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RESEARCH

FISH PASSAGE THROUGH POPLAR GROVE CREEK

FINAL REPORT

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FISH PASSAGE THROUGH POPLAR GROVE CREEK

FINAL REPORT

by

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in cooperation with

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FOREWORD

Most of this project was conceived by Mike Travis during the fall of 1984. At that time he contacted the University of Alaska-Fairbanks to determine if the project would be suitable as a research topic for a part of the program requirements for the Master of Science Degree in Environmental Quality Science. It was determined that it would be suitable.

Following extensive negotiations and revisions, the proposed project became a reality when it received funding from the Alaska Department of Transportation and Public Facilities. Mike Travis, in cooperation and consultation with me, successfully completed the project and research report in May of 1986.

The report that follows is, with few changes, the report that Mr. Travis prepared for his University of Alaska degree requirements. He is recognized and acknowledged for that effort.

An executive summary has been included with the report to provide the reader an overview of the project and its findings.

Tim Tilsworth
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16. Abstract

This study was conducted in 1985 to investigate the swimming performance of Arctic grayling through a highway culvert in Alaska. An existing culvert at Poplar Grove Creek was used for this project. The culvert is 110 ft. long, 5 ft. in diameter and is inadequate when evaluated for Alaska Department of Fish and Game fish passage criteria. The drainage area experienced a 20 year flood (Q_{20}) during the study period. Excessive pipe velocities, as high as 12 fps, prevented fish from passing the culvert for 8 days. A visual technique to observe tagged fish was used to monitor fish migration through the pipe when abnormally high velocities receded. Some 70% of the fish passed at velocities of 7.3 fps and 95% passed at velocities of 6.9 fps. The present design criteria for allowable maximum flowrate for a culvert of this size is 1.8 fps. A cost analysis of a proposed headwall and culvert installation 10 ft. in diameter and 50 ft. long, designed to replace the existing pipe, showed a 20 fold increase in cost. Fish passage observations at this site indicate that the design criteria requiring such a large replacement culvert are excessively conservative. Recommendations for improved design criteria are included with this report.

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The Sport Fisheries Division of ADF&G was very helpful during this project. In particular, Fred Williams and Butch Potterville of the Glennallen Sport Fish Division are thanked for assistance. Members of the Fairbanks ADF&G who deserve thanks include Jerry Hallberg, Rocky Holmes and Gene Roguski, who provided beach seines and, more importantly, encouragement.

Members of the Habitat Division of ADF&G were critical of this project from its inception to its conclusion, and they are acknowledged for their involvement with the project.

Doug Kane of the Water Research Center, Institute of Northern Engineering, University of Alaska-Fairbanks, is thanked for assistance and the use of equipment.

Jim Reynolds and Jackie LaPerriere of the Alaska Cooperative Fisheries Research Unit, University of Alaska-Fairbanks, are thanked for their constructive comments, advice and use of equipment.

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CHAPTER I
EXECUTIVE SUMMARY

Introduction

A study was conducted in 1985 to investigate the swimming performance of Arctic grayling (*Thymallus arcticus*) through a highway culvert in Alaska. The project used a visual technique to determine fish passage through the culvert in Poplar Grove Creek at Milepost 138.1 on the Richardson Highway, some 23 miles north of Glennallen, Alaska.

The overall objective of the project was to study the ability of Arctic grayling to pass through an existing culvert under a variety of conditions.

Project Description

The field investigation of the project occurred during the period of May 15 to June 1, 1985. This period included "breakup" when the stream went from ice-covered to free-flowing conditions. Fish were captured and tagged near the confluence of Poplar Grove Creek (PGC) and the Gulkana River. Small, light-weight, plastic streamer tags were inserted at the base of the dorsal fin of the fish. A total of 1,252 fish were tagged out of an expected population of about 4,000. The size distribution of the tagged fish included 792 greater than nine inches and 460 less then nine inches but greater than six inches. The tags were color-coded according to fish size. Following tagging, the fish were released back to Poplar Grove Creek where they were expected to migrate upstream to their spawning habitat. During their migration they transcended through about three miles of braided meandering channel before encountering the highway culvert.

Hydrological conditions were unusual during the study period. The peak discharge was 139.1 cfs, which correlates with the 20-year flood for this stream. This high flow rate resulted in very high stream velocities, which were nearly 12 feet per second (fps). The excessive velocities may have impeded the swimming performance of the fish, especially smaller ones, and delayed their arrival at the highway culvert.

Fish first arrived at the culvert on May 23, three days after the initial tagging. The culvert is a five-foot-diameter, 110-foot-long corrugated metal pipe that is skewed to the highway at about 45 degrees and on a gentle slope of 0.5%.

The observation technique consisted of stationing observers at the inlet and outlet of the culvert. Flashboards were employed to enhance visibility. As the fish entered the culvert, they were recorded and timed during their journey through the pipe.

No fish were observed passing through the culvert until May 26, three days after their arrival at the scour pool. The water velocity in the pipe at this time was about 9.2 fps. Significant numbers of fish were unable to negotiate the culvert until May 31, eight days after their arrival. During the eight-day period, average pipe velocities ranged from 12 to 7.3 fps. Water quality conditions on May 31 included apparent color of 50 units, turbidity of five NTU, dissolved oxygen of nine mg/l and a temperature of 7°C.

During the eight-day period, May 23-May 31, fish were observed attempting to enter the culvert. They seemed highly motivated to do so and frequently were observed leaping at the pipe from 5-20 feet back and 2-5 feet high. On May 25, about six p.m., the leaping attempts peaked when the frequency reached one attempt each 1.35 seconds.

Sport fishing pressure was severe during the eight-day period of May 23 to May 31. Approximately 2,600 fish were removed from the scour pool during that time as determined by creel census.

Conclusions

The cost-effective, simple techniques used during this project to monitor fish progress were successful. The procedures were experimental and we encountered unusual hydrologic conditions, so it is recommended that the procedures be further evaluated on other streams, culverts and fish species.

1. The observation technique was successful. The specific type of fish tag employed was appropriate, but it did impede the performance of small fish (less than six-inches in length) during

the high velocities encountered. The flashboards enhanced visibility, and the tags were easily observed for the existing conditions. However, it is expected that visibility would be restricted by greater turbidity, color concentrations or depth of flow greater than three feet.

2. The experimental design of the project could be improved by including upstream recapture of fish and by using more sophisticated techniques to monitor and confirm fish movement through the pipe. Improved cooperation and communication with ADF&G would also be desirable.

3. Large Arctic grayling successfully negotiated the pipe at average water velocity through the pipe of 9.2 fps. Significant numbers of grayling passed through the culvert when the velocity receded to 7.3 fps and the water temperature was 7.7°C. There is controversy regarding the definition of percent passing the culvert. The Habitat Division of the Alaska Department of Fish and Game feels that, for the purpose of evaluating the ADF&G fish passage criteria, all fish in the scour pool below the culvert should be considered as failures even when no attempts are made.

   For this study, percent passing means any fish that entered the culvert and exited at the pipe inlet was considered a successful attempt. Any fish that entered the pipe but did not exit the culvert inlet was considered a failure. The success rate at 7.3 fps and 7.7°C was 78%. A 95% success rate was achieved when the temperature was 9.5°C and the velocity had dropped to 6.9 fps.

4. Sport fishing at the culvert scour pool seriously interfered with the research activities. It also can have a devastating effect during breakup on fish populations utilizing undersized fish passage structures, such as the Poplar Grove Creek culvert.

5. The Alaska Department of Fish and Game fish passage criteria should be carefully reevaluated. Recognizing the preliminary nature of this research and the unusual hydrologic conditions encountered,

caution should be exercised in the use of this project's data. However, the proposed Poplar Grove Creek culvert replacement will occur in the near future at a 20-fold increase in cost (compared to original structure cost). Yet, even then, the pipe will not be in compliance with the present ADF&G criteria.

Information gathered from this study suggests that the ADF&G fish passage criteria may be too restrictive. A review of the variance parameters indicated some discrepancies. With a large number of state culverts presently out of compliance, conformance with conservative and possibly over-restrictive criteria will be very expensive and may not result in cost-effective use of the public's funds.

A balanced approach to protection of the resource along with the wise expenditure of the public's money for fish passage structures is desired. Results of this study may help to accomplish that goal.

CHAPTER II
INTRODUCTION

Fish populations are widely distributed throughout Alaska and must often pass through highway stream crossings. These crossings can be crucial to the seasonal migration of fish populations because of modifications to the natural flow regime. They may impede access to feeding, spawning or overwintering habitats. The proper design of highway culverts is essential to facilitate fish passage, so the design criteria should be technically supported. The criteria must ensure fish passage but still consider the hydrological conditions of the stream site, the difficulty of culvert installation, and the economics of design and construction.

The Alaska Department of Transportation and Public Facilities (DOT&PF) is the primary agency responsible for design and construction of roads in Alaska. The Alaska Department of Fish and Game (ADF&G) has authority, as provided by the Alaska Legislature, to ensure efficient fish passage through highway stream crossings (A.S. 16.05.840 and 870; see Appendix A). Many road projects are federally funded and, therefore, may require fulfillment of the National Environmental Policy Act (NEPA), as well as all pertinent state and federal laws. For these cases involving NEPA, the U.S. Fish and Wildlife Service coordinates with ADF&G and DOT&PF to maintain fish passage.

In order to facilitate fish passage, ADF&G has set maximum water velocities for varying culvert lengths that can be attained during a mean annual flood discharge ($Q_{2.33}$). This means that the mean annual flood will occur every 2.33 years. For the purpose of clarification, it is noted that the $Q_{2.33}$ represents an instantaneous discharge on a hydrograph. Refer to Figures 4 and 10 for additional information. For interior Alaska, the estimated swimming performance of Arctic grayling (<u>Thymallus arcticus</u>) is used as the design criteria, with several control parameters, for designating maximum culvert outlet velocities. These criteria were derived by the Alaska State Pipeline Coordinators Office (SPCO; 1981-1982) from data generated from MacPhee and Watts (1976). The criteria are presented in more detail in Chapter III. MacPhee and Watts analyzed the swimming performance of Arctic grayling for varying outlet velocities through a two-foot-diameter culvert during controlled conditions. There are no known additional studies that investigated the applicability of the extrapolated criteria in natural stream conditions or using culverts of larger diameter. Two other technical references are cited because they contain relevant fisheries information (Stanistaw and Stanistaw, 1962; Bell, 1973), but the studies did not include actual measurements of fish swimming performance.

Objectives

DOT&PF and the University of Alaska-Fairbanks initiated a study in 1985 to investigate a highway culvert that is inadequate for fish passage according to ADF&G criteria, yet appeared to pass a significant number of fish.

Poplar Grove Creek was selected for this project because of prior studies conducted there by MacPhee and Watts (1976) during 1973 through 1975, and by Tack and Fisher (1977) in 1976. Their research compiled extensive information on the stream's fisheries and hydrology. It was here that MacPhee and Watts recorded the data that was eventually used to generate the ADF&G fish passage criteria. The highway culvert at the stream crossing is inadequate, according to the ADF&G criteria (Travis, 1985). Nevertheless, many Arctic grayling pass through it during the upstream spawning migration following spring breakup (Williams and Potterville, 1985).

The study had four main objectives.

1. To develop a procedure for analyzing a culvert's ability to pass fish.

2. To determine the success rate of Arctic grayling passing through a highway culvert that is considered inadequate for fish passage according to ADF&G criteria.

3. To determine if additional, more comprehensive studies need to be conducted to verify or modify ADF&G's criteria.

4. To investigate what other state highway departments and resource agencies are doing to address fish-passage problems.

Justification

To meet the fish passage criteria, DOT&PF must often design and install large diameter culverts or even bridges when a small culvert might function adequately. Even after these structures have been provided, their general effectiveness for passing fish is greatly debated. As a result, some engineers feel that ADF&G's requirements are too restrictive and add an unjustified expense to highway projects. Contrary to this opinion, some fish biologists feel the criteria for design are too liberal and do not provide sufficient protection to the resource. Therefore, based on the need for additional data, further evaluation of existing criteria, and a desire to optimize cost effectiveness and resource protection, this project was undertaken.

CHAPTER III

LITERATURE SEARCH

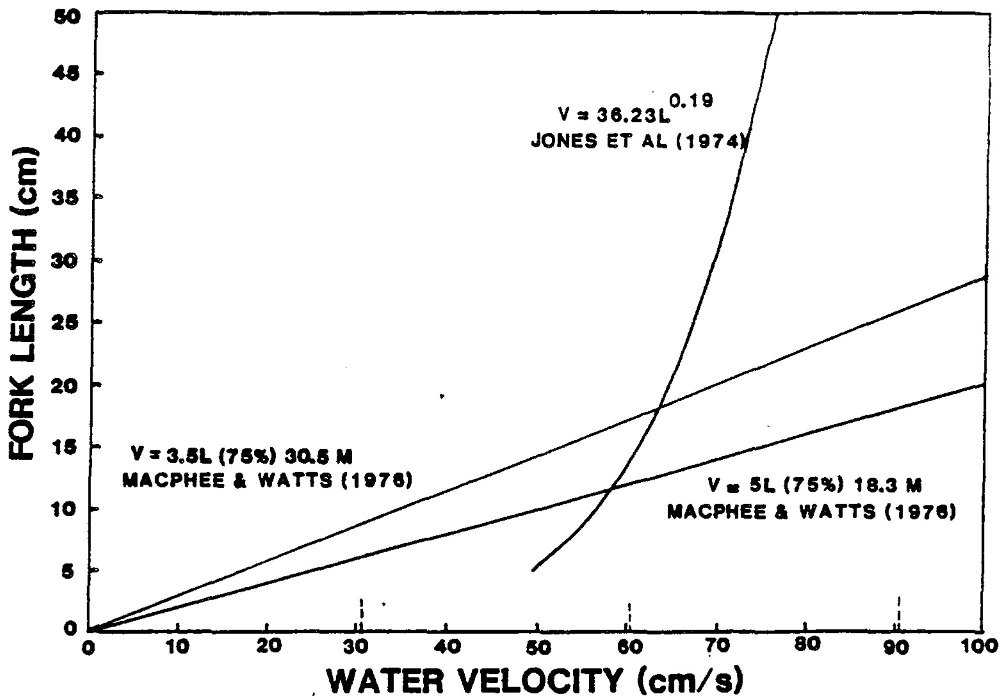
A literature search on fish passage was conducted. The main scope of the search concentrated on the swimming performance of Arctic grayling through highway drainage structures because ADF&G uses grayling as the design species for designating maximum culvert outlet velocities for interior Alaska. The search also reviewed literature on the implementation of fish passage criteria by regulatory agencies. In addition to reviewing the literature, letters were sent to highway departments and natural resource agencies in the United States and Canada requesting fish passage information from their areas. Their responses are summarized in Chapter IV.

There have been relatively few field studies performed to determine acceptable pipe velocities for fish passage through culverts. Kane and Wellen (1985) noted that "...Although numerous reports are available relative to fish swimming performance, a review of these papers reveals that a small core of papers are repeatedly cited...," and that most of the research has been done with salmon.

Arctic Grayling Swimming Abilities

Only two papers were found that address the swimming performance of Arctic grayling (Jones et al., 1974; and MacPhee and Watts, 1976). Jones et al. studied the critical velocities that Arctic grayling can negotiate, while MacPhee and Watts (1976) analyzed the grayling's ability to pass through various culvert lengths at different outlet velocities. These studies generated different results. Kane and Wellen (1985) plotted these results and they are displayed on Figure 1. Jones et al. determined that their results can be expressed as an exponential function while MacPhee and Watts found their results followed a linear relationship.

Jones et al. (1974) used the following experimental procedure to analyze the swimming performance of Arctic grayling. Between one and four fish at a time were introduced into a 25.4 cm (10 in) diameter, 152 cm (60 in) long plexiglass tube. The fish were first acclimated to



Jones et al

$V = KL^{X}$

MacPhee and Watts

V = 3.5L for 75% passing for a 30.5 meter culvert

V = 5.0L for 75% passing for a 18.3 meter culvert

Where

V = CRITICAL VELOCITY, cm/sec

K = CONSTANT

L = FORK LENGTH, cm

X = EXPONENT

FIGURE 1: COMPARING JONES ET AL WITH MCPHEE AND WATTS

FIGURE FROM KANE AND WELLEN, 1985

their surroundings by being subjected to a constant water velocity of 10 cm/sec (0.33 ft/sec) for one hour with an electrified grid covering the downstream end to provide "...the stimulus to swim..." At the end of this time, the velocity was increased 10 cm/sec every 10 minutes until the fish were carried back to the grid. The fish had no resting periods during the test.

The grayling tested had fork lengths between 7 cm (2.75 in) and 37 cm (14.6 in). The tests were performed with water temperatures between 7°C and 20°C. The grayling that were tested were not migrating upstream to spawn. Although Jones et al. (1974) did not specifically state the maximum water velocities that the fish could endure, Figure 1 shows that a fish with a fork length of 24 cm (9.5 in) would have been able to maintain their swimming position up to a maximum velocity of about 68 cm/sec (2.2 fps). Jones et al. could not verify any relationship between swimming performance and water temperature.

MacPhee and Watts (1976) analyzed the percent passing of Arctic grayling through two 24-inch-diameter culverts (60- and 100-feet long). The grayling were migrating upstream to spawn. Fish were netted behind a weir and then transferred to holding boxes that were positioned below the outlets of the culverts. Various outlet velocities were generated by tilting the culverts up or down, and by changing the headwater depth at the culvert inlet. The fish remaining in the downstream holding box after 18 hours (1973-1974) or 44 hours (1975) were deemed as unsuccessful attempts. The percent success rate of the grayling negotiating the culverts was recorded for various outlet velocities. Water velocities in the culverts ranged from 0.6 m/s to 1.9 m/s (2.0 fps to 6.2 fps). The fish studied had fork lengths between 8.5 cm (3.3 in) and 36 cm (14.2 in).

MacPhee and Watts (1976) noted that water temperature greatly influences the grayling's ability to swim longer and negotiate significantly higher water velocities. The swimming performance of grayling, conducted in circular tanks, increased about 80% with an increase in water temperature from 0°C to 14°C. They also observed that grayling migrating downstream were less motivated to swim vigorously than those migrating upstream.

It is also important to note that MacPhee and Watts conducted tests on the swimming performance of Arctic grayling by using a circular swimming channel to obtain voluntary cruising speed and sustained speed information. These swimming performance studies were then to be used to project culvert length for design purposes.

ADF&G Fish Passage Criteria

From 1976 to 1984, the Northwest Alaskan Natural Gas Pipeline project was being designed to bring natural gas from Prudhoe Bay to the Canadian Border and, eventually, to the continental United States. The gas pipeline as proposed was to approximately parallel the Trans-Alaskan oil pipeline from Prudhoe Bay to Delta Junction. From Delta Junction, the gas line would have approximately followed the Alaskan Highway to the Canadian Border. Along the proposed gas line route, project activities could potentially affect 388 water bodies by crossing or nearly crossing these areas (LGL Ecological Research Associates, 1981). A large majority of these water bodies provide fish habitat, so the project had to provide fish passage structures that would allow the resident fish species to continue to utilize these habitats.

Alaska developed a regulatory agency to oversee the environmental concerns which arose from the gas pipeline project. This agency was called the State Pipeline Coordinator's Office (SPCO). During the winter of 1981-1982, SPCO attempted to develop fish passage criteria that would be used to design drainage structures for fish sensitive streams on the gas line project.

Arctic Hydrologic Consultants (1985) summarized the technique SPCO used to generate the fish passage criteria. They developed an equation to predict the average cross-sectional velocity at which a specified percentage of a specified length class of Arctic grayling within a culvert of specified length can pass. This equation was derived by processing the MacPhee and Watts (1976) data through a multiple linear stepwise regression program, BMDP-2R (UCLA, 1979). The final equation (equation 1) was expressed as

$$V = 0.541 - 4.97 \log(CL) + 5.7 \log(FL) + 0.786 \log(T) - 1.13 \log(P+1) \quad [1]$$

where

V = the maximum average cross-sectional water velocity in a culvert at which grayling can pass, in feet per second (fps)

CL = culvert length in feet

FL = fork length of grayling class in millimeters

T = water temperature in degrees Celsius (C)

P = percentage of grayling in a given length class (FL) required to pass the culvert.

Arctic Hydrological Consultants (1985) found that the standard error of the estimates (SEE), the correlation coefficient (R), and the coefficient of determination (variation) (R^2) are as follows:

SEE = 0.700 fps

R = 0.742

R^2 = 0.550

Arctic Hydrological Consultants stated that the SEE and R^2 are "...not particularly good..." and, therefore, "...although the equation provides a useful tool, it has considerably more variability associated with it than one would like...." These investigators felt that the major source of the variability in the regression equation was possibly due to the variable swimming abilities that MacPhee and Watts (1976) observed.

To simplify the equation, SPCO (Post, 1981) adopted a reduced form of the equation (equation 2) to be used where site-specific information is unavailable.

$$V = 12.483 - 4.972 \log(CL) \quad [2]$$

This equation was derived by using the following values. The water temperature (T) was assumed to be 2.78°C. The grayling fork length (FL) was assumed to be 241 mm. The percent passing (P) was specified as 75%.

After consulting with ADF&G personnel, Post (1981) felt that a water temperature of 2.78°C (37°F) was a good estimate of the conditions that grayling would encounter during a spring discharge. ADF&G (Post, 1981) also felt that most grayling that were 241 mm (9.5 in) or larger were sexually mature, and that at least 75% of this size group should be allowed to pass through a culvert at any given time to prevent any harm to the stream's grayling population.

Figure 2 displays the maximum allowable outlet velocities for varying culvert lengths that were generated from equation 2.

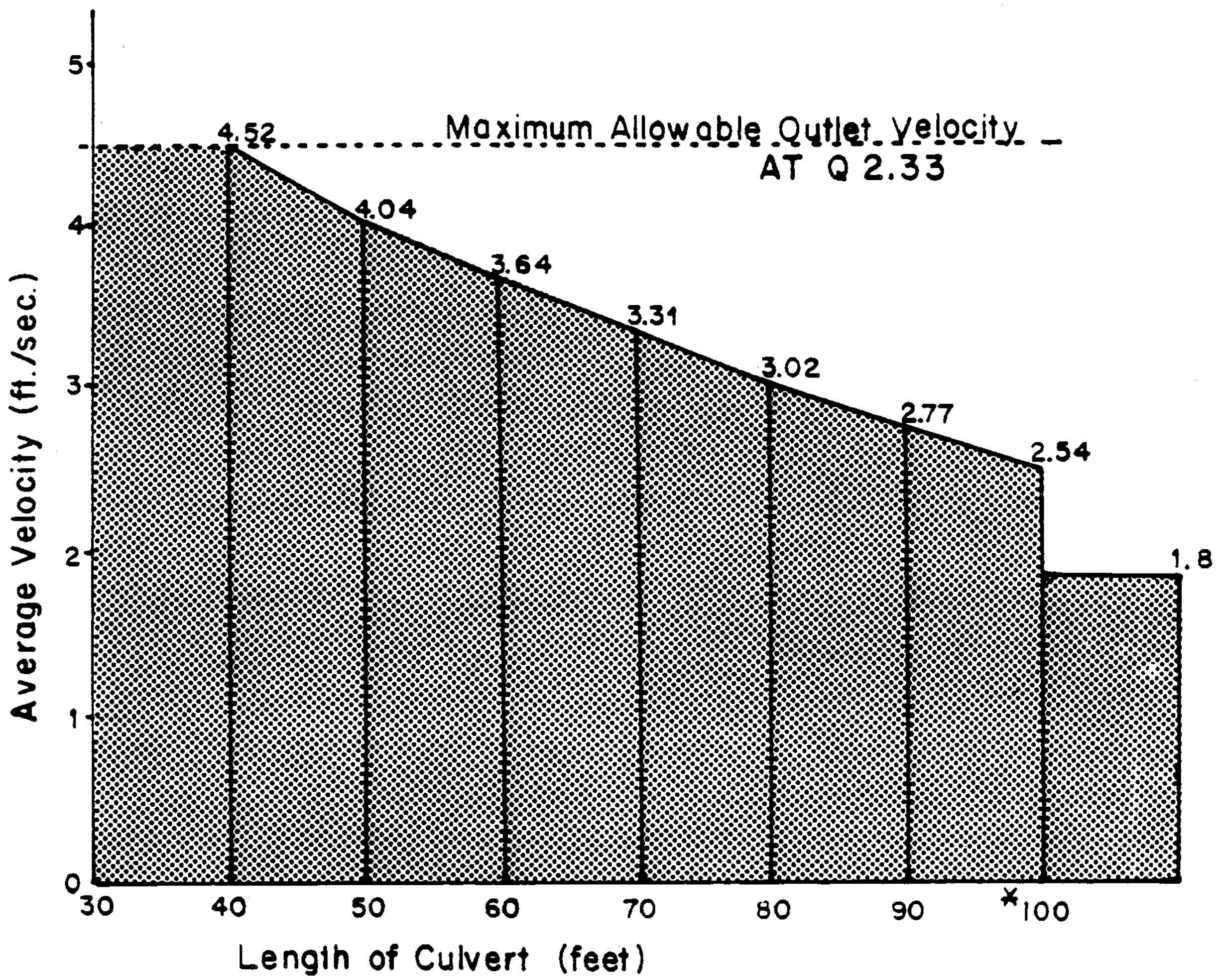
ADF&G officially adopted the SPCO fish passage criteria on April 26, 1982 (Logan, 1982). At the time, the ADF&G Habitat Division was instructed to evaluate all permit applications for drainage structures in fish streams using the fish passage criteria (based on Group II fish), regardless of what fish species was involved (Logan, 1982). The adoption and implementation of the criteria occurred without any specific investigation of its applicability in natural systems, and no follow-up investigation has occurred to verify or substantiate the use of the criteria.

Other Approaches to Fish Passage Criteria

Dryden and Stein (1975) were contracted by the Canadian Department of Environment to develop guidelines for the protection of fishery resources during highway construction and operation. They advocated using Schultz's (1974) recommended maximum velocity of 3 fps for the design of culverts. They advised that this velocity could only be exceeded for three days during the mean annual flood ($Q_{2.33}$) or seven days during a 50-year flood (Q_{50}). There was little scientific reason for these recommendations. Dryden and Stein's study was based on the review of other investigators' research and did not include actual scientific measurements. The recommendations were formed from the results of their review.

Ashton and Carlson (1984) expanded on Dryden and Stein's (1975) recommendations and developed multiple linear regression equations that determine the highest consecutive mean discharge for one-, three-, seven- and fifteen-day durations, and the lowest consecutive mean

ADF&G ASSUMES ADHERENCE TO THESE VELOCITIES WILL ALLOW 75% OF 9.5 INCH GRAYLING TO PASS THE CULVERT AT A WATER TEMPERATURE OF 2.8° C.



*1.80 ft./sec. for culverts larger than 100 feet

FIGURE 2: ALASKA DEPARTMENT OF FISH AND GAME FISH PASSAGE CRITERIA

discharge for three-, seven-, fourteen- and thirty-day durations. A log normal distribution was used to estimate the recurrence intervals of these flow durations for 1.25, 2, 5, 10 and 20 years. Ashton and Carlson concluded that the culvert designer should consider predicted peak flow durations in addition to the instantaneous peak flows when designing culverts for fish passage.

In the fall of 1978, the Canadian Department of Public Works (PWC) stated that strict adherence to Dryden and Stein's criteria was not economically viable for many crossings. PWC requested the Canadian Department of Fisheries and Oceans (DFO) to provide alternative approaches (McKinnon and Hnytka, 1979). DFO analyzed several design approaches for specific stream crossings where fish passage was required through culverts. They found that a more desirable approach to fish passage design was to shift from designated maximum velocities to culvert design criteria. This new approach was termed "stream simulation" (McKinnon and Hnytka, 1985). Stream simulation is defined as "...maintaining natural stream properties at the crossing (i.e., average cross section, width, slope, substrate) for flows up to the fish migration discharge, concentrate low flows and provide within the culvert a rock substrate, stable at the Q_{50} flood...." McKinnon and Hnytka (1979) defined the term "fish migration discharge" as "...the maximum discharge that allows fish to traverse a stream crossing..." which generally may be taken as the mean annual flood ($Q_{2.33}$).

McKinnon and Hnytka (1979) advocated installing a rock substrate within a culvert such that the stream would cut a thalweg through the substrate. During lower flow conditions, the water would concentrate in the thalweg and prevent low flow barriers to fish migration.

Two research projects recommended that fish passage criteria should take account of the slow velocities that are present along the boundaries of a drainage structure (Morsell et al., 1981; and Kane and Wellen, 1985). The concept is based on the theory that fish seek out the path of least resistance.

These low velocities are found near the banks and bottoms of streams and along culvert boundaries. By altering the roughness of a culvert, the velocity can be modified at or near the vicinity of the boundary and thus facilitate fish passage. The depth of the boundary layer is described in the following paragraphs.

Morsell et al. (1981) developed a hydrologic model that describes the velocity of a zone close to the culvert bottom, which is called V-occupied. Kane and Wellen (1985) analyzed this concept and found that if this model is valid, then V-occupied equals about 0.625 of the average cross-sectional velocity.

Kane and Wellen (1985) had some reservations about this relationship, and they developed a different approach to describing the V-occupied zone. They suggested that the depth of the occupied zone be defined by the height of the design fish in the stream. The velocity of this zone could then be found by using equation 3.

$$V = \frac{(32g)^{1/2}}{1.49} V_{ave} nR^{-1/6} \log(Y/Yo) + \frac{0.88(8g)^{1/2}}{1.49} V_{ave} nR^{-1/6} + V_{ave} \quad [3]$$

where

V = velocity of V-occupied zone (fps)

V_{ave} = average velocity in cross section (fps)

Y = depth of V-occupied zone (ft) (equal to the height of design fish)

Yo = total depth of flow in culvert (ft)

n = Manning's roughness coefficient

R = hydraulic radius (area/wetted perimeter)

g = gravitational acceleration constant (ft/sec^2)

Kane and Wellen (1985) used a modified version of this equation to predict the velocity profiles for 49 culverts where velocity profile measurements were taken. They stated that, in 34 cases, the predicted velocity profiles conformed quite well with the measured profiles, while the comparison was not very good in 13 cases.

By setting the g equal to 32 ft/sec^2, equation 3 simplifies to

$$V = V_{ave}(21.477nR^{-1/6}\log(Y/Yo) + 9.45nR^{-1/6} + 1) \quad [4]$$

Culvert Design Criteria

The literature review yielded several reports that discussed recommendations for designing and installing roadway culverts that will provide adequate fish passage (Metsker, 1970; McClellan, 1971; Gebhards and Fisher, 1972; Evans and Johnston, 1974; Lowman, 1974; Dryden and Stein, 1975; Katopodis, 1977; Dane, 1978; USDA Forest Service, 1979; Morsell et al., 1981; Arctic Hydrological Consultants, 1985). All of these papers stated that the depth of burial, slope, culvert length and hydraulic capacity were critical parameters in providing fish passage.

Due to hydraulic scour, stream bed materials often erode away from culvert outlets and produce elevated culvert inverts. This condition is termed "perched" and forces fish migrating upstream to jump into the culvert as they continue to swim upstream. If the culvert is perched higher than the jumping ability of the fish, it will become a barrier to upstream migration. To prevent perching from occurring, several authors recommend burying the culvert invert below the natural stream bed. Evans and Johnston (1974), Dryden and Stein (1975), and USDA Forest Service (1979) recommend burying the culvert invert a minimum of six inches below the natural stream bed elevation. Dane (1978) advised depressing the invert at least 1 foot. Morsell et al. (1981) recommended at least one-fifth of the culvert's diameter be set below the lowest elevation of the natural stream bottom at the place of installation. Dryden and Stein (1975) and Dane (1978) also advised placement of a "scour apron," which is an artificial substrate constructed of a nonerodable material (i.e., riprap) at the culvert outlet to prevent perching.

As the slope of the culvert increases, the velocity of the water also increases. Therefore, most researchers recommend installing culverts at the flattest gradient possible. Evans and Johnston (1974) recommend installing culverts close to zero percent. Gebhards and Fisher (1972), Dryden and Stein (1975), Dane (1978) and Morsell et al. (1981) advocate installing culverts up to a maximum slope of 0.5%. USDA Forest Service (1979) recommends placing culverts on a stream gradient less than 2%. All the literature sources that we reviewed recommend placing the culvert parallel to the natural stream gradient.

If the natural slope exceeds the maximum allowable gradient for fish passage, then the use of baffles is advised. Dane (1978) recommends using baffles up to a maximum slope of 5.0%.

In most culverts, fish do not have resting areas while swimming upstream. If the water velocity and culvert length exceed the fish's swimming endurance, then the culvert will become a barrier to fish movement. Therefore, the shorter the culvert, the less likely it will block fish migrating upstream. Dryden and Stein (1975), Dane (1978) and Arctic Hydrological Consultants (1985) recommend using the shortest culvert length possible.

Almost all of the fish passage literature recommend designing the hydraulic capacity of culverts to pass a 50-year flood (Q_{50}) with an inlet headwater depth equal to the culvert diameter. The authors felt that this criterion ensured the stability of the structure and produced outlet velocities that would allow upstream passage of fish during periods of high flow. The two exceptions to the Q_{50} criterion were Dane (1978) and USDA Forest Service (1979). They recommended a hydraulic capacity of Q_{100} and Q_{25}, respectively.

CHAPTER IV

FISH PASSAGE SURVEY

This chapter is a synopsis of a fish passage survey which was conducted during 1985. Letters were sent to highway departments and natural resource agencies in the United States and Canada requesting fish passage information from their areas.

Forty-four states and all Canadian provinces responded to the letter of inquiry for fish passage information. Their responses are summarized in Appendix B. The states that did not respond were Alabama, Colorado, New Hampshire, North Dakota and West Virginia. Twenty states reported they usually did not have problems with fish passage through highway culverts. Except for Hawaii, most of these states are in areas of flat topography (i.e., Kansas, Iowa, etc.). A number of states including Arizona, Maine, Minnesota, Nebraska, Oregon and Washington indicated close coordination between resource agencies and transportation agencies. Alaska and California were the only two states reporting use of "fish passage task forces" (refer to Appendix B). Eighteen highway departments reported having a good working relationship with resource agencies when addressing fish passage problems. These 18 departments commonly suggested that: (1) early coordination should occur between highway and resource agencies during the design phase; (2) culvert inverts should be depressed approximately 1 to 2 feet below the natural stream bed; (3) culverts having slopes greater than 1% should have a baffling system; and (4) the remaining culvert volume (after suppression and the addition of baffles) should be able to handle approximately a Q_{50} discharge.

Several highway departments have a policy of establishing either a formal or informal fish passage task force. The teams are composed of personnel from various disciplines including design and hydraulic engineers, environmental specialists and personnel from resource agencies. Early in the development of a project, the highway departments procedurally contacted pertinent resource agencies to determine: (1) whether an important fishery utilizes the stream in question; (2) if there is currently a fish passage problem; and (3) if there is sufficient spawning and rearing habitat above the culvert to warrant the costs involved in establishing, maintaining or reestablishing fish passage. Based on these determinations, fish passage either becomes a design criterion for the project, or it is not considered further. The final fish passage design is coordinated with the resource agencies and then is finally submitted to the district's hydraulic engineer for approval.

Responding agencies recommended positioning the culverts parallel to the natural stream gradient. The culverts are depressed approximately 1 to 2 feet below the stream bed to prevent perching and then are allowed to fill in naturally. If the culvert's slope is greater than 1%, either riprap or a baffling system is employed. Baffling consists of either a simple concrete weir, removable plates on hangers for simplified maintenance operations or a variety of complexed channeling techniques. Regardless of which system is used, the culvert is usually somewhat oversized to retain its hydraulic capacity for a Q_{50} discharge.

Three state resource agencies (Arizona Department of Fish and Game, Minnesota Department of Natural Resources and Wisconsin Department of Natural Resources) reported that they work with highway departments to <u>create</u> blocks to fish migration. This is done to prevent the destruction of prime upstream fisheries from the invasion of undesirable fish species (i.e., carp, lamprey, etc.).

CHAPTER V

METHODOLOGY

This chapter describes the field investigation at Poplar Grove Creek. It includes an overview of the study area, tagging procedures, observations of upstream migration, water quality measurements, and measurements of discharge and water velocity. The techniques used to analyze fish swimming performance and conduct the creel census are also presented.

Project Site Description

The field investigation took place between May 15 and June 1, 1985, along Poplar Grove Creek, which is located approximately 23.1 miles north of Glennallen, Alaska (Figure 3). The creek's width varies from 5 to 15 feet along its five-mile length. It flows through a culvert on the Richardson Highway at Milepost 138.1 and then discharges into the Gulkana River, which is about 1.8 miles below the highway crossing.

Poplar Grove Creek drains an estimated 12 square miles above the highway culvert. Additional drainage is located on the downstream side of the culvert. The upper portion of the drainage basin is relatively flat, with scattered tundra bogs and ponds. After flying over the drainage basin in a fixed-wing aircraft and studying area maps, it was estimated that approximately 20% of the drainage basin serves as hydraulic storage (Travis, 1985). The creek's first three miles follows a moderate gradient of about 0.5%. However, shortly after crossing the highway, the creek's gradient steepens to about 1.2% as the stream flows toward the Gulkana River valley. The stream's calculated magnitude and frequency of peak discharges were estimated by using Lamke's linear regression method (Lamke, 1979), and they are displayed in Figure 4. The predicted flow rates are for the 12 square miles of drainage above the highway.

Poplar Grove Creek experiences long, cold winters and short, warm summers. The average January air temperature is -12°F, and the average July temperature is 58°F. The drainage basin receives an average yearly precipitation of 15 inches. During the field investigation, the

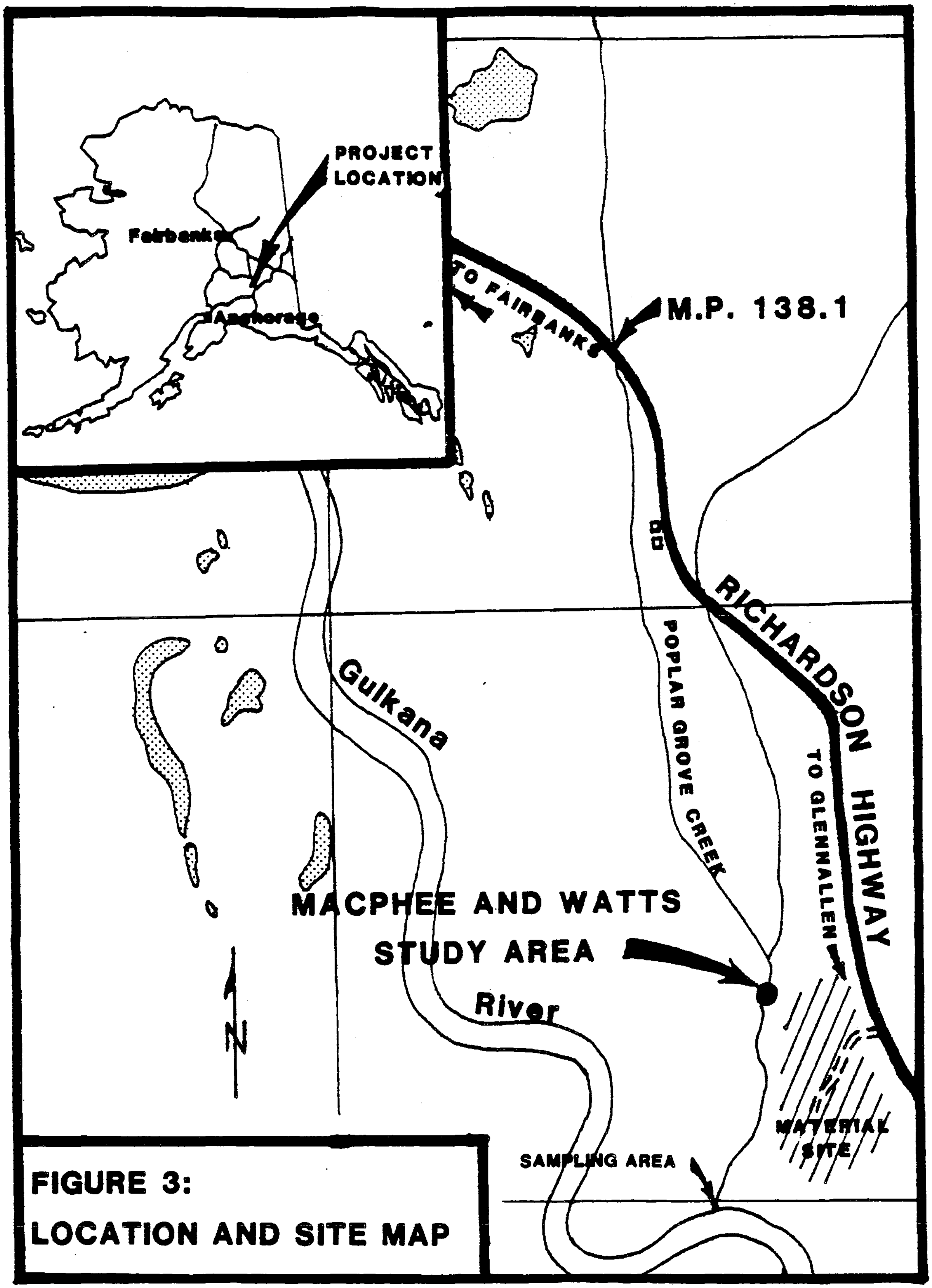


FIGURE 3:
LOCATION AND SITE MAP

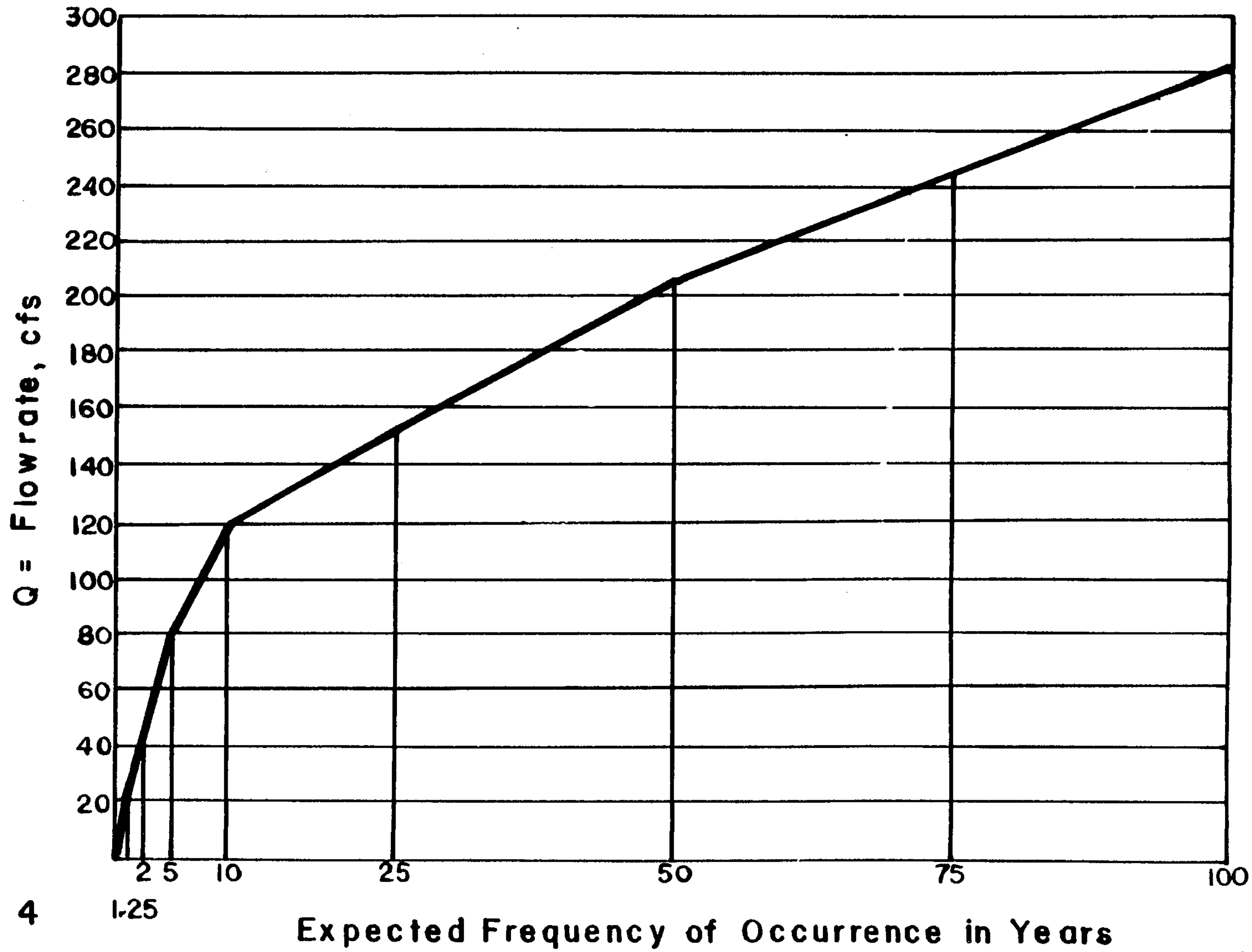


FIGURE 4

CALCULATED MAGNITUDE AND FREQUENCY OF PEAK DISCHARGE temperature ranged from 27°F to 73°F, and a total of 0.09 inches of precipitation fell (Gulkana FAA Flight Service Station, 1985).

Upstream from the highway crossing, Poplar Grove Creek is a typical tundra braided stream with relatively slow water velocities. Below the crossing, the channel becomes more confined, and the water velocity becomes more rapid. The water is humic stained which is typical of Alaskan tundra streams. The spawning habitat for the Arctic grayling is located in the headwaters about three miles upstream of the road crossing. The shallow lakes and ponds with connecting streams provide excellent spawning and rearing habitat. The ADF&G Sport Fisheries Division in Glennallen frequently takes advantage of this habitat and stocks the headwaters of Poplar Grove Creek with Arctic grayling fry (Williams and Potterville, 1985). The fry grow rapidly during the summer and migrate downstream in the fall to overwinter in the Gulkana River and Copper River drainage systems.

The Poplar Grove Creek culvert is 110-feet long (skewed to the road crossing at about 45 degrees), five feet in diameter and constructed of corrugated metal. It has been in place since 1953. The outlet is perched approximately one foot above the stream bed. In the middle of the culvert, subsiding road materials and traffic load have depressed the top of the pipe (Figure 5). The culvert is positioned on about a 0.5% slope, and no stream-bed material was present along the culvert's bottom during the field study. A 60-foot by 120-foot scour pool exists at the culvert outlet. The pool depth ranges from about 2 to 5 feet and is a popular fishing spot for local residents. The ADF&G fish passage criterion requires a maximum average outlet velocity of 1.8 fps during a $Q_{2.33}$ for a culvert of this length (Figure 2) for Arctic grayling (Logan, 1982).

The Richardson Highway is planned to be reconstructed with minor realignments between Mile 129 and 148 during the 1987 construction season. The highway crossing on Poplar Grove Creek will be realigned approximately 300 feet upstream. ADF&G has stipulated as a part of their permit process the removal of the existing culvert and the installation of a drainage structure at the new crossing that will meet their fish passage criteria (Liepitz, 1985). The design and cost of the new structure is addressed in Chapter VII.

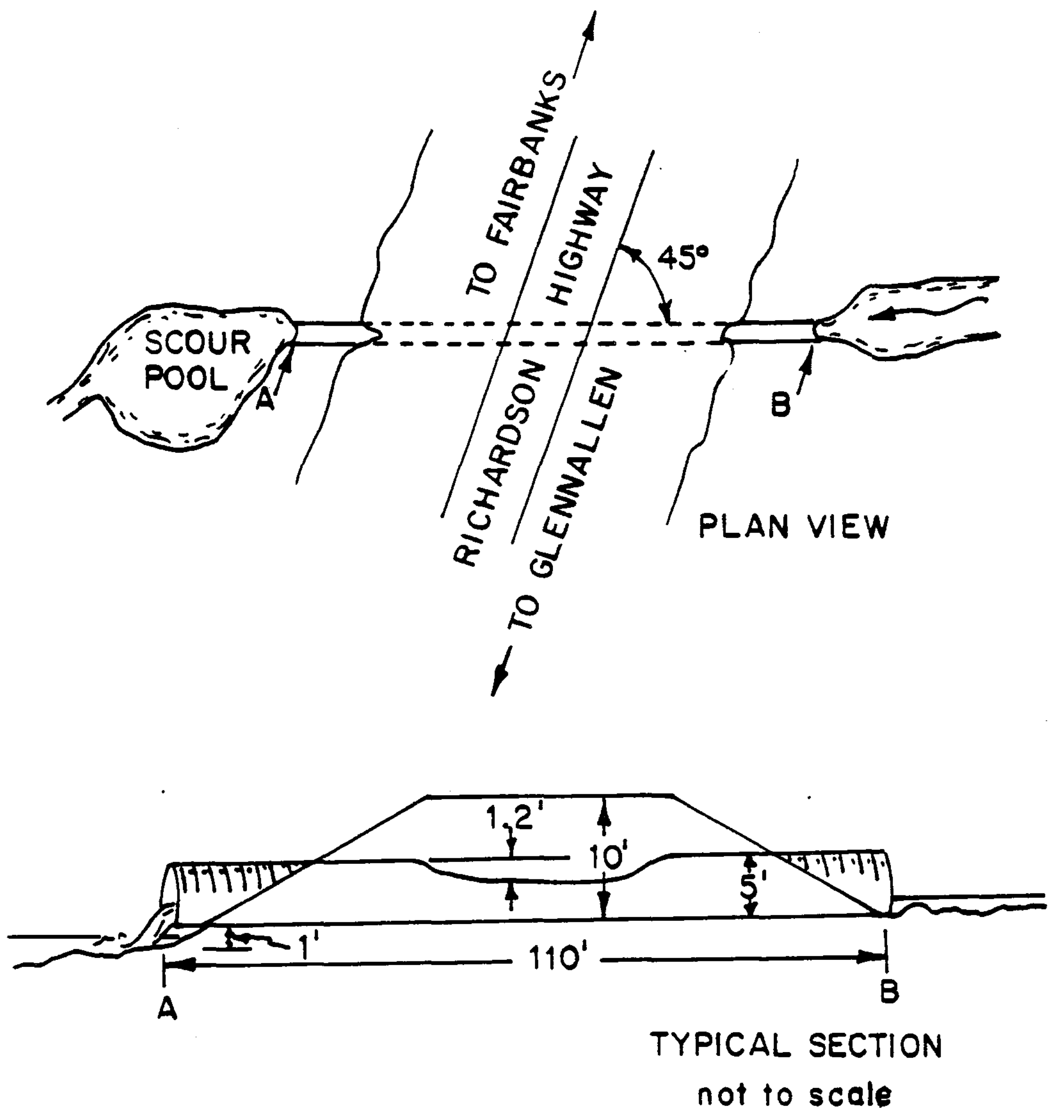


FIGURE 5: PLAN VIEW AND TYPICAL SECTION OF RICHARDSON HIGHWAY POPLAR GROVE CREEK

The project team had originally planned to arrive at Poplar Grove Creek on May 1, 1985, which historically was the time of spring thawing and breakup. However, the project area experienced an unusually late spring thaw, and the creek did not start flowing until May 12. The Glennallen ADF&G Sport Fisheries Division kept the project team in Fairbanks informed on site conditions. Finally, the team left Fairbanks and arrived at the project site on May 15.

When the team arrived at the creek, ice was still present on the stream bottom and inside the culvert. Approximately 12 cfs was flowing over the ice, and the water appeared low in turbidity and color. The water temperature was about 0°C.

General Methodology

The fish passage project required initiating several procedures. It included the capturing of Arctic grayling downstream of the culvert, tagging the fish according to length, and observing the grayling swimming through the culvert at measured water velocities and water quality parameters. A creel census was performed at the scour pool.

Tagging Operations

One of the first tasks the project team had to complete was the selection of a site for the subsequent capture and tagging of the fish. After walking downstream of the highway crossing to the mouth, three possible sampling sites were discovered: a pool about 1/4 mile downstream of the highway crossing; the MacPhee and Watts study site which is located about 1.2 miles downstream from the highway or about 0.6 mile from the mouth of Poplar Grove Creek; and the mouth of Poplar Grove Creek. With a minimum of alteration, all three sites would have been suitable for netting fish. It was felt that the pool would be the most advantageous place to tag and release migrating grayling because the fish would have sufficient distance to acclimate to the tag, but still would not have to travel a long distance to the culvert. In this way, tag losses would be minimized. The close proximity of the pond to the Richardson Highway would also facilitate the work of the research group. However, as the stream's flow rate began to increase, the only site where beach seining would be feasible was at the mouth. Therefore, the capturing and tagging operations were performed at the creek's mouth. This resulted in some inconvenience to the investigators, some potential loss of tags from fish attempting to negotiate the creek to the highway crossing, and some fish returning to the Gulkana River and migrating elsewhere.

Arctic grayling were captured near the mouth of Poplar Grove Creek at the beginning of their spawning migration between May 20 and 22, 1985. A sample size of approximately 1,000 to 1,500 tagged fish was desired. Some 1,252 fish were actually tagged. It should also be noted that the final population of tagged fish was skewed toward larger sizes because smaller fish were unable to swim with the tag. It is assumed that a lesser number of fish continued to migrate into the creek after May 22. Fish were captured by dip netting along the creek banks with a small landing net from 50 to 200 feet upstream of the mouth. Beach seining was possible but inhibited by high flow and debris along the banks.

The predicted total migrating population of about 4,000 fish was derived from prior studies (MacPhee and Watts, 1976; and Tack and Fisher, 1977). MacPhee and Watts (1976) counted 2,254 grayling from May 10 to June 5, 1973; 4,146 grayling from May 10 to June 4, 1974; and 4,237 grayling from May 10 to June 3, 1975. Tack and Fisher (1977) counted 3,722 grayling form May 5 to May 30, 1977. However, the actual total migrating population in 1985 may have been much higher than 4,000 as determined from a creel census and observations. Migration is discussed later in this report.

Fish were netted between 10:00 a.m. and 6:00 p.m., and immediately transferred to holding pens in a side channel of the creek near the mouth (Figures 6 and 7). The holding pens were two 30-gallon Rubbermaid trash cans perforated with 3/8-inch holes. These "live boxes" were weighted to the stream bottom with rocks and sandbags. To minimize mortality, only a few fish were maintained in the pens. Fish were individually transferred from the pens using wool gloves to a measuring cradle which consisted of a two-foot plywood box lined with foam rubber and a measuring stick along its bottom. Fork length was quickly

Figure 6. View of temporary weir and sampling site.

Figure 7. View of tagging operation.

measured to the nearest quarter of an inch. The fish were then tagged through the base of the dorsal fin and released. To prevent the downstream movement of tagged fish, a temporary weir was constructed from sandbags and wire mesh, approximately 20 feet downstream of the sampling area in the side channel. Fish were released upstream of the weir. Once a fish entered the main channel, it could either proceed upstream or move downstream into the Gulkana River. Due to high velocities, it is thought that some smaller fish were unable to swim upstream initially. This was subsequently confirmed by observing out-migrating tagged fish.

The tags for this study were 3-3/4-inch, thin plastic streamers approximately 1/8-inch in width (Floy Tag and Manufacturing, Inc., 1984; Model FTSL-73) (Figure 8). While originally designed for use on shrimp, the tag was selected because of its configuration and light weight.

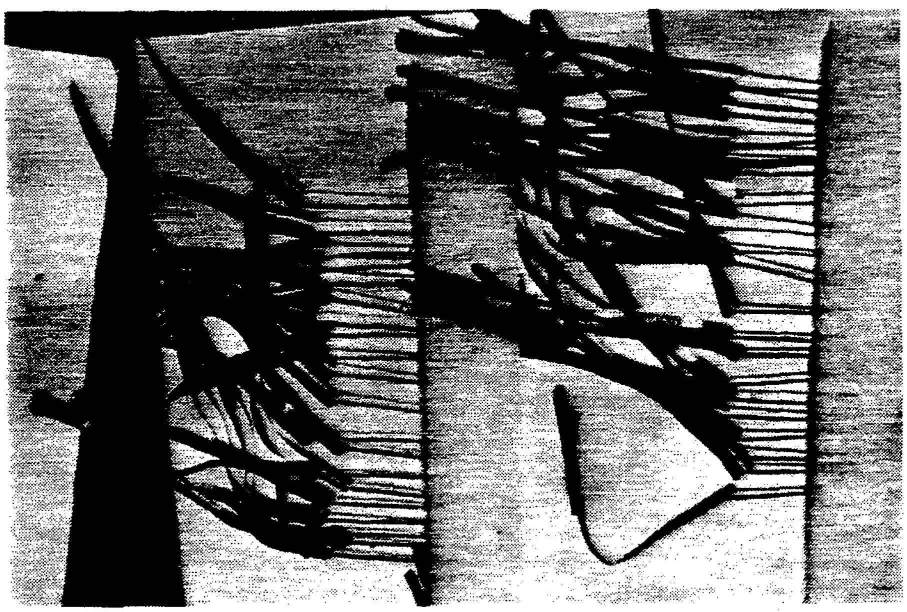


Figure 8. Floy stream tag Model FTSL-73.

Tags were colored to differentiate group sizes: orange, six to nine inches; and yellow and blue, greater than nine inches. Tag colors were selected to enhance visibility in colored, turbid water. Although the color selection was limited, better choices might be possible. Fish smaller than six inches were originally going to be tagged with the yellow streamers. Several small fish were tagged but they were having considerable difficulty in swimming with the tag in high-velocity water. Thus, the tagging of small fish (less than six inches) was suspended. The tags were not consecutively numbered because it was anticipated that recapture was not necessary and the scientific sampling permit did not allow recapture.

The subject of recapture became an important issue later in the project. In planning for the study, it was attempted to devise a visual observation process where recapture of the fish would not be necessary. This was done for two reasons: (1) a simple observation process was desired, and (2) ADF&G felt recapture could place undue stress on the fish and advised against it. Therefore, based on the advice and recommendation of ADF&G, recapture was not proposed in the permit application, except as a contingency (Tilsworth, 1985a and 1985b).

The tag was inserted into the base of the dorsal fin via a needle which detached from the tag once it was in place. A few (10-20) fish were tagged in the adipose fin, but this method proved to be inefficient and damaging to the fish, and so this method was discontinued. However, several fish arrived upstream at the culvert with tags in the adipose fin. Instructions were imprinted onto the tag requesting anglers to return the recovered tags to the Glennallen Sport Fish Division of ADF&G. Because of the substantial distance between the tagging area and the culvert (1.8 miles), it was assumed that the fish had recovered adequately from handling and tagging to become acclimated to swimming with the tag before reaching the highway crossing.

Observing Swimming Performance

Observations of tagged grayling were facilitated by using "flashboards" positioned on the stream bottom at the inlet and outlet of the culvert. The flashboards were four by eight feet and were constructed from 5/8-inch, all-weather plywood which was painted light gray. Fish swimming over the boards into and out of the culvert were more easily observed against the light background. There was some prior concern that the turbid and humic-stained water would interfere with observations. However, the flashboards did enhance visibility, and the fish and tags were clearly visible as they passed over the flashboards.

Fish were counted as they swam over the flashboard into the culvert. Fish that swam into the culvert were recorded as attempts. Fish that swam back out of the culvert were recorded as failures. Counts were made from 2:00 p.m. to 8:00 p.m. from May 31 to June 1. This time period generally corresponded to warmer daily water temperatures and the time when most of the migrating fish attempted to pass through the culvert.

Individual tagged fish entering the culvert were recorded swimming through the pipe by observers located at each end of the pipe. These observers used two-way radios and a stop watch. This procedure permitted timing of a fish as it negotiated the culvert.

Water Quality Measurements

Water quality parameters were monitored daily from the scour pool. Dissolved oxygen and apparent color were determined with a Hach DR-EL/4 water testing kit. Turbidity was monitored with a Hach Model 16800 portable turbidity kit. Temperature in degrees Celsius was measured using a pocket thermometer.

Water Velocity and Discharge Measurements

A staff gauge was installed about 20 feet upstream of the inlet and read daily. Water velocity profiles were taken at the culvert outlet at least once daily, depending on the fluctuating water levels on the staff gauge. Velocities were measured to the nearest tenth of a foot per second (fps) with a Gurley meter attached to a wading rod. Several attempts were made to measure velocities with a Marsh McBirney electromagnetic current meter. However, the Marsh McBirney correlated poorly with the Gurley meter results when subjected to velocities greater than 4 fps, so its use was discontinued. Wellen and Kane (1983) described similar discrepancies at flow rates above 4 fps.

The average velocity was found by taking an average of the centerline velocity profile. The velocity profile was generated by measuring the velocity of the water column at the following increments: surface, 0.2 depth, 0.4 depth, 0.6 depth, 0.8 depth and the bottom of the culvert.

Periodic "chip" tests were performed at the culvert and along the stream. A chip test is a method of estimating the water velocity by noting the time it takes an object (i.e., an orange) to float through a predetermined distance. The estimated water velocity is derived by dividing the distance by the time required to travel the distance. Observations indicated that this test did not produce reliable results when performed during high flows. The orange was observed to be trapped along the top of the culvert for a period of time before exiting the pipe. Therefore, its use for estimating flow in the culvert was discontinued.

The discharge rates through the culvert and stream were found by multiplying the average centerline water velocity (derived from Gurley meter readings) by the cross-sectional area of the pipe or channel that was occupied by water. The discharge rates for the culvert were recorded daily.

Velocities were often difficult to obtain with the Gurley meter when the average outlet velocities exceeded 9.5 fps. During these cases, when the depth of flow in the pipe ranged from 3.0 to 3.5 feet, the average outlet velocities were estimated by the following equation.

$$V = 2.61X + 1.81 \qquad [5]$$

where:

V = average outlet velocity (fps)

X = depth of flow at the culvert outlet (ft)

The equation was derived by correlating previously measured average outlet velocities to corresponding depth of flow. The correlation coefficient (r) was 0.99 which indicates a good linear relationship.

Creel Census

A creel census was performed by the investigating team to determine the number of fish removed from the scour pool by local fishermen. Fish were measured for approximate fork lengths and noted for any tags. Anglers were given an informational pamphlet that explained the project and requested their cooperation (Appendix C). More detailed information is provided in Chapter VI.

CHAPTER VI

RESULTS

Tagging Operation

Arctic grayling were first observed entering the mouth of Poplar Grove Creek on May 20, 1985 at 3:30 p.m., when the water temperature had risen to approximately 1°C. Observations, fishing, dipnetting and beach seining yielded no fish in Poplar Grove Creek prior to this time. The creek's mouth and the banks of the Gulkana River still had ice that was 3 to 4 feet thick. Fish were dipnetted from the banks of the creek near its mouth for tagging, which commenced on May 20 as discussed in Chapter V.

Table 1 presents daily totals of fish that were tagged. A total of 1,252 fish were tagged during the three days of sampling. The early migration began with grayling generally larger than nine inches and was followed gradually by smaller fish. The daily migration appeared to peak about 4:00 p.m. from May 21 to May 30 and, in general, corresponded to peak daily water temperatures which occurred in mid- to late afternoon.

TABLE 1. Daily tagged grayling in Poplar Grove Creek.

Color tags	Blue	Yellow	Orange	Yellow*	Daily
	Size fish				
Date	>9"	>9"	9">X>6"	<6"	Total
5/20/85	140	0	51	3	191
5/21/85	283	0	115	3	398
5/22/85	75	293	294	0	662
TOTALS	499	293	460	6	1,252

* These fish were omitted from the sample population since the tag hampered their swimming.

On May 21, at about 5:00 p.m., an ice dam broke on the Gulkana River, some distance upstream of the sampling site. This resulted in the release of a large volume of water and ice flowing rapidly down the river, forcing the project team to quickly seek higher ground. The flash flood lasted about 1/2 hour until the river had receded back to its original state. The sampling area had been completely inundated. Almost 400 grayling had been tagged and released upstream of the temporary weir in the side channel. The weir was destroyed during the flood and it is unknown if the tagged fish were flushed back into the Gulkana River or continued to migrate up the creek.

Observations of Upstream Migration

Grayling were observed migrating up the creek between May 20 and 22. Chip tests, correlated later to Gurley velocity measurements, revealed that the stream surface velocities averaged between 10 to 12 fps, and water temperatures at the time of the velocity measurements ranged between 0.3° to 3.0°C.

A large number of fish swam near the water surface close to the bank in order to exploit the slower water (Figure 9). At times fish were observed wiggling through the grasses along the banks as the creek began flowing over its concise channel. The grayling competed for the slower velocity areas along the banks. The larger fish would force the smaller fish out of the way and into the stream's main current, and then they continued swimming forward. Most of the fish were lethargic, and the stream temperatures ranged from 0.3 to 3.0°C. Cn several occasions, observers were easily able to catch fish with their hands along the banks.

The grayling were first observed at the highway culvert on May 23 at 3:40 p.m. It is estimated that the larger fish took about three days to swim the 1.8 miles to the highway crossing when the stream velocities were high. During this movement, the fish progressed forward at an average rate of 0.031 fps, well below their cruising speed which ranges from 1.7 to 3.0 fps (MacPhee and Watts, 1976). Smaller fish presumably took substantially longer to negotiate the high velocities. The first arrivals at the culvert were held in the scour pool for eight days due

Figure 9. Grayling along Poplar Grove Creek banks.

to excessive culvert outlet velocities. Figure 10 displays the daily discharge rates through the culvert. The flow peaked at 139 cubic feet/second (cfs) on May 21, at which time the velocity was estimated to be about 11 fps (see Figure 12). Therefore, the initial fish arriving at the culvert corresponded to the decrease of the flow rate as the hydrograph declined beginning May 21.

Stream Hydrology

Figure 4 shows the calculated magnitude and frequency of peak discharges for Poplar Grove Creek including only the 12 square miles of drainage above the highway. In comparing the peak discharge that occurred during the study period with the graph (Figure 4), 139.1 cfs should occur about every 20 years (Q_{20}). Therefore, the study took place during an unusually high peak discharge. MacPhee and Watts (1976) recorded discharge rates for Poplar Grove Creek at the concrete abutment facility which was located approximately one mile downstream of the

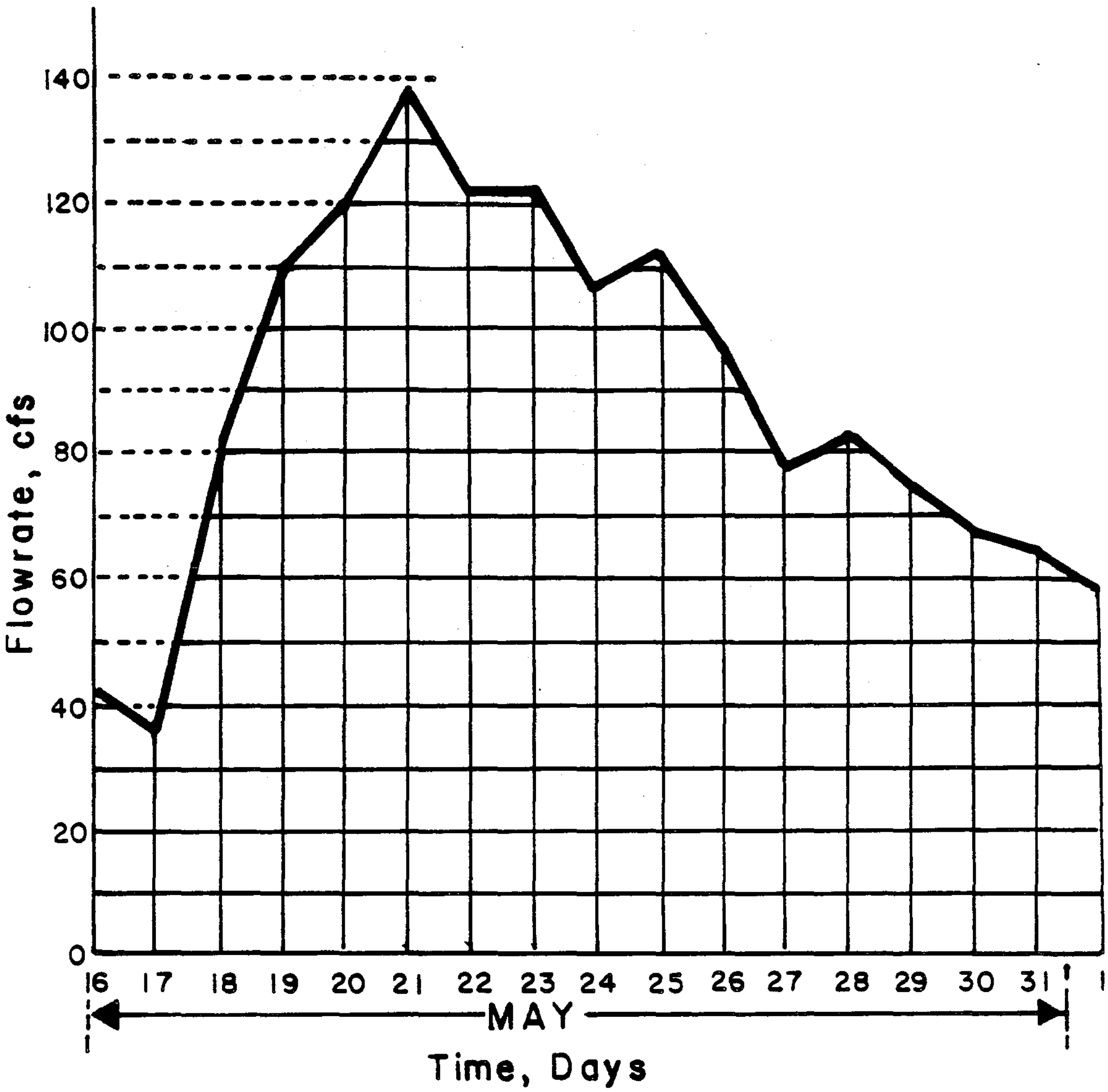


FIGURE 10

1985 DAILY DISCHARGE RATES (cfs) AT POPLAR GROVE CREEK HIGHWAY CROSSING highway crossing. They recorded peak spring discharges of 67 cfs on May 8, 1973; 156 cfs on May 10, 1974; and 74.3 cfs on May 14, 1975. Tack and Fisher (1977) recorded an estimated peak spring discharge of 156 cfs on May 7, 1977, at the same location. The techniques, procedures, and precision and accuracy of these studies are unknown.

This research team found a tributary flowing into Poplar Grove Creek about 100 yards upstream of the MacPhee and Watts (1976) and Tack and Fisher (1977) work site. Further investigation revealed that this tributary crossed the Richardson Highway about 0.7 miles south of the Poplar Grove Creek crossing. Due to high flows in both streams, water velocities could not be measured at their confluence, so respective discharge rates could not be determined. However, flow determinations at the MacPhee and Watts site along with measurements at the Poplar Grove Creek culvert indicated that the tributary was contributing about 25% to 30% of the total discharge at the MacPhee and Watts site. In addition, map interpretation of the area revealed that Poplar Grove Creek drains an additional two square miles of surrounding terrain as it flows downstream of the highway crossing to the MacPhee and Watts site. The contributions of these two sources indicate that the MacPhee and Watts site experiences a somewhat higher flow rate than at the highway crossing. This being the case, it is estimated that a peak discharge of about 180 cfs would have occurred at the MacPhee and Watts site on May 21 of the 1985 study.

Water Quality

Figure 11 is a graph depicting the water quality vs time for the scour pool during the study period May 23 to June 1, 1985. The maximum daily water temperatures ranged from 6.6°C to 12.0°C, and apparent color fluctuated from 40 to 320 units. Turbidity ranged from 3 Nephelometric Turbidity Units (NTU) to 32 NTU. Dissolved oxygen varied from 9.0 mg/l at a water temperature of 9°C to 11.2 mg/l at a water temperature of 6.5°C.

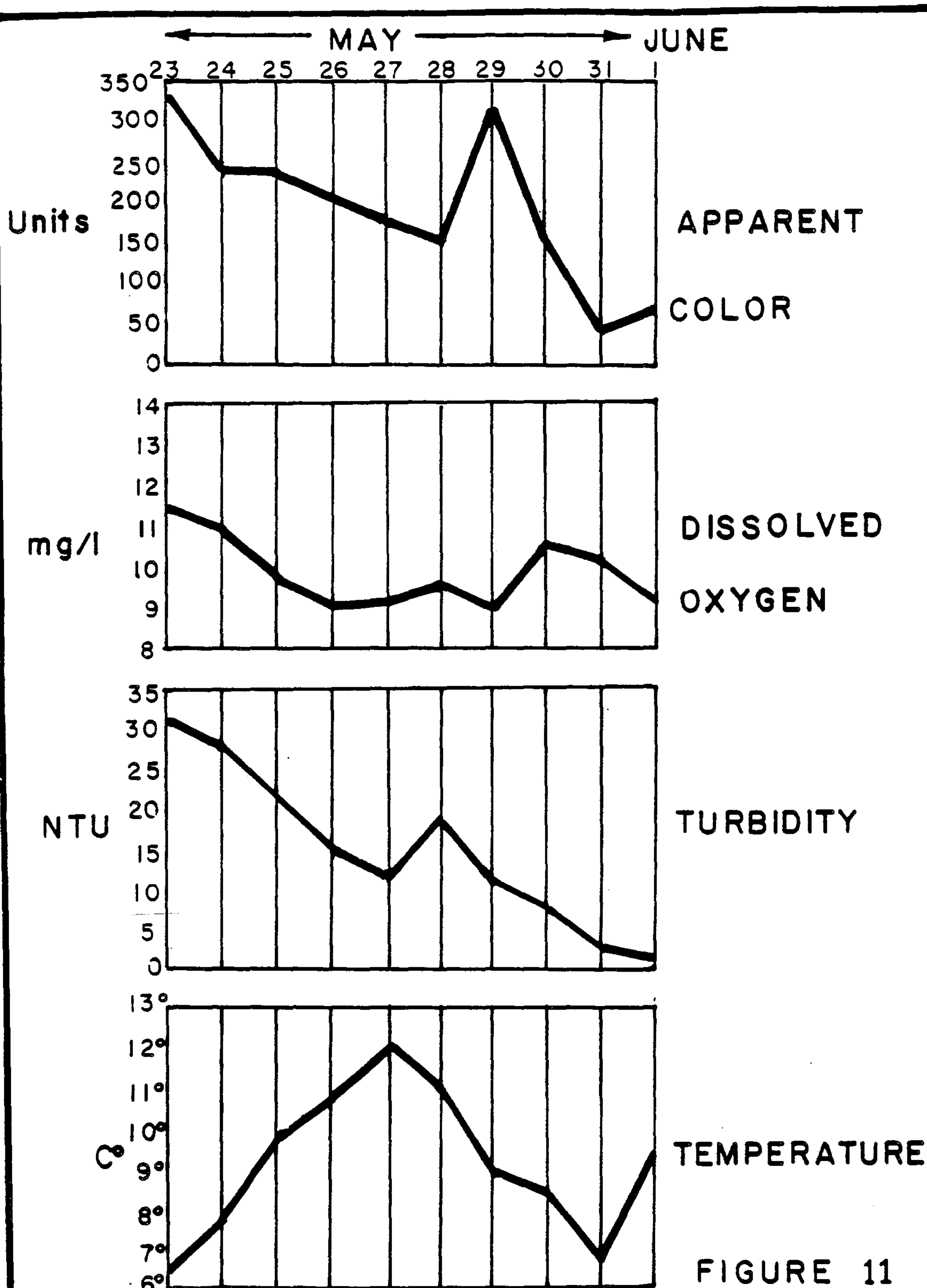


FIGURE 11
DAILY WATER QUALITY PARAMETERS AT POPLAR GROVE CREEK HIGHWAY CROSSING

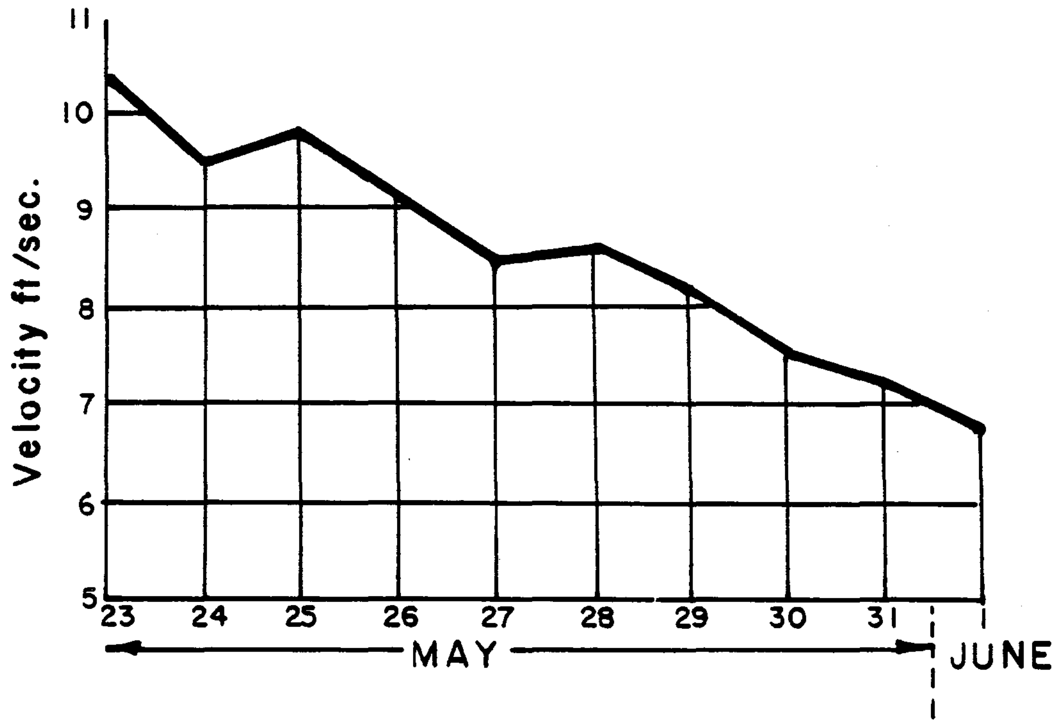


FIGURE 12

DAILY CULVERT AVERAGE CENTERLINE OUTLET VELOCITIES AT POPLAR GROVE CREEK HIGHWAY CROSSING

Swimming Performance

Fish were present in the scour pool when the daily average culvert velocities ranged from 6.9 fps to 10.3 fps from May 23 to June 1 (Figure 12.). During most of the time, the fish appeared highly motivated to swim through the culvert. On occasion, the grayling were observed hurling themselves into the culvert from as far back as 5 to 20 feet, with leaps ranging from 2 to 5 feet high. On several occasions, the number of leaping attempts per five minutes was recorded. The number of leaping attempts ranged from about two per minute to a peak of 45 per minute, which was recorded at 6:20 p.m. on May 25. The water temperature ranged from 8.5°C to 11.0°C. Review of the data indicated that leaping activity commenced with the arrival of the fish at the scour pool on May 23, and the activity stopped on May 30, with a substantial decline in air temperature and water temperature. However, observed swimming attempts to pass the culvert began on May 30 when the average centerline pipe outlet velocity subsided to below 8 fps. In summary, very little leaping occurred when the water temperature was less than 8°C, or before noon or after 8:00 p.m. Activity was most pronounced when the water temperature was above 10°C and between the hours of 3:00 and 7:00 p.m.

The only technique available to the project team to monitor successful attempts was visual observations due to permit limitations. In retrospect, recapture should have been requested as a part of the scientific sampling permit. This would have allowed confirmation of fish passage through the culvert of fish that were unobserved using the visual procedure. On May 25, a beach seine was used to attempt to capture fish that may have negotiated the culvert. No fish were caught. The velocities and depth of water were too excessive for effective seining. This effort was supervised by Butch Potterville of the Glennallen ADF&G Sport Fisheries Division.

At 1:35 p.m. on May 26, one grayling approximately nine inches in length was observed exiting the upstream end of the culvert. The water temperature was near 10.3°C, and the outlet velocity was 9.2 fps. Due to abnormally high flows, the investigating crew was unable to determine how many fish negotiated the culvert during these high flow and high velocity conditions.

Two fish with yellow tags were sighted swimming above the culvert inlet on May 27, at 5:20 p.m. One of these tagged fish was caught by an investigator using a wet fly. The fish measured 15 inches in fork length. The water temperature was approximately 12.0°C, and the pipe outlet velocity was 8.4 fps. On the same day at 10:00 p.m. three 16- to 19-inch longnose suckers (Catostomus catostomus) were seen swimming near the surface upstream of the culvert.

On May 28, 29 and 30, the culvert was closely monitored. However, no fish were observed successfully negotiating the pipe. The average outlet velocities were 8.6 fps, 8.2 fps and 7.6 fps, respectively. The maximum daily water temperatures were 11°C, 9°C and 8.5°C, respectively.

At approximately 3:20 p.m. on May 31, the first significant number of fish were observed migrating through the culvert. Prior to this time, the only known fish to successfully negotiate the culvert were those mentioned on May 26 and May 27, 1985. Eighty-two attempts were recorded with only 18 failures (those exiting the outlet). This represents a 78% success rate for those entering the culvert at the outlet and exiting at the inlet. The water temperature was approximately 7.7°C, and the average outlet centerline velocity was about 7.3 fps. No tagged fish were observed swimming through the culvert. All successful fish passing the culvert were observed swimming very close to the bottom of the culvert on entering the pipe. The ADF&G Habitat Division does not agree with this procedure for identifying successful and unsuccessful attempts. This controversy is discussed further in Chapter VII.

On June 1, the fish began attempting the culvert about 4:00 p.m. Some 1,090 attempts were counted with 52 failures. This was a 95% success rate. The water temperature was approximately 9.5°C, and the average outlet velocity was 6.9 fps. Again, successful fish were observed swimming at the bottom of the culvert as they entered the pipe at the outlet. Once through the culvert, the fish tended to rise from the bottom of the pipe and dart to slower velocity water along the banks. Table 2 displays the time required, by tagged fish only, to swim through the culvert. Larger tagged fish (greater than 9 inches) took an average time of 20.5 minutes to swim through the culvert, while smaller tagged fish (less than 9 inches) took 28.8 minutes. The time

TABLE 2. Time durations of tagged fish swimming through culvert.

Tag color	Number of fish	Mean time minutes	Range minutes
Yellow >9"	4	20.5	11.9 to 27.7
Blue >9"	3	19.9	11.5 to 27.5
Orange 9">X>6"	11	28.8	10.8 to 43.0

range for fish successfully negotiating the culvert ranged from 10.8 to 43.0 minutes. A total of 18 fish were timed.

Creel Census

The creel census was performed by members of the research team from May 23 to May 29 (Table 3). On several occasions anglers continued fishing in the scour pool late in the evening (beyond midnight) after the investigative team left the project site. Therefore, the total number of fish removed from the pool is estimated to be 10% more than what was determined by the creel census, or approximately 2,600 fish. About 4,180 fish were hooked and landed with some 1,580 released (usually the smaller fish). Rough handling of fish was observed on numerous occasions. By May 26, most fish larger than eight inches were dropping eggs or milt when they were lifted from the water by anglers.

It is also noted that, although the creel census terminated on May 29, investigators at the site on May 30 and June 1, noted fewer fishermen and, generally, smaller and fewer numbers of fish in the scour pool. On May 30, six anglers were fishing during the time investigators were present at the site, 11 fish were caught including one rainbow, and on May 31, three anglers kept 24 fish. The records for May 30 and May 31 are not complete as regards the creel census, because investigators were busy with other assignments. It is also worth noting that May 27, 1985, was a Monday (Memorial Day) and a holiday for many people. This may have contributed to increased fishing pressure at the scour pool. The following day, May 28, fishing activity was substantially reduced.

TABLE 3. Creel Census

Date	No. of anglers[1]	Angler hours[2]	Fish caught	Fish kept	Tagged fish caught			Tagged fish kept		
					Yellow	Blue	Orange	Yellow	Blue	Orange
5/23/85	12	18	103	95	0	0	0	0	0	0
5/24/85	30	37	225	221	1	6	0	1	6	0
5/25/85	65	92.5	726	557	17	35	0	9	17	0
5/26/85	83	149.5	1,370	711	53	32	6	32	28	2
5/27/86	86	143	1,534	620	11	22	4	10	12	2
5/28/85	6	10	104	33	7	13	3	7	11	2
5/29/85	11	13	118	114	2	3	4	2	2	4
TOTAL	293	463	4,180	2,341	91	111	17	67	76	10

[1] Number of anglers = number of anglers interviewed only.
[2] Angler hours = number of anglers x hours fished.

CHAPTER VII

DISCUSSION

The following chapter discusses the suitability of the study's techniques for analyzing fish passage. The study's results are then analyzed and compared with the ADF&G fish passage criteria. The ADF&G fish passage criteria and their development are commented on and compared with the approaches of other state agencies. Finally, the economic ramifications of installing hydrologically oversized culverts for fish passage are discussed.

Analysis of Techniques

The simple techniques used to observe the percent passing of fish during varying outlet velocities appeared to work adequately. It provided a cost-effective method that did not require sophisticated, expensive monitoring equipment. The flashboards materially enhanced viewing at culvert outlet water depths of 2.2 to 3.2 ft and when variable water quality parameters (3 NTU to 32 NTU, and 40 to 320 apparent color units) were experienced during the study. However, if an outlet depth of 3.5 feet, high turbidity and high color had been encountered when the fish were migrating through the culvert, some difficulties in observing fish and tags would be anticipated. For example, on May 26 a grayling was observed exiting the upstream end of the culvert (inlet). At this time the water turbidity was about 16 NTU, and the water color was about 200 color units. Comparatively, this water was relatively clear and the depth flow was 2.6 feet, which did not interfere with our observations. However, as the depth of flow increased beyond three feet, the ability to observe fish was severely hindered. During times of high flow with high turbidities, we recommend that a small, portable, sidescanning sonar counter be used at the culvert inlet to augment the use of flashboards to count fish and confirm passage.

The tags did not appear to hamper the swimming abilities of fish larger than six inches in length. If studying smaller fish, a smaller, slimmer tag is suggested. The tags were easily seen as the fish swam over the flashboards. Although the colors used were easily distinguishable, other colors may provide better viewing (such as white, international orange and red).

The study should have been designed to recapture fish upstream of the culvert. This would have allowed the investigative team to further study the condition, sexual maturity and size of fish that successfully passed the culvert at various velocities. However, the scientific sampling permit requested by the investigators and issued by the ADF&G Sport Fisheries Division did not allow recapture. If recapturing is incorporated into a study plan, then the tags should be individually numbered. In this way, the swimming performance, delay time, sexual maturity and condition of individual fish can be monitored.

The ADF&G Habitat Division disagrees with the procedure used in this study to designate successful and unsuccessful attempts (Cohen, 1985). ADF&G feels that the number of fish in the scour pool must be taken into account when calculating the percent passing at a given outlet velocity. For example, if after monitoring a daily migration run 100 fish successfully passed the culvert with 20 failures, and 1,000 fish still remain in the scour pool that never attempted to swim through the culvert, then the total percent passing would be: 100 ÷ (20 + 1,000) x 100% = 9.8%. However, based on this 1985 study procedure, the total percent passing would be: 100 ÷ 120 = 83%. Some evidence suggests "...a behavorial tendency of fish to approach and flash their lateral line across an adverse pressure gradient in order to sense the optimal point of entry, if any..." (Ott, 1986). This might be interpreted to mean that fish may not enter extreme, adverse velocity conditions. Further study is needed. This project technique calculated the percent passing by dividing the number of successful attempts by the total number of fish attempting the culvert, resulting in a passage rate of 83%.

ADF&G feels that MacPhee and Watts (1976) methodology supports their opinion (Cohen, 1985). MacPhee and Watts placed fish in a holding box that was located at the experimental culvert outlet. Fish were then allowed about 18 hours (1973-74) or 44 hours (1975) to swim through the culvert and into a holding box that was located at the culvert inlet. After this period of time, the number of fish in the upstream box represented successful attempts. ADF&G maintains that the outlet holding box is analogous to the Poplar Grove Creek scour pool and that MacPhee and Watts knew exactly how many fish were attempting their culvert during each experiment.

After analyzing MacPhee and Watts (1976) methodology, several deficiencies are noted. Once a fish swam through the culvert into the upstream holding box, there was no mechanism to prevent fish from swimming back downstream to the lower holding box. Since continual observations were not performed, MacPhee and Watts had no way of knowing if this had occurred. Therefore, MacPhee and Watts may have generated lower passing rates than what the fish actually attained. Secondly, the study fish were netted and placed directly into the outlet holding box. Although the fish were held overnight in the holding box to recover from netting effects, handling and confinement of the fish may have detrimentally affected the fish's swimming performance.

This study's in situ methodology is favored because the fish have not been recently handled, and it allows fish to naturally approach and attempt to swim through the culvert on their own accord. The technique monitors the swimming performance of fish in an actual highway culvert situation.

Several papers recommend constructing a resting pool for fish at the culvert's outlet (Metsker, 1970; Evans and Johnston, 1974; Dane, 1978; and USDA Forest Service, 1979). The pool offers the fish a quiet place to rest before attempting the culvert. The Poplar Grove Creek scour pool allows fish to rest after negotiating the steep grades downstream. Therefore, fish may naturally delay in the pool before attempting the highway culvert, regardless of what the culvert outlet velocities are.

The culvert was observed from 10:00 a.m. to 4:00 p.m. on June 2, 1985, and no fish were observed trying to negotiate it. It is assumed that most of the fish had either migrated or been caught by sport fishermen. This assumption was supported by the fact that the sport fishermen around the scour pool caught only a few fish throughout the day. Therefore, the June 1 observation of 1,038 fish successfully negotiating the culvert should have included most of the fish that were residing in the scour pool. However, there were no further observations beyond June 2, 1985, so this assumption cannot be verified.

Results

ADF&G's criteria for a 110-foot culvert (maximum outlet velocity = 1.8 fps) should allow 75% of 9.5 inch Arctic grayling to pass at 2.8°C. Yet we observed a 78% success rate by various (unknown) size fish at an outlet velocity of 7.3 fps and a water temperature of 7.7°C. This is a large discrepancy. Some successful attempts were made by fish less than 9.5 inches in length. There may be several reasons why fish were able to negotiate such a high velocity.

ADF&G fish passage criteria have fixed, maximum values for average cross-sectional outlet velocities for given culvert lengths. We observed the fish swimming very close to the culvert bottom and not utilizing the entire water column. If the Morsell et al. (1981) V-occupied concept is valid, then the water velocities along the culvert bottom where the fish were observed swimming were 62.5% of the average cross-sectional velocity (Kane and Wellen, 1985). This velocity would equal about 4.6 fps when the average velocity was 7.3 fps.

A 9.5 inch grayling is estimated to occupy approximately three inches of the water column while swimming through a culvert. If the grayling were assumed to be swimming along the culvert bottom, then equation 4 can be used to estimate the average water velocity that the grayling encountered.

$$V = V_{ave}(21.477nR^{-1/6} \log (Y/Yo) + 9.45nR^{-1/6} + 1) \qquad [4]$$

where

V = velocity of V-occupied (fps) at depths of 1, 2 and 3 inches from the culvert bottom

V_{ave} = 7.3 fps

Y = 1 inch (0.08 ft), 2 inch (0.17 ft) and 3 inch (0.25 ft)

Yo = 2.5 feet

n = 0.024

R = 1.25

which equals:

3.5 fps at 1 inch depth from bottom
4.7 fps at 2 inch depth from bottom
5.3 fps at 3 inch depth from bottom.

The average of these generated velocities equals about 4.5 fps. This value compares well with the 4.6 fps velocity occupied from the Morsell et al. (1981) model.

The extrapolated maximum outlet velocities for the ADF&G criteria were generated from studies of Arctic grayling swimming through two-foot-diameter culverts. These smaller pipes possess a much smaller wetted perimeter than the Poplar Grove Creek culvert and, thus, would generate a small V-occupied zone which the fish may not have been able to utilize.

Dryden and Jessop (1974) observed the V-occupied concept also. They monitored the success rate of northern pike (Esox lucius) attempting to negotiate a 232-foot culvert. Pike are considered poor swimmers, yet some were observed successfully passing the culvert at velocities of 6.0 and 7.1 fps. Dryden and Jessop noted that the pike were seen swimming along the bottom, and they felt that the fish utilized the slower current that exists there to successfully complete passage.

The water temperature probably influenced the swimming ability of the pike. MacPhee and Watts (1976) noted that water temperatures greatly influenced the grayling's swimming performance, which is the ability to swim longer and negotiate higher velocities. The swimming performance of grayling in their study increased about 80% with an increase in temperature from 0° to 14°C. ADF&G criteria are based on passing 75% of 9.5 inch fish at 2.8°C. Fish are poikilothermic, meaning that their metabolism is directly related to the ambient water temperature. At 2.8°C, fish metabolism would be at a lower rate than the study fish, so the expected swimming performance would be lower. When 78% of the attempts were observed passing through the culvert, the water temperature was 7.7°C.

The long transit times (Table 2) exhibited by the tagged fish swimming through the culvert suggest that resting areas may have been available along the bottom. However, this seems unlikely because of the high flow rate (65 cfs) and water velocity (7.3 fps) when 78% of the fish passed. Upstream flow conditions suggested the possibility of a hydraulic jump downstream of the culvert inlet due to supercritical upstream flow. Additionally, the pipe was on a slight slope (0.5%) and was depressed near the center of the crossing. This would have resulted in an elevated velocity for a short section of the pipe. Further, the center section of the culvert was constricted (Figure 5) which under selected flow conditions caused surging in the pipe and slower velocities within the constricted section of the culvert. The jump and surging were confirmed by observations and use of the chip test. This indicated nonuniform flow conditions (constant discharge with varying velocities) in the pipe. It is hypothesized that the fish were at the extreme limits of their swimming abilities with a slow, net forward speed, so they used a darting action as they encountered variations in velocities through this pipe. The high mean residence times for the fish in the pipe were certainly not expected, and it is unknown if other investigators have found similar occurrences.

No correlations were found among the water quality parameters that were monitored (other than water temperature) and the observed swimming performance of the fish. The frequency of leaping attempts into the culvert appeared to be related to water temperature and time of day, and may also have been influenced by spawning motivation and other factors.

During the eight days that the fish were downstream of the culvert, about 50% of the expected grayling population was removed by sport fishermen: 4,180 fish were caught and 2,341 fish were kept. Of the remainder, almost all had been hooked at least once. Because of this and the vulnerability of the fish to fishing pressure under these conditions, it is recommended that ADF&G consider emergency closure to sport fishing in areas such as Poplar Grove Creek during unusually high flows.

Dryden and Stein (1975) suggest fish migrating upstream should not be held below a culvert for more than three days. This project for the most part supports this conclusion. The study fish appeared viable and energetic for the entire eight days of delay despite the rough handling they endured by sport fishermen. However, by May 26 -- only three days after their arrival at the culvert -- most of the larger fish that were caught were dropping eggs or milt when handled by fishermen. Another five days lapsed before significant numbers of fish were able to swim through the culvert and continue their journey almost 3.5 miles to their spawning habitat. The effects on spawning are unknown.

If the number of recaptured tags is any indication of the total population of Arctic grayling in Poplar Grove Creek that migrated upstream during the study period, then the estimated population was about 19,156. This number was found by the following relationship.

$$T = \frac{MC}{T} \qquad [6]$$

where

T = estimated total population
M = total tagged fish (1,252)
C = total fish retained by sport fishing (2,341)
R = total tagged fish retained by sport fishing (153).

By comparing the estimated population with population counts from past studies (MacPhee and Watts, 1976; and Tack and Fisher, 1977), this seems unusually high. This high estimate was probably due to the loss of tags or tagged fish from the stream. There are several possible reasons for the high tag losses. When the sampling site was flooded at the creek's mouth, several hundred tagged fish had been released just upstream of the weir. The flood could have flushed them back into the Gulkana River. The tagged fish also had to swim 1.8 miles upstream to the highway crossing, and the tags could have fallen off while negotiating the high stream velocities. An abnormally low number of orange tags was recovered and observed. These orange tags were for smaller fish that were between 6 and 9 inches long. If a proportionate number of orange tags had been recovered that were comparable to the blue and yellow tags, this would have been about 117 tags as opposed to

17 tags. The estimated total population would have been 11,585. This is still a relatively high population estimate.

An alternative method for estimating Poplar Grove Creek's populations is proposed. By adding the total number of fish that was estimated to be removed from the scour pool by fishermen (2,600) to the total number of fish observed migrating through the culvert (1,120), a rough estimate of 3,702 individuals is derived. This estimate correlates well with past studies.

Approaches to Fish Passage Criteria

After analyzing the development of the SPCO (State Pipeline Coordinator's Office) fish passage formula (equation 1), it is felt that the dependent and independent values may not have been designated correctly. The dependent variable (y-value) was designated to be the average cross-sectional outlet velocity (v). The independent variables (x-values) were designated to be culvert length, fork length, water temperature and percent passing of a specified length class. The MacPhee and Watts (1976) data showed that percent passing was dependent on velocity, culvert length, fork length and temperature. Therefore, percent passing should have been the y-value and the outlet velocity should have been the x-value. The multiple linear stepwise regression program should have been run differently to reflect this change. This interchange of variables may explain some of the large variability that Arctic Hydrologic Consultants (1985) found to be present in the SPCO fish passage formula. The data analysis should be reexamined accordingly.

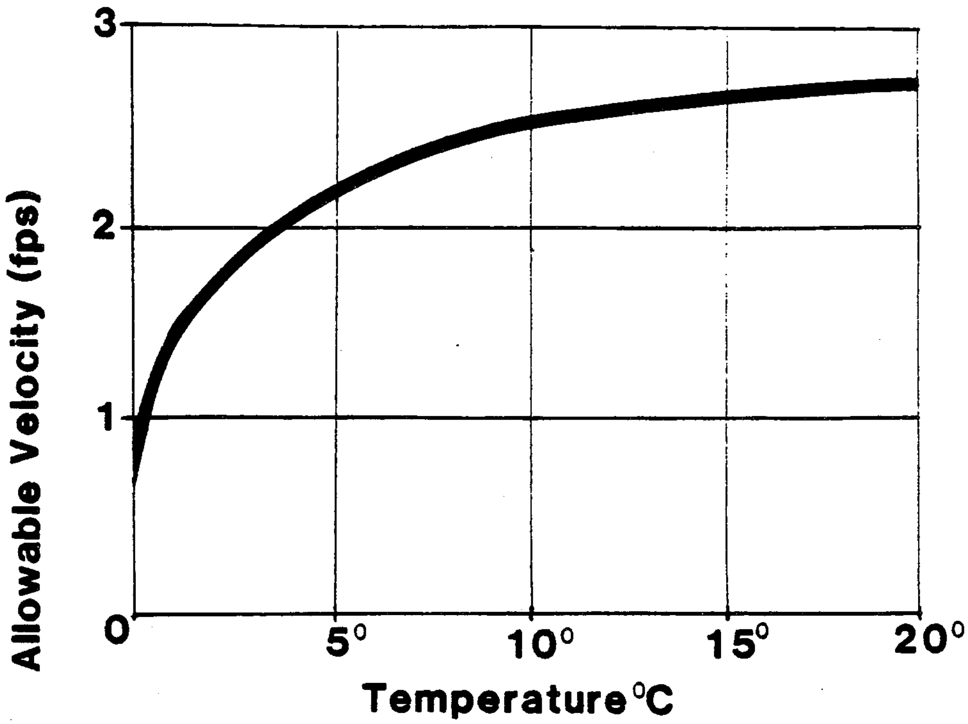
The SPCO fish passage formula has a limited data base. The formula was generated from only one study (MacPhee and Watts, 1976). This study analyzed the success rate of grayling swimming through only one diameter culvert (2 feet). The handling and confinement of the grayling during the MacPhee and Watts study may have adversely affected the fish's swimming performance.

If the SPCO fish passage formula (equation 1) was used to determine the size of fish (for length) that could attain 78% passage through a 110-foot culvert at 7.3 fps with a water temperature of 7.7°C, the resulting fork length would be about 60.7 inches -- a physical improbability for Arctic grayling. Correspondingly, for 7.7°C, 110-foot culvert, and a fork length of 9.5 inches, the velocity necessary to pass 78% of the fish should have been 2.5 fps. If the following values are used -- 7.7°C, 110-foot culvert, a fork length of 9.5 inches and a velocity of 7.3 fps -- the derived percent passing should have been 0.995%. This indicates or predicts that less than one percent of the fish were expected to pass the culvert under the noted conditions whereas 78% actually passed. Obviously, this is evidence that the ADF&G fish passage formula needs further refinement with boundary conditions established for limiting values of the equation.

Figure 13 displays the effects of varying water temperature (T) on the derived average culvert outlet velocities by using equation 1 and setting the culvert length (CL) equal to 100 ft, the fork length (FL) equal to 241 mm (9.5 in), and the percent passing (P) equal to 75%. The graph shows that the derived velocities range from about 0.5 fps to 2.8 fps with a change of water temperature from 0°C to 20°C.

Figure 14 displays the effects of varying P on the derived average outlet velocities by using equation 1 and setting the CL = 100 ft, FL = 241 mm, and T = 2.78°C. The graph shows that the derived velocities range from about 4.0 fps to 1.7 fps with a change of P from 0% to 100%. According to this formula, no 9.5 in fish are expected to pass a 100 ft culvert when the water velocity exceeds 4.0 fps and the water temperature is 2.78°C.

Figure 15 displays the effects of varying FL on the derived average outlet velocities if equation 1 is used and CL = 100 ft, T = 2.78°C and P = 75%. The graph shows that the derived velocities range from about -22.6 fps to 4.7 fps, with a change of FL from 0 m to 600 mm (24.6 in). According to this formula, fish less than 91 mm (3.6 in) would need the assistance of forward moving current (negative velocity) in order for 75% of this size range to pass. Obviously, a negative velocity would not be necessary for a 91 mm fish to pass through a culvert. Again, this illustrates the need for a boundary condition for the equation. It should be noted that MacPhee and Watts (1976) included a group of grayling in the size range of 81 to 100 mm, whereas the smallest fish



CL = 100'

FL = 241 mm

P = 75%

V = 1.5175+0.786 log (T)

FIGURE 13: AVERAGE CULVERT CENTERLINE OUTLET VELOCITIES GENERATED FROM EQUATION 1 WITH VARIABLE TEMPERATURES

CL =100'   V= 3.99 - 1.13 log (P+1)

FL =241mm   T= 2.78 °C

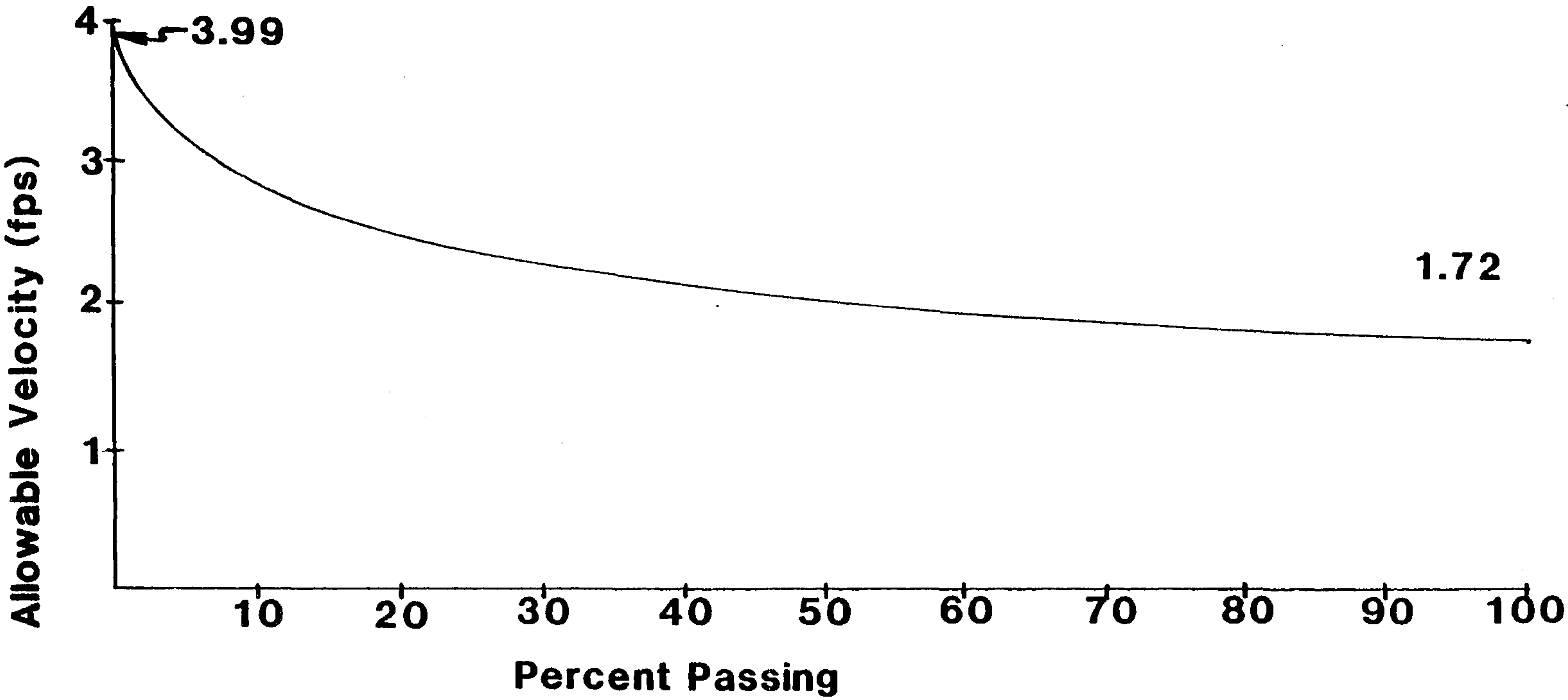


FIGURE 14: AVERAGE CULVERT OUTLET VELOCITIES GENERATED FROM EQUATION 1 WITH VARIABLE PERCENT PASSING

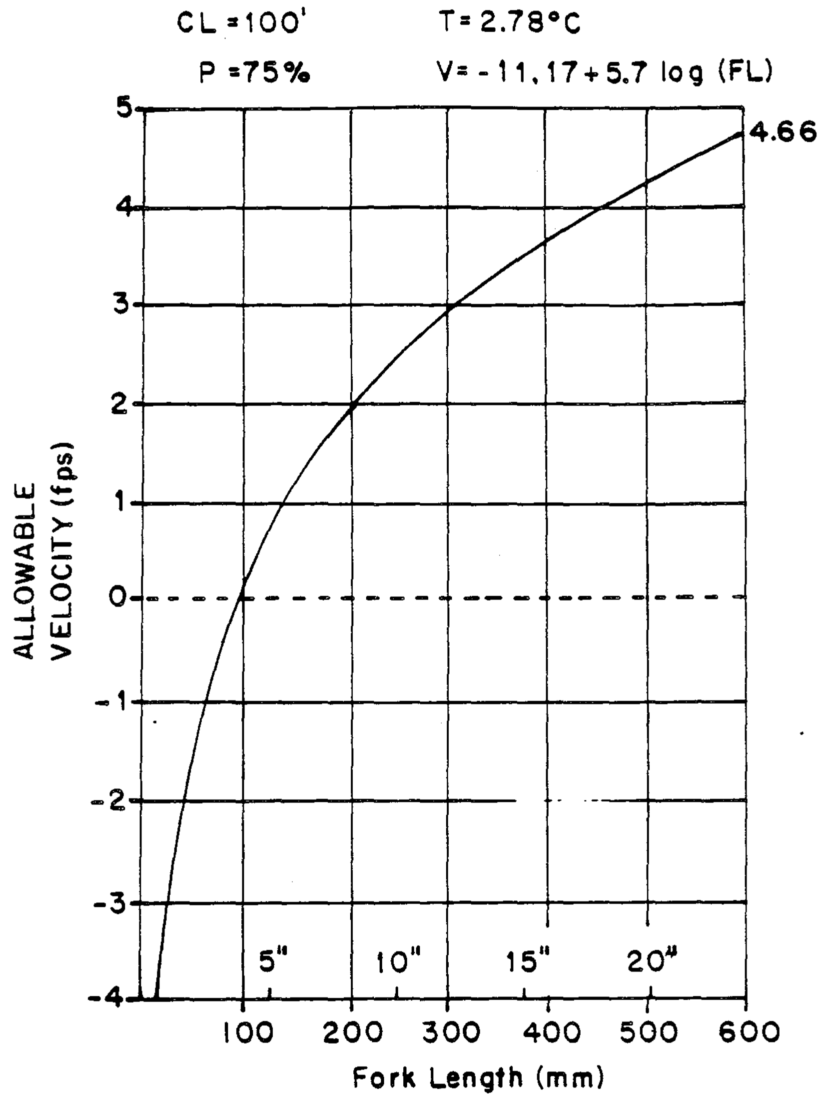


FIGURE 15: AVERAGE CULVERT CENTERLINE OUTLET VELOCITIES GENERATED FROM EQUATION 1 WITH VARIABLE FORK LENGTH

used by Arctic Hydrologic Consultants (1985) in developing the SPCO equation was 96 mm.

Although outlet velocities are ADF&G's primary criterion for issuing or denying a construction permit to place a drainage structure in a stream that provides fish habitat, other factors can be taken into consideration. These include depressing the culvert invert below the stream bed (presently required by ADF&G), installing the culvert along the natural stream gradient, timing and type of installation.

The literature search found that in areas where development and resource agencies agreed on fish passage criteria, critical outlet velocities were a secondary factor in approving a culvert design. The design and function of a proposed structure were considered the critical aspects of culvert design. For example, instead of stipulating that a structure must not exceed an outlet velocity of 3.0 fps, many states dictate that the structure have a hydraulic capacity designed for a Q_{50} discharge. The culvert must also be installed along the natural stream gradient with a depressed culvert invert of about 1.5 feet below the stream bed. For streams with gradients in excess of 1%, cost-effective baffling systems are recommended. Many agencies recognize the variability and the large number of environmental factors that affect the swimming performance of fish. By designing culverts that provide uniform flow within correctly positioned structures, fish are able to negotiate a wide range of outlet velocities.

After analyzing this study's results, a prominent question that needs to be addressed is whether the existing Poplar Grove Creek culvert is inadequate for fish passage. Based on ADF&G's specification that 75% of 9.5 inch fish pass at a $Q_{2.33}$, then the Poplar Grove Creek culvert is acceptable because it passed 78% of the population entering and exiting the culvert at approximately 65 cfs, which is about a $Q_{3.3}$ discharge. However, this ignores the eight day delay in the scour pool caused by high velocities. Further, the existing culvert has structural flows which can only be corrected by replacing the culvert with a new pipe and properly positioning the culvert along the stream bed. This would probably improve flow conditions within the pipe and may allow even a greater percentage of attempts to pass. However, the changing velocities with the present pipe might also provide for resting sections along the length of the pipe.

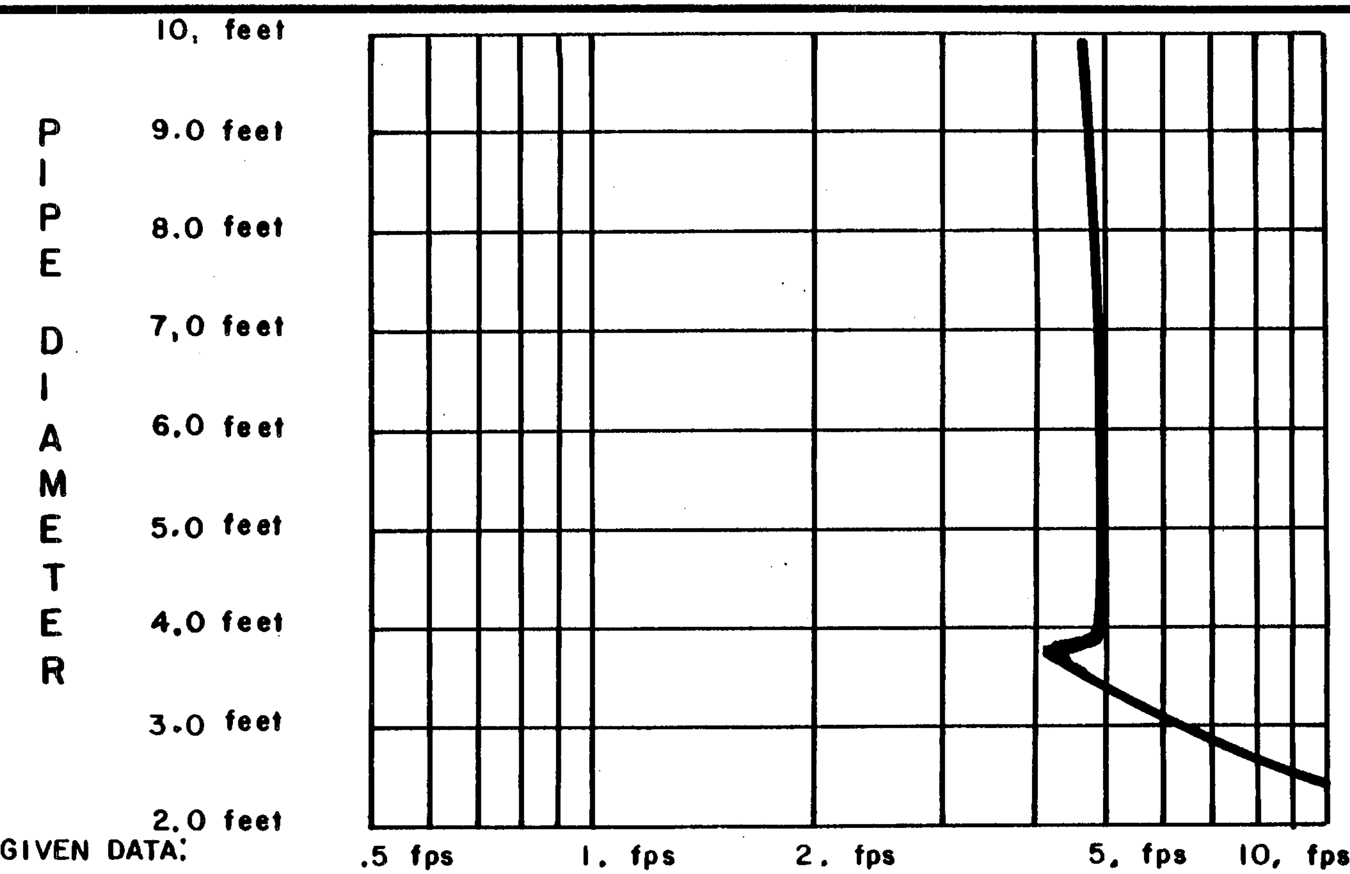
The Poplar Grove Creek culvert was designed to handle a Q_{20} discharge with a headwater depth to culvert diameter ratio (HW/D) of about 7.5/5 or 1.5. These specifications were the highway design standards when the culvert was installed in 1953. The investigation noted the headwater peaking about 3 feet above the top of the culvert, which results in a HW/D = 1.6 at the estimated discharge of approximately a Q_{20} flood.

The existing 5-foot-diameter culvert is estimated to produce an average culvert velocity of about 5.0 fps for a $Q_{2.33}$ (45 cfs) (Barber, 1986). To correctly size a culvert for a Q_{50} discharge (205 cfs) with a HW/D = 1, the required diameter is estimated to be about 7 feet (Travis, 1985). This culvert diameter would generate a culvert velocity of about 4.8 fps for a $Q_{2.33}$ (Barber, 1986), based on the existing slope. The ADF&G criteria, however, provide for a maximum velocity of 4.52 fps at $Q_{2.33}$.

Effects of Increasing the Culvert Diameter

A common approach to solving anticipated high culvert outlet velocities is to prescribe a larger diameter culvert. However, as a culvert diameter increases, the effect on reducing the outlet velocity decreases. Figure 16 illustrates the relationship between culvert diameter and culvert outlet velocity when encountering the $Q_{2.33}$ for Poplar Grove Creek (45 cfs).

According to Figure 16, the culvert outlet velocities decrease quickly to 4.1 fps as the culvert diameter increases to about 3.8 feet, and then the velocity sharply increases to 5 fps. This is due to the culvert being subjected to discharges greater than its hydraulic capacity when the diameter is less than 3.8 feet. Therefore, culverts with these small diameters develop a hydrostatic head of water at the inlet which creates accelerated velocities at the outlet. At a diameter of 3.8 feet, the culvert is completely full with a HW/D = 1. At this time, the volume of water moving through the pipe is subjected to drag forces from the entire circumference of the culvert. Therefore, the



GIVEN DATA:

n = .024
Slope = .005
Discharge = 45 cfs

VELOCITY IN FEET PER SECOND (fps)
Comps by: W.F. BARBER JR. Date: 2/20/86

FIGURE 16 PIPE DIAMETER VS OUTLET VELOCITIES culvert is exhibiting its maximum wetted perimeter and drag force against the flow of water, which slows the outlet velocity.

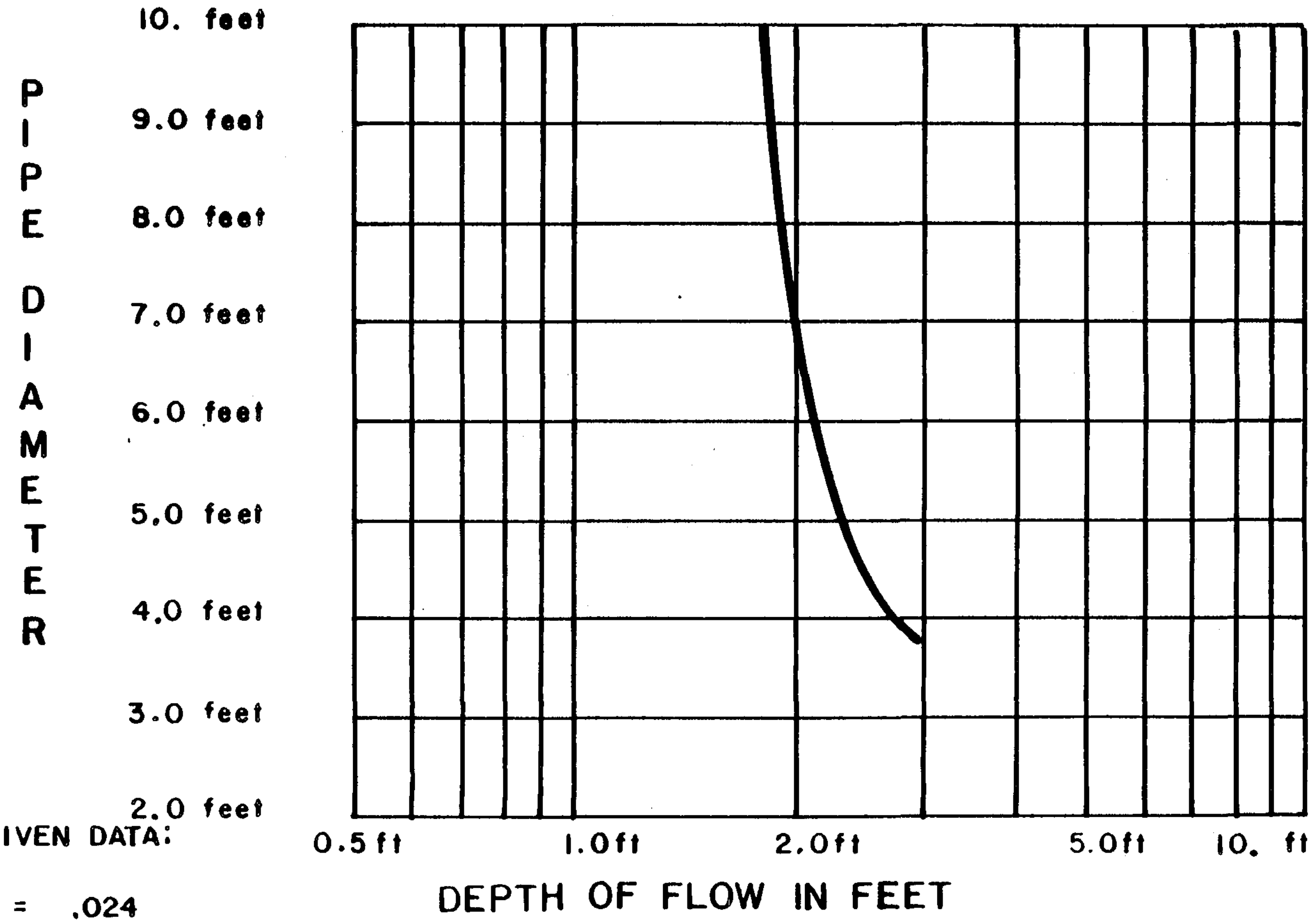
The 5-foot-diameter culvert generates the highest velocity of about 5.0 fps. As the culvert diameter increases to 10 feet, the outlet velocities change very little. The graph shows a 10-foot-diameter culvert will produce an outlet velocity of about 4.7 fps.

As the diameter of the culvert increases, the depth of flow in the culvert decreases. Figure 17 displays the relationship between the depth of flow and increasing culvert diameter for a discharge of 45 cfs. Although large diameter culverts may allow for somewhat slower velocities, they may become migration blocks at lower flows due to low depth of flow within the culvert which could occur during out-migration periods. In areas where there is a wide variation between peak flows and summer baseline flows, consideration should be given to low flow fish passage needs.

In summary, it is not possible to achieve the ADF&G maximum allowable velocity for the 5-foot pipe at Poplar Grove Creek for a $Q_{2.33}$. The lowest velocity attainable is 5.0 fps (Figure 16) with a depth of flow of about 2.3 feet. In order to approximate the ADF&G required velocity (Figure 2), a 40-foot length of culvert would be necessary and a diameter of 10 feet would be required (Figure 16).

The replacement costs per lineal foot for various culvert diameters are shown on Figure 18. These values reflect the actual cost in 1985 dollars for pipe materials and installation for highway projects in the interior region of Alaska (DOT&PF, 1985). The graph does not include the cost of constructing additional structures that may be associated with culverts (i.e., retaining walls, scour aprons, etc.).

Highway construction engineers commonly specify one-piece, corrugated metal pipe (CMP) culvert when the required diameter is 8 feet or less. When the required culvert diameter is greater than 8 feet, a structural steel pipe (SSP) that can be assembled at the project site is usually specified. The reason for this is to facilitate the transportation of materials to the project site with a minimum of cost. Culverts with diameters of over 8 feet require special handling and large trucks for shipping.

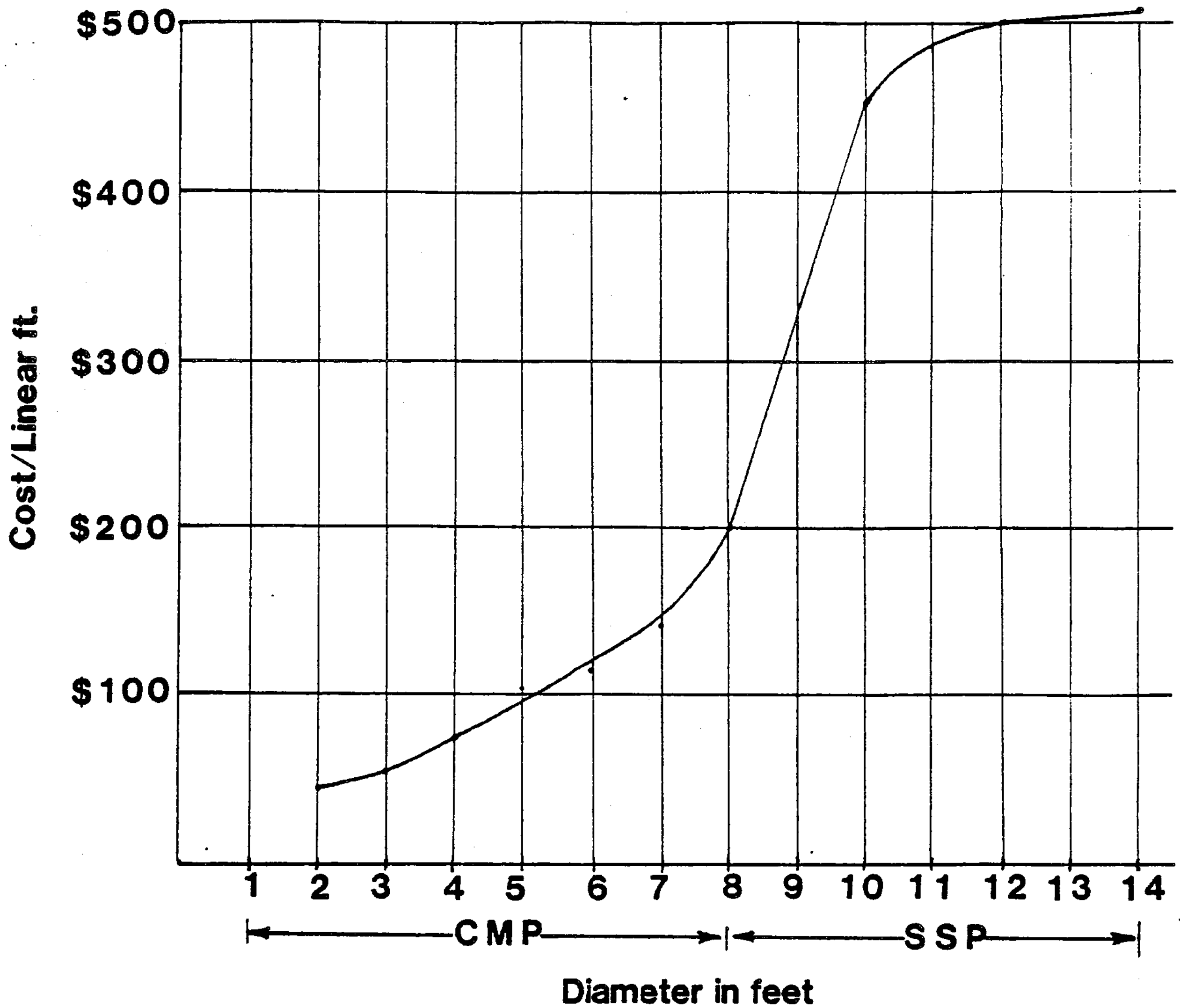


GIVEN DATA:

n = .024
Slope = .005
Discharge = 45 cfs

Comps by: W.F. BARBER JR. Date: 2/20/86

FIGURE 17 PIPE DIAMETER VS DEPTH OF FLOW IN CULVERT



CMP = CORRUGATED METAL PIPE

SSP = STRUCTURAL STEEL PIPE

Source: Alaska Department of Transportation
and Public Facilities
Northern Region
Actual Bid Tabulations (1982-1985) (Calculated in 1985 dollars)

FIGURE 18:

COST PER LINEAL FOOT VS CULVERT DIAMETER

The increase in cost/lineal foot is most dramatic between diameters of 2 feet and 8 feet ($50 to $455). After 10 feet, the increase of cost/lineal foot begins to moderate.

A 7-foot-diameter culvert is the minimum size needed to pass a Q_{50} discharge with a HW/D = 1. With this fact in mind when comparing Figures 16 through 18, it is evident that the most cost-effective culvert diameter for Poplar Grove Creek is approximately 7 feet. The resulting outlet velocity for a $Q_{2.33}$ is about 4.8 fps. This is only slightly higher than the velocity generated by a 10-foot-diameter pipe of 4.7 fps during a $Q_{2.33}$. Finally, a 7-foot-diameter culvert costs $140/lineal foot, which is about 1/3 the total cost of a 10-foot-diameter culvert at $455/lineal foot. Whether a 7-foot-diameter or 10-foot-diameter culvert is used, the estimated average outlet velocities exceed the ADF&G maximum velocities of 1.8 fps for a 110-foot culvert (Figure 2). Even for a shorter culvert length of 40 feet, the ADF&G maximum velocity of 4.52 fps is still exceeded.

The highway crossing at Poplar Grove Creek is scheduled to be realigned approximately 300 feet upstream during the 1987 construction season. To attempt to comply with ADF&G fish passage criteria, a 50-foot-long, 10-foot-diameter culvert with reinforced headwalls has been designed (Figure 19). The headwalls support the road embankment, which allows for a shorter pipe length and a higher ADF&G maximum allowable outlet velocity (4.04 fps for a $Q_{2.33}$ from Figure 2). Without the headwalls, an 80-foot culvert would be needed to span the width of the road fill in the stream. The corresponding ADF&G maximum allowable outlet velocity for an 80-foot culvert would be 3.02 fps for a $Q_{2.33}$. Although the 50-foot-long, 10-foot-diameter culvert will still exceed the ADF&G criteria, ADF&G has accepted the proposed structure (Liepitz, 1985). If ADF&G had mandated that DOT&PF strictly adhere to the criteria, then DOT&PF would have been forced to construct a bridge estimated to cost about $400,000.

The anticipated cost for the proposed structure (50-foot-long, 10-foot-diameter) is approximately $160,000 (DOT&PF, 1985). The reason for the high cost of the proposed structure is the increased cost for a larger diameter pipe and the increased amount of labor that is needed to construct the reinforced earth headwalls, the scour aprons and the large

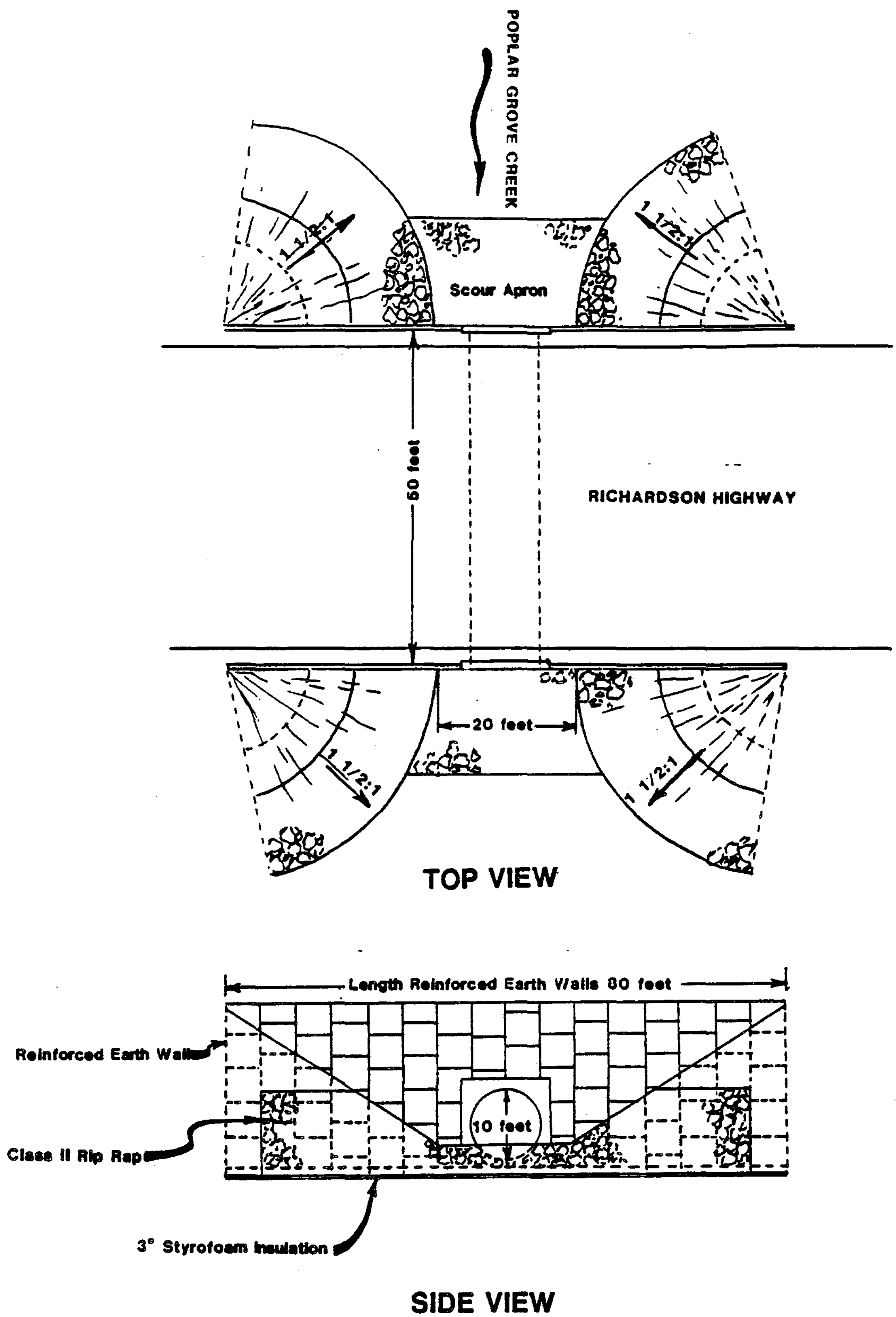


FIGURE 19: FUTURE POPLAR GROVE CREEK STRUCTURE

diameter pipe. An 80-foot-long, 5-foot-diameter culvert similar to the original crossing would cost about $8,000.

In both cases, neither the 10-foot-diameter pipe nor the 5-foot-diameter pipe would be in compliance with the ADF&G fish passage criteria because of excessive velocities. At a $Q_{2.33}$ the larger pipe would generate a velocity of about 4.7 fps, whereas the maximum allowable value is 4.04 fps. The smaller pipe would generate a velocity of about 5.0 fps and the maximum allowable value is 3.0 fps.

Such examples emphasize the need for ongoing coordination between transportation and fisheries agencies. Obviously, this is a case where better technical data on the relationship between the behavior of the "design" fish species and the hydraulic operation of highway structures can produce significant cost savings.

Initial data gathered from this study suggest that a 5-foot-diameter pipe might be adequate in terms of size and velocity requirements, and still provide good resource protection--but still be in violation of existing criteria. Caution is emphasized, however, because of the preliminary nature of this project and the need to confirm the hypothesis through more detailed study. Nevertheless, the issue is an important one because it could influence the choices between a 5-foot-diameter or 10-foot-diameter culvert, or a bridge. The examples used denote a potential cost increase ranging from 20-fold to 50-fold greater than that required for the smaller culvert. In terms of a single occurrence or stream crossing, the cost increase may not be significant. However, based on the fact that Alaska has a large number of fish passage structures in violation of existing criteria, the cost increase could be substantial. It is emphasized the preliminary nature of this study and the need for further evaluation.

In summary, it is imperative that the fisheries resource be protected and that cost effectiveness be optimized.

Concluding Remarks

Alaska is still in its developmental stage of deriving fish passage criteria and techniques that will be cost effective and protect the fisheries resources. Alaska can learn from other states how to address fish passage issues and improve on them. The underlying foundation for any criterion is adequate communication between fishery biologists and engineers. On October 12, 1984, Alaska developed a Fish Passage Task Force that is composed of representatives from ADF&G and DOT&PF. Its primary purpose is to bridge the communication gap between the two agencies and to begin working together to solve the problems of fish passage.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Summary

This project successfully used simple techniques to observe fish passage through a highway culvert. The techniques provided a cost-effective method that did not require sophisticated, expensive monitoring equipment. However, the procedures are still experimental and need further evaluation on other streams, culverts and fish species.

During this study, the drainage area produced a Q_{20} discharge which generated high pipe velocities (10 to 12 fps). Some Arctic grayling were able to negotiate a 110-foot-long, 5-foot-diameter culvert when flows receded to about 9.0 fps. A large portion of the population was unable to pass the culvert for up to eight days during these high velocities and, thus, became highly vulnerable to sport fishing. Most of the remaining fish were able to pass through the drainage structure when the velocity decreased to about 7.0 fps at a water temperature of 7.7°C.

Undersized structures can have a devastating impact on the fishery, as evidenced by the unusually high flow rates that occurred during this study. Oversized culverts may protect the fishery from these impacts, but they may create migration blocks during lower flows. A cost-effective approach to fish passage would be to develop design criteria that are not based mainly on maximum outlet velocities but on the hydraulic parameters of the structure itself. Such parameters could include matching the natural stream gradient, depressing the culvert invert about 1.5 feet below the stream bed and sizing for a Q_{50} discharge. Low flow conditions should be considered for some areas.

Conclusions

The following conclusions are made from the study.

1. The visual technique was effective for observing fish and tags during the stream conditions experienced when the fish began migrating through the culvert.

2. The visual technique could be improved to make it applicable for a variety of stream conditions.

3. The Floy tags (Model FTSL-73) did not appear to hamper the swimming abilities of Arctic grayling with fork lengths greater than six inches.

4. The flashboards did enhance the visibility of fish and tags.

5. The experimental design was not completely effective because of the study team's inability to recapture fish upstream or downstream of the culvert due to permit restrictions.

6. The sport fishing at the culvert scour pool interfered with the research activities.

7. Outlet velocities were difficult to measure with the Gurley meter when the velocities exceeded 9.5 fps.

8. The study was performed during a Q_{20} discharge. Therefore, the results should be viewed with this fact in mind, and additional research should be implemented to confirm these results.

9. The data gathered by this study suggest that the existing ADF&G fish passage criteria may be too restrictive, and follow-up studies are recommended. Additional studies may provide supporting information leading to criteria allowing for more conservative pipe sizing and more cost-effective use of public funds, while providing a high degree of protection to fish resources.

Recommendations

Based on the field study, several recommendations are proposed for future implementation of the study techniques.

1. If small fish (less than six inches) are to be tagged and monitored, a smaller, slimmer tag should be used. Other colors than those used should be tried. Colors that might be highly visible in water are international orange, red and white.

2. Recapturing fish after they have negotiated the culvert should be considered. In this way, the exact size, physical condition and sexual maturity of the fish can be monitored. If recapturing is going to be done, the tags should be individually numbered to allow the researcher to study each fish's individual characteristics such as fork length, sexual maturity and when it was tagged.

3. During high flows associated with high color and high turbidity, visibility may become impaired and the flashboards may not be effective visual aids. Therefore, a small portable side-scanning sonar or implanted radio tags in the fish could be used to augment the visual observations.

4. The capturing and tagging of fish should occur within one-half mile of the culvert in order to reduce tag loss. However, the tagging should not occur so close that the fish do not have time to acclimate to the tag before arriving at the culvert.

5. The study area around the culvert should be closed to sport fishing. This would prevent losing tagged fish from the test population. ADF&G should also consider the closure of sport fishing in scour pools below highway culverts during periods of unusually high flow when fish are migrating upstream to spawn.

6. ADF&G and DOT&PF should work cooperatively during future studies to develop a working relationship between fishery biologists and

highway engineers. Any future cooperative studies with the University of Alaska-Fairbanks should include the Civil Engineering Department and the Alaska Cooperative Fisheries Research Unit.

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APPENDIX A

ALASKA STATUTES

16.05.840 - 16.05.900

The following laws have been photocopied from the Alaska Statutes (16.05.840-16.05.900). Section 16.05.840 stipulates that any person who builds an obstruction across a stream frequented by fish must provide a durable and efficient fishway for fish migration. Section 16.05.860 states that a person who fails to provide an efficient fishway is guilty of a misdemeanor and is punishable by a fine for each day the obstruction is in the stream.

Section 16.05.870 protects anadromous fish habitats from construction impacts and mandates the installation of fish passage structures. This statute also describes how to apply for a permit to construct a drainage structure in an anadromous stream. Section 16.05.880 states that a person who fails to acquire a permit before construction of a project is guilty of a misdemeanor. The cost of restoring a stream to its original conditions is mandated to be borne by the violator.

Sections 16.05.895 and .900 state that any obstruction to the migration of anadromous fish is guilty of a misdemeanor. Anyone who violates A.S. 16.05.870-16.05.895 is guilty of a Class A misdemeanor punishable by a maximum fine of $5,000 or by imprisonment for a maximum of one year, or by both.

Sec. 16.05.831. Waste of salmon. (a) A person may not waste salmon intentionally, knowingly, or with reckless disregard for the consequences. In this section, "waste" means the failure to utilize the majority of the carcass, excluding viscera and sex parts, of salmon which are to be

(1) sold to a commercial buyer or processor;

(2) utilized for consumption by humans or domesticated animals; or

(3) utilized for scientific, educational, or display purposes.

(b) The commissioner, upon request, may authorize other uses of salmon that would be consistent with maximum and wise use of the resource.

(c) A person who violates this section or a regulation adopted under it is punishable by a fine of not more than $10,000, or by imprisonment for not more than six months, or by both. In addition, a person who violates this section is subject to a civil action by the state for the cost of replacing the salmon wasted. (§ 3 ch 99 SLA 1975)

Revisor's notes. — This section was enacted in section 3 of both ch. 89 and ch. 99, SLA 1975. Chapter 99 had an immediate effective date (May 30, 1975), so the section was already in effect when ch. 89, enacting identical language, took effect on August 20, 1975.

Collateral references. — 35 Am. Jur. 2d, Fish and Game, § 51.

Sec. 16.05.835. Maximum length of salmon seine vessels. A salmon seine vessel may not be longer than 50 feet, official Coast Guard register length, and 58 feet overall length except vessels that have fished for salmon with seines in waters of the state before January 1, 1962, as 50-foot, official Coast Guard register length vessels. (§ 1 ch 252 SLA 1970)

Sec. 16.05.840. Fishway required. If the commissioner considers it necessary, every dam or other obstruction built by any person across a stream frequented by salmon or other fish shall be provided by that person with a durable and efficient fishway and a device for efficient passage for downstream migrants. The fishway or device or both shall be maintained in a practical and effective manner in the place, form and capacity the commissioner approves, for which plans and specifications shall be approved by the department upon application to it. The fishway or device shall be kept open, unobstructed, and supplied with a sufficient quantity of water to admit freely the passage of fish through it. (§ 30 art I ch 94 SLA 1959)

NOTES TO DECISIONS

Stated in Southeast Alaska Conservation Council, Inc. v. State, Sup. Ct. Op. No. 2662 (File No. 5855), P.2d (1983).

Sec. 16.05.850. Hatchery required. If a fishway over a dam or obstruction is considered impracticable by the commissioner because of cost, the owner of the dam or obstruction, in order to compensate for the loss resulting from the dam or obstruction shall, at the owner's option (1) pay a lump sum acceptable to the commissioner to the state fish and game fund; (2) convey to the state a site of a size satisfactory to the commissioner at a place mutually satisfactory to both parties, and erect on it a fish hatchery, rearing ponds, necessary buildings and other facilities according to plans and specifications furnished by the commissioner, and give a good and sufficient bond to furnish water, lights and necessary money to operate and maintain the hatchery and rearing ponds; or (3) enter into an agreement with the commissioner, secured by good and sufficient bond, to pay to the fish and game fund such an initial amount of money and annual payments thereafter as the commissioner considers necessary to expand, maintain, and operate additional facilities at existing hatcheries within a reasonable distance of the dam or obstruction. (§ 30 art I ch 94 SLA 1959)

Sec. 16.05.860. Penalty for violating fishway and hatchery requirements. (a) The owner of a dam or obstruction who fails to comply with AS 16.05.840 or 16.05.850 within a reasonable time specified by written notice from the commissioner is guilty of a misdemeanor, and is punishable by a fine of not more than $1,000. Each day the owner fails to comply constitutes a separate offense.

(b) In addition to the fine the dam or other obstruction managed, controlled or owned by a person violating AS 16.05.840 or 16.05.850 is a public nuisance and is subject to abatement. (§ 30 art I ch 94 SLA 1959)

Sec. 16.05.865. Transplanting of musk oxen. The board may transplant surplus musk oxen from Nunivak Island to appropriate areas on the mainland of the state, when good management practices dictate the action. The board shall determine which transplant sites are appropriate and whether a surplus of animals exists. (§ 1 ch 220 SLA 1975)

Sec. 16.05.868. Fish health inspections. Fish health inspections determined to be necessary by the department shall be performed by a professional fish health specialist certified by the fish health section of the American Fisheries Society. (§ 3 ch 110 SLA 1980)

Sec. 16.05.870. Protection of fish and game. (a) The commissioner shall, in accordance with the Administrative Procedure Act (AS 44.62), specify the various rivers, lakes and streams or parts of them that are important for the spawning, rearing or migration of anadromous fish.

(b) If a person or governmental agency desires to construct a hydraulic project, or use, divert, obstruct, pollute, or change the natural flow or bed of a specified river, lake, or stream, or to use wheeled, tracked, or excavating equipment or log-dragging equipment in the bed of a specified river, lake, or stream, the person or governmental agency shall notify the commissioner of this intention before the beginning of the construction or use.

(c) The commissioner shall acknowledge receiving the notice by return first class mail. If the commissioner determines that the following information is required, the letter of acknowledgement shall require the person or governmental agency to submit to the commissioner:

(1) full plans and specifications of the proposed construction or work;

(2) complete plans and specifications for the proper protection of fish and game in connection with the construction or work, or in connection with the use; and

(3) the approximate date the construction, work, or use will begin.

(d) The commissioner shall approve the proposed construction, work, or use in writing unless the commissioner finds the plans and specifications insufficient for the proper protection of fish and game. Upon a finding that the plans and specifications are insufficient for the proper protection of fish and game, the commissioner shall notify the person or governmental agency which submitted the plans and specifications of that finding by first class mail. The person or governmental agency may, within 90 days of receiving the notice, initiate a hearing under AS 44.62.370. The hearing is subject to AS 44.62.330 — 44.62.630. (§ 31 art I ch 94 SLA 1959; am § 1 ch 180 SLA 1960; am § 1 ch 132 SLA 1962; am § 1 ch 89 SLA 1966; am §§ 1, 2 ch 84 SLA 1980)

Revisor's notes. — Former subsection (c) of this section was redrafted and reorganized into present subsections (c) and (d) in 1983.

Effect of amendments. — The 1980 amendment inserted a comma between "(AS 44.62.010 — 44.62.650)," and "specify" near the beginning of subsection (a), inserted "rearing" following "the spawning" near the end of subsection (a), and deleted the former remaining provisions of subsection (a), which read: "Before December 31, 1968, the specification may be made by designating areas within which all rivers, lakes, and streams are considered important for the spawning or migration of anadromous fish; provided, that the areas lie within 50 miles of the coastline extending from Dixon Entrance through False Pass to Cape Menshikof, including all islands east of False Pass. A person giving notice under (b) of this section before December 31, 1968, may, if the activity is to take place within such a designated area, request the commissioner to specify individually by name or number, the particular rivers, lakes, and streams or parts of them within the area of operations described in the notice which are important for the spawning and migration of anadromous fish. Upon receipt of the request the commissioner shall promptly make the designation," substituted "first class" for "air" preceding "mail" at the end of the first sentence of subsection (c), substituted the last four sentences in subsection (c) [which were rewritten and redesignated as subsection (d) in 1983 by the revisor] for the former material which followed "work or use will begin" at the end of the former second sentence, and which read: "and shall require the person or governmental agency to obtain written approval from him as to the sufficiency of the plans or specifications before the proposed construction or use is begun."

Editor's notes. — Section 11, ch. 84, SLA 1980 provides: "A specification made under AS 16.05.870(a) before June 19, 1980 expires July 31, 1982, unless the commissioner of fish and game reevaluates the specification and determines that the river, lake, stream or part of a river, lake or stream to which the specification applies is important for the spawning, rearing or migration of anadromous fish."

Opinions of attorney general. — The purpose of this section is to protect and conserve fish and game and other natural resources. 1964 Op. Att'y Gen., No. 10.

Alaska has jurisdiction to enforce its fish and game laws in national forests. 1964 Op. Att'y Gen., No. 10.

Alaska's protective fish and game laws, especially this section, complement rather than conflict with federal government functions in national forests and should be enforced by both federal and state officials. 1964 Op. Att'y Gen., No. 10.

The Department of Fish and Game has permit jurisdiction over activities affecting anadromous streams, over activities in streams "frequented by fish" if those latter activities will result in the physical obstruction of that stream, and over all land use activities within the state refuge system. March 4, 1982, Op. Att'y Gen.

This section gives the Department of Fish and Game jurisdiction over nonpoint pollutant sources adjacent to classified anadromous streams or their tributaries which, absent sufficient mitigating measures, would create a direct and substantial threat to pollution of the anadromous stream itself. March 4, 1982, Op. Att'y Gen.

The commissioner of the department of fish and game has the power to adopt procedural rules to implement this section and to establish by regulation the standards under which permits will be issued under this section. March 4, 1982, Op. Att'y Gen.

When the Department of Fish and Game or Boards of Fisheries and Game have established a general policy of requiring plans and specifications in all instances involving specific types of activities, that policy can and perhaps must be codified by regulation. March 4, 1982, Op. Att'y Gen.

The Department of Natural Resources, under the authority of AS 41.17.900(d), cannot preempt the regulatory authority of the commissioner of fish and game under this section over nonpoint source pollution of anadromous streams caused by logging activities. March 4, 1982, Op. Att'y Gen.

There is no statutory basis in either AS 46.03 or AS 41.17 for implying that the Department of Fish and Game's authority over "non-point source pollution" under this section is limited by the sec. 208 program of the 1972 Federal Water Pollution Control Act (PL 92-500). March 4, 1982, Op. Att'y Gen.

This section would seem to allow that the applicant submit, essentially, two permit applications — the first to determine whether a more detailed inquiry will be made, and the second to obtain the needed authorization. March 4, 1982, Op. Att'y Gen.

The phrase "pollution" in subsection (b) should be viewed as a jurisdictional incident distinct from the other listed results or activities in that subsection and not as a specific enumeration which is to be construed to modify and limit the more general phrases. March 4, 1982, Op. Att'y Gen.

The fundamental question concerning when a permit is required is whether the nature of the construction or work is such as to constitute a "desire to pollute," and not what the individual hopes will or will not happen. March 4, 1982, Op. Att'y Gen.

When read together, this section and AS 16.05.880 are a licensing statute. March 4, 1982, Op. Att'y Gen.

There is no conflict between this section and AS 16.10.010. March 4, 1982, Op. Att'y Gen.

This section has not been impliedly repealed by anything in Title 46, AS 41.17 or AS 16.10.010. March 4, 1982, Op. Att'y Gen.

NOTES TO DECISIONS

Procedure for gaining permission to ford controlled river or stream. — A person seeking to ford a controlled river or stream must first give notice to the commissioner and include in his notice sufficient "plans and specification" so that the commissioner will know what he intends to do, when he intends to do it, what risk he foresees from his activities to fish in the vicinity, and what steps he intends to undertake for their protection. The commissioner will then review the notification and either grant the request, reject the application, or request "full" plans and specifications requiring the actor to go into greater detail and answer specific questions. Schnabel v. State, Ct. App. Op. No. 250 (File No. 7273), 663 P.2d 960 (1983).

Rejection of a request to ford need not be preceded by a request for full plans and specifications unless the commissioner lacks sufficient information to make a determination on the application. Schnabel v. State, Ct. App. Op. No. 250 (File No. 7273), 663 P.2d 960 (1983).

Stated in Southeast Alaska Conservation Council, Inc. v. State, Sup. Ct. Op. No. 2662 (File No. 5855), P.2d (1983).

Sec. 16.05.880. Construction without approval prohibited. If a person or governmental agency begins construction on a work or project or use for which notice is required by AS 16.05.870 without first providing plans and specifications subject to the approval of the commissioner for the proper protection of fish and game, and without first having obtained written approval of the commissioner as to the adequacy of the plans and specifications submitted for the protection of fish and game, the person or agency is guilty of a misdemeanor. If a person or governmental agency is convicted of violating AS 16.05.870 — 16.05.895 or continues a use, work or project without fully complying with AS 16.05.870 — 16.05.895, the use, work, or project is a public nuisance and is subject to abatement. The cost of restoring a specified river, lake, or stream to its original condition shall be borne by the violator and shall be in addition to the penalty imposed by the court. (§ 31 art I ch 94 SLA 1959; am § 1 ch 180 SLA 1960; am § 1 ch 132 SLA 1962; am § 2 ch 89 SLA 1966)

Cross references. — For criminal penalties, see AS 16.05.900.

Opinions of attorney general. — When read together, AS 16.05.870 and this section are a licensing statute. March 4, 1982, Op. Att'y Gen.

NOTES TO DECISIONS

Procedure for gaining permission to ford controlled river or stream. — A person seeking to ford a controlled river or stream must first give notice to the commissioner and include in his notice sufficient "plans and specification" so that the commissioner will know what he intends to do, when he intends to do it, what risk he foresees from his activities to fish in the vicinity, and what steps he intends to undertake for their protection. The commissioner will then review the notification and either grant the request, reject the application, or request "full" plans and specifications requiring the actor to go into greater detail and answer specific questions. Schnabel v. State, Ct. App. Op. No. 250 (File No. 7273), 663 P.2d 960 (1983).

Rejection of a request to ford need not be preceded by a request for full plans and specifications unless the commissioner lacks sufficient information to make a determination on the application. Schnabel v. State, Ct. App. Op. No. 250 (File No. 7273), 663 P.2d 960 (1983).

Sec. 16.05.890. Exemption for emergency situations. In an emergency arising from weather or stream flow conditions, the department, through its authorized representatives, shall issue oral permits to a riparian owner for removing obstructions or for repairing existing structures without the necessity of submitting prepared plans and specifications as required by AS 16.05.870. (§ 31 art I ch 94 SLA 1959; am § 1 ch 180 SLA 1960; am § 1 ch 132 SLA 1962)

NOTES TO DECISIONS

Quoted in Schnabel v. State, Ct. App. Op. No. 250 (File No. 7273), 663 P.2d 960 (1983).

Sec. 16.05.895. Penalty for causing material damage. If a person or governmental agency fails to notify the commissioner of any construction or use that causes material damage to the spawning beds or prevents or interferes with the migration of anadromous fish, or by neglect or noncompliance with plans and specifications required and approved by the commissioner causes material damage to the spawning beds or prevents or interferes with the migration of anadromous fish, the person or governmental agency shall be guilty of a misdemeanor. (§ 31 art I ch 94 SLA 1959; am § 1 ch 180 SLA 1960; am § 1 ch 132 SLA 1962)

NOTES TO DECISIONS

Quoted in Schnabel v. State, Ct. App. Op. No. 250 (File No. 7273), 663 P.2d 960 (1983).

Sec. 16.05.900. Penalty for violations. (a) A person who violates AS 16.05.870 — 16.05.895 or 16.05.920 or any regulation adopted under this chapter is guilty of a misdemeanor and, upon conviction, is punishable by a fine of not more than $1,000 or by imprisonment for not more than six months, or by both. A person who violates a regulation adopted under this chapter for the regulation of commercial fisheries shall be punished as provided in AS 16.05.720.

(b) The court shall transmit the proceeds of all fines to the proper state officer for deposit in the general fund of the state. (§ 33 art I ch 94 SLA 1959; am § 6 ch 131 SLA 1960; am § 11 ch 208 SLA 1975)

NOTES TO DECISIONS

Subsection (a) is limited by its terms to noncommercial fishing. Theodore v. State, Sup. Ct. Op. No. 305 (File No. 550), 407 P.2d 182 (1965), cert. denied, 384 U.S. 951, 86 S. Ct. 1570, 16 L. Ed. 2d 547 (1966).

Sentence upheld. — The district court was not clearly mistaken in imposing a sentence of 360 days imprisonment with 270 days suspended and a fine of $1000 after defendant entered pleas of guilty to the separate charges of killing a cow moose out of season and unlawfully selling moose meat. Schuster v. State, Sup. Ct. Op. No. 1305 (File No. 2911), 553 P.2d 925 (1976).

Trial judge was not clearly mistaken in imposing sentence of three months in jail and $500 fine, with half the fine suspended, where hunter, who shot and killed a deer in a closed area, had prior convictions for having a loaded gun within the city and reckless driving which resulted from his apparent efforts to run down a dog with his car, revealing an antisocial nature warranting more than the minimum penalties. Gottardi v. State, Sup. Ct. Op. No. 2154 (File No. 4436), 615 P.2d 626 (1980).

Applied in Graybill v. State, Sup. Ct.

SEC. 16.05.900. Penalty for violations.

(a) A person who violates A.S. 16.05.870-16.05.895 is guilty of a Class A misdemeanor. (b) The court shall transmit the proceeds of all fines to the proper state officer for deposit in the general fund of the state. (§ 33 art I ch 94 SLA 1959; am § 6 ch 131 SLA 1960; am § 11 ch 208 SLA 1975; am § 19 ch 132 SLA 1984)

Effect of amendments.

The 1984 amendment, effective July 3, 1984, rewrote subsection (a).

NOTES TO DECISIONS

Applied in Jordan v. State, Ct. App. Op. No. 360 (File No. 7782), P.2d (1984).

Sec. 12.55.030. Discharge of indigents imprisoned for nonpayment of fine. [Repealed, § 16 ch 53 SLA 1973.]

Sec. 12.55.035. Fines. (a) Upon conviction of an offense, a defendant may be sentenced to pay a fine as authorized in this section or as otherwise authorized by law. In determining the amount and method of payment of a fine, the court shall take into account the financial resources of the defendant and the nature of the burden its payment will impose. No defendant may be imprisoned solely because of inability to pay a fine.

(b) Upon conviction of an offense, a defendant who is not an organization may be sentenced to pay, unless otherwise specified in the provision of law defining the offense, a fine of no more than

(1) $75,000 for murder in the first or second degree, sexual assault in the first degree, kidnapping, or misconduct involving a controlled substance in the first degree;

(2) $50,000 for a class A, B, or C felony;

(3) $5,000 for a class A misdemeanor;

(4) $1,000 for a class B misdemeanor;

(5) $300 for a violation.

(c) Upon conviction of an offense, a defendant that is an organization may be sentenced to pay a fine not exceeding the greater of

(1) $100,000; or

(2) an amount which is three times the pecuniary gain realized by the defendant as a result of the offense.

(d) If a defendant is sentenced to pay a fine, the court may grant permission for the payment to be made within a specified period of time or in specified installments. (§ 12 ch 166 SLA 1978; am § 17 ch 45 SLA 1982; am § 26 ch 143 SLA 1982)

Cross references. — For classification of offenses, see AS 11.81.250; for sentences of imprisonment for felonies, see AS 12.55.125; for sentences of imprisonment for misdemeanors, see AS 12.55.135; for sentences for violations, see AS 12.55.140.

Effect of amendments. — The first 1982 amendment, in subsection (b)(1), deleted "or" preceding "kidnapping" and added "or misconduct involving a controlled substance in the first degree."

The second 1982 amendment inserted "sexual assault in the first degree" in paragraph (1) of subsection (b).

While neither 1982 amendment gave effect to the other, both have been given effect in paragraph (b)(1), set out above.

APPENDIX B

STATE TRANSPORTATION AND
RESOURCE AGENCY RESPONSES

AMERICAN AGENCY RESPONSES

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Alabama Department of Conservation	NONE	NONE	No Comment
Arizona Department of Fish and Game	NONE	Coordinates with DOT to create impassable culverts to block movements of exotics.	Good
Arkansas Game and Fish Commission	NONE	Culverts are usually large enough to facilitate fish passage.	No Comment
California Department of Fish and Game	YES	Install pipe along natural stream gradient. Size culvert to accommodate a Q_{25} discharge. Depress culvert invert below streambed.	No Comment
California Department of Transportation	YES	Developed a fish passage task force which consists of highway department and resource agency personnel.	Good
Connecticut Department of Environmental Protection	YES	Install culverts below stream grade. Use "v" bottom box culverts in areas where low flow conditions are important.	Good
Connecticut Department of Transportation	YES	Install culvert inverts at least six inches below stream grade. Install baffles in problem culverts.	No Comment

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Delaware Department of Natural Resources	FEW	Use two or more culverts with one set lower than the rest to accommodate fish passage during low flow conditions.	Good
Delaware Department of Transportation	FEW	Install culverts at or below the stream bed elevation.	Good
Georgia Department of Natural Resources	YES	Same comments as Connecticut Department of Environmental Protection.	No Comment
Georgia Department of Transportation	YES	"v-notching" the bottom of culverts. Creating resting pools at both ends of the culvert. Installing baffles. Depressing the culvert invert one foot below the elevation of the streambed.	Good
Florida Game and Fresh Water Fish Commission	NONE	NONE	No Comment

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Florida Department of Transportation	NONE	Culverts sized for hydrological conditions provide sufficient passage for fish.	No Comment
Florida Department of Natural Resources	NONE	NONE	No Comment
Hawaii Department of Land and Natural Resources	NONE	Culverts sized for flood flows provide unrestricted movements of fish.	No Comment
Hawaii Department of Transportation	NONE	NONE	No Comment
Idaho Department of Fish and and Game	YES	Analysis of fish passage needs on a case by case basis.	No Comment
Idaho Department of Transportation	YES	Utilize a variety of baffling systems for culverts.	Good
Illinois Department of Conservation	YES	Installing culvert below or at stream elevation.	Good

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Illinois Department of Transportation	YES	Gradient of a culvert cannot exceed 5%. Outlet velocities cannot exceed designated maximums more than 10% of the time.	Good
Indiana Department of Highways	NONE	Install culverts at or below streambed.	Good
Iowa Conservation Commission	NONE	NONE	No Comment
Iowa Department of Transportation	NONE	Install culvert invert below streambed.	No Comment
Kansas Fish and Game	NONE	All structures can pass a Q_{100} discharge.	Good
Kentucky Department of Fish and Game	YES	Installing culverts parallel to stream gradient. Culvert diameter must be at least two feet. Culverts must not impede normal flows.	Good
Louisiana Department of Wildlife and Fisheries	NONE	NONE	No Comment

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Louisiana Department of Transportation	NONE	NONE	No Comment
Maine Department of Inland Fisheries and Wildlife	YES	Fishery Biologists coordinate with DOT personnel early in planning stages.	Good
Maine Department of Transportation	YES	Early coordination with resource agencies. Installing culverts at least six inches below stream grade. Have fishery biologist attend preconstruction conferences where they can voice their concerns to contractors. Encourage interagency visits to project site.	Good
Maryland Department of Natural Resources	YES	Depress culvert inverts below streambed.	No Comment
Maryland Department of Transportation	YES	Burying culvert invert one foot below existing grade.	Good
Massachusetts Department of Public Works	NONE	NONE	Good

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Michigan Department of Natural Resources	YES	Bury culvert inverts with stones to normal stream grade. Keep culvert slopes as low as possible.	Good
Missouri Department of Conservation	FEW	No design criteria.	Good
Missouri Highway and Transportation Commission	NONE	NONE	Good
Minnesota Department of Natural Resources	YES	Coordinate with DOT to create fish blocks to protect prime sport fisheries from the invasion of carp.	Good
Mississippi Department of Wildlife Conservation	NONE	NONE	No Comment
Montana Department of Fish, Wildlife and Parks	YES	Places boulders and rocks in the culvert bottoms.	Good

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Nebraska Game and Parks Commission	NONE	NONE	No Comment
Nebraska Department of Roads	NONE	Initiates early coordination with resource agencies	Good
Nevada Department of Transportation	YES	NONE	Good
New Jersey Department of Transportation	YES	Box culverts are used with low flow channels.	Good
New Jersey Department of Environmental Protection	YES	Special attention is given to low flow	No Comment
New Mexico Highway Department	NONE	NONE	No Comment

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
New York Department of Transportation	YES	Install culverts below streambed elevation.	Good
New York Department of Environmental Conservation	YES	Use Evans and Johnston, 1974 and Dane, 1978 for criteria.	No Comment
North Carolina Department of Transportation	YES	Depress culvert inverts 1.5 feet below the stream gradient. In culverts longer than 150 feet, the average water velocities at normal flow should not exceed 2 fps.	No Comment
Ohio Department of Natural Resources	FEW	Depress culvert inverts below stream gradient.	No Comment
Ohio Department of Transportation	FEW	Utilize Dryden and Stein (1975) criteria	Good
Oklahoma Department of Wildlife Conservation	NONE	NONE	No Comment
Oklahoma Department of Transportation	NONE	NONE	No Comment

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Oregon Department of Fish and Wildlife	YES	Maximum culvert slope of 0.5%. Use of baffles. Place rip rap in culvert bottoms. Use resting pools at the culvert outlet.	Good
Oregon Department of Transportation	YES	Early coordination with Oregon Department of Fish and Wildlife. Uses Oregon Department of Fish and Wildlife criteria.	Good
Pennsylvania Fish Commission	YES	The selection of the type of fish passage structure depends upon the conditions of the stream site, ease of installation and economy befitting the project.	Good
Rhode Island Department of Transportation	NONE	NONE	No Comment
South Carolina Wildlife and and Marine Resources Department	NONE	NONE	No Comment
South Dakota Department of Fish and Parks	NONE	Use baffles inside box culverts.	Good

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Tennessee Wildlife Resources Agency	YES	Use box culverts. Install culverts below stream grade.	Good
Texas Parks and Wildlife Resources Agency	NONE	NONE	No Comment
Texas Department of Highways	NONE	NONE	No Comment
Vermont Agency of Transportation	YES	Use railroad ties at the bottom of a concrete box culvert. Depress invert at least six inches.	Good
Virginia Department of Highways	YES	Construct low flow channels in culverts.	Good
Washington Department of Game	YES	Are currently revising their criteria.	No Comment

AMERICAN AGENCY RESPONSE (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Washington Department of Transportation	YES	Still negotiating with Washington Department of Fisheries on developing fish passage criteria.	Developing
Wisconsin Department of Natural Resources	NONE	Install culverts six inches below the existing stream bed. Develop barriers to keep out carp or sea lamprey.	Good
Wyoming Highway Department	YES	Install culverts one foot below the existing stream grade. Place rocks on the culvert bottom.	No Comment

CANADIAN RESPONSES

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Alberta Energy and Natural Resources	Yes	Currently developing baffling systems for culverts. Advoid using round corragted pipes as much as possible. Culverts are designed to pass a Q_{50} flood. Outlet velocities must not exceed for a Q_{10}. Maximum 3 day delay allowed.	Good
British Columbia Ministry of Environment	Yes	Recommend using arch culverts with naturally grading bottoms.	No Comment
Manitoba Ministry of Natural Resources	Yes	Culverts are installed according to Dryden and Stein (1975) recommendations.	No Comment
Newfouldland and Labrador Department of Environment	Yes	Install culverts along natural gradient. Low flow concerns must be considered. Scour aprons should be used.	No Comment

CANADIAN RESPONSES (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Newfoundland and Labrador Department of Transportation	Yes	Uses bottomless arch culverts on a concrete footing. Work out fish passage problem with Habitat Management Section of fisheries and Oceans. Indentify fish passage problems in the planning stage of a project.	Good
Northwest Territories Department of Renewable Resources	Yes	Utilize Evans and Johnston (1974) and Katopodis (1977) for design criteria.	No Comment
Nova Scotia Department of Fisheries and Oceans	Yes	Install culverts 6 to 12 inches below the streambed. Maximum desirable culvert slope is 0.5%. Steeper gradients may require baffles and resting pods at the culvert outlet.	No Comment
Prince Edward Island Dept. of Community and Cultural Affairs	Yes	Install culverts 6 to 12 inches below the streambed. Maximum desirable culvert slope is 0.5%. Steeper gradients may require baffles resting pads at the culvert outlet. Multiple culverts require setting one culvert lower than the rest for low flow conditions.	No Comment

CANADIAN RESPONSES (continued)

Agency	Fish Passage Problems With Highway Culverts	Comments	DOT/Resource Agency Relationship
Manitoba Freshwater Institute	Yes	Utilize Dryden and Stein (1975) guidelines. In the process of revising guidelines.	No Comment
Saskatchewan Parks and Renewable Resources	Yes	Install culverts 6 inches below streambed. Match existing stream gradient. Capable of handling a Q_{15} discharge. Outlet velocites can not exceed 4 ft./sec for culverts smaller than 80 feet. Fish can not be delayed more than 3 consecutive days during a Q_{50}.	No Comment
Yukon Territory Ministry of Fisheries and Oceans	Yes	Must pass adult grayling during a $Q_{2.33}$ discharge.	Good
Yukon Territory Department of and Transportation	Yes	The Department feels culverts are grossly oversized for fishpassage concerns.	Poor

APPENDIX C

INFORMATIONAL HANDOUT

Environmental Quality
Engineering

University of Alaska
School of Engineering
306 Tanana Drive
Fairbanks, Alaska 99701

15 May 1985

Dear Sport Fisherman:

Thank you for taking time to read this explanatory note about our "Fish Passage Study." First, however, we would like to ask for your cooperation with us in this effort. Your assistance can be of great help and basically our request is fairly simple.

1). If you should catch a tagged Arctic grayling in Poplar Grove Creek (and you intend to keep the fish or the fish is seriously injured due to capture), please turn the tag into one of our personnel near the culvert on the Richardson Highway or mail the tag to ADF&G, Box 47, Glennallen.

2). Should you catch an Arctic grayling but do <u>NOT</u> intend to keep the fish because of size limitations or whatever, and the fish is not injured, please do <u>NOT</u> remove the tag. Carefully release the fish back to the creek.

3). The tags that we are using are small plastic strips attached to the upper fin of the fish. They are either yellow, blue or orange in color and are about 1/8 inch wide and three inches long. They are printed ADOT5-85RTN ADF&GBX47GLNALLEN" which stands for Alaska Department of Transportation and Public Facilities, May 1985, Return to Alaska Department of Fish and Game, Box 47, Glennallen.

Now to explain the purpose of this study. It is co-sponsored by ADOT&PF and the University of Alaska, Fairbanks in cooperation with ADF&G. We will be capturing and tagging some 1000-1500 Arctic grayling during a week long time period. These fish will be released and allowed to continue their migration up Poplar Grove Creek and to pass through the culvert at the Richardson Highway. During their migration we will be monitoring stream flow conditions, velocity, temperature, water clarity, and other water quality parameters. As well, we will be attempting to observe the fishes' swimming ability at high water velocity conditions within the culvert proper. Hopefully, the data gathered from this study will assist ADOT&PF and ADF&G in the optimal design of highway culverts that afford a high degree of protection to the migrating fisheries resources of the State.

Your participation, cooperation and assistance will be most helpful. Good luck and GOOD FISHING.

Tim Tilsworth and Mike Travis
Principal Investigators