



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  
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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.

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HIGHWAY CULVERTS

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A thesis submitted in partial fulfillment  
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of

Master of Science

in

Fish and Wildlife Management

MONTANA STATE UNIVERSITY  
Bozeman, Montana

July 1986

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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.

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## TABLE OF CONTENTS

|                                              | Page |
|----------------------------------------------|------|
| APPROVAL. . . . .                            | 11   |
| STATEMENT OF PERMISSION TO USE . . . . .     | 111  |
| VITA . . . . .                               | iv   |
| ACKNOWLEDGEMENT . . . . .                    | v    |
| TABLE OF CONTENTS. . . . .                   | vi   |
| LIST OF TABLES. . . . .                      | viii |
| LIST OF FIGURES . . . . .                    | x    |
| ABSTRACT. . . . .                            | xiii |
| INTRODUCTION . . . . .                       | 1    |
| DESCRIPTION OF STUDY AREAS. . . . .          | 4    |
| METHODS . . . . .                            | 10   |
| Determination of Trout Movements . . . . .   | 10   |
| Cedar Creek . . . . .                        | 10   |
| Sourdough Creek . . . . .                    | 11   |
| Depuy's Spring Creek . . . . .               | 12   |
| Cottonwood Creek. . . . .                    | 12   |
| Twelvemile Creek. . . . .                    | 13   |
| Measurement of Physical Parameters . . . . . | 13   |
| Experimental Field Work . . . . .            | 15   |
| Experimental Laboratory Study . . . . .      | 16   |

## Table of Contents (continued)

|                                               | Page |
|-----------------------------------------------|------|
| RESULTS . . . . .                             | 20   |
| Cedar Creek . . . . .                         | 20   |
| Sourdough Creek. . . . .                      | 30   |
| Depuy's Spring Creek - North Channel. . . . . | 41   |
| Cottonwood Creek . . . . .                    | 45   |
| Twelvemile Creek . . . . .                    | 50   |
| Laboratory Study . . . . .                    | 53   |
| DISCUSSION . . . . .                          | 56   |
| Distance - Velocity Relationship . . . . .    | 56   |
| Other Factors Affecting Passage . . . . .     | 61   |
| Evaluation of Culvert Modifications . . . . . | 62   |
| REFERENCES CITED . . . . .                    | 65   |

## LIST OF TABLES

| Table |                                                                                                                                                                                        | Page |
|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1.    | Physical characteristics of the study culverts. . . . .                                                                                                                                | 6    |
| 2.    | Locations of rocks in the west culvert of Sourdough Creek from March 21 - April 21, 1986. All rocks were removed on April 21.                                                          | 16   |
| 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 . . . . . | 19   |
| 4.    | Characteristics of cutthroat trout that did and did not pass through the improved culvert of Cedar Creek from July 5 - 23, 1984 . . . . .                                              | 20   |
| 5.    | Characteristics of cutthroat trout that did and did not pass through the improved culvert of Cedar Creek from June 12 - 27, 1985 . . . . .                                             | 21   |
| 6.    | Characteristics of cutthroat trout that did and did not pass through the unimproved culvert of Cedar Creek from June 12 - 27, 1985. . . . .                                            | 22   |
| 7.    | Characteristics of trout that passed through the east culvert of Sourdough Creek from April 28 - May 22, 1985 . . . .                                                                  | 31   |
| 8.    | Characteristics of trout that passed through the west culvert of Sourdough Creek from March 22 - April 23, 1986 . .                                                                    | 32   |
| 9.    | Characteristics of rainbow trout that passed through the culvert of Depuy's Spring Creek from March 20 - April 19, 1985 . . . . .                                                      | 41   |

## LIST OF TABLES (continued)

| Table |                                                                                                                                                                              | Page |
|-------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 10.   | The lengths and weights of brown trout displaced below the culvert of Depuy's Spring Creek that did and did not return upstream from October 18 - December 5, 1985 . . . . . | 42   |
| 11.   | The lengths and weights of brown trout displaced below the culvert of Cottonwood Creek that did and did not return upstream from October 17 - November 21, 1984. . . .       | 46   |
| 12.   | Characteristics of trout displaced below the culvert of Twelvemile Creek that did and did not return upstream from October 17 - November 2, 1984 . . . . .                   | 51   |
| 13.   | Results of the comparative swimming stamina test . . . . .                                                                                                                   | 53   |
| 14.   | Maximum velocities and distances between rest sites for passage indicated in this study and those recommended previously. .                                                  | 59   |

## LIST OF FIGURES

| Figure |                                                                                                                                                                                                                                                                                      | Page |
|--------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 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. . . . .                                                                                                                | 5    |
| 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. . . . .                                                                                          | 17   |
| 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) . . . .                                 | 23   |
| 4.     | Water velocity profile in the improved culvert of Cedar Creek on October 11, 1984 . . . . .                                                                                                                                                                                          | 25   |
| 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 velocities recorded (July 5, 1984) . . | 26   |
| 6.     | Stage level and daily maximum and minimum temperatures of Cedar Creek during June and July, 1984. . . . .                                                                                                                                                                            | 28   |
| 7.     | Stage level and daily maximum and minimum temperatures of Cedar Creek during June, 1985 . . . . .                                                                                                                                                                                    | 29   |

## LIST OF FIGURES (continued)

| Figure |                                                                                                                                                                                                                                                                                                                             | Page |
|--------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 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).                                                                                                  | 33   |
| 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).                                                                                                 | 35   |
| 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) | 36   |
| 11.    | Stage level and daily maximum and minimum temperatures of Sourdough Creek during April and May, 1985                                                                                                                                                                                                                        | 38   |
| 12.    | Stage level and daily maximum and minimum temperatures of Sourdough Creek during October and November, 1985.                                                                                                                                                                                                                | 39   |
| 13.    | Stage level and daily maximum and minimum temperatures of Sourdough Creek during March and April, 1986                                                                                                                                                                                                                      | 40   |
| 14.    | Water velocity profile in the culvert of Depuy's Spring Creek on April 10, 1985 (closed circles), and December 16, 1985 (open circles). Closed squares indicate highest spring velocities recorded (March 18, 1985)                                                                                                         | 43   |

## LIST OF FIGURES (continued)

| Figure |                                                                                                                                                                                                                                    | Page |
|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 15.    | Stage level and daily maximum and minimum temperatures of Depuy's Spring Creek during March and April, 1985 . . . . .                                                                                                              | 44   |
| 16.    | Water velocity profile in the culvert of Cottonwood Creek on July 10, 1984 (closed circles), and November 15, 1984 (open circles). Closed square indicates the highest summer velocity recorded (July 9, 1984). . . . .            | 47   |
| 17.    | Stage level and daily maximum and minimum temperatures of Cottonwood Creek during June and July, 1984 . . . . .                                                                                                                    | 48   |
| 18.    | Stage level and daily maximum and minimum temperatures of Cottonwood Creek during October and November, 1984. . . . .                                                                                                              | 49   |
| 19.    | Water velocity profile in the culvert of Twelvemile Creek on November 17, 1984 . . . . .                                                                                                                                           | 52   |
| 20.    | Stage level and daily maximum and minimum temperatures of Twelvemile Creek during October and November, 1984. . . . .                                                                                                              | 54   |
| 21.    | The measurements of mean bottom velocity (V) and distance between rest sites (D) in the study culverts that were the most stringent tests of the trouts' swimming abilities. The line was fitted to the points of passage. . . . . | 57   |

## 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. tshawytscha) (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 fontinalis) and/or cutthroat trout present could pass through them. In addition, evaluations of the effectiveness of the fish passage structures 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.

## DESCRIPTION OF STUDY AREAS

Culverts at five sites in Montana were chosen for study (Figure 1). The characteristics of the seven culverts at these sites have been 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 ( $\text{m}^3/\text{s}$ ) 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).

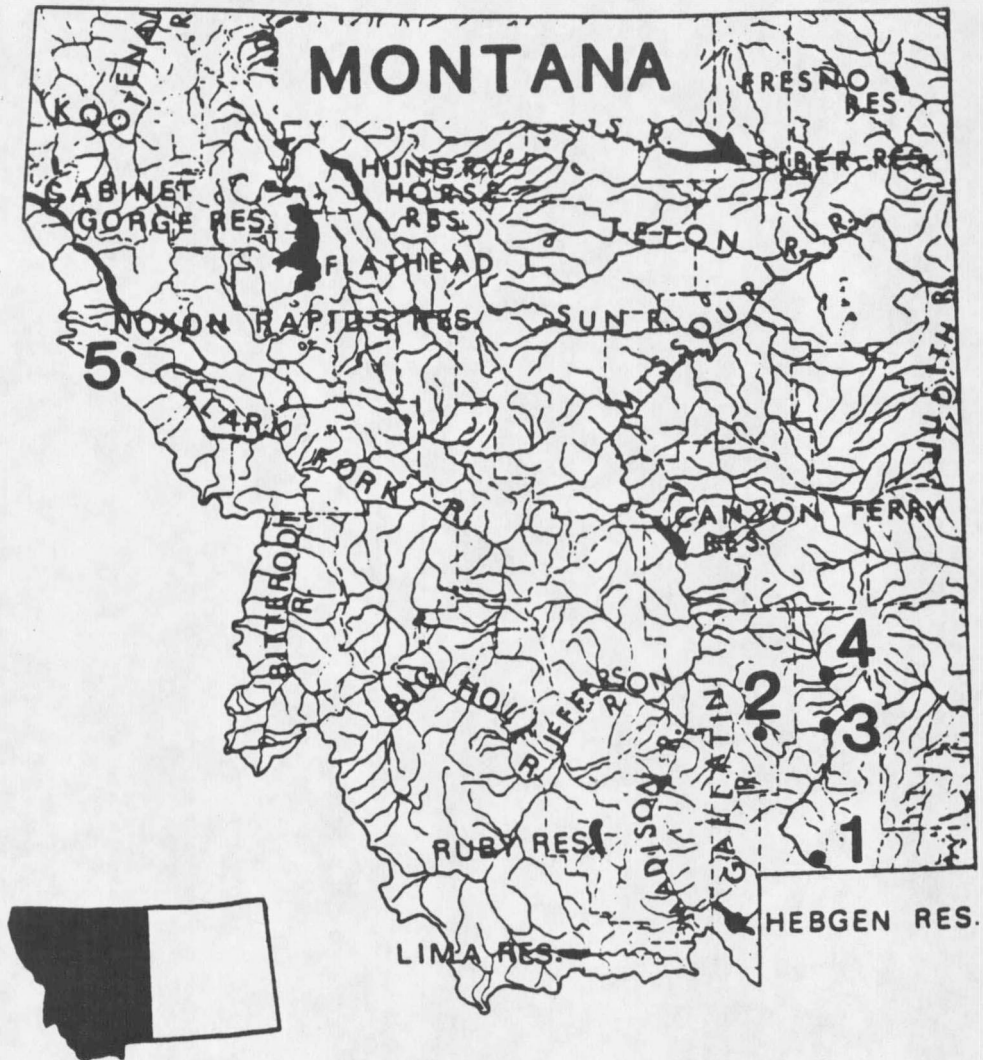


Figure 1. Locations of the study areas. 1 - Cedar Creek, 2 - Sourdough Creek, 3 - Depuy's Spring Creek - North Channel, 4 - Cottonwood Creek, and 5 - Twelvemile Creek.

Table 1. Physical characteristics of study culverts.

| Study culvert          | Slope<br>(%) | Maximum<br>width (m) | Length<br>(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  $0.48 - 2.95 \text{ m}^3/\text{s}$  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  $0.18 - 0.78 \text{ m}^3/\text{s}$ . 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<sup>3</sup>/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<sup>3</sup>/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 discharge) 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:

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

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:

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

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 unobstructed sections of circular culverts at the maximum depth. Cross-sectional area was determined by (D. E. Burkhalter, personal communication):

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

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

Discharge was calculated from:

$$(4) \quad Q = VA$$

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 continuous 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.

| Rock number       | Distance of rock from upstream end<br>of culvert (m): |      |      |      |
|-------------------|-------------------------------------------------------|------|------|------|
|                   | 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 stammas 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

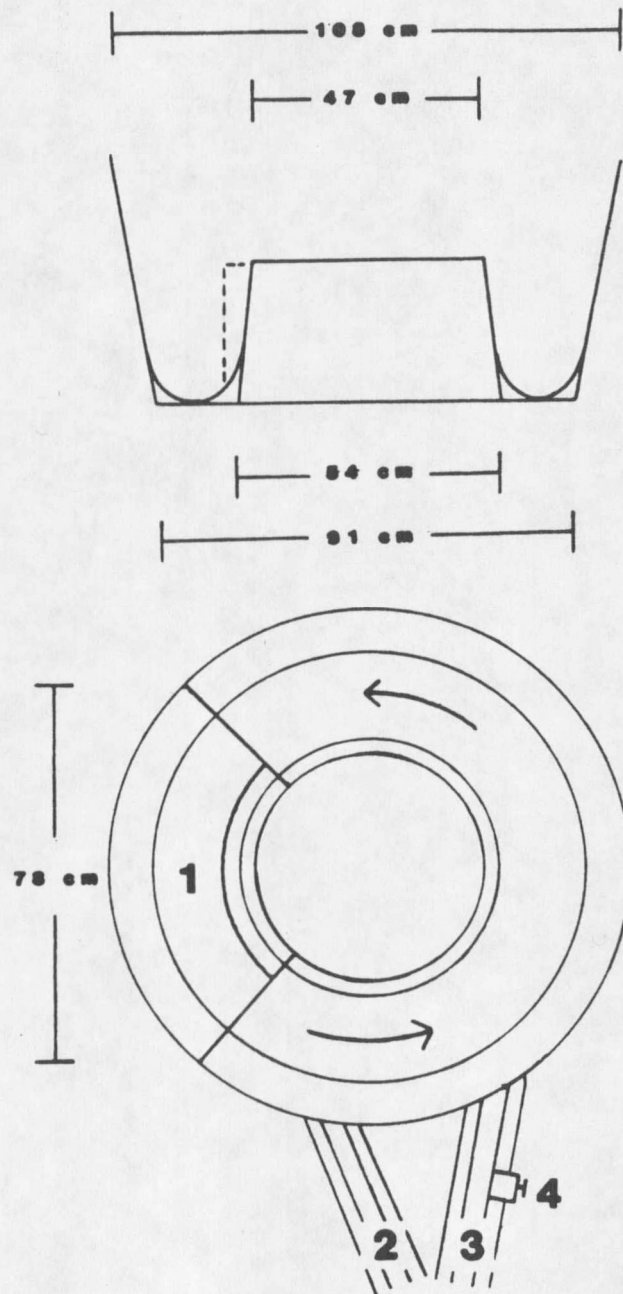


Figure 2. Diagram of the swimming stamina test apparatus showing 1 - testing section, 2 - intake pipes, 3 - outlet pipes, and 4 - control valve. Arrows indicate the direction of water flow.

centrifugal water pumps used to cycle water had a capacity of approximately 0.21 cubic meters per minute ( $\text{m}^3/\text{min}$ ). 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 continuously 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<br>interval | Mean<br>water velocity<br>(standard deviation)<br>(m/s) | Duration<br>(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.

| Sex          | N  | Length (mm) |           | Weight (g) |           |
|--------------|----|-------------|-----------|------------|-----------|
|              |    | 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.

| Sex          | N  | Length (mm) |           | Weight (g) |           |
|--------------|----|-------------|-----------|------------|-----------|
|              |    | 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 Creek from June 12 - 27, 1985.

| Sex          | N  | Length (mm) |           | Weight (g) |           |
|--------------|----|-------------|-----------|------------|-----------|
|              |    | 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

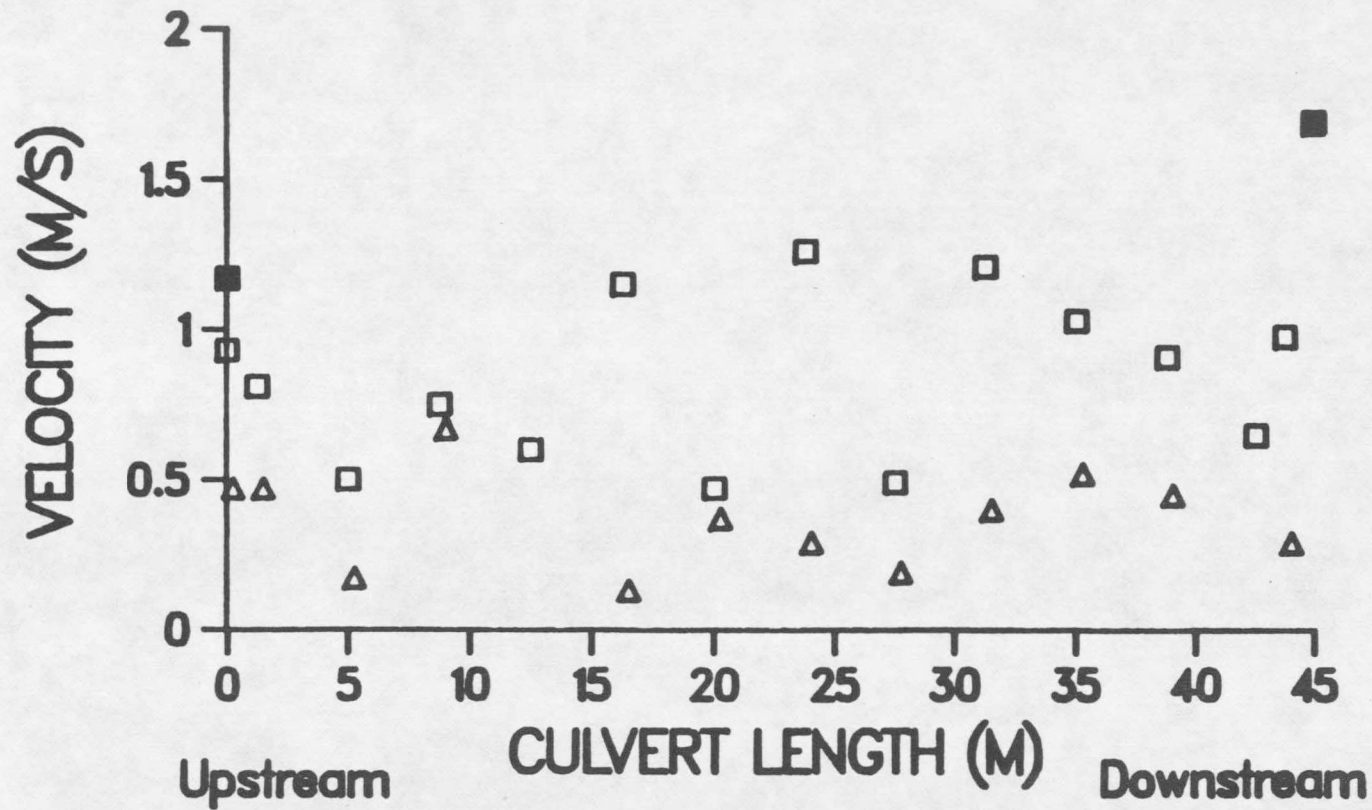


Figure 3. Water velocities at every third passage site over the rungs (open squares) and rest site (open triangles) in the improved culvert of Cedar Creek on July 13, 1984. Closed squares indicate highest summer velocities recorded (July 8, 1984).

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 occurred 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

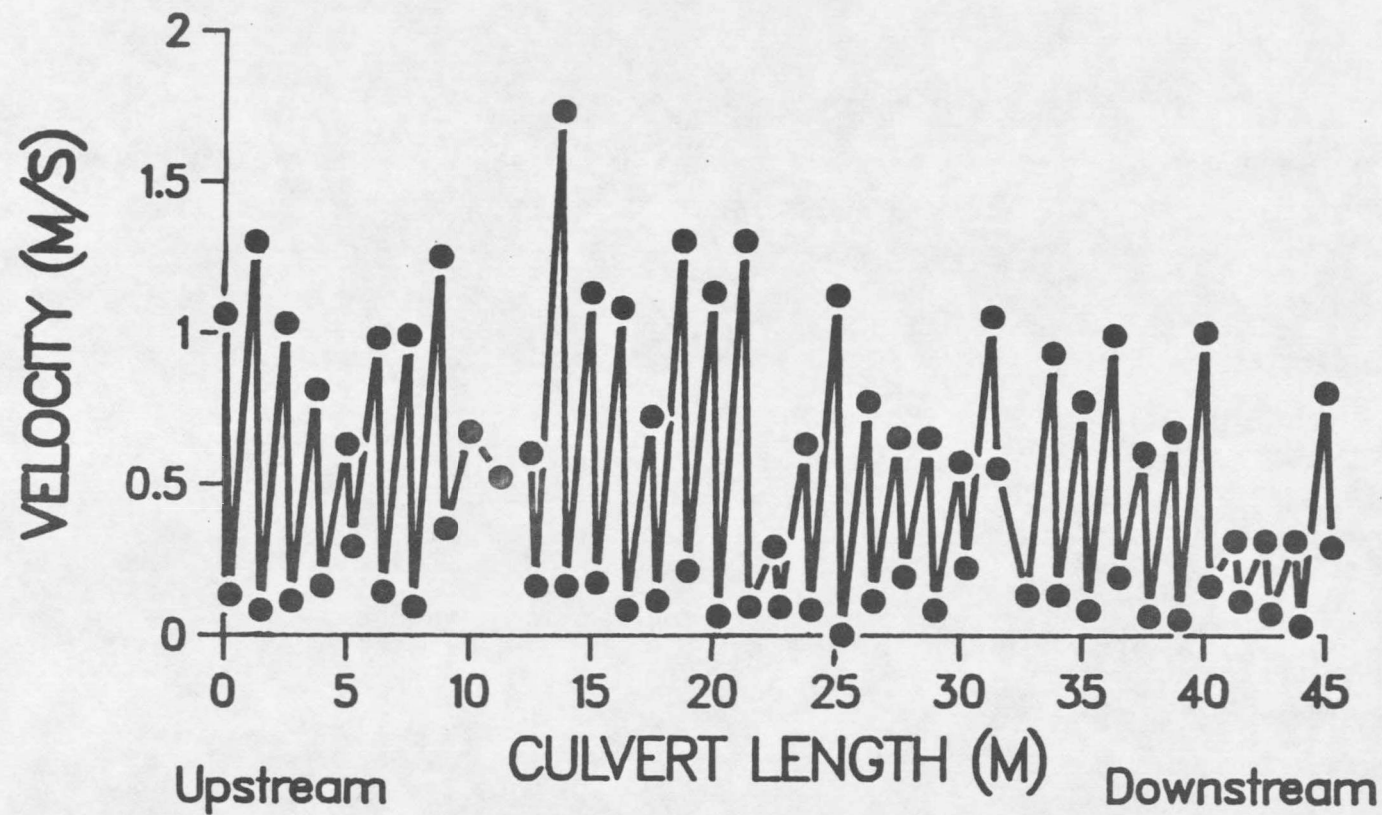


Figure 4. Water velocity profile in the improved culvert of Cedar Creek on October 11, 1984.

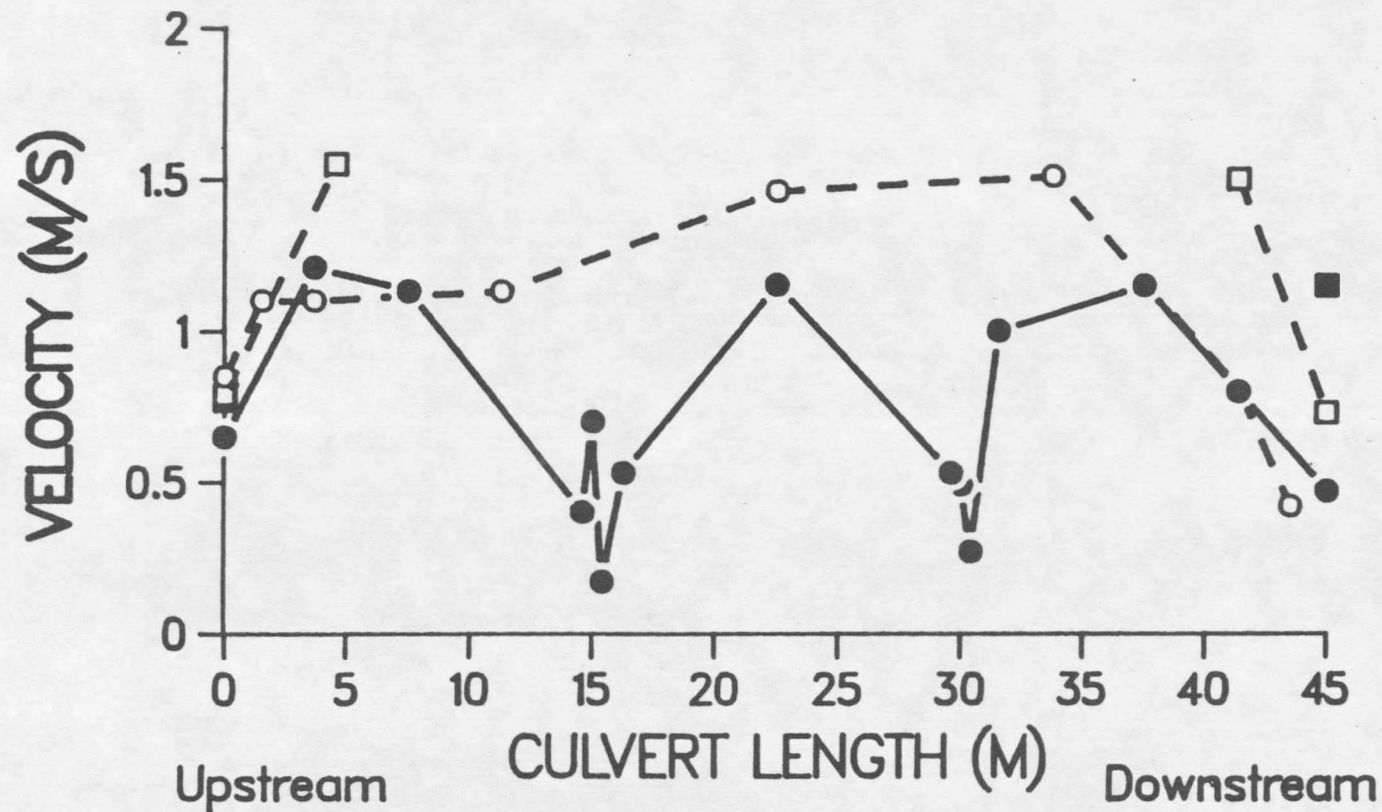


Figure 5. Water velocity profile in the unimproved culvert of Cedar Creek on July 12, 1984 (open squares), June 20, 1985 (open circles), and on June 21, 1985 (closed circles) after the placement of two rocks. Closed squares indicate highest summer velocities recorded (July 5, 1984).

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.

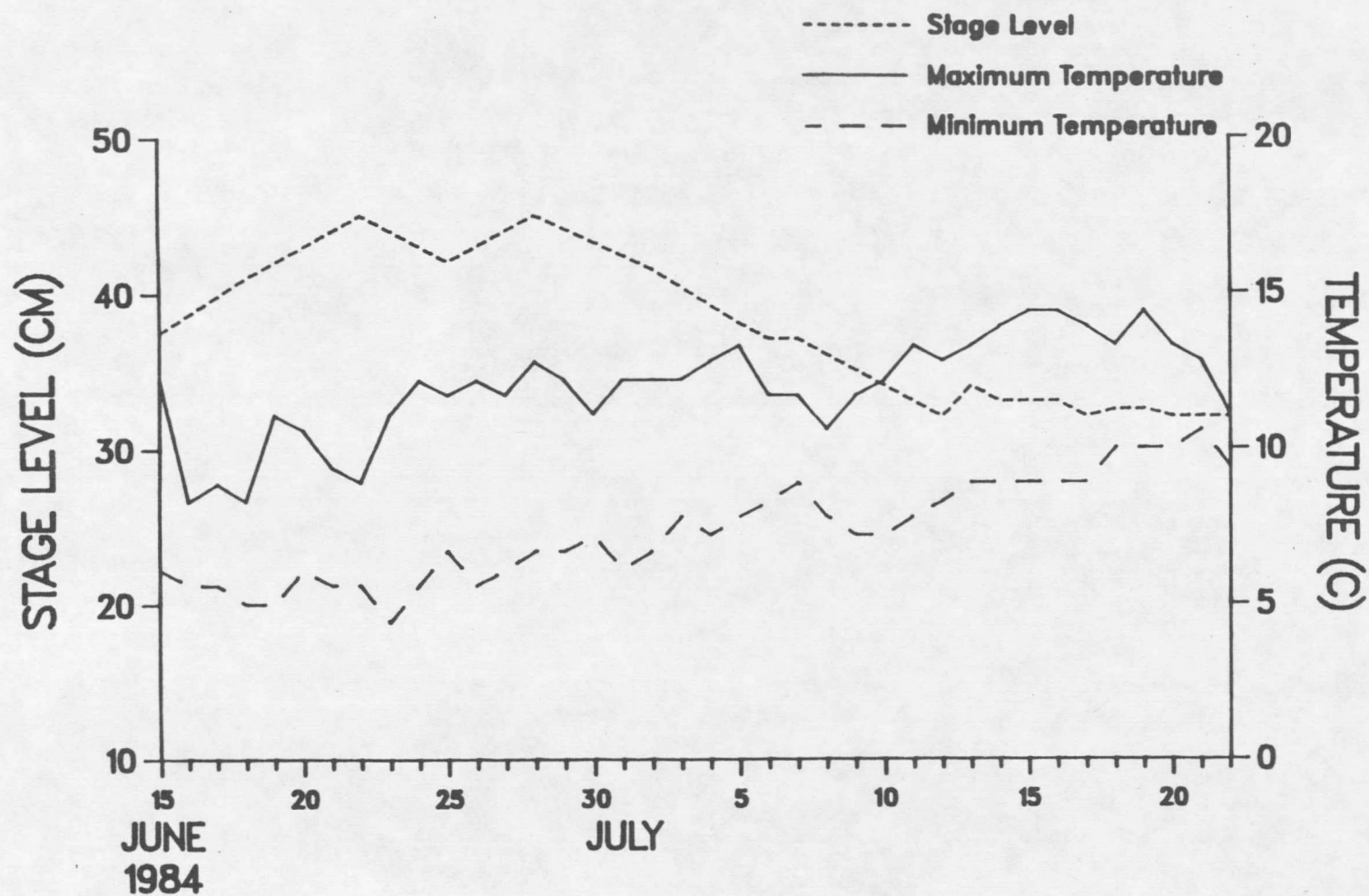


Figure 6. Stage level and daily maximum and minimum temperatures of Cedar Creek during June and July, 1984.

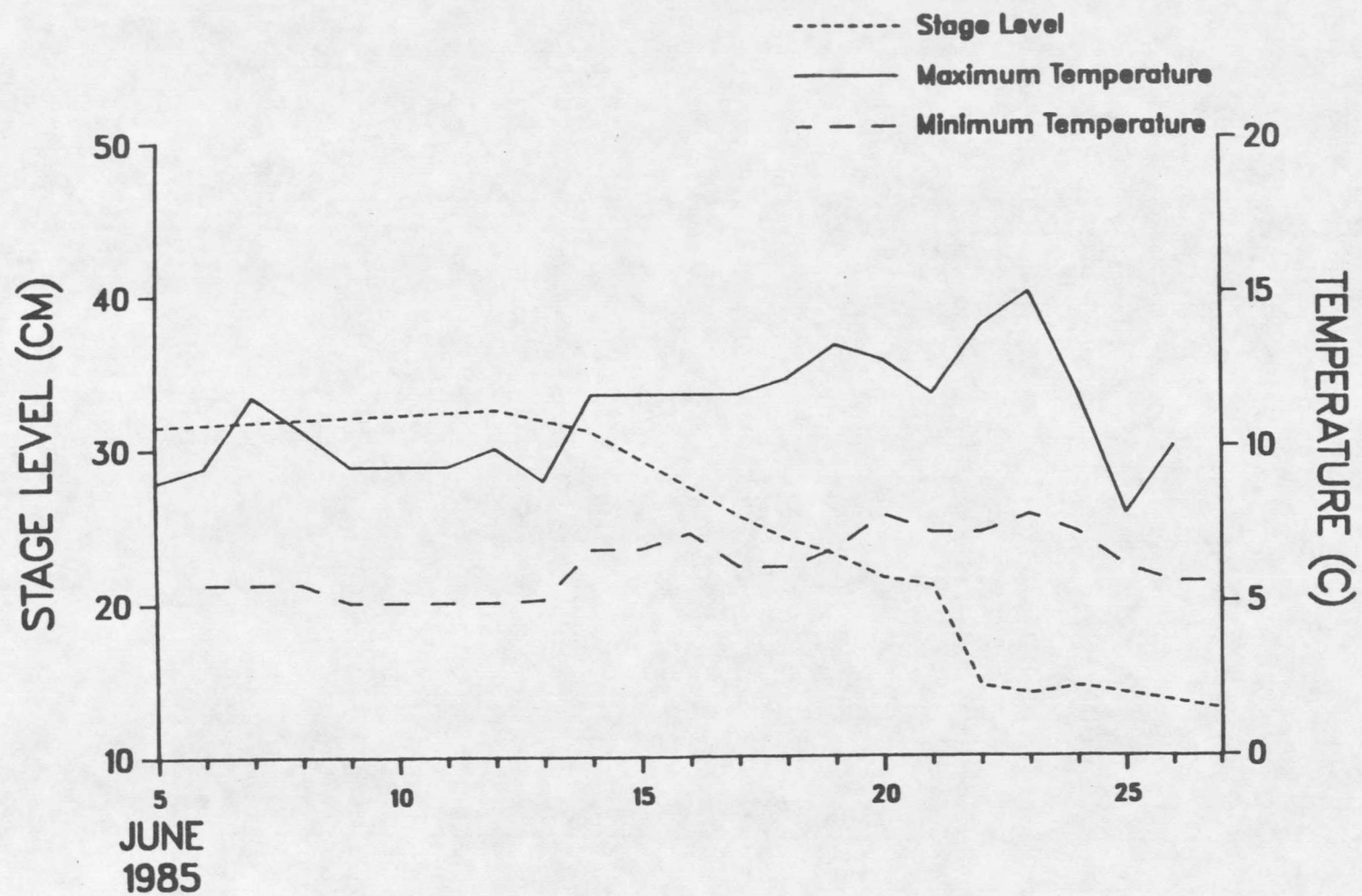


Figure 7. Stage level and daily maximum and minimum temperatures of Cedar Creek during June, 1985.

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.

| Species       | N  | Length (mm) |           | Weight (g) |          |
|---------------|----|-------------|-----------|------------|----------|
|               |    | 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.

| Species       | N  | Length (mm) |           | Weight (g) |           |
|---------------|----|-------------|-----------|------------|-----------|
|               |    | 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

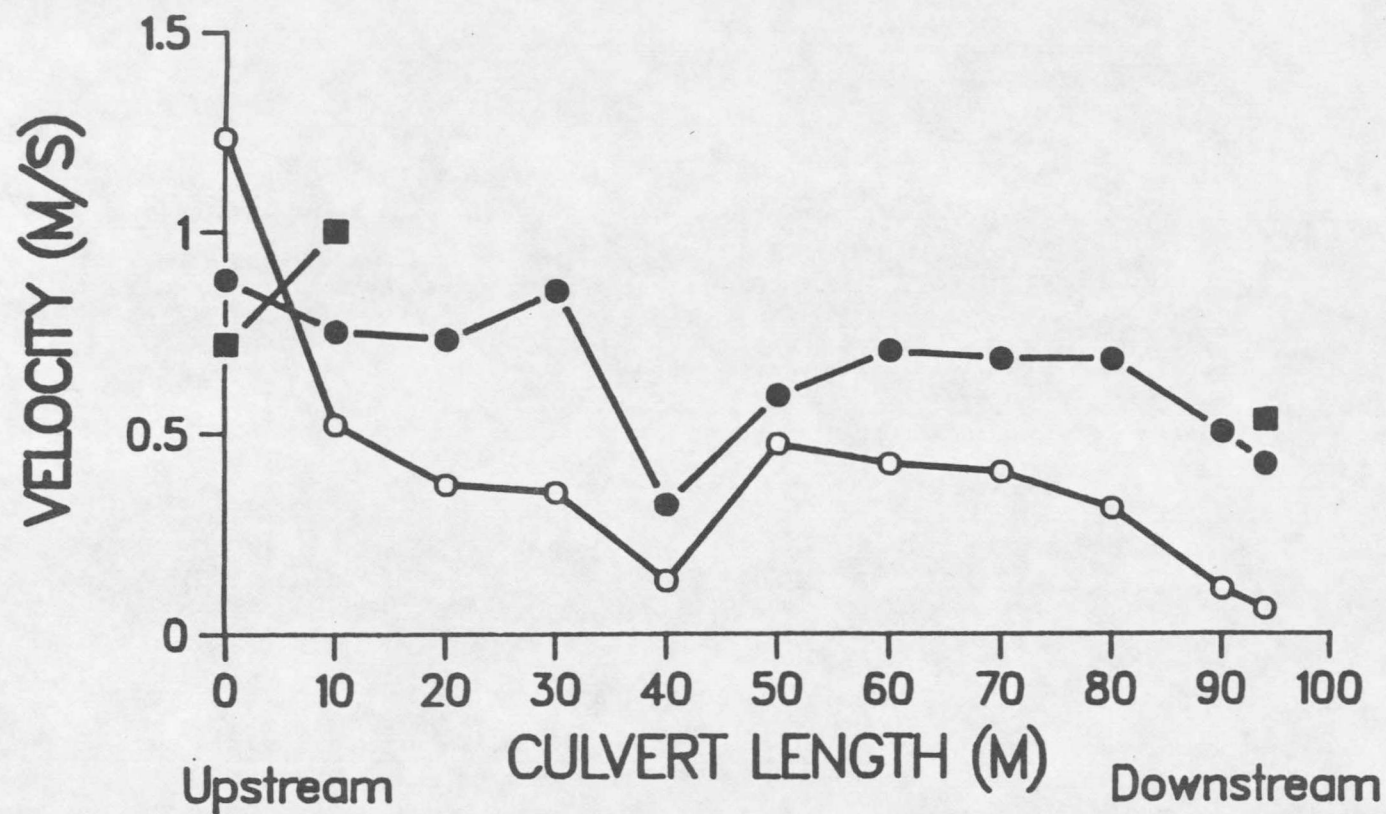


Figure 8. Water velocity profile in the east culvert of Sourdough Creek on May 1, 1985 (closed circles), and May 22, 1985 (open circles). Closed squares indicate velocities recorded during highest spring discharge (May 4, 1985).

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.

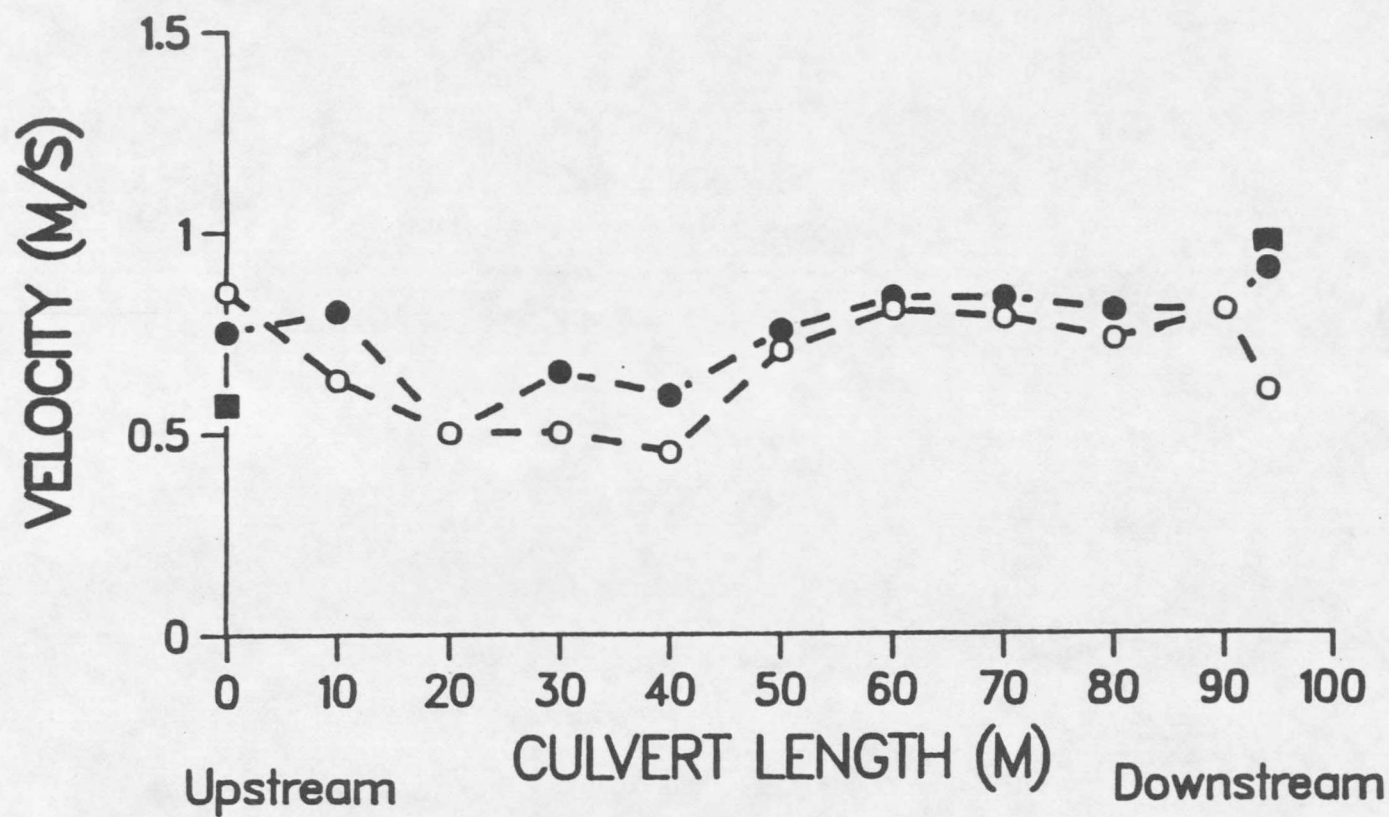


Figure 9. Water velocity profile in the west culvert of Sourdough Creek on June 5, 1985 (closed circles), and May 22, 1985 (open circles). Closed squares indicate velocities recorded during highest spring discharge (May 4, 1985).

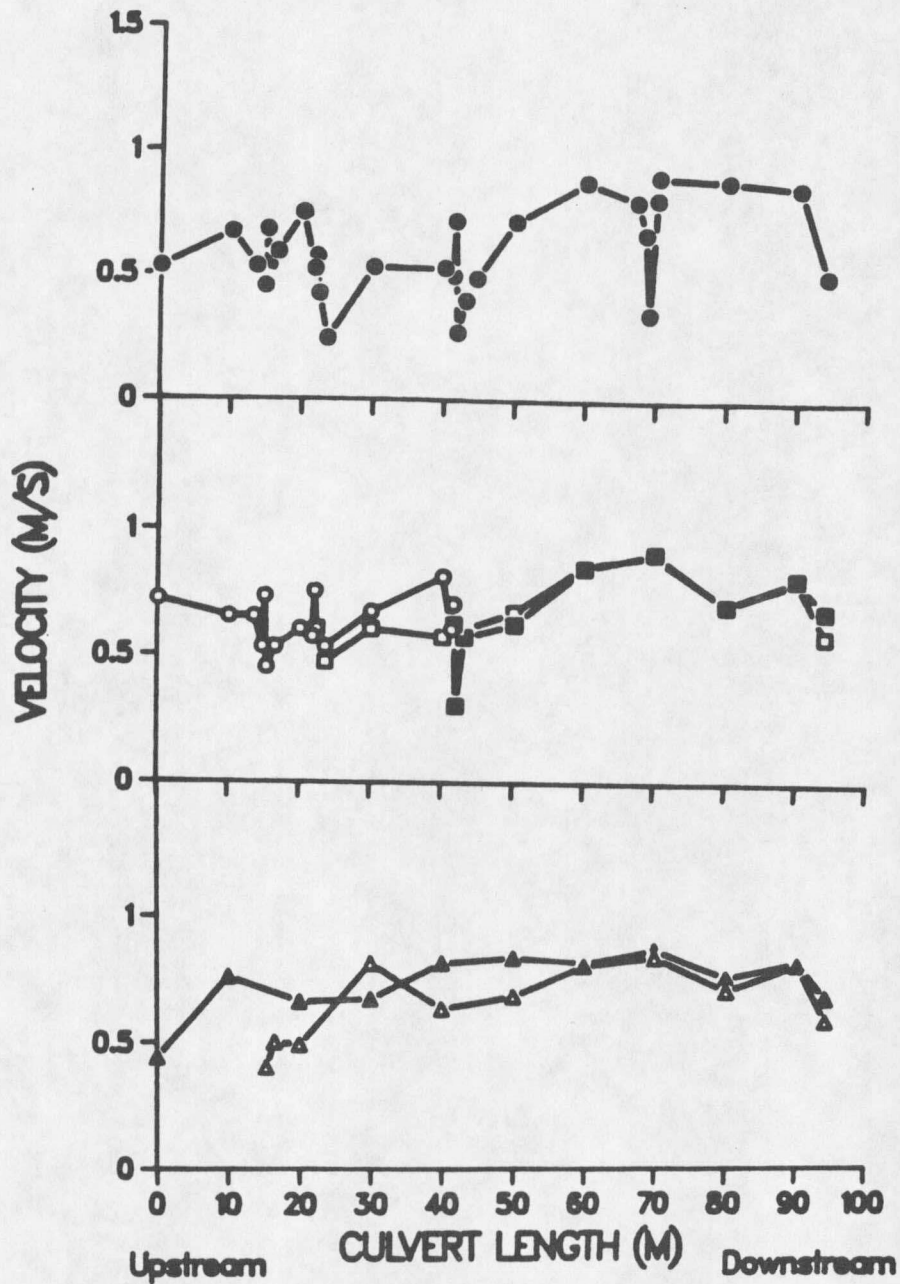


Figure 10. Water velocity profile in the west culvert of Sourdough Creek with the placements of four rocks on March 23 (closed circles), three rocks on March 21 (open circles) and April 6 (closed squares), two rocks on April 16 (open squares), one rock on April 21 (open triangles), and no rocks on April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

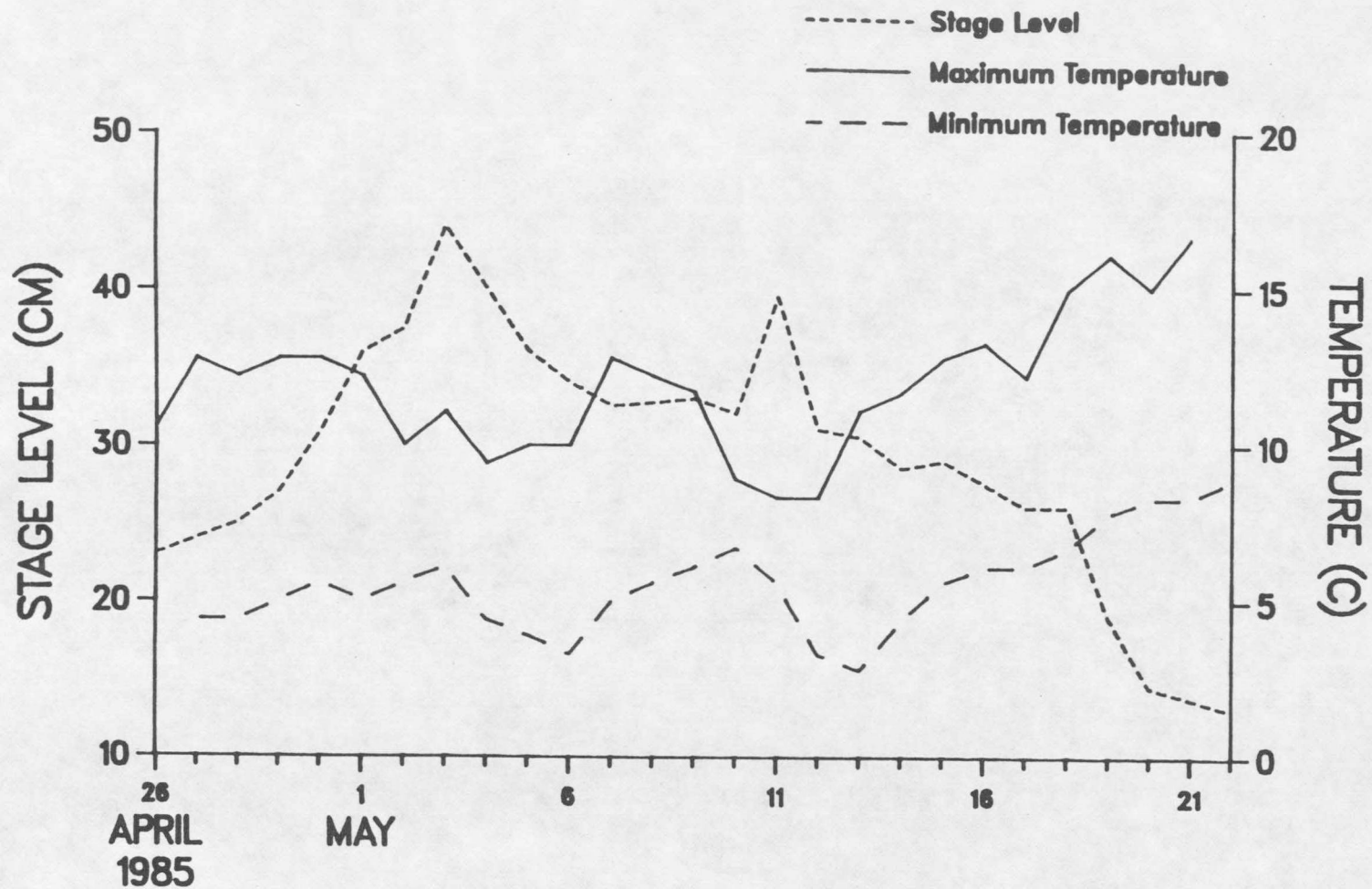


Figure 11. Stage level and daily maximum and minimum temperatures of Sourdough Creek during April and May, 1985.

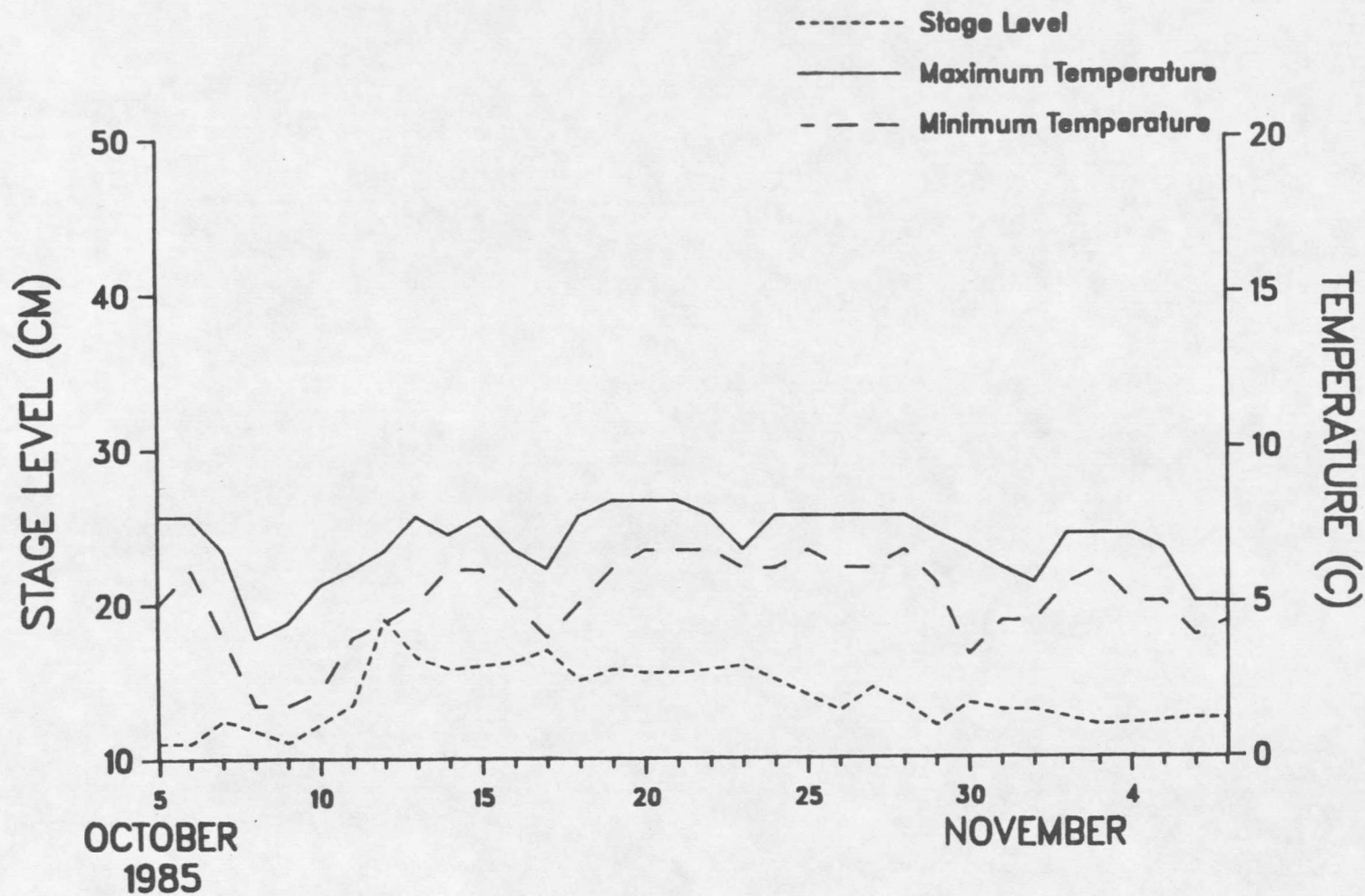


Figure 12. Stage level and daily maximum and minimum temperatures of Sourdough Creek during October and November, 1985.

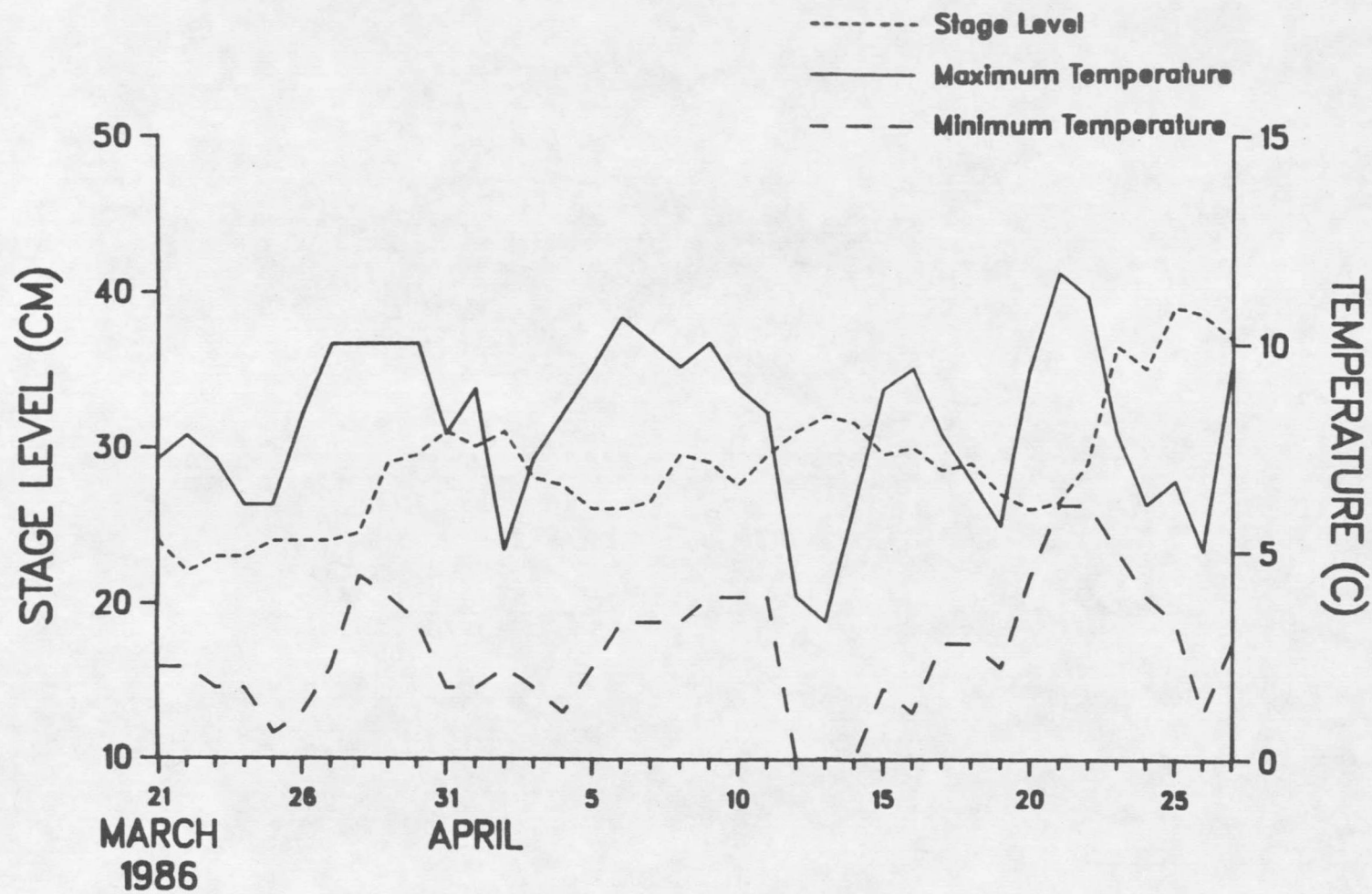


Figure 13. Stage level and daily maximum and minimum temperatures of Sourdough Creek during March and April, 1986.

maximum temperatures were above 10.0 C even though this occurred on only 24% of the study period days.

On April 28, 1986, a sunny day, light intensities were greater than 21,420 lx outside both culverts and 1.5 and 1.6 lx in the middle of the east and west culverts, respectively. This difference in light levels did not appear to affect trout passage.

#### Depuy's Spring Creek - North Channel

Forty rainbow trout passed through the culvert on this creek from March 20 - April 19, 1985 (spring) (Table 9). Rainbow trout as small as 223 mm successfully did so during this period. Two brown trout (298 - 323 mm) also swam through the culvert at this time.

Table 9. Characteristics of rainbow trout that passed through the culvert of Depuy's Spring Creek from March 20 - April 19, 1985.

| Sex     | N  | Length (mm) |           | Weight (g) |            |
|---------|----|-------------|-----------|------------|------------|
|         |    | Mean        | Range     | Mean       | Range      |
| Male    | 11 | 373.8       | 255 - 460 | 555.3      | 198 - 921  |
| Female  | 3  | 450.3       | 435 - 461 | 893.3      | 780 - 1106 |
| Unknown | 26 | 380.2       | 223 - 470 | 559.9      | 85 - 1049  |
| Total   | 40 | 387.3       | 223 - 470 | 578.6      | 85 - 1106  |

Seven of 65 brown trout displaced below the culvert from October 18 - November 2, 1985 (fall), had returned upstream by December 5 (Table 10). Smaller trout

negotiated this culvert during the previous spring when velocities were similar or greater.

Table 10. The lengths and weights of brown trout displaced below the culvert of Depuy's Spring Creek that did and did not return upstream from October 18 - December 5, 1985.

|                | N  | Length (mm) |           | Weight (g) |           |
|----------------|----|-------------|-----------|------------|-----------|
|                |    | Mean        | Range     | Mean       | Range     |
| Did return     | 7  | 369.7       | 330 - 400 | 536.7      | 340 - 709 |
| Did not return | 58 | 295.7       | 117 - 425 | 313.3      | 28 - 794  |
| Total          | 65 | 303.1       | 117 - 425 | 337.4      | 28 - 794  |

The spring 1985 velocity profile in this culvert consisted of 47.0 m with velocities of about 0.7 m/s and 4.5 m near the elevated outlet with velocities up to 1.7 m/s (Figure 14). The lowest fall 1985 water velocities recorded were approximately 0.4 m/s in 47.0 m and up to 1.1 m/s in 4.5 m of the culvert (Figure 14). Rainbow trout and brown trout passed through the culvert under all recorded velocity conditions.

From March 19 - April 14, 1985, stage level only fluctuated between 62.4 - 65.0 cm (Figure 15). From April 14 - 19, stage level dropped to 57.0 cm then rose to 69.5 cm. Rainbow trout moved through the culvert during all of these stage levels.

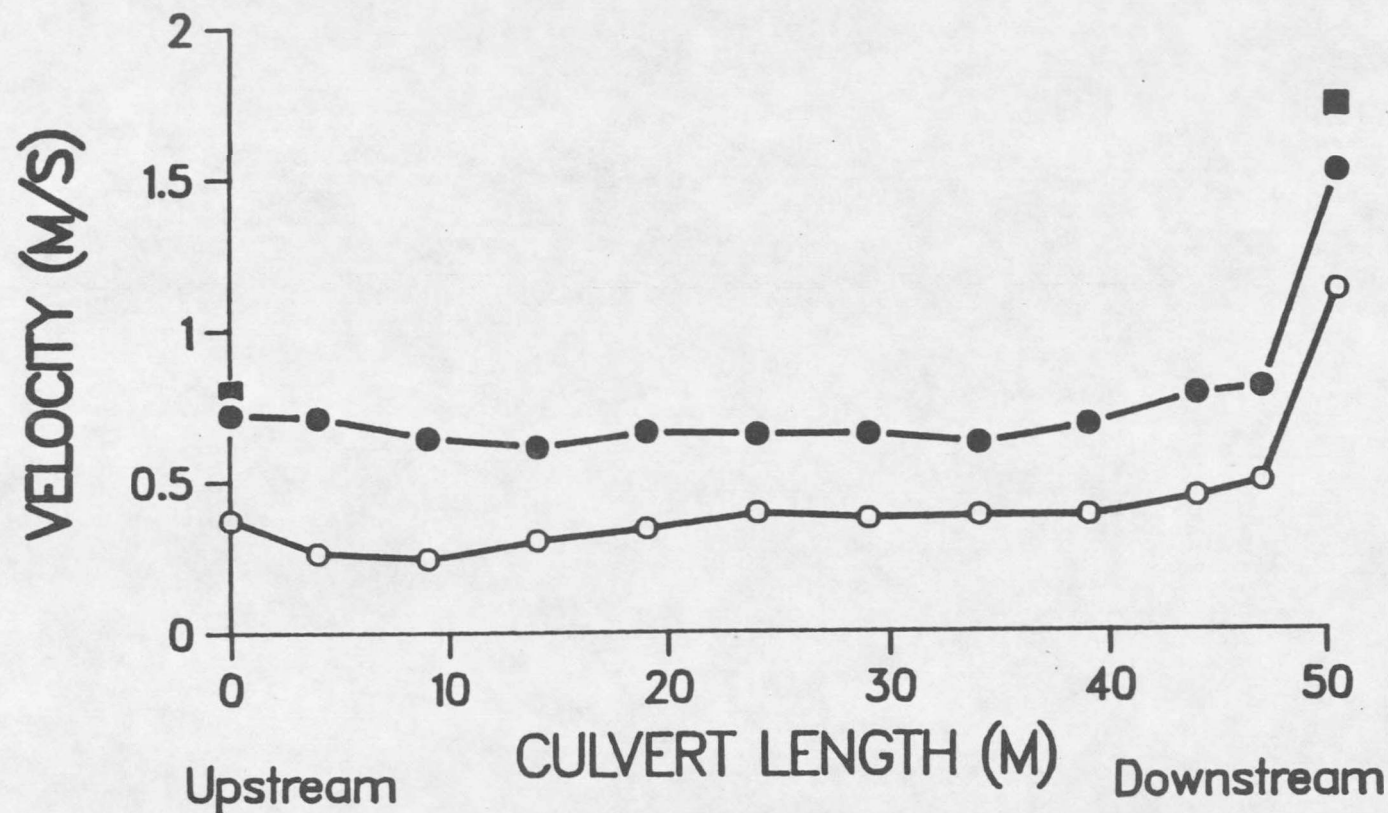


Figure 14. Water velocity profile in the culvert of Depuy's Spring Creek on April 10, 1985 (closed circles), and December 16, 1985 (open circles). Closed squares indicate highest spring velocities recorded (March 18, 1985).

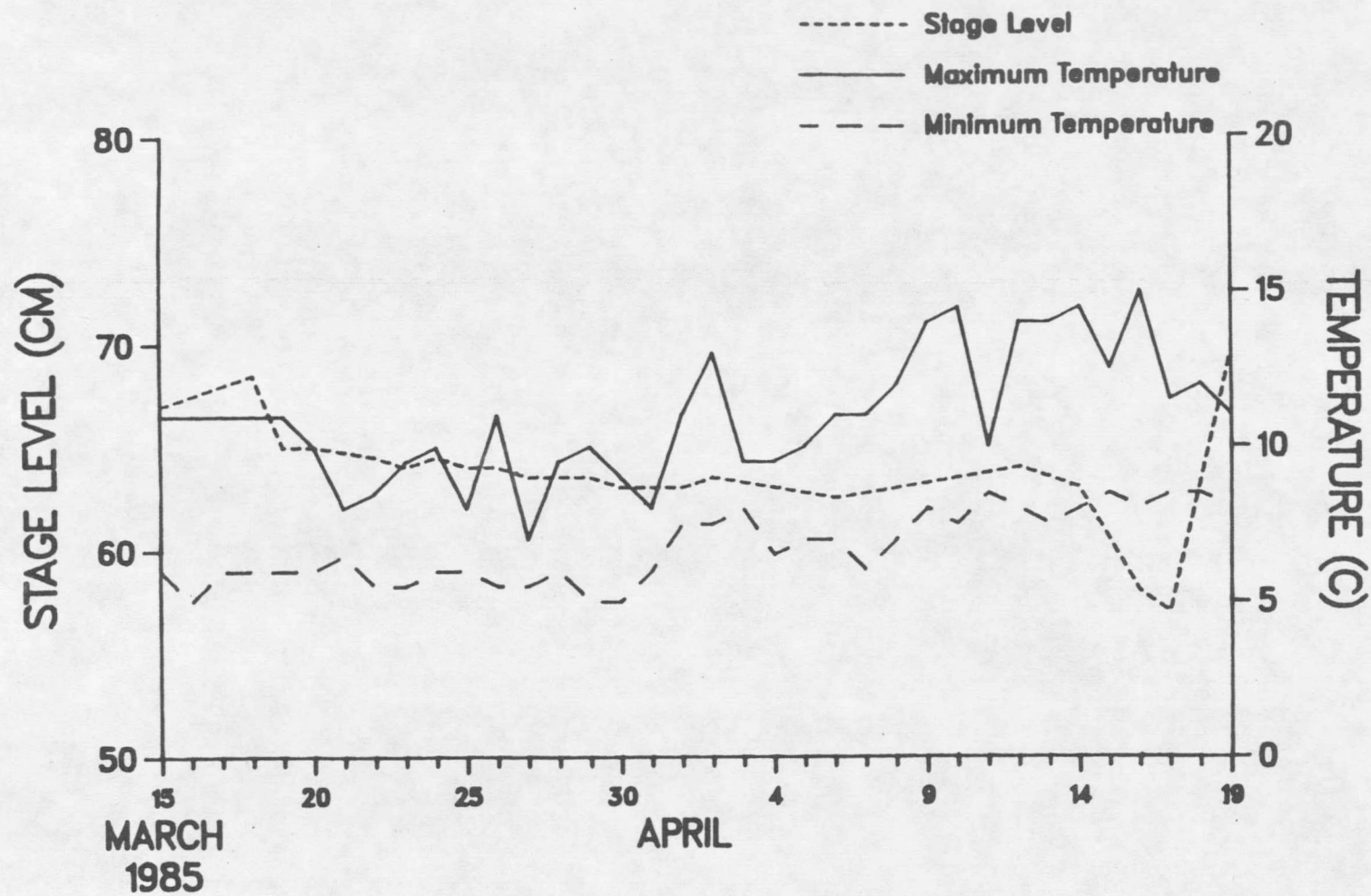


Figure 15. Stage level and daily maximum and minimum temperatures of Depuy's Spring Creek during March and April, 1985.

During the spring 1985 study period, daily maximum and minimum temperature ranges were 7.0 - 14.5 and 5.0 - 8.5 C, respectively (Figure 15). No strong relationship between rainbow trout movement and temperature was found.

Stage levels decreased from 73.0 - 42.0 cm from October 18 - December 5, 1985. Brown trout passed through the culvert throughout this period.

On April 16, 1986, a cloudy day, light intensity decreased from 8,181 lx outside the culvert to <0.1 lx in the middle of the culvert. These readings were probably similar of those in the previous spring when rainbow trout moved through the culvert.

#### Cottonwood Creek

No cutthroat trout were trapped above or below this culvert from June 12 - 19 and July 9 - 18, 1984 (summer). Only one cutthroat trout was captured by electrofishing in the stream above the culvert on July 18 indicating that Cottonwood Creek did not have a cutthroat trout spawning migration during 1984.

Twenty-four of 70 brown trout displaced below this culvert from October 17 - November 15, 1984 (fall) had returned upstream by November 21 (Table 11). All size groups swam through the culvert.

The summer velocity profile in this culvert consisted of water velocities up to 1.6 m/s between major rest sites

and less than 0.5 m/s at rest sites (Figure 16).

Accumulated bedload in the culvert provided minor rest sites which were not recorded. Fall 1984 water velocities were similar to those of the previous summer (Figure 16) indicating trout likely could have passed through the culvert in the summer.

Table 11. The lengths and weights of brown trout displaced below the culvert of Cottonwood Creek that did and did not return upstream from October 17 - November 21, 1984.

|                | N  | Length (mm) |           | Weight (g) |          |
|----------------|----|-------------|-----------|------------|----------|
|                |    | Mean        | Range     | Mean       | Range    |
| Did return     | 24 | 300.4       | 152 - 415 | 312.0      | 43 - 652 |
| Did not return | 46 | 250.7       | 103 - 450 | 216.5      | 14 - 822 |
| Total          | 70 | 267.7       | 103 - 450 | 249.9      | 14 - 822 |

During the period June 15 - July 17, 1984, peak summer stages occurred on June 28 at 66.0 cm (Figure 17). During this period, daily maximum and minimum temperature ranges were 11.1 - 19.4 and 5.0 - 12.2 C (Figure 17). These temperatures were greater than those recorded in Cedar Creek at the time of cutthroat trout movement.

During the period October 13 - November 20, 1984, stream levels were highest on November 1 at 32.0 cm (Figure 18). This was 34.0 cm below that of the previous

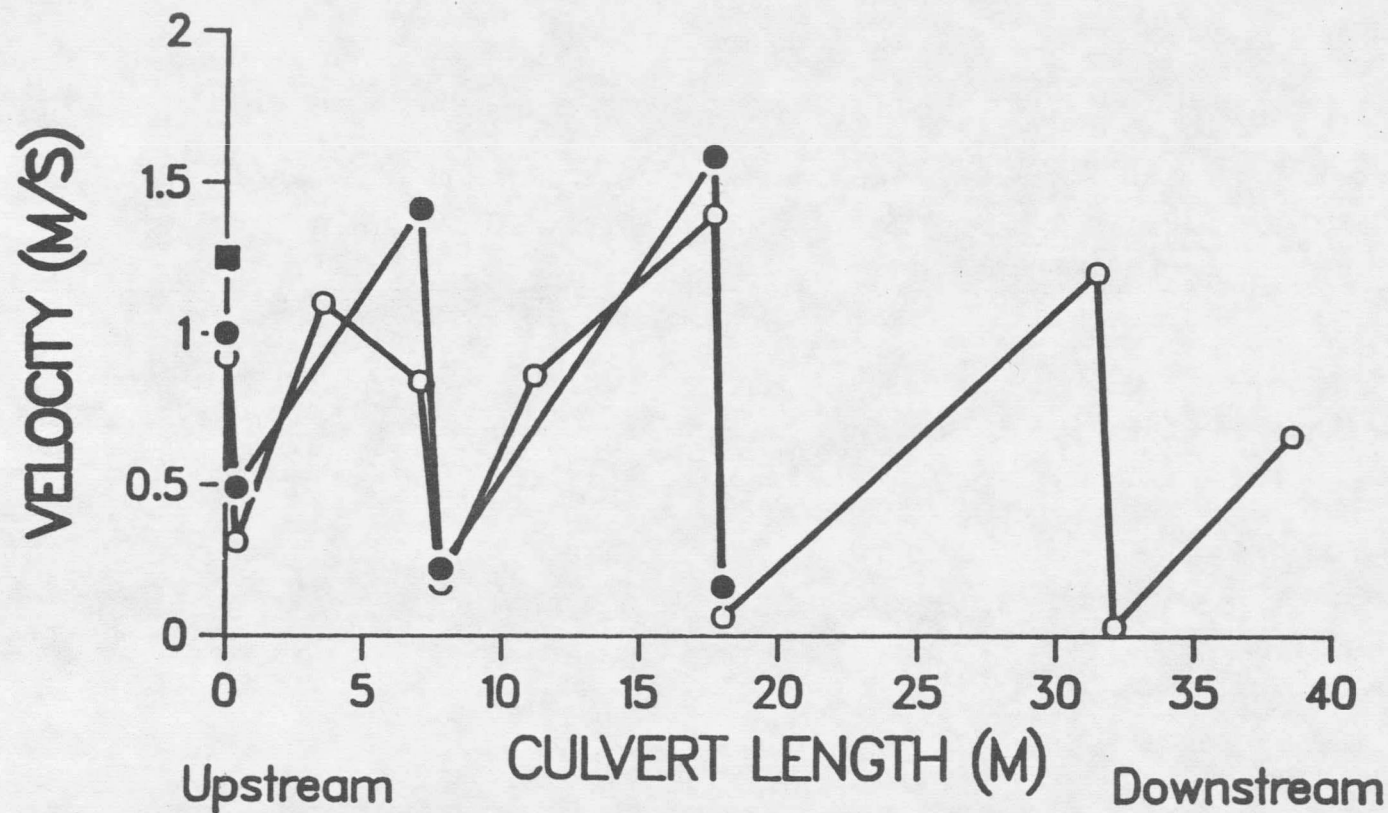


Figure 16. Water velocity profile in the culvert of Cottonwood Creek on July 10, 1984 (closed circles), and November 15, 1984 (open circles). Closed square indicates the highest summer velocity recorded (July 9, 1984).

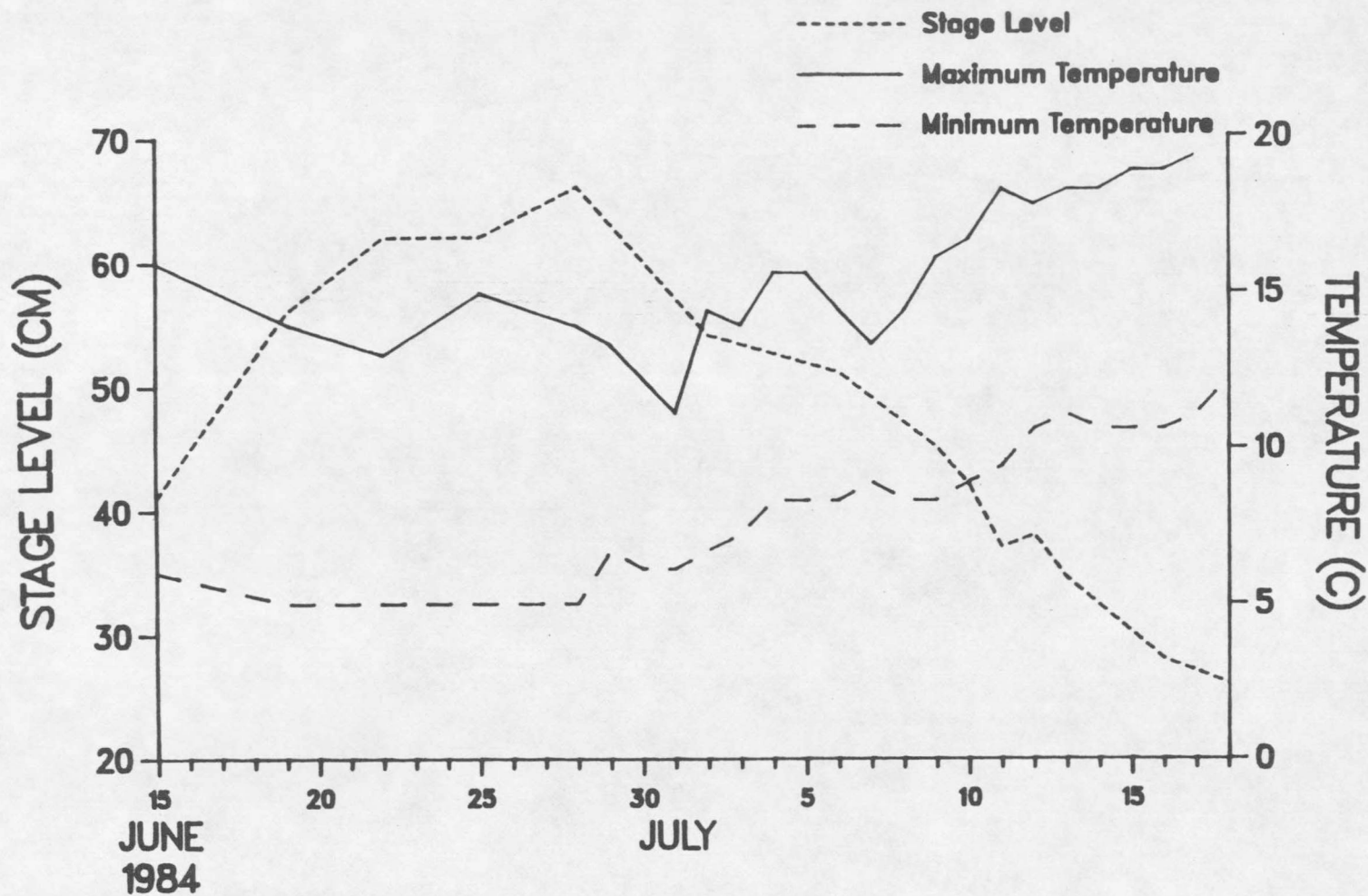


Figure 17. Stage level and daily maximum and minimum temperatures of Cottonwood Creek during June and July, 1984.

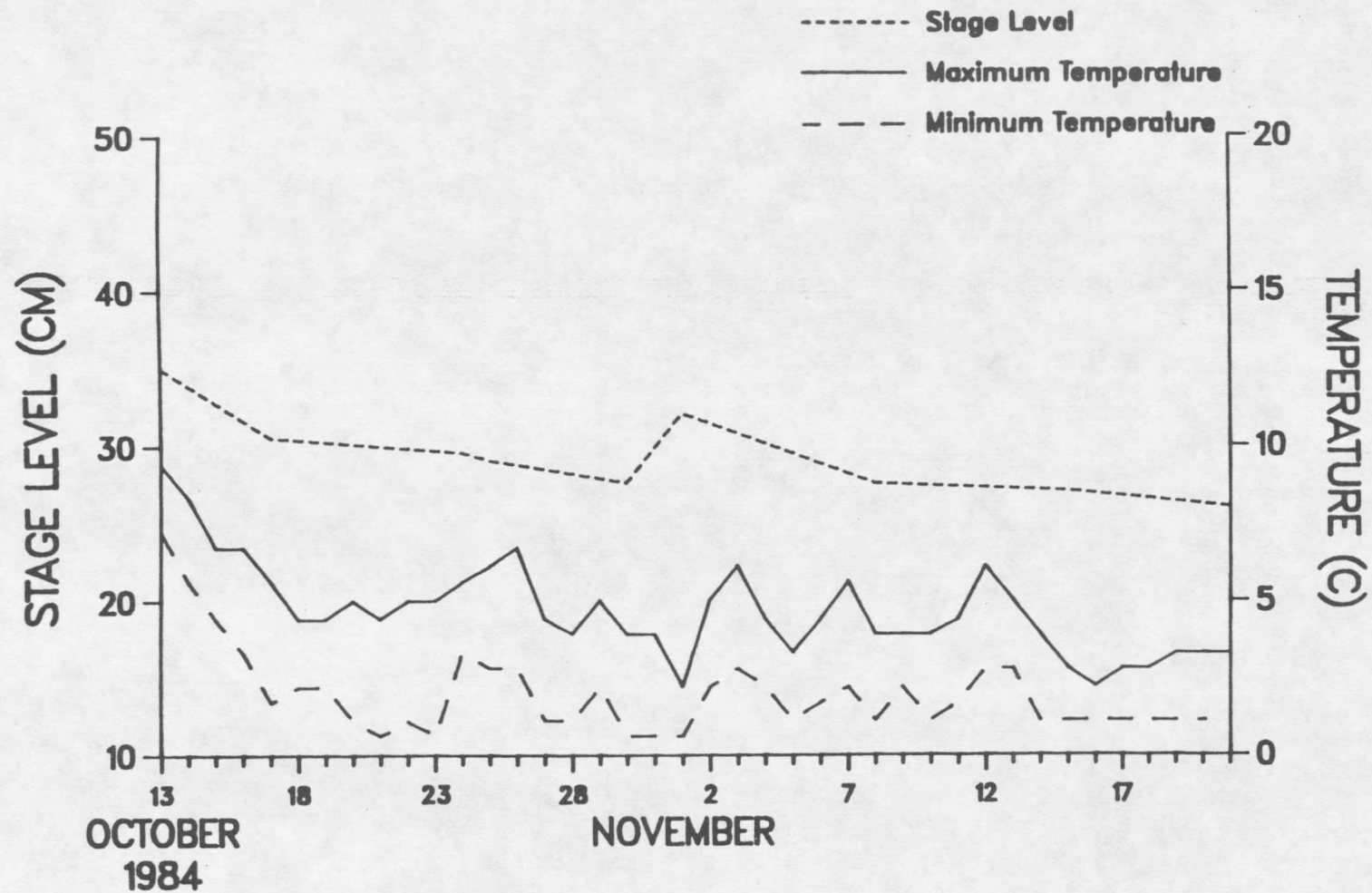


Figure 18. Stage level and daily maximum and minimum temperatures of Cottonwood Creek during October and November, 1984.

summer. Brown trout passed through the culvert from October 24 - November 20 under all recorded stage levels.

During this study period daily maximum and minimum temperature ranges were 2.2 - 9.4 and 0.6 - 7.2 C, respectively (Figure 18). Brown trout moved through the culvert when daily maximum temperatures were 2.2 - 6.7 C.

On July 18, 1984, an overcast day, light intensities decreased from an average of 17,837.0 lx outside the culvert to 215.3 lx in the middle of the culvert. This decrease in light intensity was less than those found in Cedar and Depuy's Spring creeks which did not prohibit trout passage.

#### Twelvemile Creek

Ten of the 72 trout displaced below the culvert from October 5 - 18, 1984 had returned upstream by November 17, 1984 (Table 12). In addition, one brown trout (249 mm) marked by personnel of the Montana Department of Fish, Wildlife, and Parks in the St. Regis River was captured above the culvert.

The velocity profile in this culvert had 0.4 m sections at the baffle notches with water velocities of up to 1.4 m/s (Figure 19). The 6.0 m sections between baffles had water velocities of about 0.2 m/s (Figure 19).

Table 12. Characteristics of trout displaced below the culvert of Twelvemile Creek that did and did not return upstream from October 5 - November 17, 1984.

| Species                   | N  | Length (mm) |           | Weight (g) |          |
|---------------------------|----|-------------|-----------|------------|----------|
|                           |    | Mean        | Range     | Mean       | Range    |
| Did return                |    |             |           |            |          |
| Brook trout               | 6  | 229.7       | 211 - 255 | 127.7      | 99 - 156 |
| Brown trout               | 3  | 285.0       | 225 - 341 | 274.0      | 99 - 454 |
| Rainbow trout             | 1  | 161.0       |           | 43.0       |          |
| Total                     | 10 | 239.4       | 161 - 341 | 163.1      | 43 - 454 |
| Did not return            |    |             |           |            |          |
| Brook trout               | 30 | 190.5       | 131 - 272 | 77.5       | 14 - 170 |
| Brown trout               | 15 | 232.4       | 138 - 400 | 212.7      | 28 - 794 |
| Cutthroat trout           | 9  | 202.4       | 155 - 252 | 83.7       | 43 - 156 |
| Rainbow x cutthroat trout | 4  | 172.3       | 135 - 231 | 53.3       | 28 - 99  |
| Rainbow trout             | 3  | 159.3       | 137 - 193 | 47.0       | 28 - 85  |
| Bull trout                | 1  | 319.0       |           | 269.0      |          |
| Total                     | 62 | 201.8       | 131 - 400 | 111.2      | 14 - 798 |

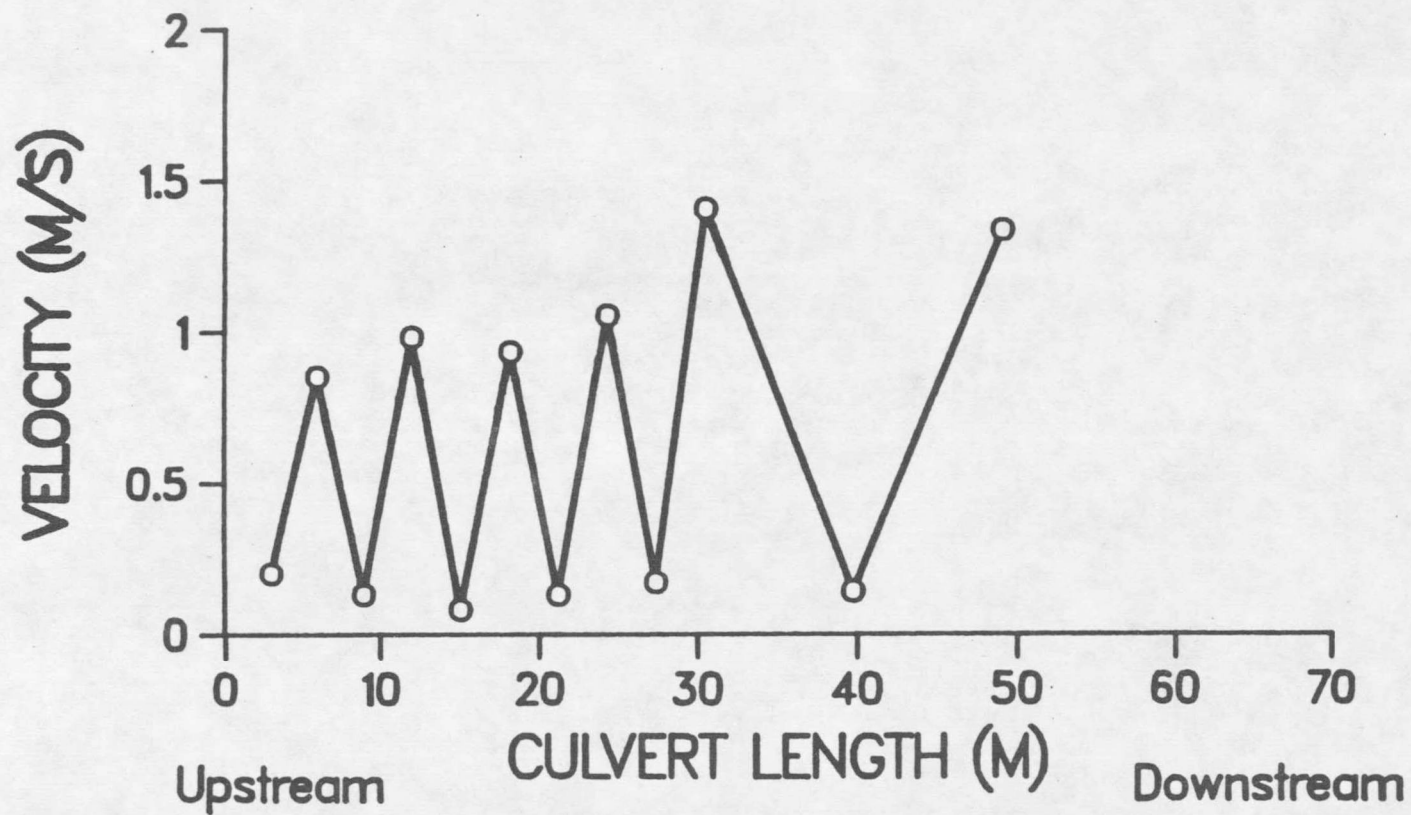


Figure 19. Water velocity profile in the culvert of Twelvemile Creek on November 17, 1984.

From October 5 - November 17, stage levels slowly increased from 26.5 - 30.0 cm (Figure 20). Daily maximum and minimum temperatures during this period were 1.4 - 9.5 and 0.4 - 5.9 C, respectively (Figure 20). Trout passed through the culvert under these stage and temperature conditions.

#### Laboratory Study

The swimming stamina of brown trout, rainbow trout and cutthroat trout (Table 13) were not significantly different ( $P > 0.05$ ). No relationship between trout length and swimming stamina was apparent for the size groups tested.

Table 13. Results of the comparative swimming stamina tests.

| Species         | N  | Length (mm) |           | Time to fatigue (min) |               |
|-----------------|----|-------------|-----------|-----------------------|---------------|
|                 |    | Mean        | Range     | Mean                  | Range         |
| Rainbow trout   | 11 | 331.3       | 286 - 395 | 14.58                 | 12.97 - 16.43 |
| Brown trout     | 12 | 336.8       | 306 - 358 | 14.74                 | 13.18 - 16.42 |
| Cutthroat trout | 5  | 327.0       | 316 - 347 | 13.32                 | 12.98 - 13.60 |

The range of water temperatures at the beginning and end of the stamina tests were 7.5 - 10.5 and 9.5 - 12.0 C, respectively. These temperatures were below the optimal swimming temperatures of 15.5 - 18.0 C for brown

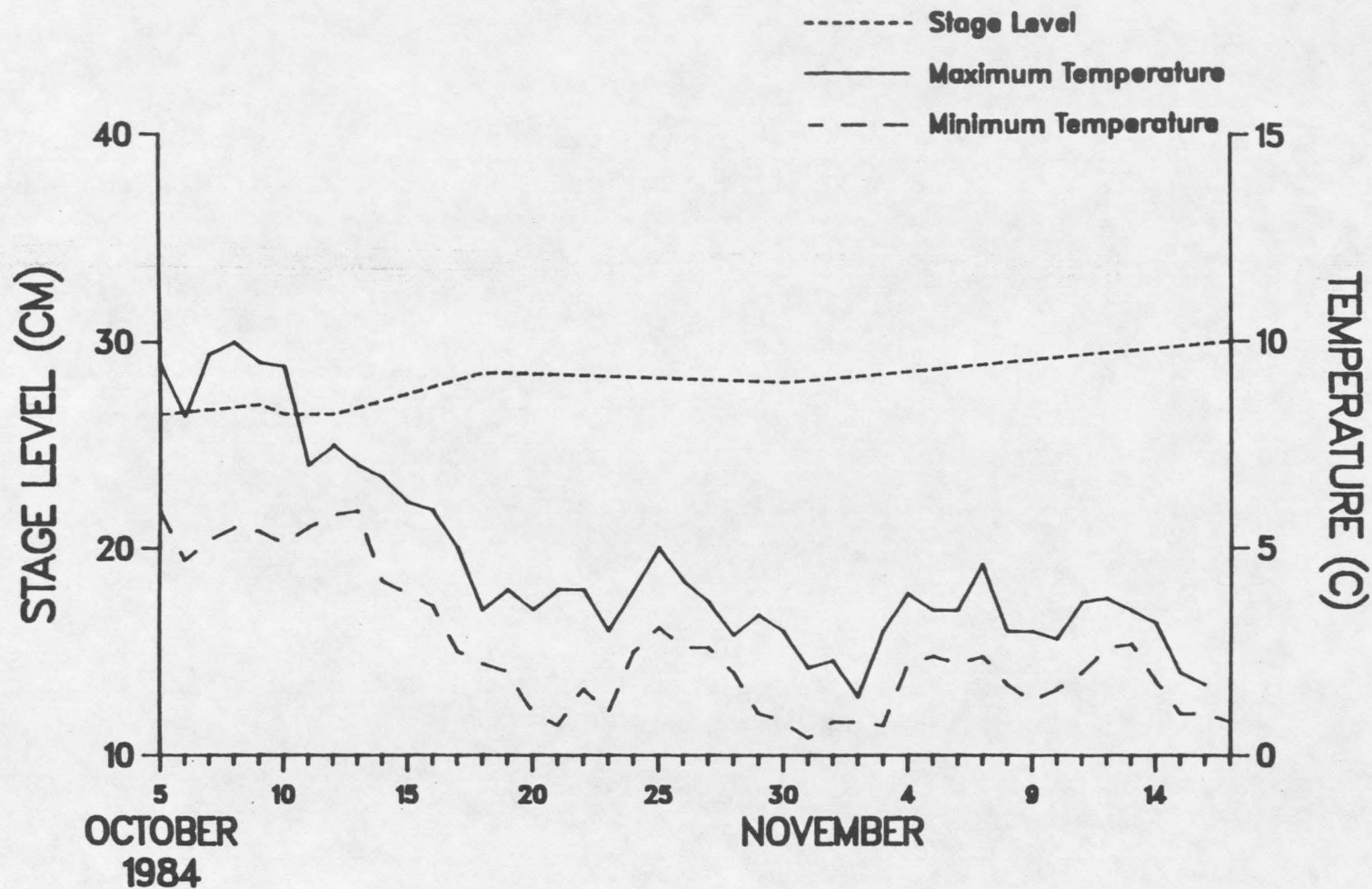


Figure 20. Stage level and daily maximum and minimum temperatures of Twelvemile Creek during October and November, 1984.

trout (Griffiths 1978) but similar to those found during trout migrations in this study. The temperatures in the holding pens were 1.5 - 7.0 C lower than the initial temperatures in the testing apparatus. These differences should not have greatly affected the performance of the trout considering the low test temperatures (Griffiths and Alderdice 1972, Griffiths 1978).

Dissolved oxygen contents at the beginning and end of the tests were 7.60 - 9.55 and 7.35 - 8.40 milligrams per liter (mg/l), respectively. These levels should not have adversely effected swimming performance (Dahlberg et al. 1968).

## Discussion

### Distance - Velocity Relationship

The ability of salmonids to swim through culverts has been described previously as a function of the distance between suitable rest sites and the water velocity between sites (Ziemer 1961; Metsker 1970; Saltzman and Koski 1971; Lauman 1976). The points of the greatest average bottom velocities for given distances between rest sites found in the present study were plotted in Figure 21. A nonlinear regression (Marquart 1963) was used to fit those points representing the maximum conditions of trout passage.

Figure 21 showed that trout passage required rest sites spaced 0.3 - 20.0 m apart in culverts having bottom velocities of 1.67 - 0.83 m/s. However, other authors have apparently found passage through greater velocities for distances in this range. Huston (1964) found some cutthroat trout passed through a 17.0 m culvert with velocities up to 3.4 m/s. This was 2.2 m/s greater than the value projected by this equation for that distance after bottom velocity was converted to 0.6 depth velocity. His velocities were calculated by averaging the measurements taken at 0.6 depth at the culvert inlet and an elevated outlet. This elevated outlet probably would

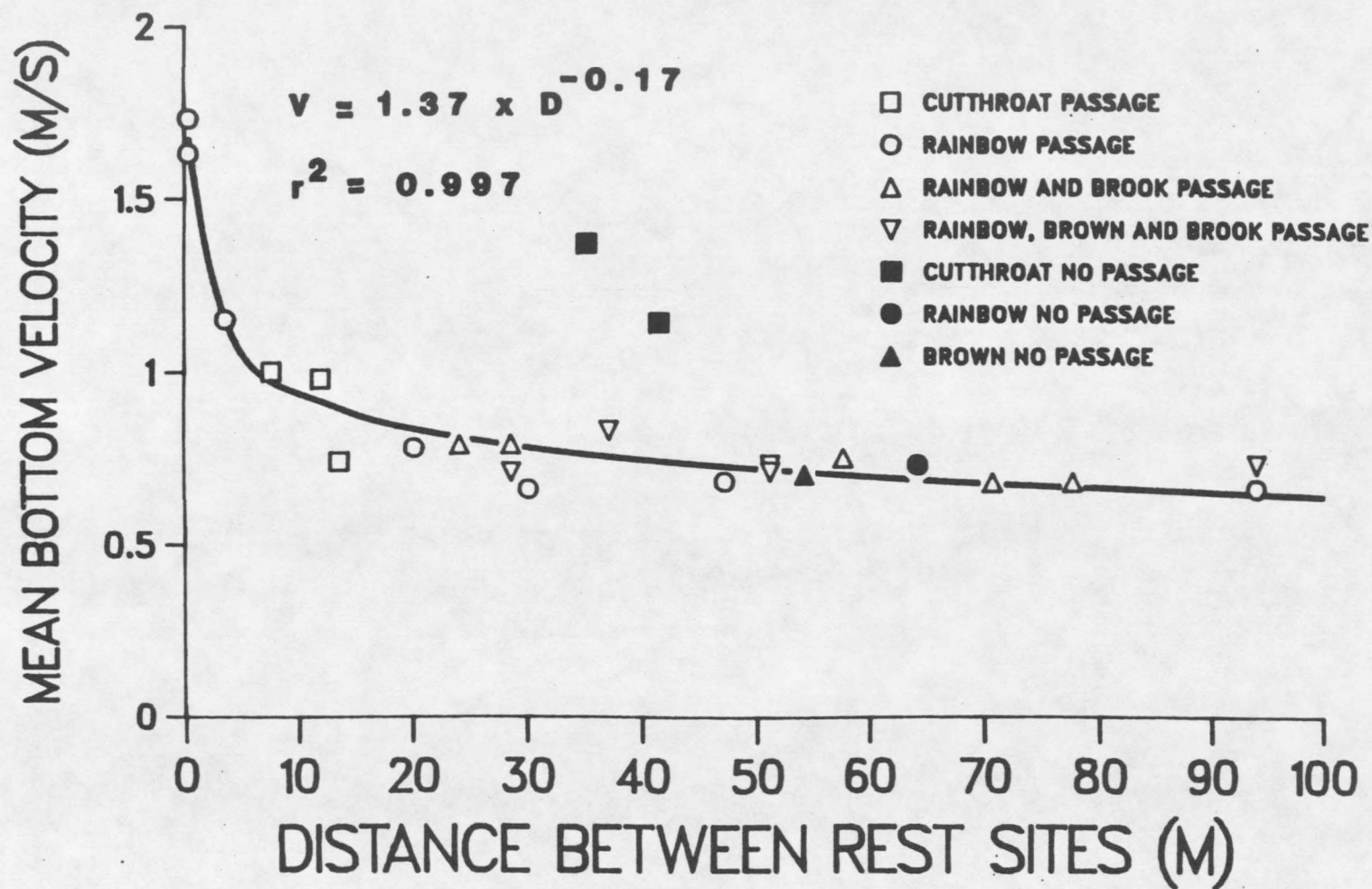


Figure 21. The measurements of mean bottom velocity (V) and distance between rest sites (D) in the study culverts that were the most stringent tests of the trouts' swimming abilities. The line was fitted to points of passage.

have given Huston (1964) greater velocity values than those prevailing in most of the culvert. MacPhee and Watts (1976) found some Arctic grayling ( $> 280$  mm in length) passed through an 18.3 m long culvert when approximate mean velocities were as high as 1.8 m/s. This was 0.6 m/s greater than the 1.2 m/s indicated by this curve after conversion of bottom velocity to the 0.6 depth velocity.

Bottom velocities of 0.83 - 0.64 m/s for distances of 20.0 - 100.0 m (Figure 21) were similar to the results obtained in other assessments and probably approached the trouts' prolonged swimming speeds. Eighty-six percent of the trout tested in the laboratory experiments were able to swim 20 - 206 s against the water velocity of 0.71 m/s which was similar to the field conditions represented in this part of the curve. Brainbridge (1960, 1962 cited in Brett 1964) reported the prolonged swimming speed of rainbow trout was approximately 1.7 - 2.8 body lengths per second (l/s). This converted to 0.49 - 1.11 m/s for the trout lengths tested here. McPhee and Watts (1976) found some Arctic grayling ( $> 280$  mm in length) passed through a 30.5 m long culvert with a water velocity of 1.2 m/s. The curve produced in the present study predicted 1.1 m/s for that distance (after conversion to 0.6 depth velocity). Points of nonpassage (Figure 21) also indicated that the

20.0 - 100.0 m part of the curve was an accurate assessment of the trouts' passage abilities.

The distance - average velocity relationship produced from data collected in the present study indicated nonanadromous salmonids could pass under higher velocities than those recommended by Saltzman and Koski (1971) and Lauman (1976) (Table 14). However, their recommendations were not field tested and were only similar to those from this study for distances of 15 - 30 m with velocities less than 1.21 m/s.

Table 14. Maximum velocities and distances between rest sites for passage indicated in this study and those recommended previously.

| Study          | Velocity (m/s) |                           |               |
|----------------|----------------|---------------------------|---------------|
|                | Present        | Saltzman and Koski (1971) | Lauman (1976) |
| Distance (m)   |                |                           |               |
| Less than 30.5 | 2.26 - 1.18*   | < 1.22                    | < 1.22        |
| 30.5 - 61.0    | 1.18 - 0.98*   | < 0.61                    | < 0.61        |
| 61.0 - 91.4    | 0.98 - 0.92*   | < 0.61                    | < 0.46        |

\* Velocities at 0.6 depth converted from bottom velocities.

Ziemer (1961) and Kay and Lewis (1970) produced curves delineating anadromous salmonid passage with distance and mean water velocity between rest sites as parameters. The curve developed by Ziemer (1961) was not based on field data and was found to underestimate

swimming abilities found in the field by Kay and Lewis (1970). The passage curve developed in the present study for nonanadromous salmonids (when converted to 0.6 depth velocities) closely parallels that of Kay and Lewis (1970) but at approximately 0.5 their reported velocity values. This relationship agrees with the literature reviewed by Beamish (1978) which showed that nonanadromous salmonids have less swimming ability than anadromous salmonids.

The passage points documented (Figure 21) represent conditions where some trout passed. It does not imply that all trout were able to move through the culvert under these conditions. Not all of the trout which approached the culvert or were displaced below the culverts moved through them. Huston (1964) found that only 29.8% of the cutthroat trout which approached a study culvert passed through it. Handling, lack of desire and/or individual capabilities undoubtedly produced differential trout passage.

The distance - velocity relationship in Figure 21 represents pooled data on all species studied because no species showed a significantly greater ability to swim through culverts. This similarity in swimming ability was also indicated by the swimming stamina tests (Table 13).

Water velocities at rest sites in the present study were as great as 0.6 m/s, but over 90% were approximately 0.4 m/s or less. These velocities were in some cases greater than the 0.15 m/s recommended by Katapodis (1977),

but since rest site velocities were usually measured approximately 0.3 m behind a structure, the lowest velocity water was not always measured.

#### Other Factors Affecting Passage

Trout have shown an increased swimming ability with increasing total length in tests in culverts (McPhee and Watts 1976) and in swimming stamina devices (Fry and Cox 1970; Jones et al. 1974). However, no relationship was found between passage ability and fish length in my study when sufficient water depth was present. Smaller trout may have been able to more efficiently utilize the zones of lower velocity water near the bottom or sides in culverts, which would have obscured the relationship between swimming ability and fish length.

Insufficient water depth can inhibit trout passage. The minimum water depth for passage is probably influenced by the distance and velocity of the passage site. In my study, cutthroat trout on Cedar Creek moved over distances of 11.8 and 13.5 m under velocities of 0.98 and 0.74 m/s, respectively, in water 8.0 cm deep which was about equal to the body depth of the size group of trout that passed. When irrigation withdrawal reduced the water depth to 4.0 cm, trout did not swim these distances under similar velocities. The depth when trout passed was less than the

minimum water depths of 12.0 and 15.0 cm recommended by Lauman (1976) and Kay and Lewis (1977), respectively.

Elevated culvert outlets also can block trout movements. The culvert sites in this study provided little information on this problem. Trout jumped up to 17 and 25 cm to swim through the DePuy's Spring and Twelvemile Creek culverts, respectively, from pools greater than 1.25 times the jump height in depth. These jumps were less than the 30 cm maximum recommended by Evans and Johnston (1977) for resident salmonids and the 46 cm known to be negotiated by cutthroat trout (Huston 1964).

Culvert lighting did not affect trout passage in this study. The darkest culvert was found on Depuy's Spring Creek and the difference in light levels there did not appear to affect trout passage.

#### Evaluation of Culvert Modifications

The evaluation of passage structures in culverts showed all three types allowed trout to pass. Though their designs were different, all provided the essential necessities of shortening the distance of difficult passage, reducing velocities and providing rest sites. The placement of individual rocks in culverts during this study also met these requirements.

Each of the passage structures studied had advantages and disadvantages. The ladder type present in Cedar Creek was best suited for watersheds with bedload large enough to become trapped by the rungs. Fine materials would have washed out and not provided rest sites. The 1.2 m distance between the rungs was unnecessarily small for Cedar Creek where the placement of two rocks 15.0 m apart in the unimproved culvert permitted passage. It appeared to be a very durable structure which showed no signs of deterioration after at least 4 years in operation.

The baffle system in Twelvemile Creek was well suited for watersheds with fine bedload materials. The baffles provided 0.1 - 0.2 m/s rest sites. This system, however, may not be very durable in areas where large boulders can roll in the culvert and flatten the baffles as in Twelvemile Creek.

The culvert in Cottonwood Creek was sunk 0.9 m below the creek bottom and had large rocks placed in it to simulate natural stream conditions. When large rocks are placed in culverts, they should be alternated from side to side. Failure to alternate placements results in long runs of fast water along the sides.

The distance - velocity curve developed in this study provides guidelines for installing future highway culvert that will permit the passage of rainbow trout, brown trout, cutthroat trout and brook trout. These guidelines

can also be used to assess the trout passage potential in existing culverts and suggest the placement of velocity reducing structures, if necessary. When assessing culverts, velocities should be measured throughout the culvert, whenever possible, since inlet and outlet velocities may be different than those prevailing throughout the culverts. Water velocity measurements should be taken near the bottom because they most nearly reflect the conditions the trout swim through.

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