Abilities of trout to swim through highway culverts

by David Andrew Belford

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

Abstract:
Seven culverts in Montana were studied from 1984 -1986 to determine conditions that allowed and prohibited the passage of rainbow trout, brown trout, cutthroat trout and brook trout. A curve was fitted to the most stringent combinations of distances and average bottom water velocities between rest sites in culverts trout swam through. This curve indicated that for distances between rest sites of 0 - 20 m, average bottom velocities of near or below 1.67 - 0.83 m/s, respectively, permitted passage. For distances of 20 - 100 m, average bottom velocities of near or below 0.83 - 0.64 m/s, respectively, permitted passage. Trout 185 - 470 mm in total length passed through culverts with these maximum conditions. No differences in swimming ability were noted among the four trout species studied in the field. Laboratory swimming stamina tests indicated that brown trout, rainbow trout and cutthroat trout had similar staminas. All three types of culvert modifications studied created conditions that permitted trout passage.

ABILITIES OF TROUT TO SWIM THROUGH HIGHWAY CULVERTS

by

David Andrew Belford

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

of

Master of Science

in

Fish and Wildlife Management

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 1986

APPROVAL

of a thesis submitted by

David Andrew Belford

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

July 17, 1986 — Date

William R. Gould — Chairperson, Graduate Committee

Approved for the Major Department

July 17, 1986 — Date

Peter F. Brussard — Head, Major Department

Approved for the College of Graduate Studies

July 26, 1986 — Date

Henry L Parsons — Graduate Dean

STATEMENT OF PERMISSION TO USE

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

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

Signature David A. Belford

Date July 26, 1986

ACKNOWLEDGEMENT

I sincerely thank the following people for help throughout this study. Dr. William Gould directed the study and assisted with the field work and preparation of the manuscript. Drs. Ray White, Lynn Irby, John Priscu and Tad Weaver critically reviewed the manuscript. Charlie Smith, Pat Dwyer and Arthur Viola at the Fish Cultural Development Center provided space and assistance at the Center. Ralph Boland and Chris Clancey, Montana Department of Fish, Wildlife and Parks, critically reviewed the study proposal and provided field assistance, respectively. Dan Gustafson provided statistical and computer assistance. Mike Hensler and other fellow students assisted me in the field. My sincere appreciation also goes to my wife, Susan, and family for encouragement throughout this study.

This study was funded by a Federal Highway Administration grant to the Montana Department of Highways (Project 8093). Special thanks are given to Les Reichelt, Paul Garrett, Donald Harriott, Stephen Kologi and Robert Garber of the above agencies for their interest and support of this study.

TABLE OF CONTENTS

Table of Contents (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

ABSTRACT

Seven culverts in Montana were studied from 1984 - 1986 to determine conditions that allowed and prohibited the passage of rainbow trout, brown trout, cutthroat trout and brook trout. A curve was fitted to the most stringent combinations of distances and average bottom water velocities between rest sites in culverts trout swam through. This curve indicated that for distances between rest sites of 0 - 20 m, average bottom velocities of near or below 1.67 - 0.83 m/s, respectively, permitted passage. For distances of 20 - 100 m, average bottom velocities of near or below 0.83 - 0.64 m/s, respectively, permitted passage. Trout 185 - 470 mm in total length passed through culverts with these maximum conditions. No differences in swimming ability were noted among the four trout species studied in the field. Laboratory swimming stamina tests indicated that brown trout, rainbow trout and cutthroat trout had similar staminas. All three types of culvert modifications studied created conditions that permitted trout passage.

INTRODUCTION

In many instances, conditions permit highway management agencies to design either culverts or bridges when crossing streams. In these situations, the highway management agencies often prefer to install culverts rather than bridges because of reduced costs. In contrast, conservation agencies often prefer that bridges be used because the literature contains documentation of culverts impeding or preventing fish movements.

Culvert installations often cause high water velocities which impede or block fish movements. High velocities in culverts have been found to prevent the passage of Arctic grayling (Thymallus arcticus), longnose suckers (Catostomus catostomus), northern pike (Esox lucius) (Derksen 1980), steelhead (Salmo gairdneri), coho salmon (Onocorhynchus kisutch), chinook salmon (O. tshawytcha) (Kay and Lewis 1970) and cutthroat trout (S. clarki) (Huston 1964). Higher velocities can develop in culverts than in natural streams because culverts have lower roughness coefficients or steeper slopes. Agencies have tried to mitigate this passage problem by installing velocity reducing structures in some culverts. Fish passage may also be prohibited because of high velocities in adjacent stream sections caused by culvert hydraulics which can prevent fish from either entering or leaving the culverts (Evans and Johnston 1977).

Oversized culverts or culverts with steep gradients have produced shallow water conditions which can block fish passage (Bryant 1981). Shallow water can block fish movements because it reduces the fish's swimming ability. (Webb 1975). Evans and Johnston (1977) have recommended that minimum water depths for passage in culverts be 15 and 30 centimeters (cm) for resident trout and anadromous salmonids, respectively.

Elevated culvert outlets also can prevent fish passage. Evans and Johnston (1977) recommended that single jumps not exceed 30 cm in height for resident trout and 61-91 cm for anadromous salmonids. A jumping pool depth of 1.25 times the jump height is also recommended for these situations (Gebhards and Fisher 1972).

Light levels within culverts were once thought to influence fish passage (Metsker 1970). However, it is now generally regarded as an insignificant factor (Bell 1973; Lauman 1976).

The study of fish passage through culverts or steep pass fishways has largely focused on the abilities of anadromous salmonids (Gauley 1960, 1967; Kay and Lewis 1970; Slatick 1971). It has been assumed that anadromous salmonids have greater passage abilities than nonanadromous salmonids, but the actual capabilities of the latter have largely been unmeasured.

The goal of this study was to relate the physical conditions in and around selected highway culverts in Montana to salmonid passage. The specific objectives were to measure the velocities, distances between rest sites and water depths in culverts and determine if the brown trout (*S. trutta*), rainbow trout (*S. gairdneri*), brook trout (*Salvelinus frontinalis*) and/or cutthroat trout present could pass through them. In addition, evaluations of the effectiveness of the fish passage stuctures present in three culverts and the relative swimming abilities of brown trout, rainbow trout and cutthroat trout were made. The findings of this study can be used to help determine if planned and existing highway culverts will prevent or allow nonanadromous salmonid passage.

DISCRIPTION OF STUDY AREAS

Culverts at five sites in Montana were chosen for study (Figure 1). The characteristics of the seven culverts at these sites havebeen given in Table 1. Cedar Creek, tributary to the Yellowstone River, was located in Park County approximately 44 air kilometers (km) south of Livingston. It flowed under U.S. Highway 89 through two culverts lying side by side.

Discharges in Cedar Creek were estimated to have been 0.02 - 1.22 cubic meters per second (m^3/s) during the study periods. The creek has resident brown trout, cutthroat trout and brook trout. It was also a spawning site for migrating cutthroat trout from the Yellowstone River.

The north culvert was fitted with a ladder - like structure on the bottom. The ladder rungs were spaced at mean (range) distances of 1.22 m (1.13 - 1.45 m) apart and held bedload which provided rest sites for trout. The structure was approximately 1.1 m wide and extended the full length of the culvert. The south culvert contained no structures. Prior to the installation of the ladder both culverts blocked migratory cutthroat trout movement (Berg 1975).

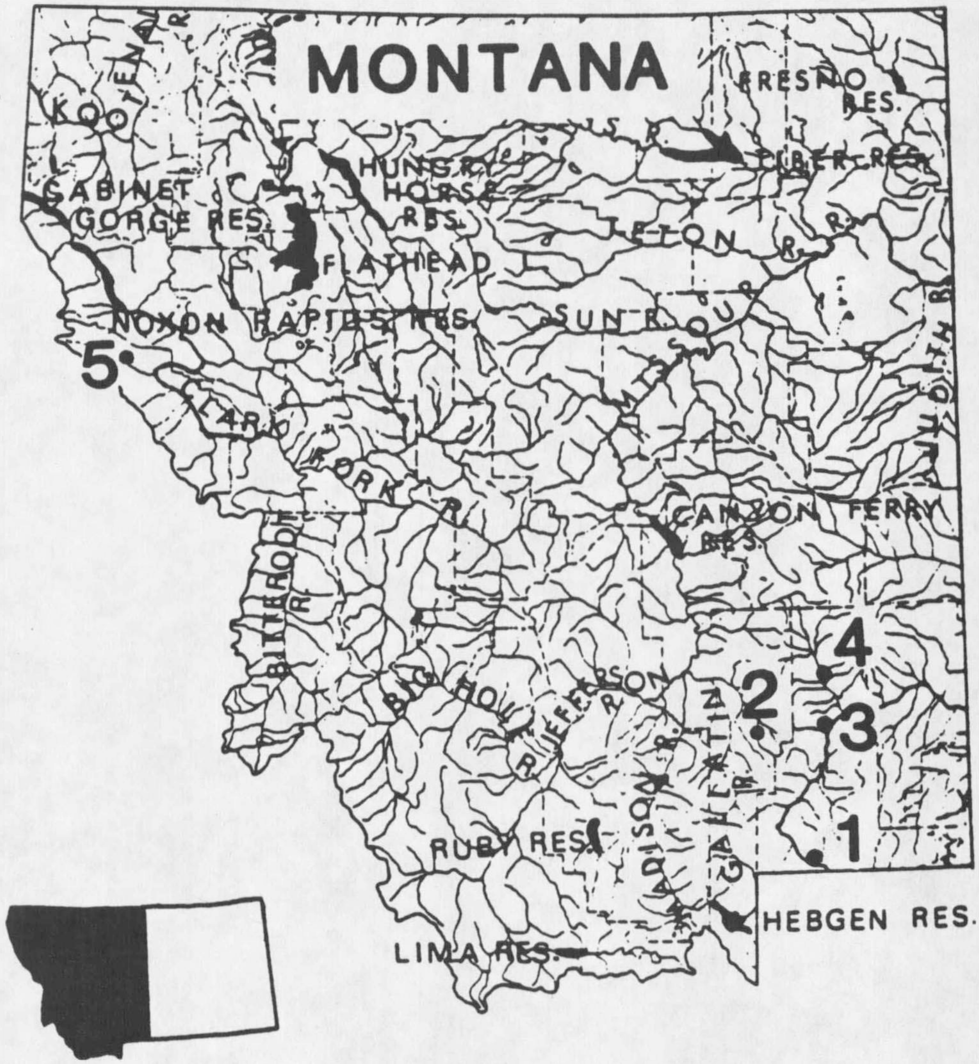

Figure 1. Locations of the study areas. 1 - Cedar Creek, 2 - Sourdough Creek, 3 - Depuy's Spring Creek - North Channel, 4 - Cottonwood Creek, and 5 - Twelvemile Creek.

Table 1. Physical characteristics of study culverts.

Study culvert	Slope (%)	Maximum width (m)	Length (m)	Type
Cedar Creek - south	4.4	1.9	45.0	Round Corrugated Metal
Cedar Creek - nouth	4.4	1.9	45.0	Round Corrugated Metal
Sourdough Creek - east	1.2	3.0	94.0	Round Corrugated Metal
Sourdough Creek - west	1.2	3.0	94.0	Round Corrugated Metal
Depuy's Spring Creek	0.2	1.6	50.5	Round Corrugated Metal
Cottonwood Creek	2.0	6.1	38.0	Corrugated Metal Pipe Arch
Twelvemile Creek	1.8	5.3	69.5	Round Corrugated metal

Sourdough Creek (Bozeman Creek), tributary to the East Gallatin River, was located in Gallatin County near Bozeman. Under U.S. Interstate 90, it flowed through two round corrugated metal culverts lying side by side. These culverts did not contain improvement structures. A greater volume of water flowed through the west culvert. More bedload has accumulated in the east culvert.

Discharges in Sourdough Creek were calculated to be 0.48 - 2.95 m^3/s during the study period. Near the culvert, the stream contained brown trout, rainbow trout and brook trout.

Depuy's Spring Creek - North Channel (Armstrong Spring Creek), tributary to the Yellowstone River, was located in Park County approximately 6 air km south of Livingston where it flowed under U.S. Highway 89. This culvert contained no improvement structures. The outlet of the culvert was elevated 0 - 17 cm above the Yellowstone River during this study.

Calculated discharges in Depuy's Spring Creek were approximately 0.18 - 0.78 m^3/s. The stream section immediately above the culvert contained resident brown trout and rainbow trout. Spawning rainbow trout migrated into the creek from the Yellowstone River.

Cottonwood Creek, tributary to the Shields River, was located in Park County near Clyde Park where it flowed under U.S. Highway 89. The bottom of the culvert was placed below the stream bed approximately 0.9 m to allow bedload recruitment. In addition, large boulders were placed at intervals of about 0.8 - 8.0 m in the culvert to create rest sites for fish.

Estimated mean discharges in Cottonwood Creek were 6.37 and 0.43 m^3/s for the 5-day peak spring flow and low fall flow periods, respectively (Montana Department of Highways 1977). This section of stream had resident brown trout, rainbow trout and cutthroat trout (Berg 1975). It also had a migration of spawning brown trout.

Twelvemile Creek, tributary to the St. Regis River, was located in Mineral County approximately 5.3 air km southeast of DeBorgia where it passed under U.S. Interstate 90. Ten plate metal baffles were originally installed in the culvert to promote fish passage. The mean (range) distance between the baffles was 6.3 m (5.9 - 7.8 m). The maximum baffle height was 0.65 m. The baffles were notched on alternating sides with a notch depth of approximately 0.15 m.

At the time of this study, five baffles were still operational. A large boulder had knocked down several baffles but was itself acting as an additional velocity reducing structure. Fish had to jump a maximum height of about 25 cm to pass through the culvert.

Average stream discharges for Twelvemile Creek in October and May were estimated to be 1.3 and 13.4 m^3/s

(Menasco 1972). The stream had resident brook trout, brown trout, rainbow trout, cutthroat trout and bull trout (*S. confluentus*).

METHODS

Determination of Trout Movements

Trapping and electrofishing were used to determine trout passage through culverts. Traps and leads were placed immediately above culverts to capture fish that had passed through the culverts. Traps were sometimes placed below culverts to determine when and how many fish approached the culverts. Traps were constructed of wood and 2.5 cm mesh poultry wire. Nylon netting or poultry wire with 2.5 cm mesh was used for the trap leads. A Smith-Root Type V or VII backpack unit was used in electrofishing. The species, length, weight and sex (if obvious) of each trout captured were recorded. Fish were marked with a Floy T tag or fin clip.

Cedar Creek

Two upstream traps (one above each culvert) and one downstream trap, were installed in Cedar Creek on June 6 and June 8, 1984, respectively. On June 22 high water made them ineffective. They were reinstalled on July 5 and remained in operation until July 23, 1984.

In 1985, a trap was in place upstream from each culvert from June 12 - 27 and a downstream trap was operated from June 19 - 24. The pool between the culverts and the downstream trap was partitioned into two longitudinal sections with a net. Equal numbers of trout caught in the downstream trap were placed in each of the divisions of the pool which permitted them access to only one culvert.

A section of Cedar Creek above the culverts was electrofished on July 5, 1984, to determine if fish had passed through the culverts during the June 22 - July 4 high water period when traps were not operating effectively. On October 17 and 26, 1984, a stream section above the culvert was electrofished. The fish captured were marked and displaced below the culverts. This section was electrofished on October 26 and November 18, 1984, to determine if previously displaced fish had moved through the culvert(s) and returned upstream.

Sourdough Creek

A trap was placed above each of the two Sourdough Creek culverts from April 24 - May 22 and October 4 - November 4, 1985. On March 8, March 27 and April 3, 1985, trout were electrofished from the stream above the culverts, marked and released below the culverts. On October 25 and November 2, 1985, trout were electrofished in the stream below and above the culverts, respectively, marked and released below the culverts.

Depuy's Spring Creek

A trap was in place above the culvert on DePuy's Spring Creek - North Channel from March 15 - April 19 and November 2 - 18, 1985. Trout were electrofished in the stream above the culvert, marked and displaced into the Yellowstone River below the culvert on February 27, March 6, 15, 18, 19, October 18 and November 2, 1985. This section was electrofished on November 2 and December 5, 1985, to determine if the trout displaced in the fall had moved through the culvert and returned upstream.

Cottonwood Creek

Traps were in place above and below the Cottonwood Creek culvert from June 12 - 19 and from July 9 - 18, 1984, (pre- and post-peak dicharge) and above the culvert from October 25 - November 1, 1984. On July 18, a section of stream was electrofished to determine if trout had moved through the culvert during the June 20 - July 8 high flow period when traps were inoperable. Trout were electrofished from above the culvert, marked, and displaced below the culvert on October 17, 24, 26, and November 2, 8, and 15, 1984. On the five later dates and November 21, 1984, electrofishing was used to determine if previously displaced trout had moved upstream through the culvert.

Twelvemile Creek

Traps were in operation above and below the Twelvemile Creek culvert for 10 days between October 5 - October 31, 1984. Trout were electrofished from above the culvert, marked and released below the culvert on October 9 and 18, 1984. The stream above the culvert was electrofished on October 18 and November 17 to determine if previously marked trout had passed through the culvert and returned upstream.

Measurement of Physical Parameters

Water velocities were measured at the inlets and outlets, at obvious rest sites and in the deepest water in passage areas throughout the lengths of the culverts. The velocities in the passage areas were usually measured at 5.0 - 10.0 m intervals. Calculated mean velocities for distances between rest sites did not include measurements of the slower water associated with the rest sites. Calculations usually included measurements 0.3 m in front of and 1.2 m to the rear of the structure creating the rest site, but was variable with structure type. These measurements included water that was rapidly decelerating or accelerating.

Velocities were measured with a Gurley No. 622 current meter, or where conditions dictated, a Gurley No. 625 or Montedoro - Whitney Model PVM - 2 instantaneous current meter. Velocity measurements were taken approximately 5 cm above the culvert bottom (bottom velocity) and, at some sites, at 0.6 of the water depth from the surface (0.6 depth velocity). Bottom velocities were used in this study since trout were observed swimming along the bottom or the sides of the culverts. They also reflected bottom materials present more than those taken at 0.6 depth. The relationship of bottom velocities to those at 0.6 depth in culverts without bedload was described by:

(1) $$A = 0.0615 + 1.317B$$

where A is the water velocity at 0.6 depth (meters per second (m/s)) and
B is the water velocity near the bottom (m/s).

The correlation coefficient of this equation was 0.74. This increased to 0.84 with water depth added as a second parameter:

(2) $$A = -0.1055 + 1.281B + .0053C$$

where C is the water depth (cm) and
A and B are defined as above.

Formula 1 was used to convert bottom velocity to 0.6 depth velocity for comparison to other studies.

Discharges were determined by multiplying the water cross-sectional area and the 0.6 depth velocity measured in unobstucted sections of circular culverts at the maximum depth. Cross-sectional area was determined by (D. E. Burkhalter, personal communication):

(3) $A = r^2/2\ (\theta/28.65 - \sin 2\theta)$

where A is the cross-sectional area (square meters (m^2))
r is the hydraulic radius (m)
d is the water depth (m) and
θ is the angle of hydraulic radius from the water depth line (arc cos (1 - d/r)).

Discharge was calculated from:

(4) $Q = VA$

where Q is the water discharge (m^3/s)
V is the water velocity at 0.6 depth (m/s) and
A is the cross sectional area.

Staff gauges were placed near each study culvert to determine the relative stream stage when fish were captured. Water temperatures during the study were recorded using either a Taylor 8-day or Peabody-Ryan Model "J" 90 day continous recording thermograph. The slopes of the culverts were measured with a Wild Nak I automatic level and stadia rod. Light intensities were measured with a Tektronix J - 16 digital photometer.

Experimental Field Work

From June 20 - 24, 1985, two rocks, about 32 - 34 cm in diameter, were placed at sites about 15 and 30 m from the upstream end of the south (unimproved) culvert in Cedar Creek. During this period the downstream pool was partitioned into two sections so that the trout in each division only had access to one culvert.

On March 21, 1986, a trap was installed above the Sourdough Creek west culvert and trout access to the east culvert was blocked with 2.5 cm mesh poultry wire. Rocks (40 - 51 cm in diameter) were placed at different intervals in the west culvert to provide rest sites (Table 2). This work was terminated on April 27, 1986.

Table 2. Locations of rocks in the the west culvert of Sourdough Creek from March 21 - April 21, 1986. All rocks were removed on April 21.

	Distance of rock from upstream end of culvert (m):			
Rock number	1	2	3	4
Date of placement				
March 21	15.0	22.0	41.5	68.7
March 27	15.0	22.0	41.5	64.0
March 29	15.0	22.0	41.5	55.5
March 31	15.0	22.0	41.5	
April 6	15.0	22.0	35.0	
April 8	15.0	22.0	41.5	55.5
April 11	15.0	22.0		
April 18	15.0			

Experimental Laboratory Study

The swimming staminas of rainbow trout, brown trout and cutthroat trout were compared in a swimming speed testing apparatus (Figure 2). The test apparatus was constructed of a washtub inverted in a circular stock tank. The space between the tubs was formed into a U - shaped trough with fiberglass. Each of the two

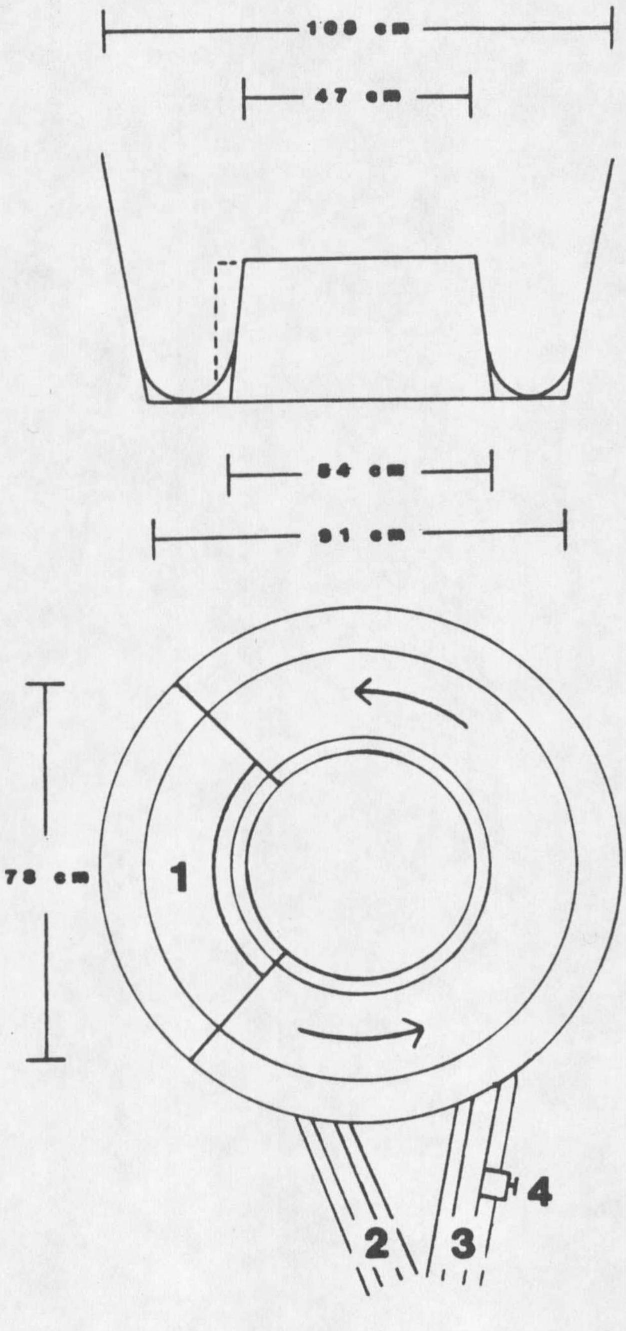

Figure 2. Diagram of the swimming stamina test apparatus showing 1 - testing section, 2 - intake pipes, 3 - outlet pipes, and 4 - control valve. Arrows indicate the direction of water flow.

centrifugal water pumps used to cycle water had a capacity of approximately 0.21 cubic meters per minute (m^3/min). Water velocities were controlled with a valve placed between one pump and the tank. Velocities were measured with a Gurley No. 622 Current Meter at each valve setting.

The testing section confined the test fish to the fast area of the trough and prevented movement around the channel (Figure 2). A screen with a 1.3 cm grid was used for the head of the testing section and aided in producing microturbulence in the testing section (Bell and Terhune 1970). Poultry wire with a 2.5 cm mesh was used for the lower and inside boundaries. Two circular copper electrodes were placed just behind the downstream boundary to produce an electrical field to stimulate fish to swim as long as possible. About 10 - 25 volts AC from an variable transformer was used as a stimulus.

Wild trout of 280 millimeters (mm) length or greater were tested during November and December 1985. Cutthroat trout were from the Yellowstone River and brown trout and rainbow trout were from DePuy's Spring, Sourdough and Bridger creeks. Fish were held in a raceway at the Bozeman Fish Cultural Development Center at least 1 day before being tested. Water temperatures in the raceway were 3.0 - 8.0 degrees centigrade (C) at test time.

In the swimming test, trout were forced to swim continously for a specified time at successively higher water velocities until they fatigued (Table 3). They were determined to be fatigued when they collapsed against the downstream end of the testing section and could not be stimulated to swim again by a electrical or mechanical prodding. Temperature and dissolved oxygen were measured at the beginning and end of each test with a YSI Oxygen Meter. Multiple regression analysis was used to test for species differences in swimming ability.

Table 3. The structure of the swimming stamina test. Each fish began the test under conditions of interval one and was subjected to the states of successive intervals until fatigued.

Test interval	Mean water velocity (standard deviation) (m/s)	Duration (min)
1	0.22 (0.04)	5
2	0.40 (0.03)	2
3	0.47 (0.04)	2
4	0.52 (0.02)	2
5	0.57 (0.04)	2
6	0.71 (0.06)	

RESULTS

Cedar Creek

Thirty cutthroat trout passed through the improved culvert from July 5 - 23, 1984 (summer) (Table 4). No trout moved through the unimproved culvert during this period. The lengths of trout that did and did not move through the improved culvert were similar indicating that size was not the determining factor in passage.

Table 4. Characteristics of cutthroat trout that did and did not pass through the improved culvert of Cedar Creek from July 5 - 23, 1984.

		Length (mm)		Weight (g)	
Sex	N	Mean	Range	Mean	Range
		Did pass			
Male	15	357.5	266 - 416	478.3	199 - 709
Female	14	341.9	309 - 426	443.6	340 - 907
Unknown	1	224.0		113.0	
Total	30	345.8	224 - 426	449.9	113 - 907
		Did not pass			
Male	9	342.2	277 - 399	434.3	227 - 680
Female	10	354.7	332 - 389	533.0	425 - 680
Unknown	2	233.5	223 - 249	127.5	113 - 142
Total	21	337.8	223 - 399	452.2	113 - 680

A total of ten trout were captured above the culvert and displaced below on October 17 and 26, 1984 (fall).

Two brown trout (196 - 199 mm) and one brook trout (234 mm) had returned upstream by November 18 which indicated that some movement through the culvert(s) was possible under low flows. Three brown trout (115 - 205 mm), two brook trout (160 - 251 mm) and two cutthroat (160 - 168 mm) did not return.

From June 12 - 27, 1985 (summer), nine cutthroat trout passed through the improved culvert on Cedar Creek and 15 did not (Table 5). Seven of the nine were allowed access to both culverts while two only had access to the improved culvert. The lengths of trout that did and did not pass through the improved culvert were similar.

Table 5. Characteristics of cutthroat trout that did and did not pass through the improved culvert of Cedar Creek from June 12 - 27, 1985.

		Length (mm)		Weight (g)	
Sex	N	Mean	Range	Mean	Range
		Did pass			
Male	7	336.6	312 - 369	411.1	312 - 539
Female	1	398.0		610.0	
Unknown	1	359.0		468.0	
Total	9	345.9	312 - 398	439.6	312 - 610
		Did not pass			
Male	11	325.1	273 - 368	355.7	213 - 510
Female	3	371.7	311 - 434	598.7	312 - 794
Unknown	1	321.0		312.0	
Total	15	334.1	273 - 434	389.4	213 - 794

Prior to June 20, 1985, no cutthroat had passed through the unimproved culvert. After two rest sites were created on June 20, eight cutthroat trout passed through the unimproved culvert (Table 6). The length of the two female trout that passed through the culvert were less than those of the four which did not pass. The largest males also did not pass through the culvert, possibly indicating that culvert conditions may have favored the passage of smaller trout.

Table 6. Characteristics of cutthroat trout which did and did not pass through the unimproved culvert of Cedar Creekfrom June 12 - 27, 1985.

		Length (mm)		Weight (g)	
Sex	N	Mean	Range	Mean	Range
		Did pass			
Male	6	321.3	294 - 356	328.3	255 - 425
Female	2	315.5	308 - 323	287.5	269 - 326
Total	8	319.9	294 - 356	320.6	255 - 425
		Did not pass			
Male	8	352.4	261 - 442	462.5	156 - 879
Female	4	353.8	328 - 383	422.0	369 - 553
Unknown	1	341.0		454.0	
Total	13	351.9	261 - 442	449.4	156 - 879

In the summer 1984 water velocities in the improved culvert (Figure 3) were 0.5 - 1.6 m/s over the structure rungs and their captured bedload and 0.1 - 0.7 m/s in rest

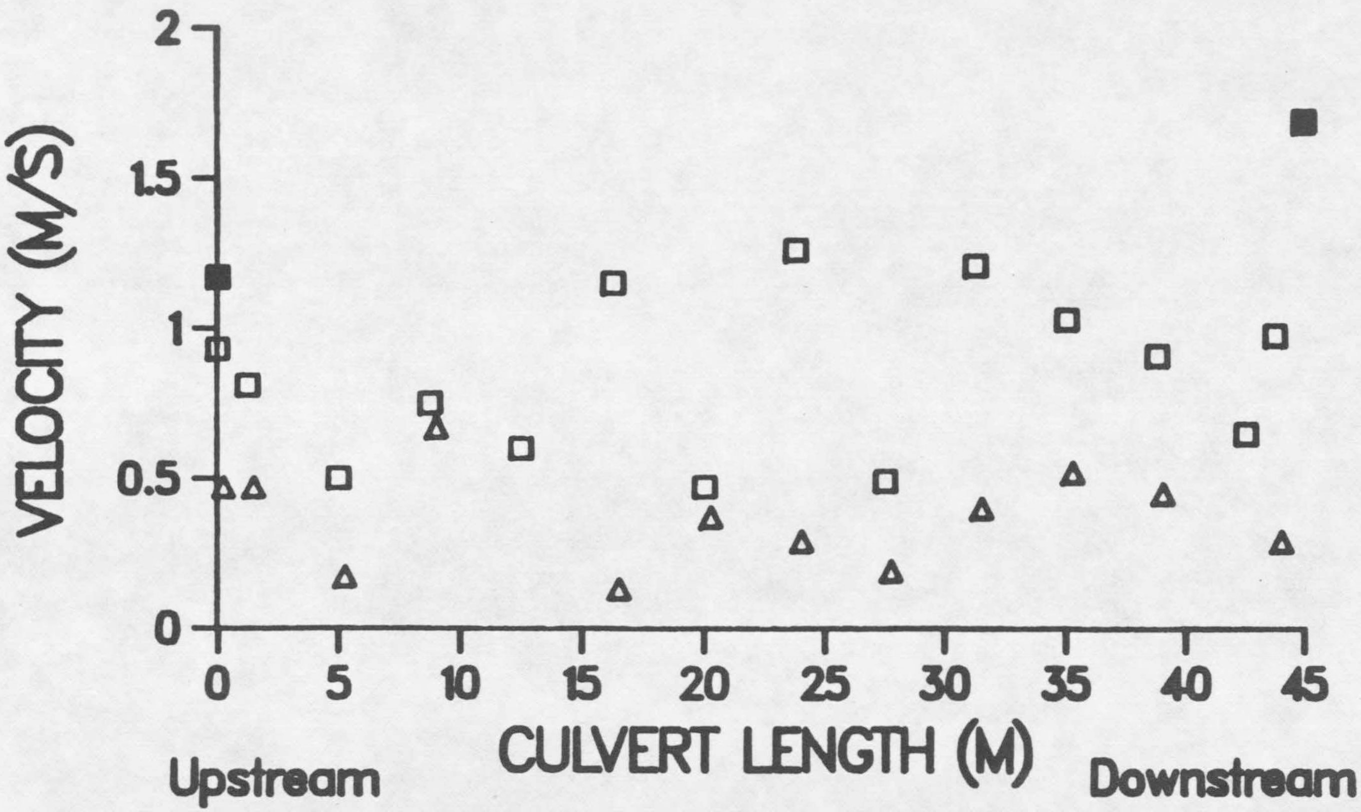

Figure 3. Water velocities at every third passage site over the rungs (open squares) and rest site (open triangles) in the improved culvert of Cedar Creek on July 13, 1984. Closed squares indicate highest summer velocities recorded (July 8, 1984).

sites behind the bedload. Trout passed through the culvert under these velocities.

In the fall 1984, velocities over the rungs and at rest sites were 0.3 - 1.7 and 0.0 - 0.6 m/s, respectively (Figure 4). These velocities were similar to those in the summer 1984, possibly due to an accumulation of debris on the rungs. In the summer 1985, velocities were similar to those in 1984.

The velocity pattern in the unimproved culvert on Cedar Creek was more uniform than in the improved culvert (Figure 5). Maximum velocities occured in the summer 1984, when velocities reached at least 1.6 m/s at locations 4.6 m inside the ends of the culvert. Fall 1984 velocities were similar or less than those in the summer 1984. Velocities in the summer 1985 peaked at 1.5 m/s (Figure 5) which were less than those of the previous summer. These maximum velocities were similar to those in the improved culvert, yet, they prohibited trout passage. The similarity of fall 1984 velocities to those in the two summers indicated that passage through the unimproved culvert at this time of year was unlikely.

After the placement of two rocks 15 m apart in the unimproved culvert on June 20, 1985, the maximum velocity was reduced to 1.2 m/s and rest site velocities of 0.2 - 0.3 m/s were produced (Figure 5). Cutthroat trout passed through the culvert under this profile when the water

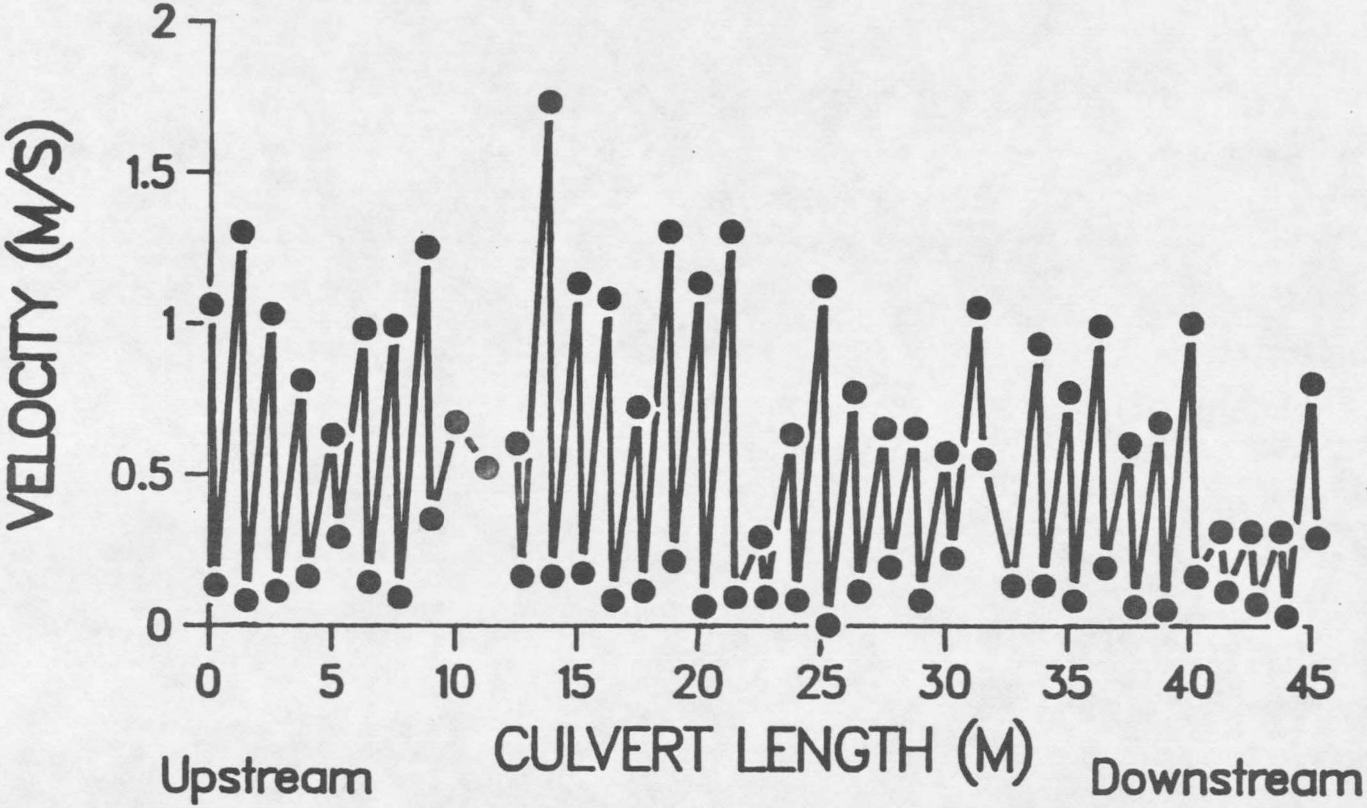

Figure 4. Water velocity profile in the improved culvert of Cedar Creek on October 11, 1984.

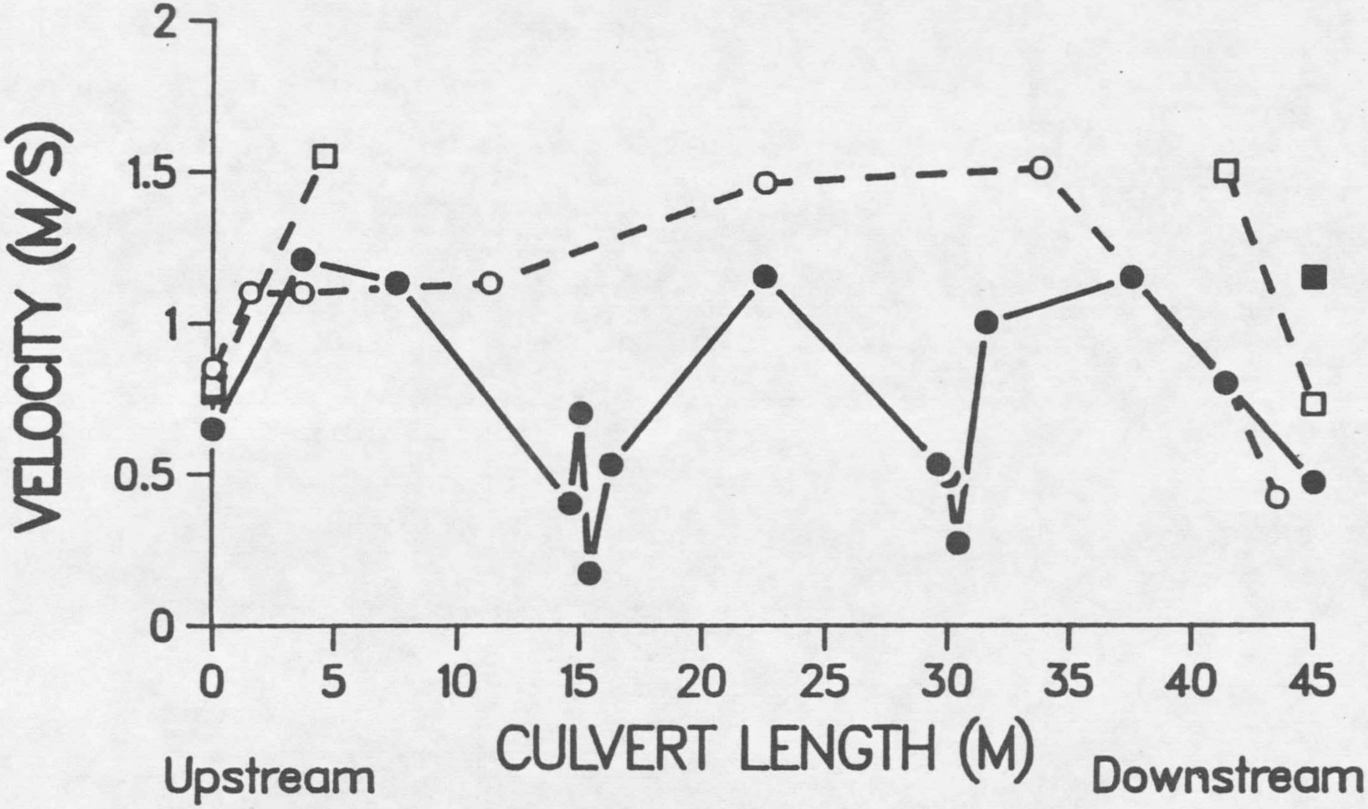

Figure 5. Water velocity profile in the unimproved culvert of Cedar Creek on July 12, 1984 (open squares), June 20, 1985 (open circles), and on June 21, 1985 (closed circles) after the placement of two rocks. Closed squares indicate highest summer velocites recorded (July 5, 1984).

depth was 8 cm or greater. When irrigation withdrawal reduced water depth to 4 cm, trout did not swim through the culvert.

In 1984, peak summer stage was 45.0 cm on the staff gauge on June 22 and 28 (Figure 6). Cutthroat trout moved upstream to the culverts during these peak flows as indicated by the capture of three trout (297 - 307 mm) in the downstream trap from June 22 - July 2 and the capture of 19 migratory cutthroat trout (259 - 393 mm) by electrofishing above the culvert on July 5. However, most of the cutthroat trout captured (51) moved to below the culvert(s) after peak flows.

From June 13 - July 23, 1984, daily maximum and minimum temperatures were 8.3 - 14.4 and 5.0 - 10.6 C, respectively (Figure 6). Cutthroat trout movements up Cedar Creek and through the culverts occurred when daily maximum temperatures were consistently above 10.0 C which occurred after peak stage.

During October and November 1984, the stage levels gradually increased from 25.0 - 29.0 cm but were more uniform and lower than in the previous summer. Stage levels were 28.5 - 29.0 cm when the displaced trout moved upstream through the culvert.

In 1985, the peak summer stage of 32.5 cm occurred on June 12 (Figure 7). This peak was 10 days earlier and the stage was 9.5 cm lower than the previous summer.

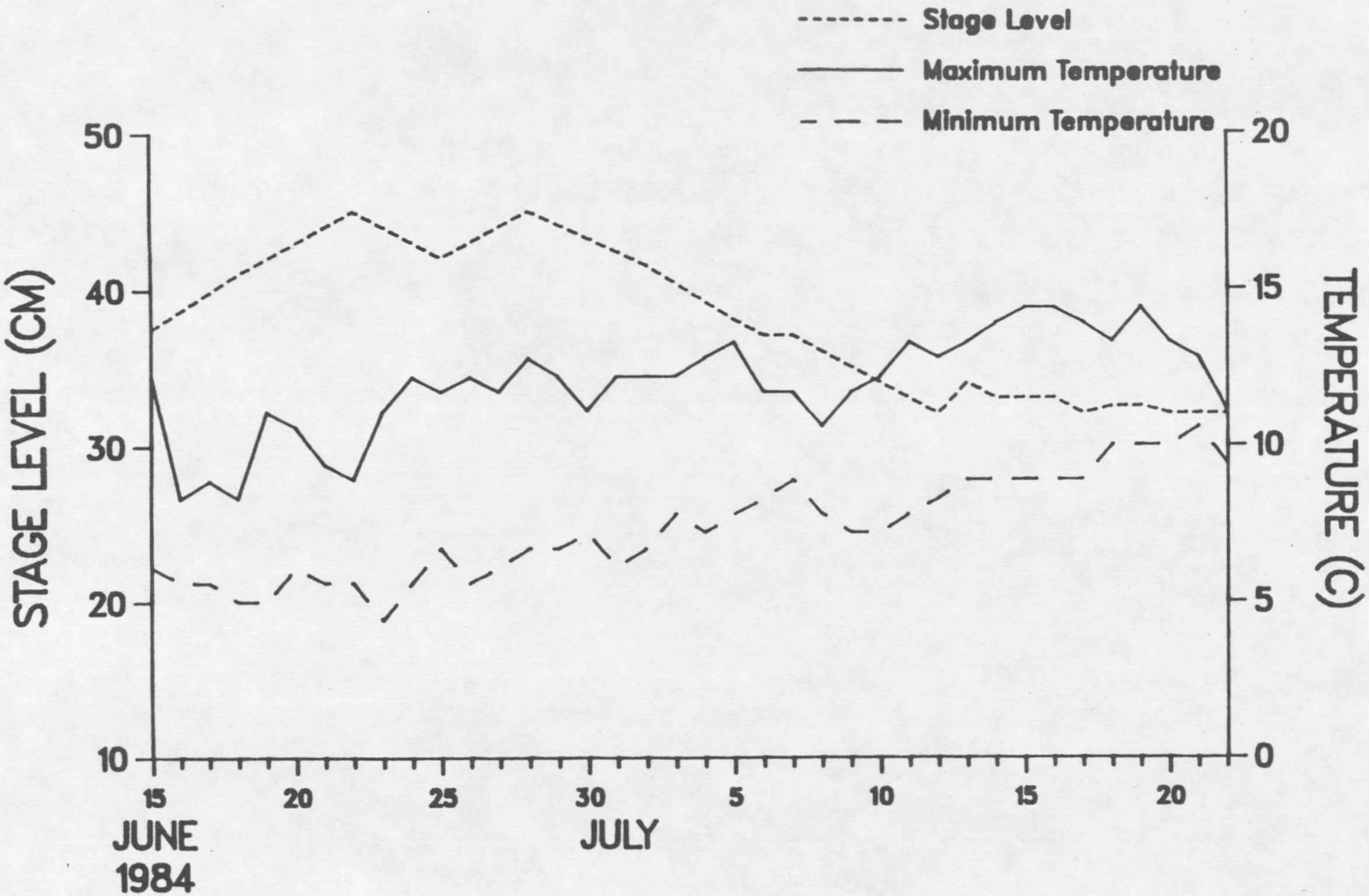

Figure 6. Stage level and daily maximum and minimum temperatures of Cedar Creek during June and July, 1984.

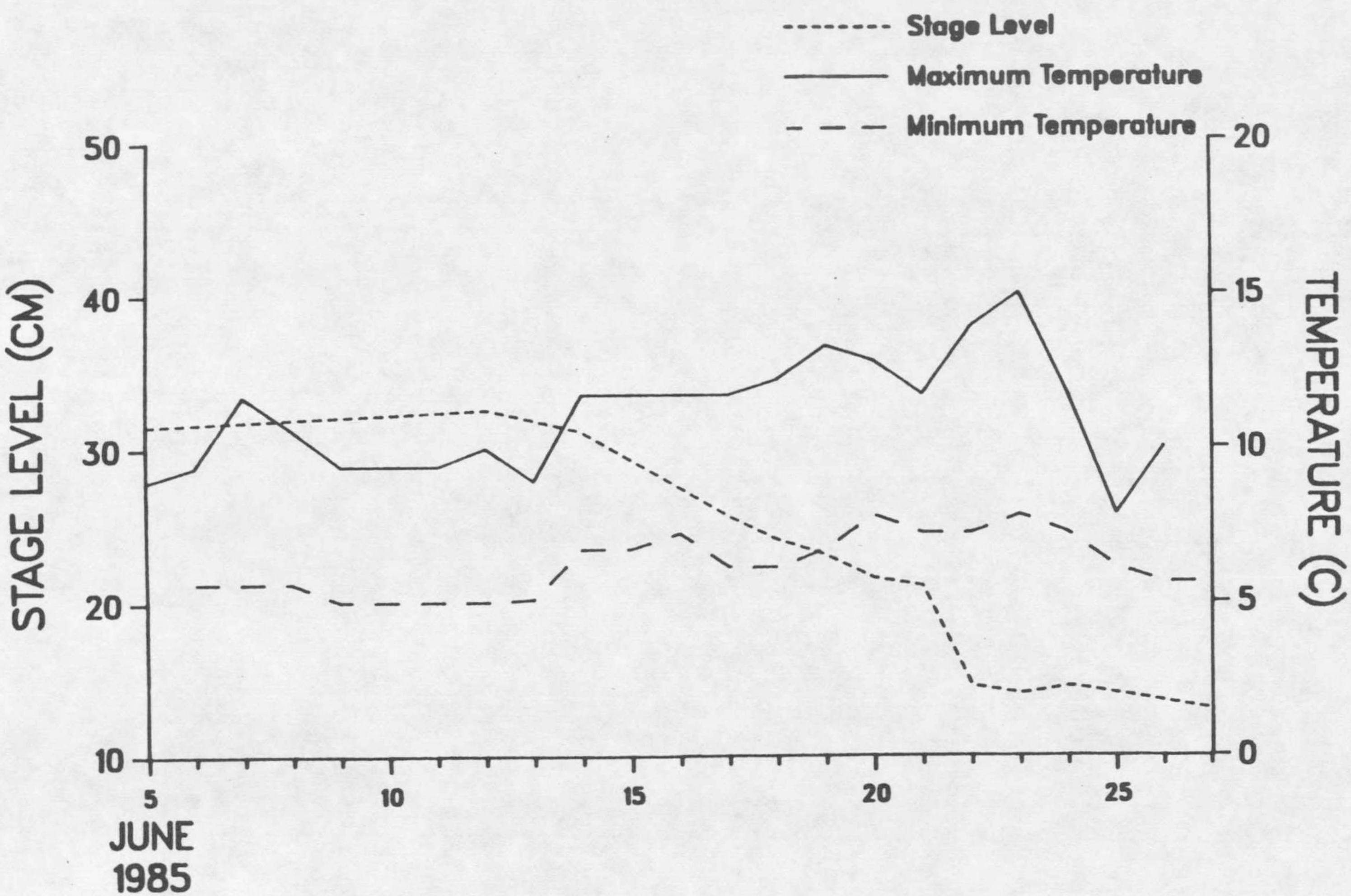

Figure 7. Stage level and daily maximum and minimum temperatures of Cedar Creek during June, 1985.

Cutthroat trout movement to and through the culvert(s) occurred on receding flows in this year until an irrigation withdrawal on June 21 reduced stages from 21.0 to 14.5 cm.

From June 5 - June 27, 1985, daily maximum and minimum temperatures were 8.9 - 15.0 and 5.0 - 7.8 C, respectively (Figure 7). Cutthroat trout movements up Cedar Creek and through the culverts occurred again when daily maximum temperatures were consistently above 10.0 C. This occurred after peak stage.

On July 18, 1984, an overcast day, light intensity decreased from an average of 14,854.7 and 8,665.2 lux (lx) outside to 0.4 and 0.5 lx in the middle of the improved and unimproved culverts, respectively. On July 30, 1984, a sunny day, light intensities decreased from an average of 17,276.6 and 15,608.2 lx outside to 1.6 and 0.9 lx in the middle of the improved and unimproved culverts, respectively. Since light intensities inside the culverts were similar, they did not appear to be responsible for observed differences in trout passage.

Sourdough Creek

From April 28 - 22, 1985 (spring), a total of 19 trout passed through the east culvert (Table 7). No trout were captured after passing through the west culvert. From October 14 - November 20, 1985 (fall), two brook trout (213 - 215 mm) and two brown trout (222 - 430 mm) passed through the east culvert. No trout were captured after passing through the west culvert.

Table 7. Characteristics of trout that passed through the east culvert of Sourdough Creek from April 28 - May 22, 1985.

		Length (mm)		Weight (g)	
Species	N	Mean	Range	Mean	Range
Rainbow trout	17	277.9	192 - 393	212.8	71 - 482
Brown trout	1	244.0		128.0	
Brook trout	1	229.0		99.0	
Total	19	273.6	192 - 393	201.7	71 - 482

From March 21 - April 27, 1986 (spring), 46 rainbow trout, 20 brook trout and four brown trout passed through the west culvert (Table 8). During this period, trout access to the east culvert was blocked. Thirty rainbow trout (185 - 368 mm), eight brook trout (225 - 308 mm) and two brown trout (257 - 350 mm) moved through the west culvert when four rest sites were provided (March 22 - 31 and April 9 - 11). Six brook trout (235 - 306 mm), three rainbow trout (189 - 278 mm) and one brown trout (334 mm) swam through this culvert when three rest sites were present (April 1 - 9). Five rainbow trout (224 - 303 mm) and two brook trout (262 - 282 mm) moved through the culvert with two rest sites (April 12 - 18). When one rest site was present (April 19 - 21), three rainbow trout (191 - 263 mm) and one brook trout (255 mm) swam through the culvert. After all rest sites were removed on April 21, five rainbow trout (199 - 355 mm), three brook trout (251 - 308 mm) and one brown trout (224 mm) were captured above the culvert.

Table 8. Characteristics of trout that passed through the west culvert of Sourdough Creek from March 22 - April 23, 1986.

		Length (mm)		Weight (g)	
Species	N	Mean	Range	Mean	Range
Rainbow trout	46	270.7	185 - 368	197.9	57 - 482
Brook trout	20	262.0	225 - 308	164.7	113 - 284
Brown trout	4	291.3	224 - 350	230.5	113 - 369
Total	70	269.4	185 - 368	191.7	57 - 482

The velocity profile of the east culvert during the spring 1985 study period showed the presence of major rest sites at approximately 40 and 90 m from the upstream end (Figure 8) in addition to minor rest sites created by accumulated bedload. These major rest sites had water velocities of 0.1 and 0.5 m/s, while water velocities between rest sites were 0.3 - 0.9 m/s. Highest velocities on these dates occurred at the culvert inlet under less

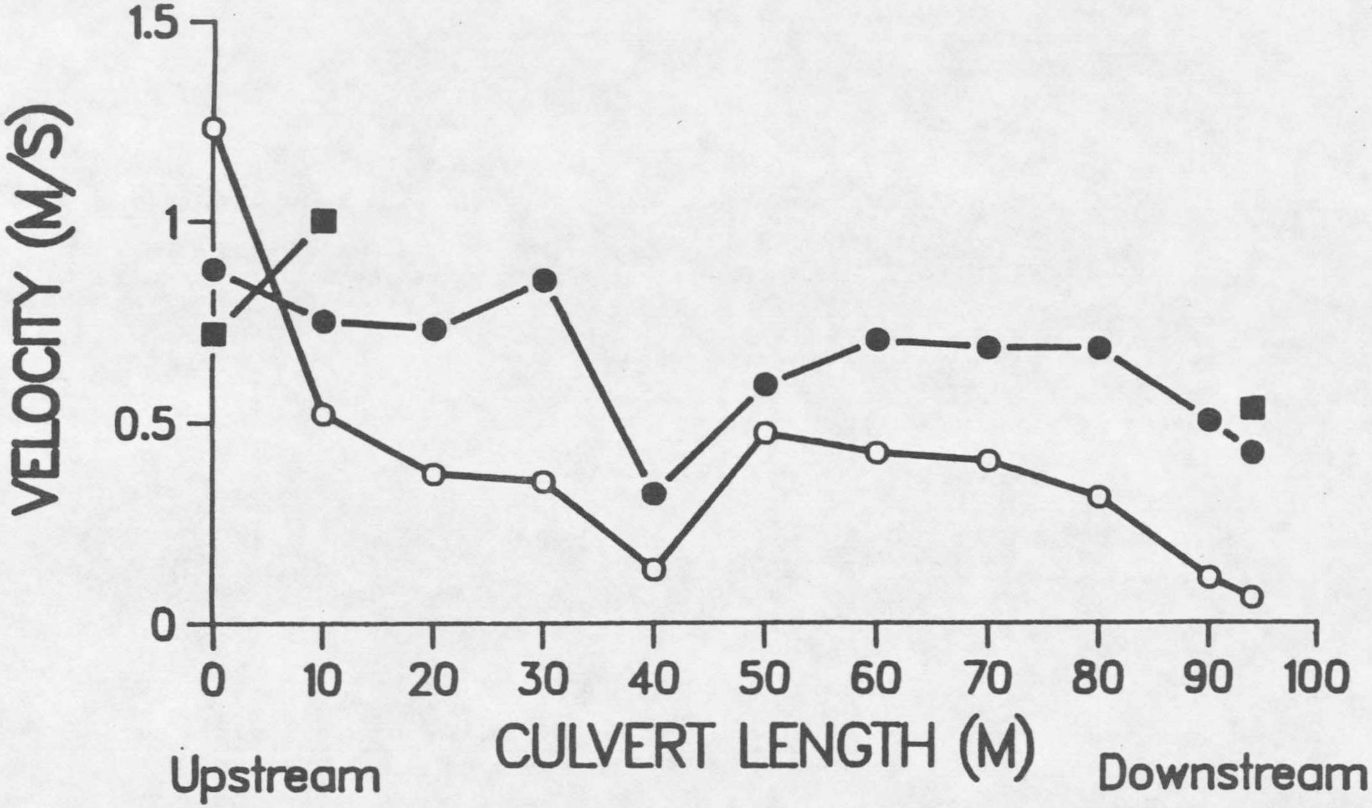

Figure 8. Water velocity profile in the east culvert of Sourdough Creek on May 1, 1985 (closed circles), and May 22, 1985 (open circles). Closed squares indicate velocities recorded during highest spring discharge (May 4, 1985).

than peak flows. Peak flows created velocities of at least 1.0 m/s between rest sites (Figure 8). Velocities during the fall 1985 study period were similar to those found in the spring 1985. Trout passed through the culvert under all recorded velocity ranges found.

The velocity profile in the west culvert during the spring 1985 was more uniform than in the east culvert with highest velocities (0.8 - 0.9 m/s) occurring in the lower 44 m (Figure 9) because some bedload had accumulated in the upper end of the culvert. The velocity profile under various spring flows and during the fall 1985 were all similar. No trout passed through this culvert with these velocity profiles during the spring or fall 1985 study periods.

During the spring 1986, water velocities up to 0.6 m/s in rest sites behind the introduced rocks and up to 1.0 m/s in passage areas between the rocks occurred in the west culvert (Figure 10). The velocities between the rest sites remained relatively constant as the distances between rest sites varied from 7.0 - 94.0 m (no rocks). These velocities were similar to those found in the previous spring and fall. In 1986 trout passed through the west culvert under all of the recorded velocity profiles.

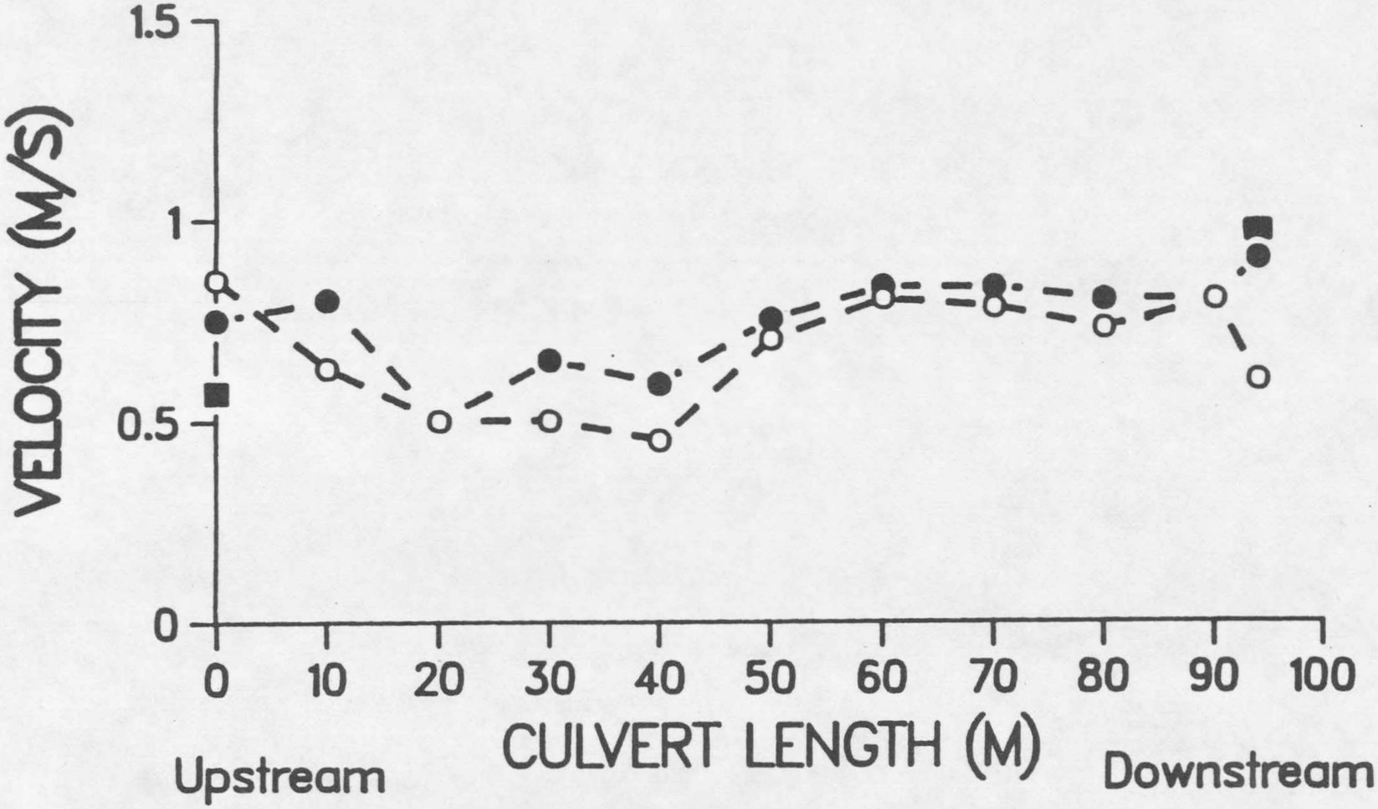

Figure 9. Water velocity profile in the west culvert of Sourdough Creek on June 5, 1985 (closed circles), and May 22, 1985 (open circles). Closed squares indicate velocities recorded during highest spring discharge (May 4, 1985).

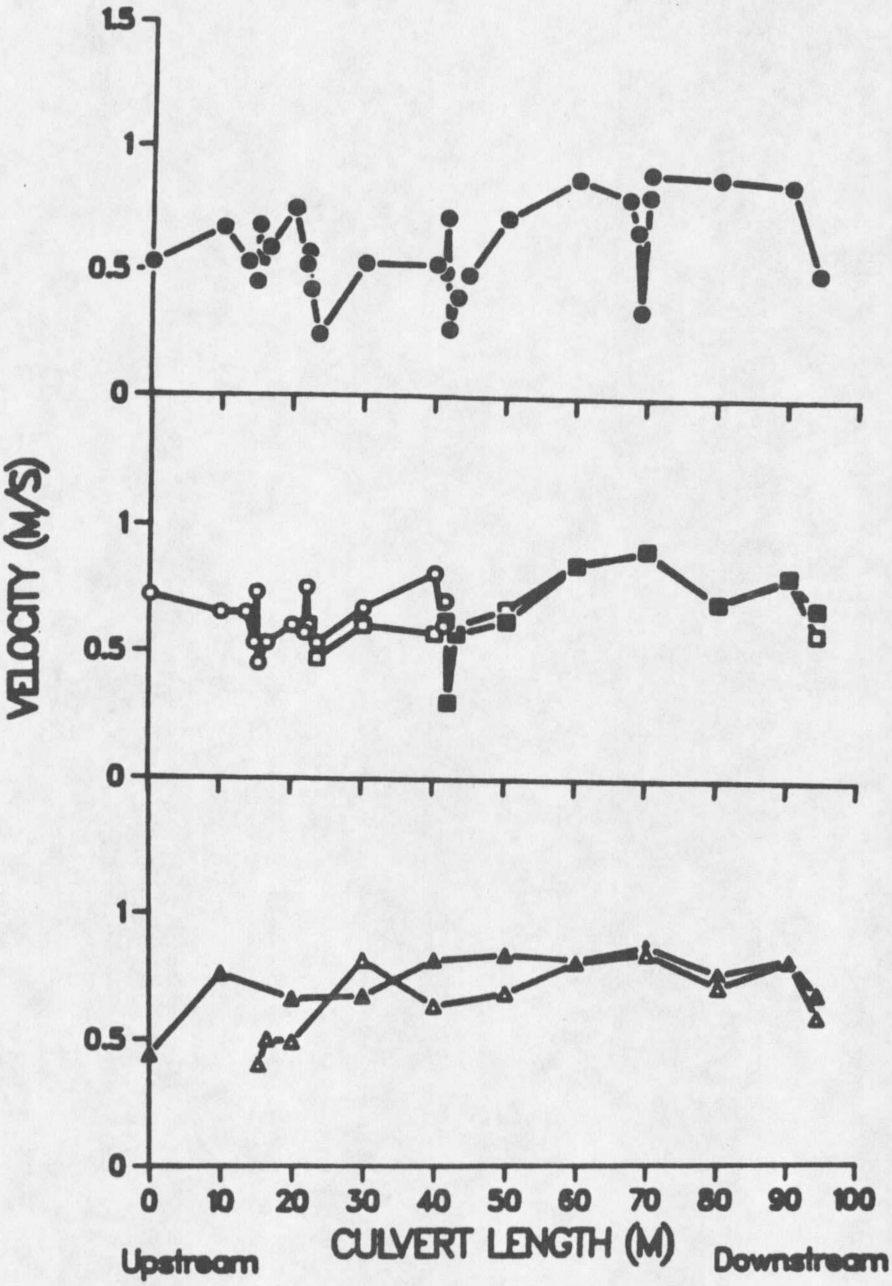

Figure 10. Water velocity profile in the west culvert of Sourdough Creek with the placements of four rocks on March 23 (closed circles), three rocks on March 21 (open circles) and April 6 (closed squares), two rocks on April 16 (open squares), one rock on April 21 (open triangles), and no rocks on April 23 (closed triangles).

In 1985, the peak spring stage observed occurred on May 4 at 48.0 cm (Figure 11). Trout were able to pass through the east culvert under peak flow conditions.

From April 26 - May 24, 1985, daily maximum and minimum temperatures ranged from 8.3 - 16.7 and 2.8 - 8.9 C, respectively (Figure 11). No relationship between temperature and trout passage was apparent.

During the period October 5 - November 7, stream stages peaked on October 12 at 19.0 cm (Figure 12) which was 29.0 cm below the previous spring peak. Trout passed through the east culvert from October 14 - November 3 at stages of 15.8 - 12.0 cm. However, based on data collected the previous spring, trout probably could have passed under peak flows as well.

During the fall 1985 study period, daily maximum and minimum temperatures were 3.9 - 8.3 and 1.7 - 6.7 C, respectively (Figure 12). No relationship of temperature to trout movement through the east culvert was apparent.

In 1986, the peak spring stages observed occurred on April 25 at 39.0 cm (Figure 13), or 9.0 cm less than that of the previous spring. Trout passed through the west culvert when stages were as high as 36.0 cm.

From March 21 - April 27, 1986, daily maximum and minimum temperatures were 3.3 - 11.7 and 0.0 - 6.1 C, respectively (Figure 13). Fifty-four percent of the rainbow trout passed through the west culvert when daily