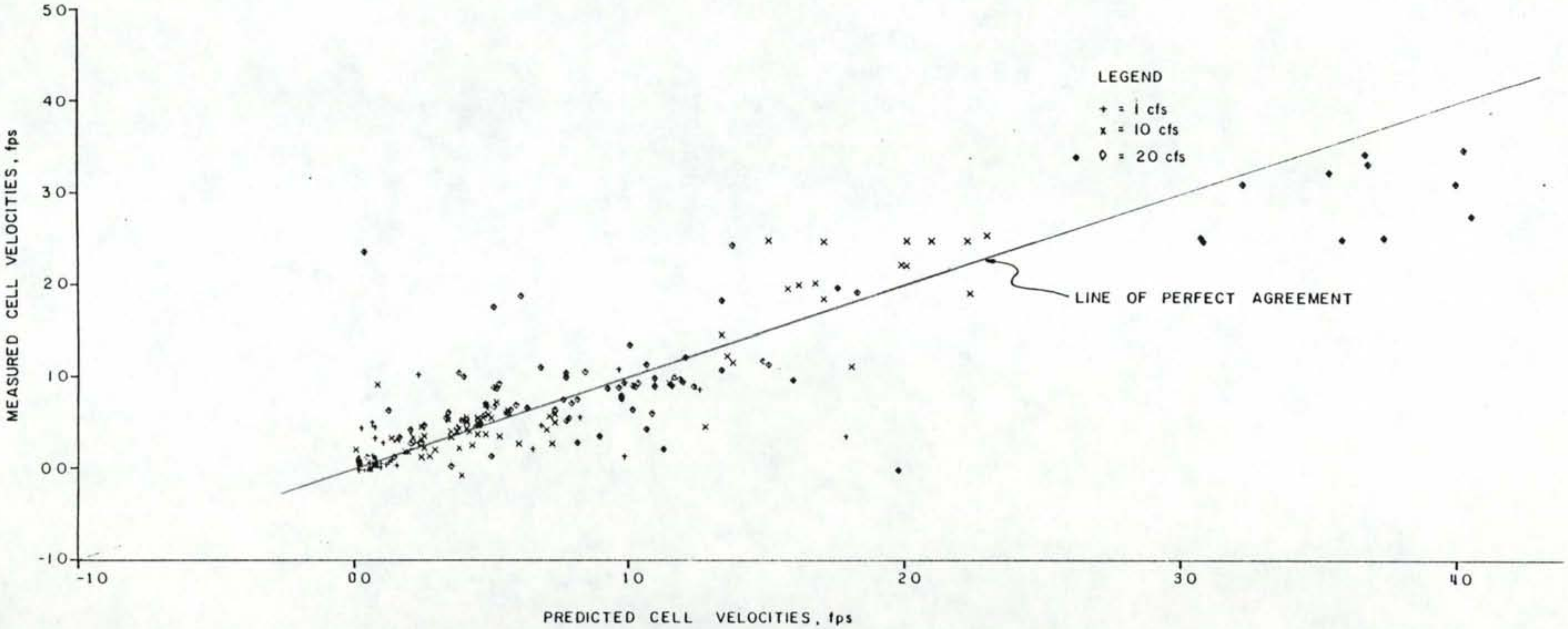

Figure 60. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the east channel for summer 1982. Velocities are averaged and velocity adjustment was used.

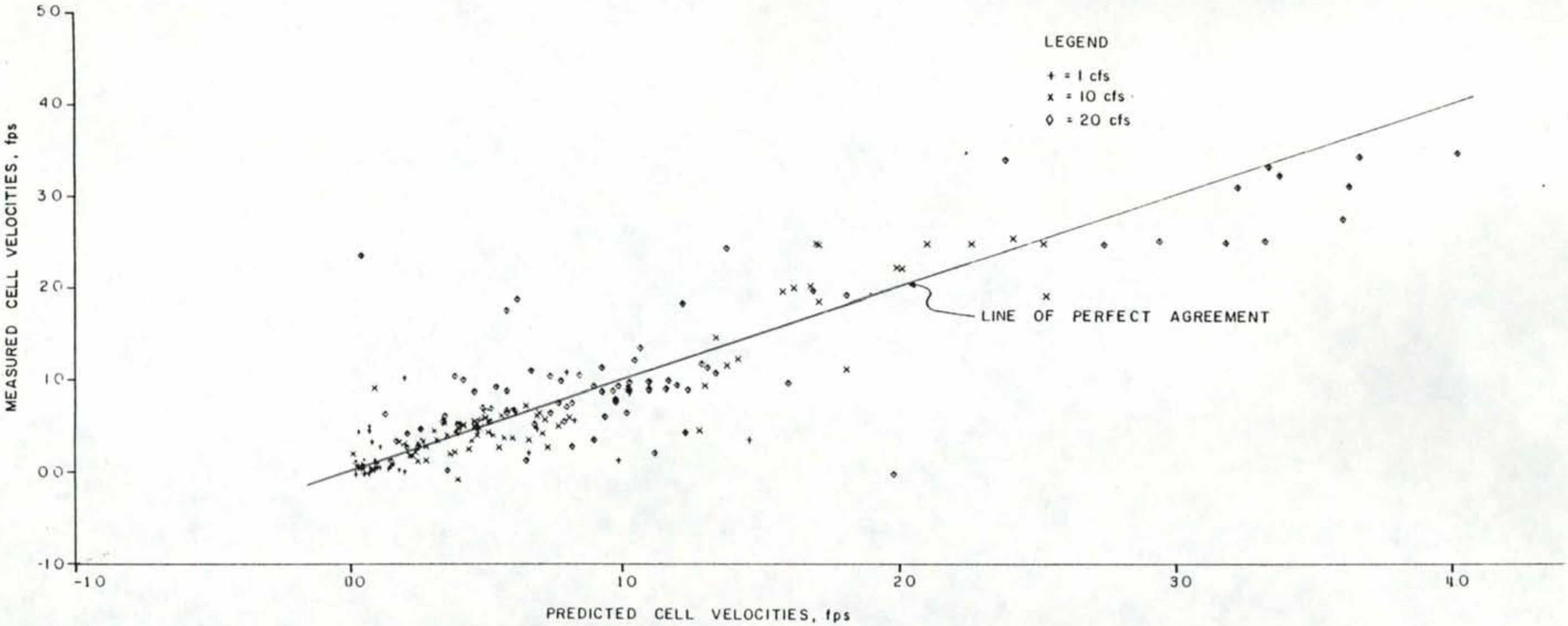

Figure 61. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the east channel for summer 1982. Velocities are averaged and water surface elevation adjustment was used.

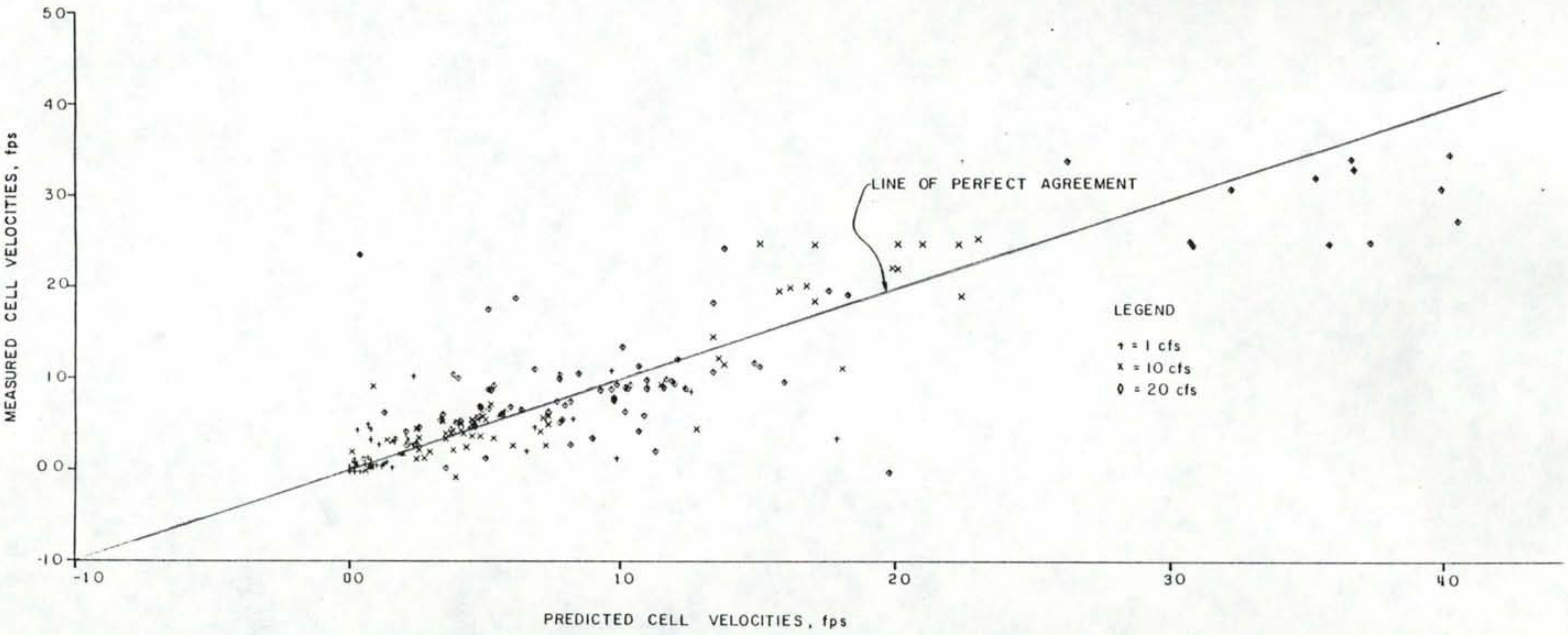

Figure 62. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the east channel for summer 1982. Velocities are at 0.6D and velocity adjustment was used.

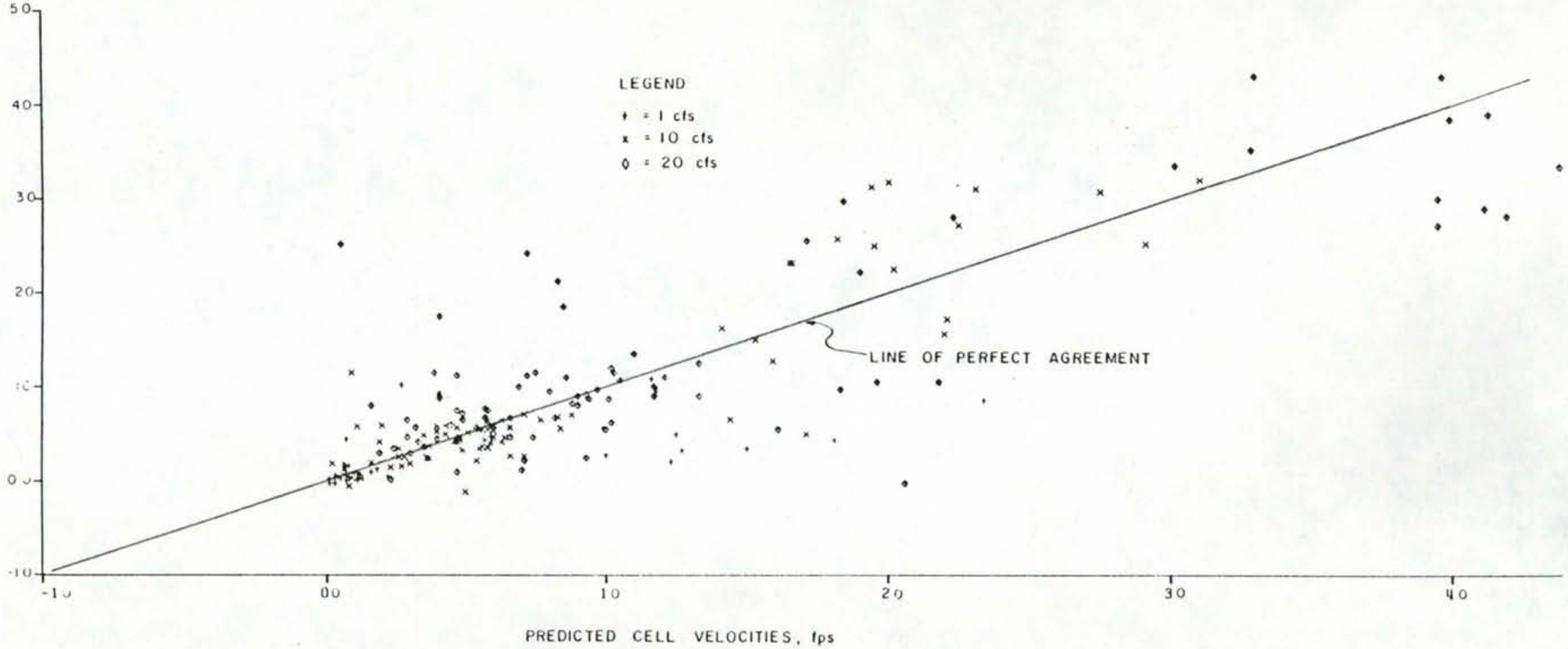

Figure 63. Cell velocities predicted by the IFG4 model versus measured cell velocities for all cross-sections and flow rates in the east channel for summer 1982. Velocities are at 0.6D and velocity adjustment was used.

3. Neither velocity adjustment nor water surface elevation adjustment gave better prediction results.
4. Overall, the IFG4 passed the chi-square test on cross-sections in 39 of the 80 instances, and in three of nine instances on the entire channel.

Based on the individual summaries of the combinations of data collection period and channel, the following conclusions were developed regarding the ability of the IFG4 model to predict velocities.

1. By far, the best results were obtained when velocities at 10 cfs and 20 cfs were used to predict velocities at 1 cfs. This result is due primarily to the fact that the flow conditions at the higher flow rates more closely resemble uniform or gradually varied flow. This leads to more accurate and reliable velocity measurements at the higher flows. It is evident that prediction of velocities at the 10 cfs and 20 cfs flows was progressively worse (see Figure 64).
2. There was a decided advantage to using averaged velocities over those at 0.6D with either type of adjustment (see Table 24).
3. No increased predictive reliability was achieved by using one form of adjustment over the other (see Table 24).
4. In all the chi-square tests run on all the cross-sections for all the flow rates, the IFG4 model passed the test one-half the time.

Water Surface Elevation Prediction

Although the IFG4 model was designed primarily to predict velocities, it also predicts water surface elevation. Table 25 through 28

							COMPUTED χ^2[1]							COMPUTED χ^2						COMPUTED χ^2	
							1 cfs						10 cfs						20 cfs	
DATA COLLECTION PERIOD	CHANNEL	TOLERANCE[5] (ft)	n[2]	TABULAR χ^2[3]	VAVV[4]	VAVW	V6DV	V6DW	n	TABULAR χ^2	VAVV	VAVW	V6DV	V6DW	n	TABULAR χ^2	VAVV	VAVW	V6DV	V6DW
WINTER	WEST	0.05	4	9.49	438.23	724.73	414.26	933.19	6	12.59	84.69	124.72	94.60	170.24	6	12.59	195.18	195.18	159.12	248.96
WINTER	WEST	0.10	4	9.49	109.56	181.18	103.57	233.30	6	12.59	21.17	31.18	23.65	42.56	6	12.59	48.79	48.79	39.78	24.75
WINTER	EAST	0.05	3	7.81	108.16	808.43	91.67	729.37	5	11.07	65.35	56.29	58.11	252.24	5	11.07	95.61	479.78	66.92	79.93
WINTER	EAST	0.10	3	7.81	27.04	202.11	22.92	182.34	5	11.07	16.33	14.07	14.53	63.06	5	11.07	23.90	119.95	16.73	19.98
SUMMER	WEST	0.05	6	12.59	206.88	502.86	185.55	406.70	7	14.07	610.80	41.38	799.33	660.52	7	14.07	1329.24	1272.30	2936.93	1933.37
SUMMER	WEST	0.10	6	12.59	31.72	125.71	46.39	101.67	7	14.07	152.70	10.35	199.83	165.13	7	14.07	332.31	318.08	734.23	495.84
SUMMER	EAST	0.05	6	12.59	236.49	633.06	227.99	333.73	7	14.07	84.44	68.74	118.01	41.34	7	14.07	135.85	103.56	213.14	248.96
SUMMER	EAST	0.10	6	12.59	59.12	165.77	57.00	83.43	7	14.07	21.11	17.18	29.50	10.33	7	14.07	33.96	25.89	53.29	62.24

1. Computed $\chi^2 = \dfrac{\sum_{i=1}^{n} (WSEP-WSEM)^2}{\sigma^2}$, where:
   WSEP = water surface elevation predicted by IFG4, ft
   WSEM = measured water surface elevation, ft
   $\sigma^2 = E^2/Z^2$
   E = tolerance, ft
   Z = standard normal deviate for $\alpha = 0.05$ (two-tailed)

2. n = number of pairs of predicted and given water surface elevation.

3. Tabular χ^2 based on n degrees of freedom and $\alpha = 0.05$

4. VAVV = Averaged velocities with velocity adjustment
   VAVW = Averaged velocities with water surface elevation adjustment by IFG4
   V6DV = Velocities at 0.6D with velocity adjustment
   V6DW = Velocities at 0.6D with water surface elevation adjustment by IFG4

5. Tolerance = absolute value of maximum allowable difference between predicted and measured water surface elevations

Figure 64. Results of chi-square analysis of the ability of the IFG4 model to predict water surface elevation.

TABLE 24

Composite Summary for Chi-Square Tests Made on velocities

Type of Adjustment	Averaged Velocities				Velocities at 0.6D				Subtotal[1]			
	Section		Channel		Section		Channel		Section		Channel	
	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)
					1 cfs							
Velocity	17	2	3	1	13	6	2	2	30	8	5	3
Water Surface Elev.	17	2	3	1	16	6	1	3	30	8	4	4
Subtotal	34	4	6	2	26	12	3	5	60	16	9	7
					10 cfs							
Velocity	17	8	1	3	14	11	1	2	31	19	2	6
Water Surface Elev.	18	7	1	3	15	10	0	4	33	17	1	7
Subtotal	35	15	2	6	29	21	1	7	64	36	3	13
					20 cfs							
Velocity	5	20	0	4	2	23	0	4	7	43	0	8
Water Surface Elev.	5	20	0	4	3	22	0	4	8	42	0	8
Subtotal	10	40	0	8	5	45	0	8	15	85	0	16
									GRAND TOTAL			
Velocity	39	30	4	8	29	40	3	9	68	70	7	17
Water Surface Elev.	40	29	4	8	31	38	1	11	71	67	5	19
GRAND TOTAL[2]	79	59	8	16	60	78	4	20	139	137	12	36

1. Subtotals are horizontal or vertical summations of the appropriate plus (+) and minus (-) signs.

2. Grand totals are horizontal or vertical summations of the subtotals.

present a summary of the measured and predicted water surface elevations for each of the IFG4 runs. A chi-square analysis was done to assess the ability of the IFG4 model to predict water surface elevation (see Figure 64). Two maximum tolerable differences (tolerances) between measured and predicted water surface elevation were used, 0.05 ft. and 0.10 ft. When a tolerance of 0.05 ft. was used, the IFG4 model failed the chi-square test in all of the 48 cases, and, when the tolerance was 0.10 ft., the model passed the test only twice. The only possible conclusion is that this version of the IFG4 model is not reliable for predicting water surface elevation.

TABLE 25

WATER SURFACE ELEVATION[1] SUMMARY FOR THE WEST CHANNEL AND THE WINTER DATA COLLECTION PERIOD

		1 cfs				10 cfs				20 cfs			
SECTION		VAVV[2]	VAVW	V6DV	V6DW	VAVV	VAVW	V6DV	V6DW	VAVV	VAVW	V6DV	V6DW
2	WSEM[3]	-	-	-	-	99.34	99.34	99.34	99.34	99.66	99.66	99.66	99.66
	WSER	-	-	-	-	99.45	99.45	99.47	99.47	99.50	99.50	99.49	99.49
	WSEA	-	-	-	-	0.0	0.0	0.0	-0.16	0.0	0.0	0.0	0.19
	WSEP	-	-	-	-	99.45	99.45	99.47	99.31	99.50	99.50	99.49	99.69
3	WSEM	-	-	-	-	99.33	99.33	99.33	99.33	99.63	99.63	99.63	99.63
	WSER	-	-	-	-	99.42	99.42	99.45	99.45	99.50	99.50	99.52	99.52
	WSEA	-	-	-	-	0.0	-0.11	0.0	0.0	0.0	0.0	0.0	0.0
	WSEP	-	-	-	-	99.42	99.32	99.45	99.45	99.50	99.50	99.52	99.52
5	WSEM	98.18	98.19	98.19	98.18	98.69	98.69	98.96	98.69	98.92	98.92	98.92	98.92
	WSER	98.09	98.09	98.17	98.17	98.72	98.72	98.70	98.70	98.89	98.89	98.90	98.90
	WSEA	0.0	-0.31	0.0	-0.39	0.0	-0.22	0.0	-0.29	0.0	0.0	0.0	0.13
	WSEP	98.09	97.78	98.17	97.78	98.72	98.50	98.70	98.41	98.89	98.89	98.90	99.03
9	WSEM	98.01	98.01	98.01	98.01	98.59	98.59	98.59	98.59	98.89	98.89	98.89	98.89
	WSER	97.74	97.74	97.82	97.82	98.74	98.74	98.74	98.74	98.71	98.71	98.73	98.73
	WSEA	0.0	0.0	0.0	-0.15	0.0	0.0	0.0	-0.23	0.0	0.0	0.0	0.21
	WSEP	97.74	97.74	97.82	97.68	98.74	98.74	98.74	98.50	98.71	98.71	98.73	98.94
11	WSEM	97.49	97.49	97.49	97.49	98.05	98.05	98.05	98.05	98.37	98.37	98.37	98.37
	WSER	97.11	97.11	97.01	97.01	98.08	98.08	98.10	98.10	98.19	98.19	98.18	98.18
	WSEA	0.0	-0.05	0.0	-0.06	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WSEP	97.11	97.07	97.01	96.96	98.08	98.08	98.10	98.10	98.19	98.19	98.18	98.18
12	WSEM	97.49	97.49	97.49	97.49	98.05	98.05	98.05	98.05	98.38	98.38	98.38	98.38
	WSER	97.24	97.24	97.40	97.40	98.14	98.14	98.12	98.12	98.24	98.24	98.34	98.34
	WSEA	0.0	0.0	0.0	-0.13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WSEP	97.24	97.24	97.40	97.27	98.14	98.14	98.12	98.12	98.24	98.24	98.34	98.34

1. All water surface elevations are referenced to a weir crest height of 100 ft.

2. VAVV = Averaged velocities with velocity adjustment
VAVW = Averaged velocities with water surface elevation adjustment
V6DV = Velocities of 0.60 with velocity adjustment
V6DW = Velocities at 0.60 with wqter surface elevation adjustment

3. WSEM = Measured water surface elevation, ft
WSER = Water surface elevation from the flow rate versus stage calibration equation, ft
WSEA = Water surface elevation adjustment, ft
WSEP = Water surface elevation predicted by the IFG4 model (WSER + WSEA), ft

TABLE 26

WATER SURFACE ELEVATION[1]. SUMMARY FOR THE EAST CHANNEL AND THE WINTER DATA COLLECTION PERIOD

		1 cfs				10 cfs				20 cfs			
SECTION		VAVV[2].	VAVW	V6DV	V6DW	VAVV	VAVW	V6DV	V6DW	VAVV	VAVW	V6DV	V6DW
5	WSEM[3].	-	-	-	-	98.53	98.53	98.53	98.53	98.82	98.82	98.82	98.82
	WSER	-	-	-	-	98.61	98.61	98.62	98.62	98.68	98.68	98.76	98.76
	WSEA	-	-	-	-	0.0	0.0	0.0	-0.46	0.0	-0.38	0.0	0.17
	WSEP	-	-	-	-	98.61	98.61	98.62	98.16	98.68	98.30	98.76	98.93
6	WSEM	-	-	-	-	98.54	98.54	98.54	98.54	98.84	98.84	98.84	98.84
	WSER	-	-	-	-	98.63	98.63	98.63	98.63	98.66	98.66	98.66	98.66
	WSEA	-	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WSEP	-	-	-	-	98.63	98.63	98.63	98.63	98.66	98.66	98.66	98.66
7	WSEM	97.89	97.89	97.89	97.89	98.47	98.47	98.47	98.47	98.77	98.77	98.77	98.77
	WSER	97.73	97.73	97.67	97.67	98.59	98.59	98.57	98.57	98.75	98.75	98.75	98.75
	WSEA	0.0	-0.53	0.0	-0.45	0.0	-0.20	0.0	-0.19	0.0	0.0	0.0	0.0
	WSEP	97.73	97.20	97.67	97.22	98.59	98.38	98.57	98.38	98.75	98.75	98.75	98.75
8	WSEM	97.88	97.88	97.88	97.88	98.47	98.47	98.47	98.47	98.78	98.78	98.78	98.78
	WSER	97.74	97.74	97.85	97.85	98.57	98.57	98.55	98.55	98.71	98.71	98.74	98.74
	WSEA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.13	0.0	0.0
	WSEP	97.74	97.74	97.85	97.85	98.57	98.57	98.55	98.55	98.71	98.84	98.74	98.74
9	WSEM	97.88	97.88	97.88	97.88	98.47	98.47	98.47	98.47	98.78	98.78	98.78	98.78
	WSER	97.72	97.72	97.79	97.79	98.54	98.54	98.54	98.54	98.69	98.69	98.71	98.71
	WSEA	0.0	0.0	0.0	-0.06	0.0	0.0	0.0	-0.12	0.0	0.0	0.0	0.14
	WSEP	97.72	97.72	97.79	97.72	98.54	98.54	98.54	98.42	98.69	98.69	98.71	98.85

1. All water surface elevations are referenced to a weir crest height of 100 ft.

2. VAVV = Averaged velocities with velocity adjustment
VAVW = Averaged velocities with water surface elevation adjustment
V6DV = Velocities of 0.60 with velocity adjustment
V6DW = Velocities at 0.60 with wqter surface elevation adjustment

3. WSEM = Measured water surface elevation, ft
WSER = Water surface elevation from the flow rate versus stage calibration equation, ft
WSEA = Water surface elevation adjustment, ft
WSEP = Water surface elevation predicted by the IFG4 model (WSER + WSEA), ft

TABLE 27

WATER SURFACE ELEVATION[1]. SUMMARY FOR THE WEST CHANNEL AND THE SUMMER DATA COLLECTION PERIOD

		1 cfs				10 cfs				20 cfs			
SECTION		VAVV[2].	VAVW	V6DV	V6DW	VAVV	VAVW	V6DV	V6DW	VAVV	VAVW	V6DV	V6DW
2	WSEM[3].	98.81	98.81	98.81	98.81	99.33	99.33	99.33	99.33	99.63	99.63	99.63	99.63
	WSER	98.62	98.62	98.63	98.63	99.44	99.44	99.45	99.45	99.49	99.49	99.48	99.48
	WSEA	0.0	-0.22	0.0	-0.19	0.0	-0.18	0.0	-0.19	0.0	0.16	0.0	0.22
	WSEP	98.62	98.40	98.63	98.44	99.44	99.26	99.45	99.25	99.49	99.65	99.48	99.70
3	WSEM	98.82	98.82	98.82	98.82	99.32	99.32	99.32	99.32	99.63	99.63	99.63	99.63
	WSER	98.58	98.58	98.63	98.63	99.44	99.44	99.44	99.44	99.50	99.50	99.49	99.49
	WSEA	0.0	-0.09	0.0	-0.08	0.0	-0.11	0.0	-0.11	0.0	0.13	0.0	0.12
	WSEP	98.58	98.49	98.63	98.54	99.44	99.33	99.44	99.33	99.50	99.62	99.49	99.61
3.1	WSEM	98.75	98.75	98.75	98.75	99.12	99.12	99.12	99.12	99.33	99.33	99.33	99.33
	WSER	98.69	98.69	98.64	98.64	99.16	99.16	99.15	99.15	99.36	99.36	99.27	99.27
	WSEA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WSEP	98.69	98.69	98.64	98.64	99.16	99.16	99.15	99.15	99.36	99.36	99.27	99.27
3.2	WSEM	98.56	98.56	98.56	98.56	98.93	98.93	98.93	98.93	99.07	99.07	99.07	99.07
	WSER	98.58	98.58	98.53	98.53	98.88	98.88	98.88	98.88	99.13	99.13	99.05	99.05
	WSEA	0.0	-0.08	0.0	-0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WSEP	98.58	98.49	98.53	98.43	98.88	98.88	98.88	98.88	99.13	99.13	99.05	99.05
7	WSEM	-	-	-	-	98.63	98.63	98.63	98.63	98.89	98.89	98.89	98.89
	WSER	-	-	-	-	98.03	98.03	97.94	97.94	97.98	97.98	97.53	97.53
	WSEA	-	-	-	-	0.0	0.70	0.0	1.34	0.0	0.0	0.0	0.23
	WSEP	-	-	-	-	98.03	09.73	97.94	99.27	97.98	97.98	97.53	97.76
9	WSEM	98.09	98.09	98.09	98.09	98.62	98.62	98.62	98.62	98.87	98.87	98.87	98.87
	WSER	97.93	97.93	97.97	97.97	98.68	98.68	98.70	98.70	98.84	98.84	98.78	98.78
	WSEA	0.0	0.0	0.0	0.05	0.0	0.0	0.0	-0.12	0.0	0.0	0.0	0.16
	WSEP	97.93	97.93	97.97	98.02	98.68	98.68	98.70	98.59	98.84	98.84	98.78	98.94
13	WSEM	97.52	97.52	97.52	97.52	98.00	98.00	98.00	98.00	98.24	98.24	98.24	98.24
	WSER	97.40	97.40	97.36	97.36	98.06	98.06	98.06	98.06	98.19	98.19	98.20	98.20
	WSEA	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WSEP	97.40	97.40	97.36	97.38	98.06	98.06	98.06	98.06	98.19	98.19	98.20	98.20

1. All water surface elevations are referenced to a weir crest height of 100 ft.

2. VAVV = Averaged velocities with velocity adjustment
   VAVW = Averaged velocities with water surface elevation adjustment
   V6DV = Velocities of 0.60 with velocity adjustment
   V6DW = Velocities at 0.60 with wqter surface elevation adjustment

3. WSEM = Measured water surface elevation, ft
   WSER = Water surface elevation from the flow rate versus stage calibration equation, ft
   WSEA = Water surface elevation adjustment, ft
   WSEP = Water surface elevation predicted by the IFG4 model (WSER + WSEA), ft

TABLE 28

WATER SURFACE ELEVATION[1]. SUMMARY FOR THE EAST CHANNEL AND THE SUMMER DATA COLLECTION PERIOD

		1 cfs				10 cfs				20 cfs			
SECTION		VAVV[2]	VAVW	V6DV	V6DW	VAVV	VAVW	V6DV	V6DW	VAVV	VAVW	V6DV	V6DW
2	WSEM[3]	98.65	98.65	98.65	98.65	99.16	99.16	99.16	99.16	99.45	99.45	99.45	99.45
	WSER	98.52	98.52	98.49	98.49	99.22	99.22	99.22	99.22	99.35	99.35	99.35	99.35
	WSEA	0.0	-0.07	0.0	-0.06	0.0	-0.15	0.0	-0.10	0.0	0.0	0.0	0.0
	WSEP	96.52	98.46	98.49	98.43	99.22	99.07	99.22	99.12	99.35	99.35	99.35	99.35
4	WSEM	98.25	98.25	98.25	98.25	98.57	98.57	98.57	98.57	98.74	98.74	98.74	98.74
	WSER	98.17	98.17	98.15	98.15	98.58	98.58	98.56	98.56	98.74	98.74	98.67	98.67
	WSEA	0.0	0.02	0.0	0.0	0.0	-0.04	0.0	-0.05	0.0	0.05	0.0	0.0
	WSEP	98.17	98.19	98.15	98.15	98.58	98.54	98.56	98.51	98.74	98.79	98.67	98.67
7	WSEM	-	-	-	-	98.47	98.47	98.47	98.47	98.79	98.79	98.79	98.79
	WSER	-	-	-	-	98.63	98.63	98.68	98.68	98.64	98.64	98.60	98.60
	WSEA	-	-	-	-	0.0	-0.27	0.0	-0.19	0.0	0.0	0.0	0.32
	WSEP	-	-	-	-	98.63	98.37	98.68	98.49	98.64	98.64	98.60	98.92
8	WSEM	97.92	97.92	97.92	97.92	98.47	98.47	98.47	98.47	98.78	98.78	98.78	98.78
	WSER	97.70	97.70	97.72	97.72	98.54	98.54	98.56	98.56	98.68	98.68	98.66	98.66
	WSEA	0.0	-0.27	0.0	-0.05	0.0	0.0	0.0	-0.11	0.0	0.0	0.0	0.16
	WSEP	97.70	97.43	97.72	97.66	98.54	98.54	98.56	98.45	98.68	98.68	98.66	98.62
9	WSEM	97.91	97.91	97.91	97.91	98.47	98.47	98.47	98.47	98.77	98.77	98.77	98.77
	WSER	97.72	97.72	97.85	97.85	98.55	98.55	98.54	98.56	98.67	98.67	98.69	98.69
	WSEA	0.0	-0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.16
	WSEP	97.72	97.67	97.85	97.85	98.55	98.55	98.56	98.56	98.67	98.67	98.69	98.53
9.1	WSEM	97.83	97.83	97.83	97.83	98.29	98.29	98.29	98.29	98.63	98.63	98.63	98.63
	WSER	97.64	97.64	97.62	97.62	98.37	98.37	98.37	98.37	98.49	98.49	98.44	98.44
	WSEA	0.0	0.0	0.0	-0.05	0.0	0.0	0.0	0.0	0.0	0.09	0.0	0.0
	WSEP	97.64	97.64	97.62	97.57	98.37	98.37	98.37	98.37	98.49	98.58	98.44	98.44
9.2	WSEM	97.74	97.74	97.74	97.74	98.09	98.09	98.09	98.09	98.39	98.39	98.39	98.39
	WSER	97.64	97.64	97.58	97.58	98.18	98.18	98.17	98.17	98.25	98.25	98.21	98.21
	WSEA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	WSEP	97.64	97.64	97.58	97.58	98.18	98.18	98.17	98.17	98.25	98.25	98.21	98.21

1. All water surface elevations are referenced to a weir crest height of 100 ft.

2. VAVV = Averaged velocities with velocity adjustment
VAVW = Averaged velocities with water surface elevation adjustment
V6DV = Velocities of 0.60 with velocity adjustment
V6DW = Velocities at 0.60 with wqter surface elevation adjustment

3. WSEM = Measured water surface elevation, ft
WSER = Water surface elevation from the flow rate versus stage calibration equation, ft
WSEA = Water surface elevation adjustment, ft
WSEP = Water surface elevation predicted by the IFG4 model (WSER + WSEA), ft

CRITIQUE OF THE IFG4 MODEL

The version of the IFG4 model used in this study was released for use in 1978. Any critical statements (positive or negative) made about the IFG4 model refer to that 1978 version of the model. Suggested areas of improvement to the IFG4 model fall into two categories: operational and cosmetic. The operational improvements will be discussed in some detail while the cosmetic improvements will be listed only.

OPERATIONAL IMPROVEMENTS

Manning's Equation

The weakest part of the IFG4 model is the values it used for "n and slope in Manning's equation. The only time a user would need to specify an "n" value is when either no calibration velocities or only one calibration velocity is known for any cell in a cross-section. However, the model disallows that very same user specification of an "n" value when only one calibration velocity is known. Further, when an "n" value is computed for this situation, the slope is fixed at 0.0025, regardless of the channel. This is a very dubious assumption which in fact yielded "n" values of greater than 1.0 from data taken in this study. Values of greater than 0.1 were quite common. Also when a cell velocity is computed using Manning's equation, the same assumption of slope is used.

Limiting Velocities

Another aspect of the IFG4 model which does not reflect situations in the "real" world is the model's treatment of maximum velocities. At present, the model limits either input or predicted velocities to an absolute value of 15.0 fps, regardless of flow rate. In many instances during the processing of the data from this study, a very steep velocity versus flow rate regression curve created from velocities at 10 cfs and 20 cfs yielded astronomical velocities at 1 cfs. These then were reduced to 15.0 fps (too high for 1 cfs) and the run was allowed to continue. The user should be allowed to properly limit velocity based on the flow rate.

Decimal Places

Many of the input and output formats have seriously restricted decimal representation. Frequently not even the correct number of decimal places of the input data would be assigned to the variables, which diminished accuracy and reliability. Also, the printed predictive results often had no decimal places at all which makes manual checking of model computations impossible.

COSMETIC IMPROVEMENTS

Following is a list of items which could help enhance the ease of operation of the model and the interpretation of its results:

1. Printout of velocity versus flow rate regression equation coefficients.
2. Printout of flow rate after all adjustments have been made.
3. Printout of whether velocity adjustment or water surface elevation adjustment is being performed and what is the initial ratio of desired to computed flow rate if water surface elevation is used.

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APPENDICES

Appendix A. Dates of test and control flows from five experiments at the Troy Channels, Troy, Oregon, 1980-1981.

Season,	Year	Dates	Control Flow (m^3/s)	Test Flow (m^3/s)
Spring	1980	21 Mar. - 19 Apr.	.57	.57
		19 Apr. - 15 May	.57	.57
Summer	1980	21 May - 18 June	.57	.57
		18 June - 2 July	.57	.28
		2 July - 16 July	.57	.03
Fall	1980	2 Aug. - 30 Aug.	.57	.57
		30 Aug. - 13 Sept.	57	.28
		13 Sept. - 26 Sept.	.57	.03
Spring	1981	9 Mar. - 4 Apr.	.57	.57
		4 Apr. - 17 Apr.	.57	.28
		17 Apr. - 2 May	.57	.03
Fall	1981	9 Aug. - 5 Sept.	.57	.57
		5 Sept. - 19 Sept.	.57	.28
		19 Sept. - 3 Oct.	.57	.03

Appendix B. Checklist of aquatic insects collected from the Troy Channels, Troy, Oregon, 1980 - 1981.

Order and Family	Genus/Species
Ephemeroptera	
Baetidae	*Baetis bicaudatus* Dodds
	B. tricaudatus Dodds
	B. parvus Eaton
	Centroptilum sp.
Ephemerellidae	*Ephemerella flavilinea* McDunnough
	E. grandis Eaton
	E. hecuba (Eaton)
	E. heterocaudata McDunnough
	E. inermis Eaton
	E. margarita Needham
	E. tibialis McDunnough
Heptageniidae	*Epeorus albertae* (McDunnough)
	Heptagenia criddlei McDunnough
	H. simplicioides McDunnough
	H. solitaria McDunnough
	Rhithrogena hageni Eaton
	Stenonema reesi Edmunds and Jensen
Leptophlebiidae	*Paraleptophlebia bicornuta* (McDunnough)
	P. heteronea (McDunnough)
Polymitarcidae	*Ephoron album* (Say)
Siphlonuridae	*Amelutus connectus* McDunnough
	A. oregonensis McDunnough
Tricorythidae	*Tricorythodes minutus* Traver
Plecoptera	
Chloroperlidae	*Alloperla* sp.
Nemouridae	*Nemoura* sp.
Perlidae	*Calineuria californica* (Banks)
	Claassenia sabulosa (Banks)
	Hesperoperla pacifica (Banks)
Perlodidae	*Cultus* sp.
	Isogenoides elongatus (Hagen)
	Isoperla spp.
	Skwala sp.
Taeniopterygidae	*Taenionema pacificum* (Banks)

Appendix B. Checklist of aquatic insects collected from the Troy Channels, Troy, Oregon, 1980 - 1981 (continued).

Order and Family	Genus/Species
Trichoptera	
Brachycentridae	*Brachycentrus* sp.
	Amiocentrus aspilus (Ross)
Glossosomatidae	*Glossosoma* sp.
Hydropsychiae	*Arctopsyche* sp.
	Cheumatopsyche sp.
	Hydropsyche sp.
Hydroptilidae	*Hydroptila* sp.
	Leucotrichia sp.
Lepidostomatidae	*Lepidostoma* sp.
Leptoceridae	*Ceraclea* sp.
	Oecetis sp.
Limnephilidae	*Dicosmoecus* sp.
Psychomyiidae	*Psychomyia* sp.
Rhyacophilidae	
Diptera	
Blephariceridae	
Ceratopogonidae	*Palpomyia* sp.
Chironomidae	
Deuterophlebiidae	*Deuterophlebia* sp.
Empididae	*Hemerodromia* sp.
Rhagionidae	*Atherix variegata* Walker
Simuliidae	*Simuluim* sp.
Stratiomyiidae	*Hermione* sp.
Tabanidae	
Tanyderidae	*Protanyderus margarita* Alexander
Tipulidae	*Antocha* sp.
	Hexatoma sp.
	Tipula sp.
Coleoptera	
Dytiscidae	
Elmidae	*Ampumixus* sp.
	Cleptelmis sp.
	Dubiraphia sp.
	Heterelmnis sp.
	Narpus sp.
	Optioservus sp.
	Ordobrevia sp.

Appendix B. Checklist of aquatic insects collected from the Troy Channels, Troy, Oregon, 1980 - 1981 (continued).

Order and Family	Genus/Species
Hydrophilidae	*Helophorus* sp.
Psephenidae	*Psephenus* sp.
Lepidoptera	
Pyralidae	*Parargyractis* sp.