# A Tool for Monitoring the Effectiveness of V-Weirs for Over-Wintering Salmonids in the Crowsnest River

by

**Leah Carlson**

**A Masters Degree Project submitted in partial fulfillment of the requirements for the degree of**

**Master of Environmental Design (Environmental Science)**

**University of Calgary**

**2000**

National Library of Canada
Acquisitions and Bibliographic Services
395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque nationale du Canada
Acquisitions et services bibliographiques
395, rue Wellington
Ottawa ON K1A 0N4
Canada

*Your file Votre référence*

*Our file Notre référence*

The author has granted a non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of this thesis in microform, paper or electronic formats.

The author retains ownership of the copyright in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de cette thèse sous la forme de microfiche/film, de reproduction sur papier ou sur format électronique.

L'auteur conserve la propriété du droit d'auteur qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

0-612-48252-9

Canada

# EXECUTIVE SUMMARY

Construction of the Oldman River Dam (OMRD) in southern Alberta, resulted in an estimated loss of 225,000 $m^2$ of critical salmonid habitat (R.L. & L. Environmental Services Ltd. 1993). To compensate for this loss, numerous artificial habitat structures were erected upstream in the Castle, Crowsnest and Oldman rivers. One such artificial structure type is a V-weir; a boulder structure designed to increase pool and run habitat for trout and mountain whitefish during periods of low flow and overwintering (Lowe 1996). This type of instream habitat may be particularly important refuge to endure harsh winter conditions, such as; freezing water temperatures, low flow and subsurface ice development.

Instream evaluations of artificial structure effectiveness in winter are scarce. One of the barriers to assess fish use of reclaimed habitat in winter is the limitation of existing field techniques under shallow, ice-covered lotic conditions. This investigation tested a SONY high-8 video camcorder and underwater housing as a technique for monitoring winter salmonid use of V-weir pools. The relative abundance of salmonids in Crowsnest River pools (both V-weir and natural high quality controls) were examined under ice-covered and open-water conditions.

To film ice-covered pools, the housing was lowered close to the stream bottom through ice holes. Sampling was conducted by slowly, smoothly rotating the camera 360° twice in each hole. Each filming rotation commenced facing upstream, then briefly paused every 90° (90°, 180°, 270° and 360°). The camera was manoeuvered via a modified aluminum pole (2.03 m long and 1.3 cm diameter). Open-water sampling was accomplished by filming pools from shore. The housing was extended into the stream by means of a distally held pole (3.11 m long and 2.5 cm diameter). Horizontal filming progressed upstream, until the entire pool area was covered. A light weight, 40 m rope was attached to the top of the housing and held taught by an assistant positioned on the upstream bank. This system provided extra leverage to aid camera movement upstream and ease downstream movement. Under both ice-covered and open-water conditions, automatic focus resulted in the best quality observations.

The focal capability of the camera was influenced by several factors. Warm winter conditions during the study led to considerable reduction in visibility, especially in ice-covered conditions. Instream debris and turbulence also decreased the focal distance. Cloud cover increased the visibility by reducing light penetration of the water column, thus, instream particle reflection was reduced. Consequently, optimal video quality resulted on cold, cloudy days in calm portions of stream pools with minimal instream debris. The level of enumeration and positive identification of fish observed was also dependent on the distance between camera and fish and fish activity. Fright response to the presence of camera and light was rare.

In the Blairmore and Coleman open-water study areas, a total of 195 salmonids was enumerated. Whether sport fish observations were examined as a whole (all salmonids) or grouped separately into trout and mountain whitefish, the median number of salmonids enumerated among treatment

sites were significantly different ($P < 0.001$) in both open-water study areas. In the Blairmore area, one V-weir contained significantly more salmonids than any other pool. In the Coleman study area, one control contained significantly more salmonids than any other pool. Of the total fish enumerated in open water sites, approximately 9 % of individuals were not possible to identify as trout or whitefish. Groups of sport fish, containing 3 to 22 individuals, were documented at several sites. Aggregations consisted of whitefish alone, trout alone or trout and mountain whitefish. Behavior of congregations varied from actively feeding and schooling to resting in sheltered resting areas. High-use areas were deep, low velocity pool habitats.

Regardless of whether a pool was artificial or natural, it is evident that fish use of open-water overwintering pools was inconsistent and that variation was greater between individual pools than between control and V-weir sites. As a result, modification of the standard control versus treatment monitoring study design may be warranted. Resource Selection Probability Functions (RSF) is an alternative approach by which the relative importance of all environmental parameters potentially influencing resource use may be examined. RSF may clarify the quality and quantity of resources selected by salmonids in winter and thereby improve our definition and understanding of effective overwintering habitat

A total of 30 salmonids was observed in the four ice-covered sites. There was no significant difference in the median number of salmonid observed in any of the Lundbreck pools. Due to elevated turbidity conditions during the study period, it was not possible to differentiate between trout and mountain whitefish for 27 % of fish observed. No fish were observed in groups. Salmonids were relatively inactive, usually resting or slowly swimming in deep, low velocity pool areas.

With an understanding of technique limitations, underwater video is an appropriate field method to sample shallow, ice-covered and open water river systems in cold winter conditions. This method is effective to assess relative abundance, species composition, behavior and habitat-use of sport fish. The unobtrusive nature of video sampling is particularly favorable when dealing with an important recreational fishery and "species of concern" such as the bull trout. This technique should be considered an affordable option which takes little time and personnel to operate. The findings of this methodological exploration are preliminary and should be expanded by long term assessment of the capabilities of underwater video observation.

To sustain healthy fisheries, fish use of artificial structures must be evaluated throughout the year. V-weir pools do provide overwintering habitat for adult salmonids under open-water and ice-covered conditions. In years of extensive subsurface ice development, the presence of more deep, low velocity habitat may increase overwinter survival of sport fish. With respect to the evaluation of salmonid use of V-weirs in winter, conclusions of this investigation were inconclusive due to small sample size, inconsistent use of pools and only one season of winter observations. Recommendations which arose in this investigation focused on several subjects, such as; continued effectiveness monitoring of artificial structures throughout the year, the role of subsurface ice in streams and further experimentation with underwater video.

# ACKNOWLEDGEMENTS

I would like to acknowledge the exceptional guidance and expertise provided by Michael Quinn in his supervisory role on this project. I wish to thank Kerry Brewin of Trout Unlimited Canada, for his valuable counsel and detailed review comments as an external committee member. I also want to thank the Dean's Appointed Examiner, Cormack Gates, whose constructive criticism strengthened this document.

Project development advice and content reviews contributed by Lorne Fitch (Alberta Environment, Lethbridge, AB) were instrumental in accomplishing this research and greatly appreciated. I am extremely grateful to several individuals who offered valuable advice and aided in the access and interpretation of the OMRD fisheries data: Rick Pattenden and Jim O'Neil (R.L & L Environmental Services Ltd., Edmonton, AB), John Englert (Alberta Public Works, Supply and Services, Aquatic Resources Environmental Branch, Edmonton, AB) and Jim Allan (Pisces Environmental Consulting Services Ltd., Red Deer, AB). I also wish to thank the staff members of Alberta Environment, Lethbridge, Alberta, for their time and effort in fish identification.

Special thanks to Trent Carlson, Stephen Lebeuf, Vernon Andres and Shawn Tratch for their innovative technical ideas and invaluable field support. I would like to thank Bob Fisher (Faculty of Environmental Design, University of Calgary) who was instrumental in the construction and design of the pole and housing bracket. I wish to express my gratitude to the many other people not mentioned who have shown interest in the project over the past several months.

The funding for the study was supplied by Alberta Sport, Recreation, Parks and Wildlife, Alberta Environment and the Faculties of Graduate Studies and Environmental Design, University of Calgary. I am grateful to my parents, they were fundamentally important to accomplishing this goal. Last, but certainly not least, I wish to express my appreciation to my husband Stephen Lebeuf for his inexhaustible support and encouragement and his angler perspective.

# TABLE OF CONTENTS


EXECUTIVE SUMMARY I

ACKNOWLEDGMENTS II

1.0 INTRODUCTION 1

2.0 OBJECTIVES 5

3.0 BACKGROUND - LITERATURE REVIEW 6

3.1 **Ecological, Economic and Social Importance** 6
3.2 **Winter Habitat Requirements** 7
3.2.1 Ice Conditions 8
3.2.1.1 Sub-Surface Ice (Frazil and Anchor Ice) 8
3.2.1.2 Surface Ice 9
3.2.2 Overwintering Habitat 10
3.2.3 Overwintering Strategies 12
3.2.4 Winter Movement 14
3.3 **Review of Winter Sampling Techniques** 16
3.3.1 Underwater Video Surveillance 16
3.3.2 Electrofishing 17
3.3.3 Ice Fishing 20
3.3.4 Under-Ice Netting 20
3.3.5 Radiotelemetry 21
3.3.6 Scuba and Snorkel 21
3.3.7 Other Underwater Observation Techniques 22
3.4 **OMRD Fisheries Mitigation Program** 25
3.4.1 V-Weirs 26
3.4.1.1 Physical Success 30
3.4.1.2 Biological Success 32
3.4.1.3 Anglers Opinions 37
3.4.1.4 Choice of V-weirs as the Focus of the Study 38

4.0 STUDY AREA 39

5.0 METHODS 43

5.1 **Site Choice** 43
5.2 **Site Descriptions** 44

5.2.1 Blairmore and Coleman Open-Water Sites 44
5.2.2 Lundbreck Ice-Covered Sites 47
**5.3 Physical Measurements** 49
**5.4 Materials** 51
5.4.1 Camera Housing Equipment 51
5.4.2 Housing Bracket 51
5.4.3 Pole Extension 52
5.4.4 Nuts and Bolts 54
5.4.5 Ice Auger 55
5.4.6 Safety Equipment 55
5.4.7 Ice Clearing 56
**5.5 Description of the Open-Water Underwater Video Method** 57
**5.6 Description of the Ice-Covered Underwater Video Method** 62
**5.7 Fish Identification and Enumeration** 64
**5.8 Statistics** 65

**6.0 RESULTS** **66**

**6.1 Relative Abundance Between V-Weir and Natural High Quality Open-Water Pools** 66
6.1.1 Summary of Open-Water Results 80
**6.2 Relative Abundance Between V-weir and Natural High Quality Ice-Covered Pools** 82
**6.3 Utility of Night Filming** 87

**7.0 DISCUSSION** **88**

**7.1 Evaluation of V-Weirs for Provision of Winter Habitat** 88
7.1.1 Open-Water Sites 89
7.1.1.1 Considerations in Salmonid Pool Selection 91
7.1.1.1.1 Sheltered Overwintering Habitat 91
7.1.1.1.2 Aggregations 92
7.1.1.1.3 River Location 95
7.1.1.1.4 Trout and Mountain Whitefish 96
7.1.1.1.5 Anglers 97
7.1.1.1.6 Small Population Size 97
7.1.1.1.7 Juvenile Concealment 98
7.1.2 Ice-Covered Sites 99
**7.2 Appropriateness of Underwater Video to Assess Effectiveness of V-Weir Artificial Habitat Structures in an Open-Water River** 102
**7.3 Appropriateness of Underwater Video to Assess Effectiveness of V-Weir Artificial Habitat Structures in an Ice-Covered River** 104
**7.4 Fisheries Management** 108
**7.5 Recommendations** 110
7.5.1 OMRD Fisheries Mitigation Program 110

7.5.2 Underwater Video 111
7.5.3 General Fisheries Management 113

**8.0 SUMMARY** **117**

**LITERATURE CITED** **120**

**APPENDICES**

A. Glossary 130
B. OMRD Artificial Habitat Structures 132
C. Open-Water Study Sites 134
D. Ice-Covered Study Sites 139
E. Physical Measurements 142
F. Risk Management Plan 152
G. Previous Snorkel Observations 154

## LIST OF FIGURES

**Figure 1** Diagram of a Typical Single-Crested V-Weir Constructed in the Upper Crowsnest River 28
**Figure 2** Diagram of a Typical Double-Crested V-Weir Constructed in the Lower Crowsnest River 29
**Figure 3** Map of the Crowsnest River 40
**Figure 4** Map of the Oldman River Reservoir 41
**Figure 5** Blairmore, Coleman and Lundbreck Study Areas 48
**Figure 6** Photo of Video Housing and Bracket 52
**Figure 7** Photo of Video Housing and Open-Water Pole 53
**Figure 8** Photo of Video Housing and Ice Pole 54
**Figure 9** Diagrammatic Example of Order and Locations of Filming Positions 58
**Figure 10** Camera-Pole Angle Required for Parallel Filming with Steep Stream Banks 59
**Figure 11** Photo of Rope Leverage System 60
**Figure 12** Photo of V-weir site Bv-17 Filming the Portion of the Pool Where Sport Fish Aggregated 74
**Figure 13** Photo of Control Site Cc-242 Delineating the Two Preferred Areas 242 - A and 242 - B 79

## LIST OF TABLES

**Table 1** Utility of Alternative Methods to Sample River Pools in Winter 24
**Table 2** Approximate River Location and Construction Dates of the Open-Water Sites 46

| | | |
|---|---|---|
| **Table 3** | Approximate River Location and Construction Dates of the Ice-Covered Sites | 48 |
| **Table 4** | Summary of the Number of Mountain Whitefish Depicted in Video Observations in the Blairmore Open-Water Study Section | 67 |
| **Table 5** | Summary of the Number of Trout Depicted in Depicted in Video Observations in the Blairmore Open-Water Study Section | 68 |
| **Table 6** | Summary of the Number of Sport Fish Depicted in Video Observations in the Coleman Open-Water Study Section | 69 |
| **Table 7** | Identification of Trout Species and Mountain Whitefish Observed in Blairmore and Coleman Sites | 73 |
| **Table 8** | Physical Characteristics of Coleman Open Water Sites | 77 |
| **Table 9** | *T* - test Results Comparing Mean Physical Measurements Between Control Site 242 with All Other Coleman Sites | 77 |
| **Table 10** | Identification of Trout and Mountain Whitefish Observed in Lundbreck Sites | 83 |
| **Table 11** | Summary of Mountain Whitefish Observed During Ice-Covered Sampling | 83 |
| **Table 12** | Summary of Trout Observed During Ice-Covered Sampling | 84 |
| **Table 13** | Velocity Measurements Through Observation Holes at Ice-Covered Sites | 85 |
| **Table 14** | Depth Measurements Through Observation Holes at Ice-Covered Sites | 86 |

# 1.0 INTRODUCTION

Construction of the Oldman River Dam (OMRD), precipitated the largest fisheries mitigation program ever undertaken in Alberta. Throughout the past century, the Oldman River Sub-Basin has also been altered by a multitude of other human activities, such as; mining, livestock grazing, urban encroachment, pollution, channelization and agricultural practices. As a consequence of such activities, current North American estimates on the state of freshwater ecosystems predict that 21 % of fish species are in danger of extinction (Ricciardo and Rasmussen 1999). Due to the rising human population and associated resource demands, protection and restoration of watershed health is essential.

To preserve the natural structure and function of a freshwater ecosystem, identification and prevention of ecologically destructive practices must be a fisheries management priority. In many cases, however, the damage has already occurred. As a result, restoration and mitigation[1] of critical fish habitat loss may be a fundamental part of sustaining healthy salmonid populations in the future. Considering the current and potential role of stream alteration in fisheries management, assessment of the physical and biological performance of artificial habitat structures is vitally important. Even though artificial fish habitat has been used to "enhance" fish populations since the 1920's in North America, the utility of these structures is often hindered by

[1]For the purposes of this document, the terms 'mitigation' and 'compensation' are used interchangeably, referring to compensation in one area for losses ensued in another (Appendix A - Glossary).

inadequate assessment of their success (Fitch et al. 1994; Kondolf and Micheli 1995; Minns et al. 1996; Pattenden et al. 1998; Reeves et al. 1991).

Monitoring is an essential part in the evaluation of artificial structure performance (Fitch et al. 1994). "Effectiveness monitoring" is conducted to assess whether the intended management goals have been achieved (Noss and Cooperrider 1994). Structure evaluation should involve long term collection of data on physical and biological performance, as well as, identification of improvement needs (Fitch et al.1994). For maximum scientific rigor, monitoring should involve the systematic collection of pre- and post-mitigation data with replications and controls over several years (Noss and Cooperrider 1994; Riley and Fausch 1995; Underwood 1991 in Minns et al. 1996). To ensure that fisheries management actions benefit the intended population, fish use of artificial habitat structures must be monitored throughout the year. One important component that is often missing in monitoring programs is evaluation of structure effectiveness during low flow, overwintering periods (Pattenden et al. 1998).

To compensate for an estimated 225,000 $m^2$ of critical salmonid habitat lost to the OMRD reservoir, numerous artificial habitat structures were constructed upstream in the Castle, Crowsnest and Oldman rivers (R.L. & L. Environmental Services Ltd. 1993). The goal of the OMRD Fisheries Mitigation Program was to achieve "no net loss of recreational fishing opportunities"(Dominion Ecological Consulting Ltd. 1988,1). For quantification purposes, loss of high quality sport fish habitat was equated with loss of recreational fishing opportunities. In order to be wholly counted as reclaimed habitat by the mitigation program, artificial habitat must

contain at least 80% as many sport fish as high quality natural habitat (Lorne Fitch, Alberta Environment, Lethbridge, Alberta; personal communication).

One type of artificial structure that was used extensively in the OMRD Fisheries Mitigation Program was a V-weir; a boulder structure designed to increase pool and run habitat for trout and mountain whitefish (*Prosopium williamsoni*) during periods of low flow and overwintering (Lowe 1996). In a natural system, these types of feeding and holding habitats are essential for the maintenance of healthy salmonid populations. The deep, low velocity sheltered conditions provided by these instream habitats may be particularly important refuge during winter.

As instream conditions change throughout the year, so do the challenges stream life must adapt to. The quality and quantity of overwintering habitat play a critical role in enabling salmonids to survive extreme winter conditions (Campbell and Neuner 1985; Chapman 1966; Griffith and Smith 1995; Hunt 1971). The availability of winter refuge may significantly influence the biotic carrying capacity of a stream (Chapman 1966). Winter habitat may be especially limiting in areas that experience extensive ice development and/or reduced flow (Brown 1994; Brown and Mackay 1995; Chisholm et al. 1987; Jakober 1995).

A U.S. Forest Service survey sent out to aquatic biologists, researchers and natural resource managers ranked "research to define critical salmonid overwintering habitat" as the second most important salmonid research need in the central Rocky Mountain region (Marcus et al. 1990). When the critical habitat requirements are not well researched, the importance of monitoring is

increased (Minns et al. 1996). More research has focused on this area since 1990, however, data pertaining to ice-covered rivers and streams are still scarce.

There are several reasons that may explain the scarcity of winter stream data. The lack of an effective, consistent sampling technique to observe and enumerate fish under extreme winter conditions may be the principle reason for the research shortage. In particular, the logistical difficulties associated with conducting winter field studies under shallow, ice-covered river conditions limits progress. Another influential factor may be a preference for field work under more hospitable conditions. The demand to complete the documentation and analysis phase of summer fisheries studies may also reduce the likelihood of continued data collection through the winter (Hubbs and Trautman 1935 in Brewin et al., in preparation). Perhaps, earlier scientific views assumed that habitat utilized in winter differs little from that occupied in summer. Whatever the reasons, the less complete our knowledge of fish habitat requirements throughout the year, the greater the likelihood of failures in fisheries management.

# 2.0 OBJECTIVES

This study was designed to accomplish the following objectives:

- To compare the abundance of sport fish populations between artificial and high quality natural pool and run habitats during overwintering (low flow) periods. This objective is addressed with respect to the OMRD fisheries mitigation goal of "no net loss of recreational fisheries opportunities" and the following hypothesis:

  **Ho:** There is no difference in the relative abundance of trout and mountain whitefish between pools (both V-weir and natural high quality controls) in the Crowsnest River.

- To document the winter habitat characteristics correlated with high and low fish usage of pools and runs
- To evaluate the utility of winter underwater video surveillance as a technique for determination of V-weir structure effectiveness
- To make recommendations to improve existing and future fisheries mitigation programs

# 3.0 BACKGROUND - LITERATURE REVIEW

## 3.1 Ecological, Social and Economic Importance

Riverine areas are extremely important to societal well-being. Rivers and riparian areas supply several highly valued goods and services, for example: flood control, water quality and quantity improvement, energy yield, agricultural, municipal and industrial water supply, animal waste recycling and livestock food (Doppelt et al. 1993; Stromberg et al. 1996). Extensive recreational values directly and indirectly provided by river valley landscapes, such as; cycling, canoeing, hiking, swimming, wildlife watching and camping, must also be taken into account. In the case of the Crowsnest River, angling is likely the most economically significant recreational value.

The Crowsnest river is currently an internationally renowned, blue ribbon trout fishing stream and angling popularity is increasing. A productive fishery is not only important in the primary angling enjoyment it provides, but also in the secondary economic activities it fosters. In 1998, 210,166 resident, 2446 non-resident annual and 5023 non-resident five day fishing licences were sold in the province of Alberta (Verna Wolfram, Natural Resource Services, Edmonton, Alberta; personal communication). The most recent provincial survey indicates that anglers spent an estimated 311.5 million dollars on goods and services directly related to sport fishing in 1995 (Berry 1997). Increased recreational tourism may be particularly socially and economically important in the Crowsnest Pass, where employment opportunities are limited.

From an ecological perspective, robust rivers and riparian forests are vital to the survival and propagation of numerous interconnected floral and faunal species. Intrinsically valuable for its own sake, a healthy ecosystem is essential to preserving biodiversity (Walker 1995). Clearly, one of the greatest challenges to fisheries management is to find a balance between human demands and the maintenance of natural processes and elements (Grumbine 1997; Sparks 1995).

## 3.2 Winter Habitat Requirements

Survival and propagation of stream salmonid populations is fundamentally dependent on the ability of fish to successfully grow to maturity, spawn and produce young. Depending on the particular life stage and/or season, habitat utilized and behavior exhibited by an individual changes (Campbell and Neuner 1985; Cunjak and Power 1986; Heggenes et al. 1991). Factors, such as sheltered feeding positions and territoriality, which are extremely important to salmonid survival during the rest of the year become secondary to other priorities, such as energy conservation and protection from severe environmental conditions, during overwintering periods (Campbell and Neuner 1985; Chapman 1966; Cunjak 1988; Gosse 1982; Heggenes et al. 1993; Jakober 1995; Jakober et al. 1998). The availability of instream habitat to accommodate each life stage throughout the year is essential to sustaining a healthy salmonid population.

Several factors make salmonid survival in northern temperate streams challenging during winter. First, cold water temperatures result in decreased digestion rates, food requirements, and swimming ability, and elevated net energy costs for salmonids (Cunjak 1988; Cunjak and Power

1986; Hartman 1963; Heifetz 1987; Macioleck and Needham 1952). Ice development below the stream surface (sub-surface ice formation) can severely decrease habitat accessability and utility (Berg 1994; Brown 1994; Brown and Mackay 1995; Jakober 1995). Low river flow levels due to moisture trapped as ice and snow increase the harshness of the stream environment (Prowse 1994; Prowse and Gridley 1993). The myriad of environmental challenges associated with overwintering survival point to the necessity of sufficient deep, sheltered instream habitat.

### 3.2.1 Ice Conditions

Formations of surface and subsurface ice in streams is highly variable and affected by several site specific environmental factors. The degree and nature of stream icing is influenced by a combination of physical and environmental components, for example: climate, stream order, ground water source, altitude, watershed character, riparian vegetation, channel morphology, instream debris and snow accumulation (Berg 1994; Brown et al. 1993; Chisholm et al. 1987; Prowse 1994). There are two main ice categories which influence stream inhabitants: subsurface (anchor and frazil ice) and surface ice.

#### 3.2.1.1 Sub-Surface Ice (Frazil and Anchor Ice)

Frazil ice is needle-like ice crystals that develop under conditions of supercooled (slightly below zero), turbulent water. As frazil ice forms, it bonds to other ice crystals and surrounding instream debris forming anchor ice (Prowse and Gridley 1993). Anchor ice commonly develops upward

from the stream channel bottom or associated with submersed objects (Prowse and Gridley 1993). These qualities of ice formation can result in rapid infilling of pools containing coarse materials, such as; woody debris, aquatic plants or large substrate (Brown et al. 1993; Prowse 1994). The combination of stream hydraulics and ice formation can lead to ice scour, ice dams, reduced wetted pool area and stream de-watering (Brown and Mackay 1995; Cunjak 1986; Maciolek and Needham 1952; Prowse 1994). Consequently, extensive subsurface ice development can lead to decreased availability of pool space, barriers for fish movement between pools and fish kills.

The combination of altitude, climate and stream character influence snow accumulation and ice development (Chisholm et al. 1987). Deep, narrow, high elevation streams which commonly develop snow bridges in winter are less disposed to surface and subsurface ice formation than shallow, wide streams. Mid-elevation streams are characterized by the most anchor and frazil ice development because of minimal snow buildup and incomplete ice cover conditions. Low altitude streams develop some subsurface ice and minor subsurface ice formation. Due to the increased likelihood of snow bridging in high elevation streams, minimal surface or subsurface ice is produced (Chisholm et al. 1987). These high altitude lotic systems can provide crucial overwintering habitat.

#### 3.2.1.2 Surface Ice

Surface ice can be beneficial to winter survival of river fish (Brown et al. 1993; Maciolek and

Needham 1952). Surface ice development, coupled with insulating snow cover, can prevent supercooling of water (Brown et al.1993; Chisholm et al. 1987). Under these conditions, usable habitat available to trout may be maximized due to reduced anchor ice development. Surface ice may also function as cover to protect fish from terrestrial predators in some streams (Brown et al. 1993; Meyer and Griffith 1997).

There are a few circumstances in which surface ice can be detrimental to salmonid populations. Under conditions of complete surface ice cover and relatively deep, stagnant water, oxygen depletion can lead to inhospitable instream conditions (Cunjak 1996; Power et al. 1993). Oxygen content may be further reduced when primary productivity is hindered by thick ice formation. Without a layer of snow to insulate, surface ice can continue freezing to the stream bed (Berg 1994). Additionally, ice damming of surface and subsurface can lead to stream de-watering (Maciolek and Needham 1952).

### 3.2.2 Overwintering Habitat

In order to deal with the challenges presented by temperate winters, preferred adult overwintering habitat commonly exhibits a combination of low water velocity, depth and extensive cover (Brown 1994; Cunjak and Power 1986; Gosse 1982; Heggenes et al. 1991; Jakober 1995). In winter, stream salmonids are not commonly found in shallow, high velocity habitats, such as center stream, shallow riffles or the upstream portion of pools (Cunjak and Power 1986). A major challenge to defining effective overwintering habitat is that it is stream-specific. Varying

environmental features, such as; stream morphology, watershed character, elevation and climate, are important in determining the degree and nature of ice development (Chishlom et al. 1987). The combination of instream characteristics resulting in the most effective overwintering habitat may differ between lotic systems.

Large woody and other organic debris has been documented as providing effective overwintering habitat for juvenile and adult stream salmonids (Bustard and Narver 1975; Contor1989; Heifetz et al. 1986; Jakober 1995; Ward and Stanford 1989). The presence of this instream debris, in combination with river hydrology, often results in formation of numerous deep, low flow pools which may provide cover and shield fish from fast flowing ice and water. Large woody debris (LWD) may also benefit trout survival in that it traps sediment which may otherwise settle in interstitial substrate spaces (Gregory et al. 1991). Sedimentation of these micro-habitats can be particularly problematic for juvenile salmonids which often rely on the shelter of organic debris and interstitial substrate spaces in winter (Smith and Griffith 1994).

Several other channel characteristics have been cited as important overwintering habitat for salmonids. Beaver ponds can create preferred overwintering conditions of slow (< 5cm/s), deep pools (> 80 cm) with surface ice cover (Chisholm et al. 1987; Jakober 1995). Undercut banks, boulders and aquatic vegetation are commonly utilized as concealment and shelter in streams (Campbell and Neuner 1985; Chapman and Bjornn 1969; Cunjak and Power 1986; Jakober 1995). Stream areas with groundwater upwellings and backwater areas have been documented as valuable winter refuges for salmonids (Brown 1994; Cunjak 1996; Cunjak and Power 1986;

Smith and Griffith 1994; Swales et al. 1986). Warmer water conditions in these stream areas can decrease the severity of local instream conditions (Cunjak 1996; Swales et al. 1986). Such localized conditions can reduce the likelihood of extensive subsurface ice development and maintain fish metabolism above other stream areas (Brown 1994; Cunjak and Power 1986).

Winter habitat preferences of juveniles vary somewhat from that generally utilized by adults. The preference for abundant cover and low velocity flows is similar to adults, but juveniles commonly occupy shallower depths (Contor 1989; Cunjak and Power 1986). Cover used by juveniles may consist of interstitial substrate spaces, dense woody debris, aquatic vegetation and undercut banks (Campbell and Neuner 1985; Chapman and Bjornn 1969; Contor 1989; Contor and Griffith 1995; Heggenes et al. 1993; Riehle and Griffith 1993). Interstitial spaces are believed to provide vital refuge from high velocity flows and predators, and a warmer microclimate (Heggenes and Borgstrom 1988; Smith and Griffith 1994).

### 3.2.3 Overwintering Strategies

Fundamental behavioral differences between juvenile and adult salmonids have been observed in winter. Juvenile salmonids often display daytime concealment and nocturnal emergence, while adults form aggregations during the day (Heggenes et al. 1993). There are several biophysical reasons which may explain this type of winter behavior in juvenile salmonids. Ice or debris displacement is greater during the night, thus nocturnal activity may decrease the likelihood of ice damage (Hartman 1963; Heggenes et al. 1993). In addition, concealment of salmonids in the

stream substrate means that fish conserve energy and avoid diurnal predators in a time when energy reserves and metabolism are low (Giger 1973 in Campbell and Neuner 1985; Heggenes et al. 1993).

There are many potential environmental stimuli for diurnal concealment. Baltz et al.(1991) revealed that a seasonal change in microhabitat selection was not attributed to flow reduction, but alternatively to temperature and/or photoperiod change. The water temperature at which juvenile trout concealment behavior commences ranges from 6 - 8.5 °C (Campbell and Neuner 1985; Contor 1989; Riehle and Griffith 1993). Contor (1989) found that moonlight and artificial light decreased numbers of juveniles which emerged at night; this suggests that decreased light is a stimulus for nighttime emergence from cover.

Throughout most of the year, competition for a preferred feeding position can lead to territorial behavior. As water temperatures and the demand for sustenance decline in winter, intra and inter-specific salmonid dominance and aggression is decreased (Cunjak and Power 1986; Hartman 1963). Various studies have recorded large groups of adult salmonids of varying size and species sharing deep, low velocity pools (Brown et al. 1993; Cunjak and Power 1986; Gosse 1982; Heggenes et al. 1993; Jakober 1995; Jakober et al. 1998; Riehle and Griffith 1993). Aggregations of many fish in deep pools is likely an adaptive behaviour which reduces the likelihood of individual predation and also serves to maximize use of limited, sheltered habitat which does not develop significant subsurface ice (Brown and Mackay 1995; Cunjak 1996; Jakober 1995). This behavioral change is commonly associated with habitat exclusion by

extensive sub-surface ice formation, where high quality overwintering habitat may be in greater demand (Brown et al. 1993; Heggenes et al. 1993; Jakober 1995).

Diel behavioural changes are not limited to juveniles in winter. Larger salmonids which congregate during the day, may move out into areas without cover at night (Campbell and Neuner 1985; Heggenes et al. 1993). This behavioral shift may occur for similar reasons that it does in juveniles; a reduction in swimming ability and elevated energetic costs in winter lead to increased risk of diurnal predation (Contor 1989; Hartman 1963; Jakober 1995; Riehle and Griffith 1993). The likelihood of diurnal predation may be lessened by use of cover during the day and feeding at night. Heggenes et al. (1993) describes the daytime concealment of juveniles and aggregation overwintering tactics of adult brown trout *Salmo trutta* as a "cost-minimizing shelter-and-move strategy" (Heggenes et al. 1993, 305). These overwintering strategies are described as "an ecologically adaptive homeostatic behavioral response to buffer the energy deficit and adverse environmental conditions" (Heggenes et al. 1993, 295).

### 3.2.4 Winter Movement

The degree and timing of winter movements of salmonids may vary depending on the biological demands of a species or population, such as, migration to spawning grounds. Whether or not extensive movements occur throughout the winter may also be influenced by stream-specific physical factors, such as, flow conditions and the quantity and nature of ice conditions (Brown et al. 1993; Brown and Mackay 1995; Jakober 1995). Several studies have noted a two-stage

movement in adults, one in early-winter when water temperatures begin to decline and another in late-winter when first stage habitat becomes crowded with sub-surface ice formation (Brown et al. 1993; Brown and Mackay 1995; Jakober 1995). The first move involves fish aggregating in deep pools with extensive cover (i.e., large woody debris) in the fall. This initial shift is likely a physiological response to temperature changes (Jakober 1995).

Second-stage, late-winter habitat tends to be free of woody debris, and is often associated with groundwater sources; conditions which exhibit minimal anchor and frazil ice development (Brown et al.1993; Cunjak and Power 1986; Jakober 1995). Those fish initially occupying pools which do not develop sub-surface ice, may not undergo a second-stage move (Jakober 1995). Jakober (1995) and Jakober et al. (1998) found that in streams with variable ice conditions, bull trout *Salvelinus confluentus* and cutthroat trout *Oncorhynchus clarki* habitat use changed throughout the winter. In response to frazil and anchor ice development, Brown et al.(1993) observed movement of cutthroat trout from pools with large woody debris to pools lacking woody debris with groundwater sources or thick, insulating snow and ice cover.

## 3.3 Review of Winter Sampling Techniques

A central objective of this study was to determine the effectiveness of underwater video as a method to compare sport fish habitat use of artificially (V-weir) created pools to natural high quality pools in winter. Numerous other field techniques may be considered to accomplish this objective. However, the shallow ice-covered conditions exhibited in portions of the Crowsnest River pose difficulties for existing methodological options. A summary of sampling technique capabilities under river ice is presented in Table 1, at the end of this section.

### 3.3.1 Underwater Video Surveillance

Lotic fisheries studies that have utilized underwater visual recording devices under surface ice are few. Schmidt et al.(1989) tested a self-contained VHS mini-cam and artificial lights in a water-proof housing during fish survey studies in the Sagavanirktok River Delta, Alaska. They lowered the camera into the river through a hole drilled in the ice. For periods of 20 minutes (camera battery life), fish observations were collected at various depths by several 360° rotations of the camera. A 2.4 m stainless steel pole attached to the housing allowed vertical and rotational maneuvering of the camera. Due to the large scale nature of the survey, a stationary camera was considered restrictive. Following experimentation with stationary camera filming, the equipment was successfully used by divers under the ice to record live and dead fish densities in extensive river sections. Groves and Garcia (1998) utilized an underwater video camera

connected to a monitor in a large ice-free river. This setup enabled them to observe "real-time" video results of chinook salmon *Oncorhynchus tshawytscha* redds and spawning habitat. The Alaska Department of Fish and Game (1976) attempted under ice river sampling using a closed-circuit underwater television camera. They collected data in the Sagavanirktok and Kuparuk rivers on overwintering fish habitat, species and location. It appears to have been successful; no difficulties encountered with this technique were recorded in the report.

Sampling river pools by video surveillance has several other potential advantages and disadvantages in winter. As long as the equipment functions well in cold temperatures, this method may also be utilized to record fish behavior and relative abundance. The nature of video sampling would not allow for collection of detailed morphological data or estimate population size and demographics.

### 3.3.2 Electrofishing

Electrofishing is likely the most frequently utilized method to collect fish population data in open-water conditions. The two standard electrofishing units are the backpack and boat mounted units. The backpack system is functional in wadeable water and requires less equipment than the boat unit. The boat mounted electrofisher is generally used in deeper, faster flowing water. An alternative electrofisher is the shore-based method. This specialized system functions on the same basic principles as the backpack and boat units, but is operated from the river bank and produces a more effective current appropriate for large order rivers (Reynolds 1996). These

methods all require open water for effective fish collection. For areas of milder climate or rivers with extensive groundwater sources, electrofishing in mid-winter may be an option.

Electrofishing through river ice presents several logistical problems. The limited area possible to shock and net fish through ice holes deem the standard units inappropriate for rivers that freeze in winter. There have been a couple of alternative electrofishing tools which may be adapted for use under river ice. A "submersible electrofisher" has been designed by Emmett et al. ( 1992). This unit may be used for subsurface shocking and potentially effective through river ice. However, the problem of retrieving stunned fish under ice still exists. Another electrofisher which can be submersed under water is the "Diver Operated Electrofishing Device" (James et al. 1987). Replacement of standard anode and cathode with 4 m of sealed cables enable a diver to stun fish from within a river or lake. This unit was tested in ice-free conditions and may have utility under ice. Both of the above mentioned electrofishing techniques require that the river be deep enough for safe ice diving. Under any field conditions, risk associated with electrical shocking with a diver in the water is unavoidable. Danger may be reduced by pretesting the device at predicted conductivity levels and awareness of safety issues (James et al. 1987).

Electrofishing has many useful capabilities for open-water winter sampling. The hands-on nature of this method allows collection of individual fish data, such as, weight, length, age, stomach contents and positive species identification. However, electrofishing efficiency is influenced by a variety of environmental (i.e., conductivity, flow, temperature, turbidity, in-stream debris), biological (i.e., scale size, fish size, fish morphology) and technical aspects (i.e., field crew

expertise, equipment servicing, battery power) (McMichael et al. 1998; Reynolds 1996). As long as the operators have managed and assessed the relative importance of these factors, bias in fish sampling can be reduced (Reynolds 1996).

Both open-water and ice-covered electrofishing exhibit disadvantages which are more difficult to overcome. First, observation of fish behavior and habitat-use is limited. As well, stunning and handling fish can lead to injury, stress and mortality (McMichael et al. 1998; Reynolds 1996; Schill and Beland 1995; Strange et al. 1978). Improved techniques and equipment are being developed to decrease the deleterious effects of electrofishing (Sharber et al. 1994). However, reducing the negative affects of electrofishing may not be sufficient when dealing with declining fish populations (i.e., bull trout, westslope cutthroat trout ) (Fitch 1978, 1997; Van Eimeren 1996), where mortality is unaffordable.

Electroshocking injury is more common and severe in larger fish (Hauck 1949; McMichael et al. 1998; Reynolds 1996). This risk may be augmented in long-term monitoring situations, where the potential of multiple exposures may further increase the likelihood of negative effects (McMichael et al. 1998). In this case, older fish may be selected for because of their large size and repeatedly shocked throughout their life over several sampling seasons. In a popular angling river such as the Crowsnest River, this potentiality has great significance because of possibly impacting the conservation target population: "catchable size" sport fish.

### 3.3.3 Ice Fishing

Angling through river ice, as a winter sampling technique, allows in-depth fish data to be collected (Cunjak and Power 1986; Maciolek and Needham 1952). However, fishing success is not guaranteed. Catching fish in winter may be problematic given the lower metabolism and decreased feeding (Cunjak 1988; Hartman 1963). In addition, there is always the possibility of fish injury, stress and mortality. Fish samples collected may not be representative of the population due to varying food preferences of age classes and species. Ice fishing population estimates may be possible using a mark-recapture technique, but it may require significant time to complete. The inability of observe fish would prohibit collection of behavior (with the exception of feeding) and habitat-use data under in either ice-covered or open-water pools.

### 3.3.4 Under-Ice Netting

Schmidt et al. (1989) collected fish by under-ice nets. Nets were installed and retrieved by divers. An innovative alternative used to set nets under reservoir and river ice is described by Hill et al. (1996). This method employs a series of boards and ropes which make setting and retrieving nets possible without divers. Proper use of these tools of fish collection allow detailed individual and population data to be collected, but would not be functional for collection of behavioral or habitat-use information.

### 3.3.5 Radiotelemetry

Radiotelemetry involves the collection of scientific data by a transmitter which is secured to the test subject. The transmitter emits radio waves which are tracked by a remote sensing system. Signals can be received through ice, instream debris and turbulence allowing movement of several individuals to be mapped in any season (Winter 1996).

Radiotelemetry enables researchers to record winter habitat-use and movement information for salmonids in both ice-covered and ice-free rivers (e.g., Brown 1994; Brown and Mackay 1995; Chisholm et al 1987; Jakober et al. 1998; Jakober 1995). One limitation of this tool is that the information collected is confined to those individuals which have been captured and tagged. Also, stress may be associated with handling and tag implantation.

### 3.3.6 SCUBA and Snorkel

Underwater observation by SCUBA and snorkel have been utilized in winter studies under both ice-covered and ice-free lotic conditions. Several studies have collected habitat use data by winter snorkeling surveys under river ice (Jakober 1995; Jakober et al. 1998; Schmidt et al. 1989). Emmett (1989) and Emmett and Convey (1990) utilized SCUBA to explore habitat use and abundance of chinook salmon in an ice covered river. Similar to underwater video observation, both SCUBA and snorkel enable researchers to collect data simultaneously on fish behavior, habitat-use and fish abundance. These observation techniques have advantages over

many others (i.e., netting, electrofishing, radiotelemetry) in that handling stress is not an issue.

However, the combination of ice cover, shallow depths, instream debris and considerable flow rates which characterize the Crowsnest River mean a high safety risk is involved in undertaking this field work. Logistical difficulties associated with freezing air temperatures must also be considered when frequent movement between several study sites is required. For sampling river pools, these drawbacks are overcome with underwater video observation.

### 3.3.7 Other Underwater Observation Techniques

Some of the earliest lotic fish observations in winter were conducted by Needham and Jones (1959) who constructed an observation tank mounted with an artificial light source. The waterproof container allowed researchers to observe winter behavior and habitat of salmonids in Sagehen Creek. Site disturbance and movement between several sites may be problematic with this type of sampling.

Other underwater methods, such as the ROV (Remotely Operated Video), have been employed in lakes. The device is connected to a monitor and controlled via an umbilical cable. Thus, "real time" observations are possible. The camera can be adjusted to various speeds and depths allowing physical characteristics and active underwater life to be recorded. Davis et al.(1997) successfully filmed juvenile and adult lake trout along an Ontario lake bottom in October. This equipment can record fish species, habitat-use and density data. Due to its non-lethal nature, this

technology is particularly useful when sampling fish populations where loss is unaffordable. The significant cost of the equipment may be a major consideration limiting the utility of this technique (Davis et al. 1997).

There are several factors which may pose difficulties with an ROV in ice-covered river conditions. The connection between umbilical cord and ROV, may lead to tangling or loss of expensive equipment in rivers with instream debris (i.e., logs, root wads, large boulders), shallow or rapid flow conditions. In addition, cold winter air and water temperatures can cause operational equipment problems (Craig Mushens, University of Calgary, Calgary, Alberta; personal communication).

**Table 1 :** Utility of alternative methods to sample river pools in winter

| Sampling Method | Population Estimate and Demographics | Habitat-Use | Behavior | Morphological | Use Under River Ice | Species Present | Relative Abundance |
|---|---|---|---|---|---|---|---|
| Video | 1 | 5 | 5 | 2 | 5 | 4 | 5 |
| Electrofishing | 5 | 2 | 1 | 5 | 2 | 5 | 5 |
| Ice Fishing | 4 | 2 | 2 | 4 | 5 | 4 | 4 |
| Under-Ice Netting | 5 | 2 | 1 | 5 | 5 | 5 | 5 |
| Radiotelemetry | 1 | 4 | 4 | 3 | 4 | 2 | 1 |
| SCUBA/Snorkel | 1 | 5 | 5 | 2 | 3 | 4 | 5 |
| ROV | 1 | 4 | 4 | 2 | 3 | 4 | 5 |

1 - no utility, 2 - low utility , 3 - moderate utility, 4 - limitations to utility , 5 - excellent utility

## 3.4 OMRD Fisheries Mitigation Program

The Crowsnest River was considered a priority for habitat compensation because of its significant sport fish population and high predicted habitat losses due to reservoir inundation (Dominion Ecological Consulting Ltd. 1988). In addition, considering the urbanization, mining and transportation corridors which had already severely altered the Crowsnest River from its original condition, suitability of this river for fisheries mitigation was high.

In order to assess the goal of "no net loss of recreational fisheries opportunities" (Dominion Ecological Services Ltd. 1988, 1) for the OMRD fisheries mitigation program, several definitions are necessary. As previously mentioned, the loss of high quality sport fish habitat was equated with loss of recreational fishing opportunities. Thus, a central objective of the upstream portion of the fisheries mitigation program was to compensate for sport fish habitat lost to reservoir inundation (Dominion Ecological Consulting Ltd. 1988).

In order to evaluate the physical and biological success of compensation efforts, structures were constructed in a "phased approach" (Dominion Ecological Consulting Ltd. 1988). To facilitate improvement and learning from successes and failures, this conservative approach was designed to test the physical and biological success of various structures by monitoring over several years. (Dominion Ecological Consulting Ltd. 1988). Mitigation began in 1987, with three artificial habitat structures in the Crowsnest River. During the following 10 years, over 300 more structures were installed throughout the OMRD basin (Lowe 1996). Refer to Appendix B for

wing deflector, groyne, fish run and boulder garden structure descriptions.

There were several steps the OMRD fisheries mitigation program which were designed to monitor the effectiveness of instream structures. Prior to dam construction, detailed fish habitat and population surveys were conducted in the inundation area to quantify and qualify predicted losses. Data on sportfish habitat and populations were also conducted upstream of the predicted reservoir area to serve as a "pre-dam baseline" and to identify the most appropriate locations for habitat alteration sites. The baseline information was intended to assess the biological effectiveness of the various structures.

### 3.4.1 V-weirs

According to Lowe (1996), the purpose of single (Figure 1) and double (Figure 2) crested V-weir artificial habitat structures is "to provide a stable, high quality, self maintaining run and pool habitat, with feeding, resting and escape cover for adult trout. Rock and tree cover in the pool provide shelter from the current and predators, and visual isolation from other fish. Rock clusters at the sides and end of the run provide feeding opportunities. If the pool depth is greater that 1.5 m overwintering habitat is possible"(Lowe 1996, 13, 14).

One or two (depending on whether it is a typical single or double crested V-weir) layers of large rocks form the foundation of the "V" across the stream, with the largest (4-8) rocks placed at the

midstream point. All base rocks are half buried in a streambed trench to secure them in position. The base rocks are packed tightly together, smaller rocks and spoil are then added to increase structure strength and limit the amount of water which flows through the V-weir. The rocks forming the V-weir slope gradually down from the river banks (1.5 m above the stream surface) to the centre of the stream (0.6 m above the stream substrate). Thus, the lowest point is mid-stream. The V-weir is angled upstream with the submersed "V" point located furthest upstream (Lowe 1996). This design is engineered to dissipate the force of the river flow through the rocks from the tip through to the river bank boulders (Jim Allan, Pisces Environmental Consulting Services Ltd., Red Deer, Alberta; personal communication).

This rock pattern forces the stream flow into the middle 1/3 of the river (Lowe 1996). Thus, the stream banks are not eroded away, and a deep pool is eroded immediately downstream followed by a deep run. Mid-stream pools are generally excavated during construction and maintained by the erosional forces resulting from the combination of the V-weir's presence and river hydrology. The total V-weir width, along the stream bank, should measure 1.5 m. Double-crested V-weirs have a double layer of rocks forming the weir crest; these larger structures are intended for larger order rivers. Resulting pool depths should vary from 1.5 - 2 m for single and 1.5 - 2.5 m for double crested V-weirs. Bank protection directly downstream of the weir may be necessary in some cases.

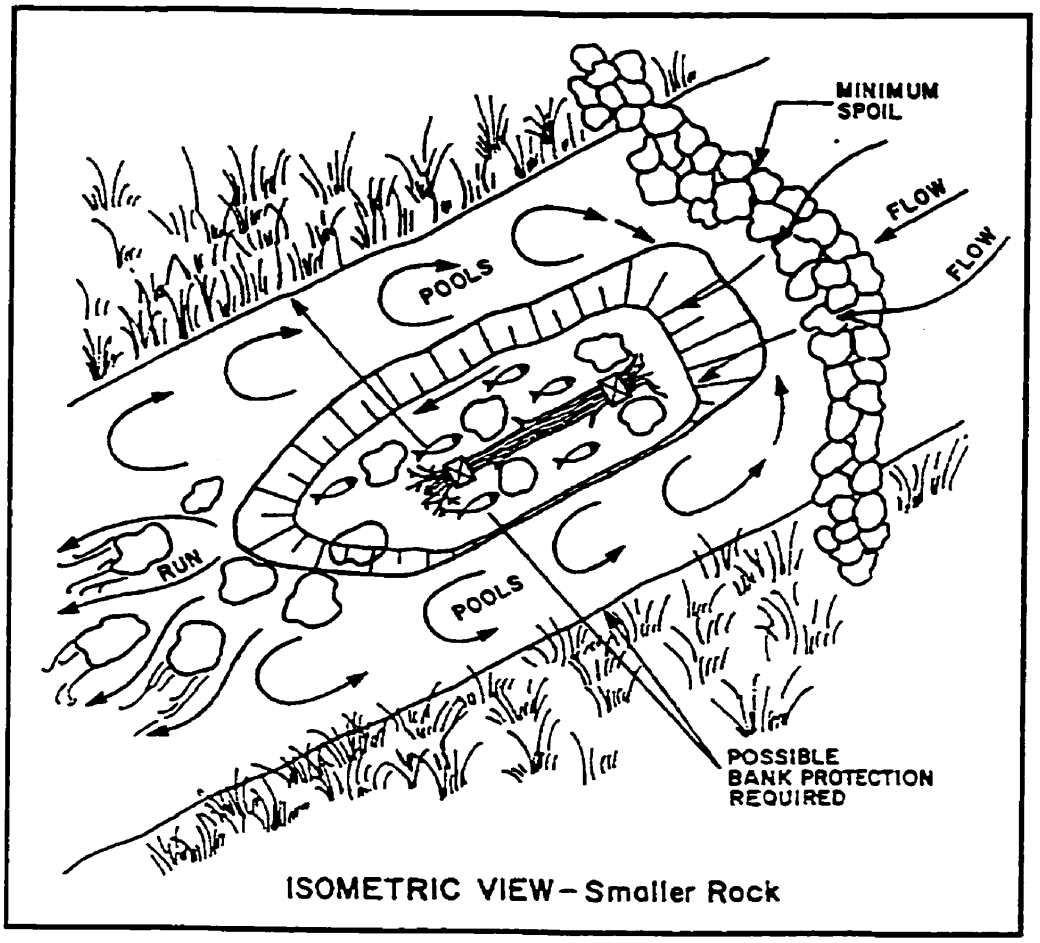


**Figure 1:** Diagram of a typical single-crested V-weir constructed in the upper Crowsnest River (figure from Lowe 1996)

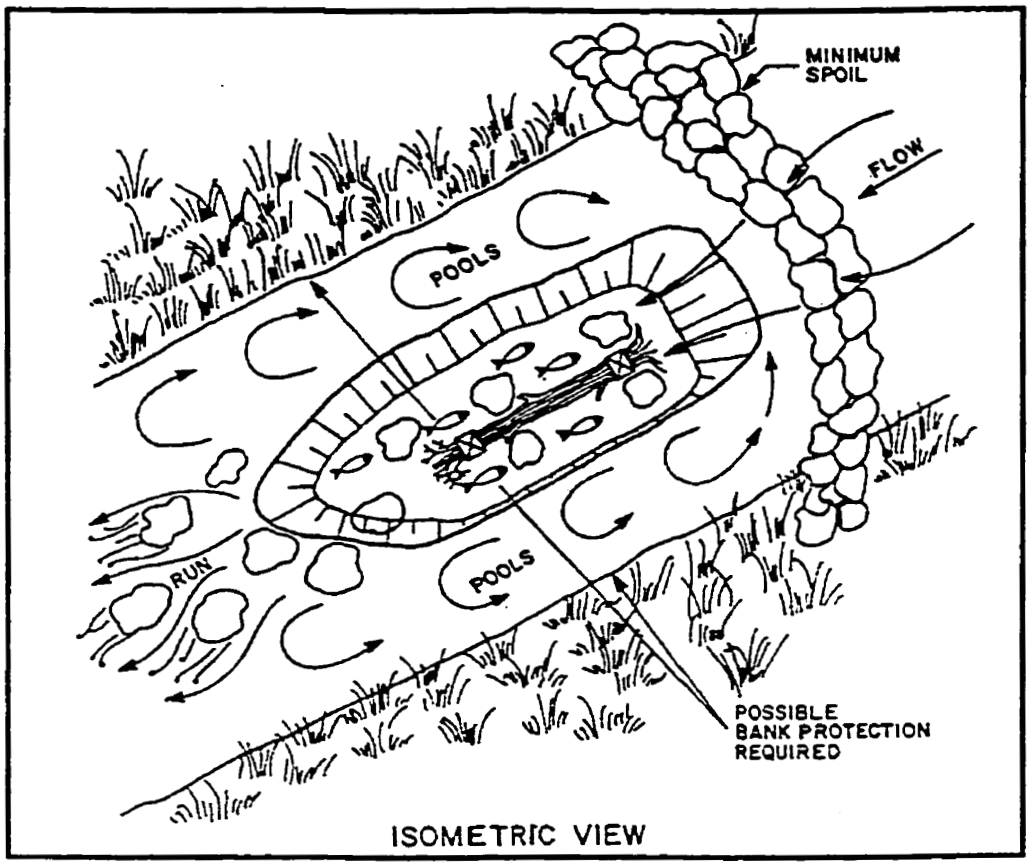


**Figure 2:** Diagram of a typical double-crested V-weir constructed in the lower Crowsnest River (figure from Lowe 1996)

There are a number of factors which may lead to variation in the physical and biological success of V-weirs. First, V-weir construction and design should involve the supervision and collaborative effort of experienced engineers, biologists and hydrologists (Fitch et al. 1994; Lowe 1996). Lack of supervision during these initial stages can influence structure effectiveness (Lowe 1996). Regular maintenance also plays a critical role in increasing structure longevity (Fitch et al. 1994; Hartman and Miles 1995; Pattenden et al. 1998). In addition to proper

installation and maintenance, reach and basin character influence structure performance and durability (Fitch et al. 1994; Pattenden et al. 1998). Inconsistencies in success rates between fisheries management programs, such as construction procedures, maintenance frequency, evaluation criteria and stream size/character, may explain some of the variation in the following artificial structure evaluations (Fitch et al. 1994; Hartman and Miles 1995; Lowe 1996).

#### 3.4.1.1 Physical Success

Through the analysis of surveys, reports and publications, Hartman and Miles (1995) evaluated 97 "fish habitat improvement" projects in British Columbia. For each project and structure type, they analysed and compared biological effectiveness, physical robustness and maintenance and construction costs. Physical success is defined by structure durability and that the intended physical habitat feature resulted. Their analysis revealed that structures with a well-defined construction design (e.g.,V-weir) or minimal construction design (e.g., gravel placement) had similar physical success rates of approximately 75 %. However, structures with limited size specifications or in-stream location information in the design literature (e.g., boulder gardens) had lower physical success rates of 50 % or less. V-weirs with excavated runs and pools had a physical success rate of 82 %.

In general, V-weir physical durability and performance has been exceptional in the Oldman River Dam Fisheries Mitigation Program (Lowe 1996). Irrespective of river flow conditions, these structures function consistently in the formation of a deep "self-scouring" pool (Lowe 1996).

Requiring a limited financial investment, these structures seem to provide stable fish habitat with minimal aesthetic impact on the natural landscape (Lowe 1996).

V-weirs in the Oldman Basin have endured high in-stream sediment loads coupled with 2 m submersion for periods in excess of two months (Lowe 1996). Compared to other artificial structures, V-weirs in the Crowsnest River had the best physical success when subjected to the 1995 flood (approximately 1:500 year) (Lowe 1996). However, many V-weirs in the larger, higher power Oldman River were either left dry (by extreme river meandering) or destroyed by this massive flood event (John Englert, Alberta Public Works, Supply and Services, Edmonton, Alberta; personal communication).

Initial physical deterioration of V-weirs in the Crowsnest River was high. However, following repairs, subsequent physical endurance was 84 %. According to the structure history in the Oldman River Basin, physical failure appears to be linked to inadequate supervision during installation (Lowe 1996) and construction of structures in high power river conditions. Two major sources of V-weir deterioration were back scour and excess space between rocks, causing erosion and loosening of key structural components (Jim Allan, Pisces Environmental Consulting Services Ltd., Red Deer, Alberta; personal communication; Fitch et al. 1994).

Other evaluations of artificial structures installed in southern Alberta have reported a less favourable assessment of V-weirs physical endurance. Pattenden et al. (1998) evaluated over 300 artificial structures (weirs, groynes, boulders and revetments) installed by private industry,

NGOs and government. Through visual inspection by an experienced observer, structural stability was rated from one (best) to four (worst), with the best signifying that the original physical design and function was intact. In comparison with other structures, V-weirs received the worst mean physical success rating of 2.6.

Due to the high likelihood of rapid structure degradation, installation of V-weirs should be generally avoided in high power streams (Jim Allan, Pisces Environmental Consulting Services Ltd., Red Deer, Alberta; personal communication; Pattenden et al. 1998). V-weirs do not endure well in large (> 60 m width), high gradient rivers (Allan and Lowe 1997). Furthermore, placement of V-weirs in stream sections with vertically and laterally stable banks and low sediment load may increase the likelihood of physical endurance (Fitch et al. 1994; Pattenden et al. 1998). Considering the dynamic nature of lotic systems, it is possible that instream structures should generally be considered temporary fisheries enhancement measures (Pattenden et al. 1998).

#### 3.4.1.2 Biological Success

In Hartman and Miles' (1995) analysis of fish habitat improvement projects, biological success was determined by use of the physical habitat by the intended fish species and life stage. Success in the biotic context appears to be closely linked to physical success. V-weirs, log placement, rip-rap and gravel placement all had greater than 73 % biological success ratings. However, in the majority of the programs evaluated by Hartman and Miles (1995), biological success was

assumed if physical changes were achieved. The lack of biological quantification may reduce the validity of the above mentioned biological success ratings.

Overall biological success of the Oldman River Dam Project is still unclear. R. L.& L Environmental Services Ltd. (1993) conducted a preliminary evaluation, which examined the first five years of the fisheries project. This document reviewed all fisheries mitigation data available from 1987-1991 and presented a limited assessment of fish use of several artificial habitat structures in the Crowsnest River. This review included an assessment and summary of fish population data (i.e., density, biomass, age-structure, etc ) collected at pre-mitigation, post-mitigation and control sites during this period. Based on these data, the role of outside variables, such as: water temperature, flow regime, angler harvest, season of sampling, year-class variability and stream productivity, in controlling fish population density and biomass was estimated. As well, structure effectiveness was evaluated between structure type, individual reaches, individual species and age groups.

Five years of open-water (spring, summer and fall) results indicated that excavated V-weirs were the most successful in providing adult feeding and holding habitat for rainbow trout *Oncorhynchus mykiss*, bull trout and brown trout (R. L. & L Environmental Services Ltd. 1993). Success rates of individual enhancement sites was inconsistent. Specific sites which were effective in some years were used by few fish in other years. As well, variability in population density was apparent between sites in the same sampling season.

Failure of individual structures to support adult sport fish was thought to be caused more by the placement location, rather than the performance of the structure type (R. L. & L Environmental Services Ltd.1993). Other factors, such as low population density and declining productivity levels over sampling years were likely the cause of poor structure performance[2]. Low use of structures under normal flow conditions, suggests that high quality adult habitat provided by these artificial structures was only a limiting factor in low water periods. Increased angling pressure, over the five year period, was another consideration potentially counteracting the population increase at mitigation structures.

Open-water results from 1989 to 1991 showed increased use by fish of artificial structures in the lower Crowsnest River. Artificial habitat contained as many, or more, legal-sized rainbow trout and brown trout than comparable high quality reference sites (R. L. & L Environmental Services Ltd. 1993). Use of these pool habitats may reflect the decrease in available high quality pool habitat due to reservoir inundation.

Results from 1988 indicated that after one year, many artificial structures had populations of catchable-size rainbow trout similar to high quality control sites in the upper Crowsnest River reaches (Blairmore, Hillcrest and Coleman areas) (R. L. & L. Environmental Services Ltd.1993). Contrasting this initial increase, first year results from a later mitigation phase (1990 to 1991) revealed low effectiveness of artificial structures compared to high quality controls. The

---

[2]Productivity of the Crowsnest River has been reduced due improved sewage treatment facilities (R.L. & L. Environmental Services Ltd. 1997).

difference in performance from 1987 and 1991, may be influenced by the reduction in river productivity and the consequent decline in fish growth rate and density during this time period.

Comparison of the 1995 and 1996 monitoring results revealed significantly more legal-sized rainbow trout in both artificial and natural deep-water pool habitats in 1996 than in 1995 in the lower Crowsnest River (R.L. & L. Environmental Services Ltd.1997). Considering that the 1996 evaluations were conducted during a low flow period and the river discharge was 28 % lower in 1996 than 1995, these results indicated that high quality control and artificial pools provided shelter during low flow periods (R.L. & L. Environmental Services Ltd. 1997). Artificial habitat contained lower numbers of catchable-sized rainbow trout than natural high quality pools, however, all artificial pools contained sizable numbers of large rainbow trout. This difference may have been attributed to the location of most control sites near Lundbreck Falls and all V-weirs located further downstream. Based on the assumption that fish often move upstream, a barrier at Lundbreck Falls could have resulted in higher fish numbers in pools located close to the falls.

Monitoring results from 1995 and 1996 in the upper Crowsnest River did not show differences in use of artificial and natural pools as shown in the lower Crowsnest River sites. This may indicate that there were few legal-sized rainbow trout in this less productive area of the river. Thus, even under lower flow conditions, the amount of this type of refuge may not be a limiting factor in the upper Crowsnest River (R.L. & L. Environmental Services Ltd. 1997).

In order to assess whether or not habitat enhancement has actually increased the population of catchable sized rainbow trout in the upper Crowsnest River, reach evaluations were conducted on comparable mitigated and natural stream sections. This study indicated 1.6 to 1.9 times more fish in mitigated sections compared to natural reaches (R.L. & L. Environmental Services Ltd. 1997). Some artificial sites in this study area were not used by any legal-sized rainbow trout (R.L. & L. Environmental Services Ltd. 1997). Overall, artificial sites were as effective as control sites.

Several other investigators have studied the response of trout populations to artificially created pool habitat. White's (1975) 10 year study examined the response of brown trout, brook trout *Salvelinus fontinalis* and rainbow trout to wing deflector pools in Big Roche-a-Cri, Wisconsin. Hunt (1976) studied the long term responses of brook trout to deflector pools in Lawrence Creek. Wisconsin. These evaluations were conducted in single streams, where several years of post- and pre-treatment data were collected. Both studies found significant increases of adult trout in artificially created pools during low flow periods. Successful enhancement of trout was attributed to increased overwintering survival.

Studies by Riley and Fausch (1995) and Gowan and Fausch (1996) involved evaluations of artificial (log weir) pools from seven Colorado streams. Eight years of research included comparisons of fish abundance and biomass between adjacent altered and unaltered reaches, before and after treatment and measurement of pre and post-treatment cover, depth and velocity characteristics. Unaltered sections were located close to treatment sections and represented pre-

treatment conditions. Prior to installation of artificial structures, differences in depth, velocity and cover conditions between sections were insignificant. The research examined artificially created pools in four high elevation streams (2730 m - 2925 m) containing brook trout and cutthroat trout, and two lower elevation systems (2425 m - 2470 m) with brook trout, brown trout and rainbow trout. Evaluation of the biological success of artificial pools was assessed by comparison fish abundance and biomass between treatment sections and unaltered sections. Riley and Fausch (1995) and Gowan and Fausch (1996) reported significant increases of age-2 (and less often age 1) trout during low flow periods within two years. Increases of trout in treatment sections showed steady increases over the eight year evaluation (Gowan and Fausch 1996). Examination of causative factors indicated that the increase was likely a result of immigration from stream areas outside the study area.

#### 3.4.1.3 Angler's Opinions

V-weirs were the most favoured artificial structure in the Crowsnest River by surveyed anglers (R.L. & L Environmental Services Ltd. 1992). Numerous elements were considered in angler's opinions. Aesthetic quality and "fishability" were the most significant factors which influenced angler's preference or dislike of artificial structures. Included in the definition of "fishability" was the presence of legal-sized sport fish and angling manoeuverability at the site. Vehicle and site access were of secondary importance. Thirty-nine percent of anglers surveyed preferred V-weirs as the most aesthetically appealing artificial structure. V-weir fishability received a high rating with 88 % considering these structures "easy" to fish (R.L. & L. Environmental Services

Ltd. 1992).

#### 3.4.1.4 Choice of V-weirs as the Focus of this Study

There were several reasons for the decision to study trout and mountain whitefish use of V-weirs over other OMRD structure types constructed in the Crowsnest River. As outlined above, monitoring during low flow periods has shown high use of these structures by catchable-sized sport fish. Furthermore, significant increases in trout numbers in artificially created pools has been documented by several other investigations (i.e., Gowan and Fausch 1996; Hunt 1971; White 1975). The positive angler perspective and relatively low maintenance and construction costs of V-weirs were also considered. The combination of all of the above aspects mean that this structure is an artificial habitat option with potential approval for use in future fisheries mitigation programs. Lastly, V-weirs are abundant and easily accessible in winter on the Crowsnest River.

# 4.0 STUDY AREA

The Crowsnest River is located in southwestern Alberta, on the eastern slopes of the Rocky Mountains (Figure 3). A portion of the South Saskatchewan River Basin, headwaters of this river lie in the Bow-Crow Forest Reserve. Prior to construction of the OMRD, the Crowsnest River began at the Crowsnest Lake at an elevation of 1386 m, flowed through the Crowsnest Pass and finally joined with the Oldman River at an elevation of approximately 1100 m (Fitch 1978). As a result of dam construction, the Crowsnest, Castle and Oldman rivers now meet at the Oldman River Reservoir (Figure 4). Inundation of the reservoir reduced the tailwaters of the Crowsnest River from 55.2 km to 46.1 km (Dominion Ecological Consulting Ltd. 1988). Lundbreck Falls, located approximately 6.9 km upstream of the reservoir, is the only barrier to fish movement in the Crowsnest River (Fitch 1978). Recorded at the Frank station in the lower Crowsnest River (near Lundbreck Falls), the minimum and maximum flow measurements from 1950 to 1998 were 0.505 ( December 22, 1987) and 92.8 (June 7, 1995) $m^3$ / second, respectively.

Six sport fish species are present in the Crowsnest River: mountain whitefish, rainbow trout, brown trout, westslope cutthroat trout, brook trout and bull trout (Ash et al. 1987; Page and Burr 1991). Of these salmonids, cutthroat trout, bull trout and mountain whitefish are native species. Rainbow trout, brook trout and brown trout were introduced through various stocking programs. Other fish species recorded in the Crowsnest River are longnose sucker *Catostomus catostomus*, white sucker *Catostomus commersoni*, longnose dace *Rhinichthys cataractae*, brook stickleback

*Culaea inconstans*, lake chub *Couesius plumbeus* and trout-perch *Percopsis omiscomaycus*.

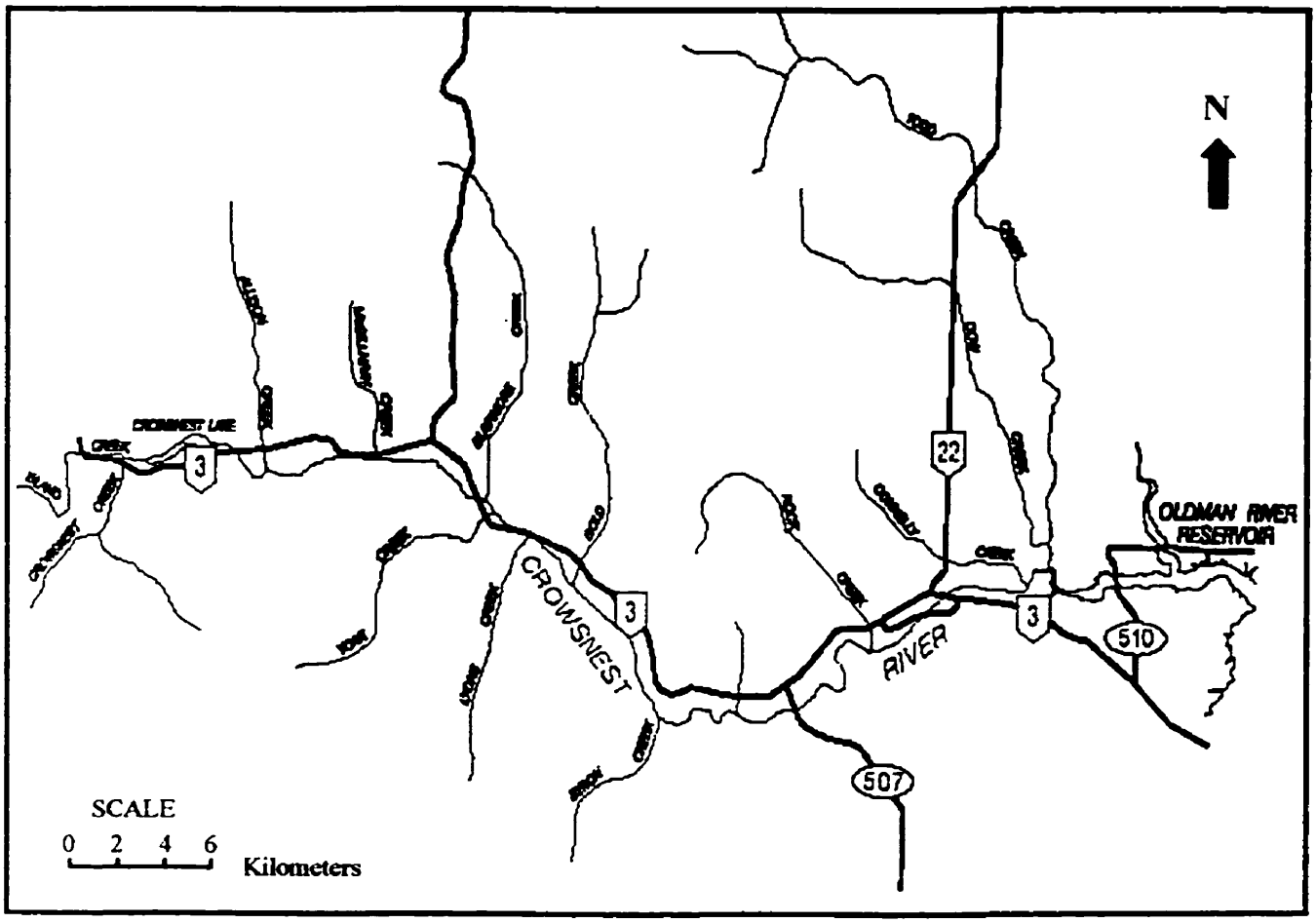


**Figure 3:** Map of the Crowsnest River (courtesy of Alberta Environment)

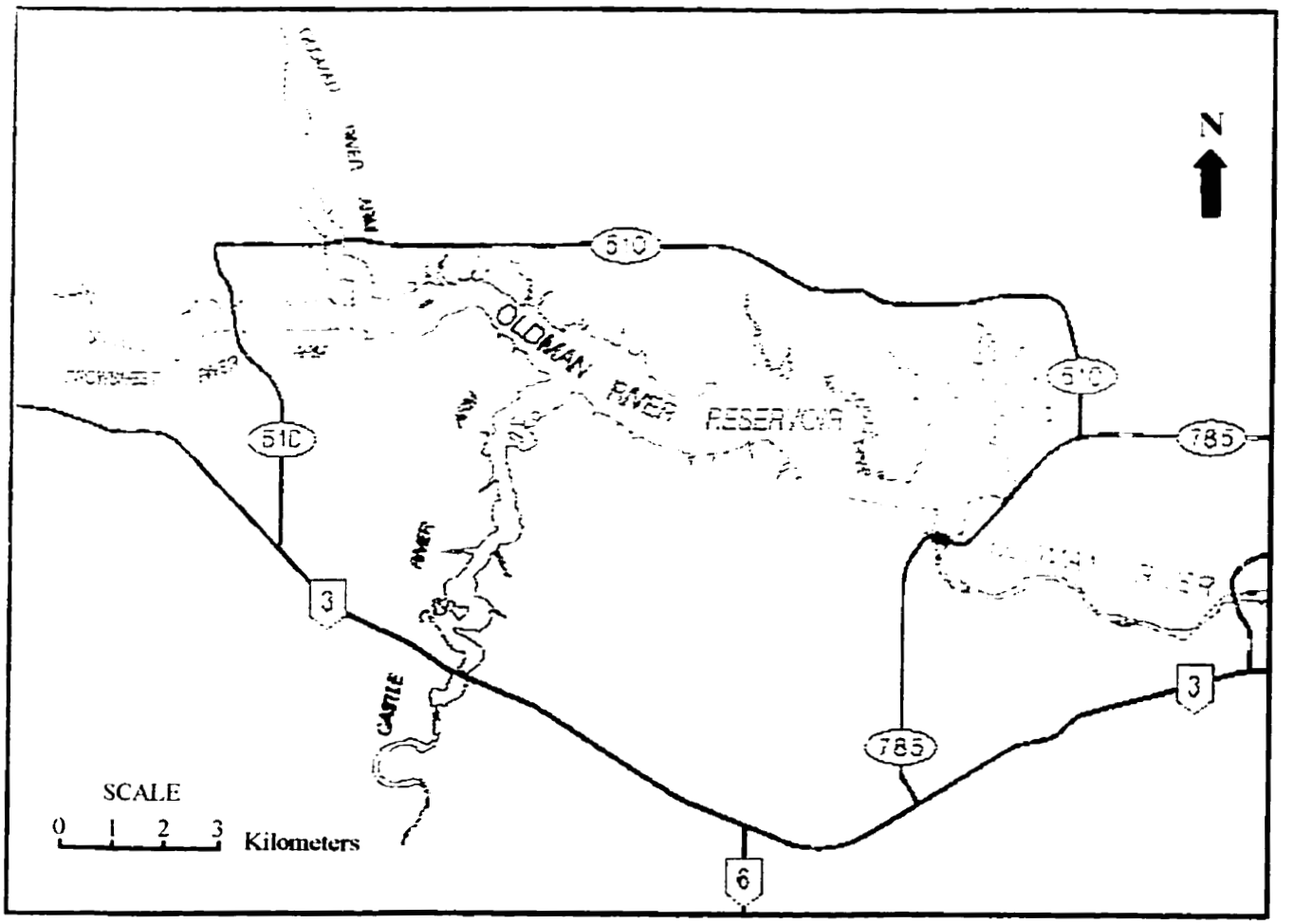


**Figure 4:** Map of the Oldman River Reservoir (courtesy of Alberta Environment)

The most abundant sportfish species present throughout the Crowsnest River are mountain whitefish (approximately 60 %) and rainbow trout (approximately 30 %). The remaining sportfish species comprise less than 10 % of the total sport fish population (Ash et al. 1987; R.L. & L Environmental Services Ltd. 1994). Brown trout are found only in the lower (below

Lundbreck Falls) Crowsnest River. Bull trout have been observed throughout the Crowsnest River, but are thought to be extirpated or very rare in the upper Crowsnest River (Fitch 1997; Rick Pattenden, R.L. & L Environmental Services Ltd., Edmonton, Alberta; personal communication).

Since the early 1900's, the Crowsnest Pass has been actively used for coal mining and transportation. Encroachment of five rural communities and rail and road construction throughout the valley has resulted in significant channelization, stream bank alteration and river basin modification. Natural disturbance has also played a role in the history of river alteration; a major rock slide in 1903 temporarily dammed the Crowsnest River near the town of Frank.

# 5.0 METHODS

## 5.1 Site Selection

In November 1998, prior to freezing of the Crowsnest River, approximately 45 potential V-weir and high quality control sites were identified for study. Due to an unseasonably warm winter in southern Alberta, final choice of the ice-covered sites was limited. A small portion of the river froze and only four (two V-weir and two controls)of all potential sites were located in this ice-covered reach.

For the open-water study, the highest quality control sites were chosen. Definition of high quality natural pools was based on professional judgement and the existence of low velocity, deep habitat. In addition, to increase the potential for comparisons with past spring and summer evaluations conducted by R.L. & L Environmental Services Ltd., previously sampled high quality control sites were given priority. To increase the validity of comparisons, V-weir selection was influenced by proximity of these artificial pools to the highest quality natural pool sites. Finally, V-weirs chosen in each study area were similar in size and character.

## 5.2 Site Descriptions

All four ice-covered sites were located in the lower Crowsnest River, downstream of Lundbreck Falls (Lundbreck Study Area). Of the ten ice-free sites in the upper Crowsnest River, four were directly east (downstream) of the town of Blairmore (Blairmore Study Area) and the six remaining were on the west (upstream) side of the town of Coleman (Coleman Study Area). Individual sites were named according to pool type (c - control or v - V-weir), previous OMRD coding and study section (B - Blairmore, C - Coleman, or L - Lundbreck) (Table 2 and 3).

### 5.2.1 Blairmore and Coleman Open-Water Sites ( Upper Crowsnest River)

The Blairmore study section was approximately three kilometers in length and was directly upstream from the town of Blairmore. Two single-crested V-weir (sites Bv-17 and Bv-N) and two high quality pool (Bc-Z and Bc-83) sites were sampled in this area (Figure 5 and Appendix C). Sites Bc-83 (furthest upstream), Bv-N and Bv-17 (furthest downstream) were located within the first 1.5 km upstream of Blairmore, in a channelized east-flowing section of the river. The south river bank of this section was a steep cobble bank. The river terrace was bordered by a gravel walking path within a narrow band of vegetation (trees, shrubs and grass), followed by Highway # 3. The north bank of site Bv-N was a gently sloping gravel-cobble bank followed by dense shrubs and a steep gravel-cobble hill side. The north bank of site Bc-83 was a steep rocky

cliff with a couple of coniferous trees. The north bank of site Bv-17 was a gently sloping gravel-cobble bank with shrubs and a few trees followed by a coniferous hillside forest.

Control site Bc-83 was enhanced by Alberta Public Works (APW) in 1988 as part of the OMRD pilot mitigation program. A 60 m section of river was excavated and 12 boulders were placed in the excavated area. The excavated run filled in almost immediately leaving only a few boulders above the stream bed. Due to the natural alteration of this site since mitigation activities in 1988, this site was sampled as a control.

Control site Bc-Z was located in a more natural, south-flowing river portion, approximately 1.5 km further downstream, south of Highway #3. The west bank of the river was a gravel floodplain with large woody debris. The east river bank was undercut and characterized by sparse trees, large woody debris, grasses and shrubs.

The Coleman portion of the Crowsnest River flows through the west side of the town of Coleman. Three natural high quality and three single-crested V-weir pools were tested in this reach (Figure 5 and Appendix C). Control site Cc-242 was downstream of V-weirs Cv-241, Cv-240 and Cv-61 (furthest upstream) in a relatively straight east flowing river portion. The dominant land-use to the north of this river section was industrial; it consisted of a field and gravel road littered with coal mine tailings. The river bank was thinly vegetated with cobble-gravel stream edges. Another coal road followed by a coniferous forest characterized the area to

the south site Cc-242. A coniferous forest dominated the landscape to the south of sites Cv-241, Cv-240, Cv-61, Cc-D and Cc-226.

Coleman control sites Cc-D and Cc-226 were located in meandering river sections further upstream. The south-east river banks of these two sites were steep rocky outcrops followed by forest. The north-west bank of the furthest upstream site (Cc-226) was a gravel/grass floodplain followed by a gravel access road. The north-west bank of site Cc- D was residential with a gently sloping gravel bank.

**Table 2:** Approximate river location and construction dates (where applicable) of the open-water sites

| OPEN-WATER SITES | YEAR OF CONSTRUCTION | APPROXIMATE RIVER KM |
|---|---|---|
| **BLAIRMORE SITES** | | |
| **Control Bc-Z** | **N / A** | **41** |
| **V- Weir Bv-17** | **1987** | **42.29** |
| **V- Weir Bv-N** | **1989** | **42.45** |
| **Control Bc-83** | **N /A** | **42.47** |
| **COLEMAN SITES** | | |
| **Control Cc-242** | **N / A** | **50.3** |
| **V- Weir Cv-241** | **1991** | **50.44** |
| **V- Weir Cv-240** | **1991** | **50.55** |
| **V- Weir Cv-61** | **1991** | **50.69** |
| **Control Cc-D** | **N / A** | **51.08** |
| **Control Cc-226** | **N / A** | **51.14** |

### 5.2.2 Lundbreck Ice-Covered Sites (lower Crowsnest River)

The Lundbreck sites were located approximately 2.5 km (control site Lc-75) and 4.5 -5.5 km (V-weir sites Lv-77, Lv-233 and control site Lc-291) downstream from Lundbreck Falls (Figure 5 and Appendix D). Of the four ice-covered sites, two double-crested V-weir and two natural high quality pools were sampled.

Control site Lc-75 was the furthest upstream site. The north bank of this river section was a steep rocky out crop, free of vegetation. The south bank was covered with shrubby riparian vegetation with no bank overhang. Control site Lc-291 was the furthest downstream site. The north bank sloped gently, with a mixture of riparian shrubs, trees and woody debris followed by a steep grassy bank and gravel road. The south bank was grass and shrubs followed by fenced grazing land. The surrounding land-use around V-weir sites Lv-233 and Lv-77 was livestock grazing on the south side of the river. The north bank of these sites is a gravel bank followed by a gravel road.

Table 3: Approximate river location and construction dates (where applicable) of the ice-covered sites

| | Year of Construction | Approximate River Km |
|---|---|---|
| Control Lc-291 | N / A | 11.37 |
| V- Weir Lv-233 | 1989 | 11.69 |
| V- Weir Lv-77 | 1989 | 11.79 |
| Control Lc-75 | N /A | 13.7 |

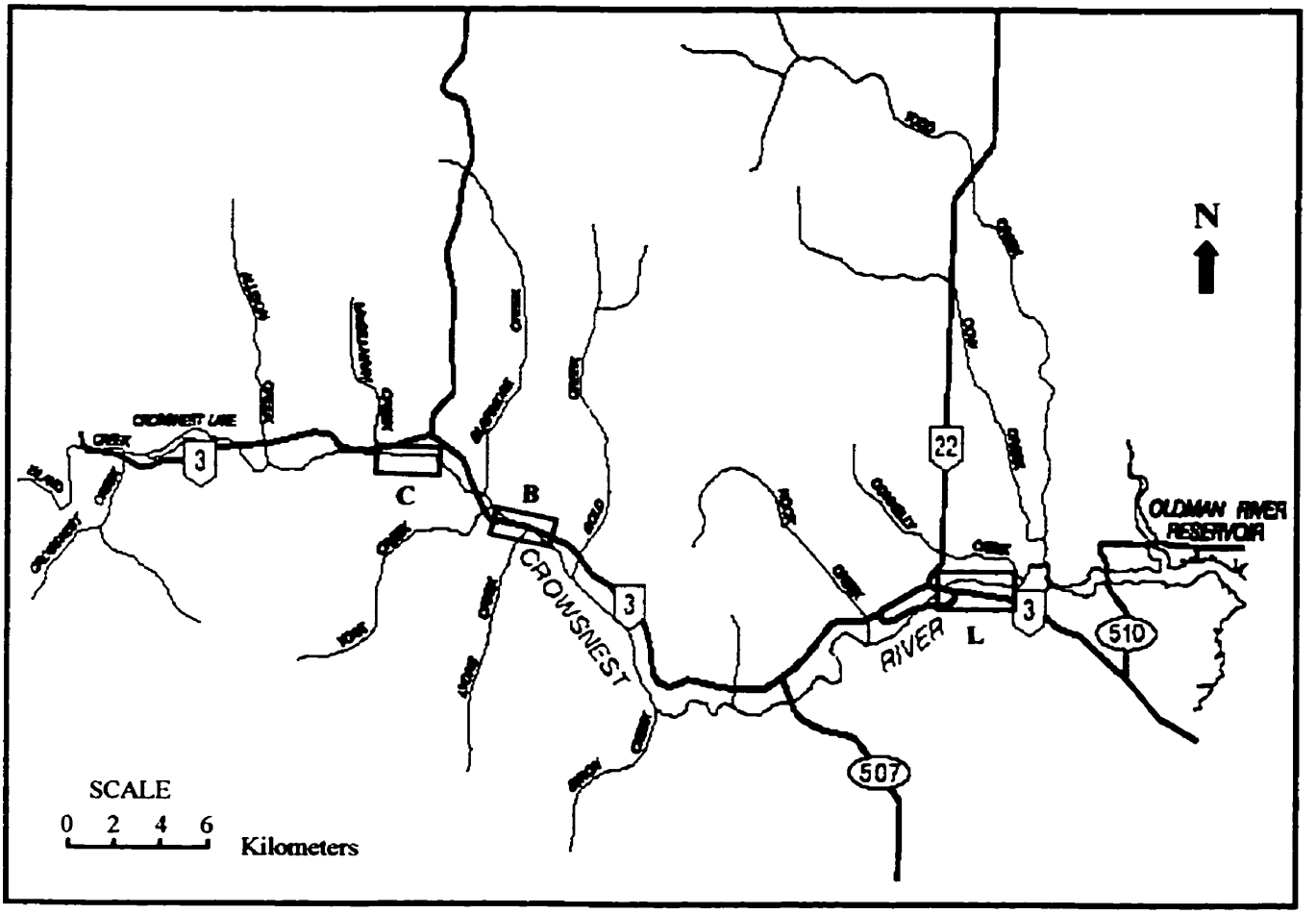


Figure 5: Blairmore (B), Coleman (C) and Lundbreck (L) study areas (Map courtesy of Alberta Environment). The black boxes delineate each study area.

## 5.3 Physical Measurements

Physical measurements of each open-water V-weir and control site were collected between March 5th and March 12th, 1999 (Appendix E). At the pool-head, pool-center and pool-tail of each site, stream transects perpendicular to the stream channel were conducted. Transects were intended to describe the general physical character of each pool. Measurements were not collected in deep (>120 cm) midstream areas. Water depth, velocity and substrate were recorded at 1.0 m intervals across each transect. Water depth was determined to the nearest centimeter. Measurements of water velocity were collected by a 622 Teledyne Gurley current meter. At each interval along the transect, velocity was calculated at 0.2 and 0.8 of total water depth. Total wetted width, bank-full and undercut banks were also recorded at each transect.

Substrate size was estimated in the following manner, according to a modified Wentworth classification scale (Cummins 1962 in Brown and Mackay 1995). Substrate size was visually estimated to correspond to the following categories: silt (< 0.5 mm), sand (0.5 - 2.0 mm), gravel (3-64mm), cobble (65-256mm) and boulder (>256mm). Bedrock or organic debris were also noted, if they dominated the streambed. The two most abundant substrate categories were recorded for each interval along transects.

At the ice-covered sites, physical measurements were collected between February 23rd and 25th, 1999. Only those environmental variables not limited by ice coverage were collected. Through each ice observation hole, water velocity and depth measurements were recorded. Surrounding

land-use, approximate wind velocity, cloud cover and bank (riparian) character were documented for each open-water and ice-covered site. During every sampling period, water and air temperature were measured to the nearest degree with a mercury thermometer. Maximum and minimum daily temperatures were validated with the government weather station measurements.

## 5.4 Materials

With the exception of the filming equipment, majority of the materials which made this project possible were inexpensive, modified hardware supplies.

### 5.4.1 Camcorder and Housing Equipment

Observations were recorded with a SONY high 8 video camcorder (CCD-TRV72 model). The water-proof camera housing was a SONY Underwater Video Marine Pack (MPK-TRV2 model) (Figure 6). One SONY MP light was mounted on top of the housing exterior for ice-covered sampling. Camcorder and light battery power was supplied by 12 and 8 hour lithium batteries.

### 5.4.2 Housing Bracket

A 4.2 cm (wide) steel bracket was molded around the housing to provide a frame for pole attachment. The bracket base (under the housing) was widened into a steel foot (24.2 cm x 8.9 cm) to provide a protective and stable resting platform. Between the housing and bracket, a 5 cm rubber strip limited bracket slippage. The bracket was tightened around the housing by a steel bolt, nut and lock washer.

**Figure 6:** Photo of underwater video housing (photo courtesy of Alberta Environment)

### 5.4.3 Pole Extension

Two modified aluminum pipes were tested as extension devices to maneuver the housing in ice-covered and open-water river studies. Field testing revealed that a 1.3 cm (0.5 inch) diameter pole was too weak to withstand the pressure of the camcorder/housing weight and river current under the river conditions. The 2.5 cm (1.0 inch) diameter pole was durable, but heavy to maneuver. Pole lengths utilized in sampling were 3.11 m for open-water (Figure 7) and 2.03 m for ice-covered (Figure 8) sites. The poles were composed of several detachable sections (each ranging in size from approximately 30 to 100 cm long) allowing length and angle adjustment

when required. Each section was fitted with a bicycle handle or foam tubing to provide grip and protection from the cold. A light-weight polypropylene rope was attached to the top of the housing through to the end of the pole: this set-up functioned as a safety line to retrieve the housing camcorder in the event of pole or bolt breakage.

Figure 7: Photo of underwater housing and open-water pole

**Figure 8:** Photo of video camcorder, housing and ice pole

### 5.4.4 Nuts and Bolts

Pole sections were secured to one another and to the housing by steel nuts and bolts and lock washers. The equipment weight and current force lead to loosening of bolts when small teeth washers were tested. Large lock washers prevented slippage, allowing the pole to be secured at any angle. Frigid temperatures caused breakage of light bolts, thus, steel bolts were required. Bolt holes were tested in flattened aluminum pole ends and separate welded end-pieces. Welding resulted in a point of pole weakness at the welding point, thus flattening is the recommended design.

### 5.4.5 Ice Auger

A 45 cm x 60 cm hole was required to submerse the camcorder and housing through the ice, thus an effective method of ice opening was vital. An 8 inch (20.03 cm) industrial strength gasoline-powered ice auger with sharp, heavy-weight blades was the preferred method of drilling through river ice. Other methods of ice penetration attempted, such as hand auger and chain saw, presented logistical difficulties.

### 5.4.6 Safety Equipment

Any field work which involves walking on river ice is inherently dangerous. A belay system is recommended as a precautionary measure when testing river ice (as described in Strassman 1989: Long 1993). Thus, an onshore assistant and materials, such as harnesses, climbing rope and a figure 8 (or equivalent belay system) were required. In the event of falling through the ice, life jackets and access to a long pole can reduce the risk of being swept under by the current. These safely measures were particularly important in the unstable ice conditions in the study area. which is well known for chinook conditions (warm winter winds). The risk management plan is presented in Appendix F.

### 5.4.7 Ice Clearing

The best ice chipper and ice sieve to use were the heavy weight, metal variety. A sharp chipper was essential to productive ice clearing. The ice sieve cleared fine ice crystals from the hole; this action reduced the likelihood of particles adhering to the housing face and potential interference in filming results.

## 5.5 Description of Open-Water Underwater Video

In March 1999, I evaluated the utility of a video camcorder in a waterproof housing in open-water pools of the Crowsnest River. A light was not utilized because it was ineffective under open-water video recording conditions. Five V-weir and five natural high quality pools were tested.

The camcorder operator began filming standing on the stream bank. The preferred stream bank was determined by accessibility and the sun's position (avoiding casting shadows over the pool). The operator held on to the distal end of the pole and swept the camcorder/housing in an upstream direction. The first sweep was shallow, moving upstream from the furthest downstream portion of the pool, then moved back downstream. The second sweep reached as deep into the pool as possible and continued upstream and downstream as the first sweep. For the third sweep, the operator moved upstream in the pool and continued filming as described for sweeps one and two. Operation from the stream bank continued upstream the length of the pool. Following filming from the bank, larger pools required the operator wade in to stream margins and finally film from the opposite bank (if possible)[3]. These sweeps continued until the pool area was covered (Figure 9).

[3]Some sites were only accessible from one bank.

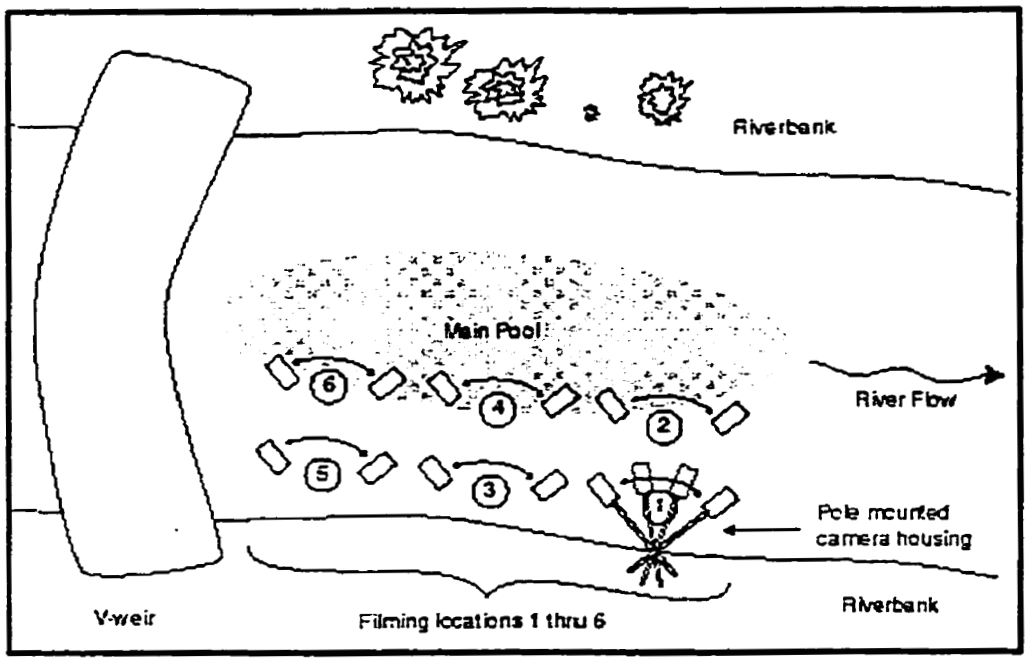


**Figure 9:** Diagrammatic example of order and locations of filming positions. Order of camcorder sweeps is indicated by filming sequence 1 to 6

Camcorder focus settings of approximately 1/4, 1/3, ½, 2/3 and 3/4 zoom were tested. All specific focus settings were found to be inappropriate because of the limited area resulting in-focus. The camcorder setting which allowed the greatest fish enumeration and species identification was automatic focus. Automatic focus also clearly recorded the surrounding habitat and the fish's relative position (i.e. distance from and type of cover / substrate).

A variety of pole and housing angles were tested in the field. Optimal visibility was achieved with the camcorder filming parallel with the river bottom. The appropriate pole angle (relative to the housing) depended on the steepness of the river bank and pool depth. In order to film parallel to the river bottom, the pole angle was adjusted at each site to account for the above mentioned factors (Figure 10).

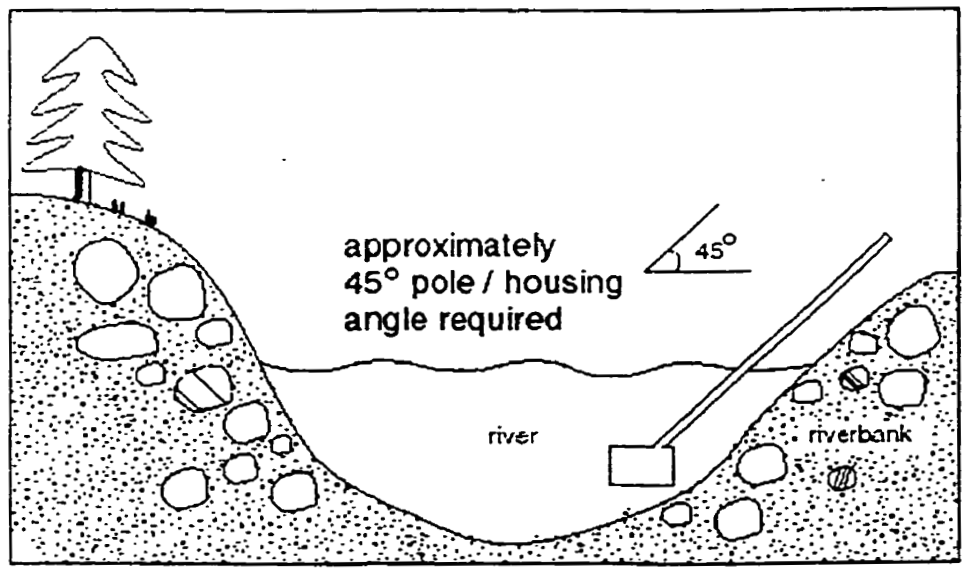


**Figure 10:** Conceptual representation of camcorder-pole angle required for parallel filming in a stream with steep banks.

A 40 m light-weight polypropylene rope was attached to the top of the housing and held taut by an assistant positioned on the upstream bank. This extra leverage aided in housing movement upstream and eased downstream movement. As a result, pressure on the pole was decreased, filming was smoother and more controlled, and video quality was improved (Figure 11).

**Figure 11:** Photo of rope leverage system

The angle of the sun influenced the best time of day to film at each site. Video quality was degraded when the sun's rays penetrated the water column, resulting in high light refraction and reflection off in-stream particles. This problem would not be an issue in conditions of very low turbidity or in river sections shaded by dense coniferous riparian vegetation. Optimal filming times were the early morning, later afternoon or cloudy days.

During a seven day sampling period (March 7th - 13th), collection of video data was replicated seven times at each of the five V-weir and five control open-water sites. For each site, the poorest quality video sample was disregarded; the six remaining video samples were included as study results. Samples were not included in the statistics if the area captured by the camcorder was greatly reduced by some factor, such as; the camera angled toward the substrate, or physical conditions causing reduced focal distance. Samples included in the results had similar video quality. Sampling times varied at each site throughout the daylight hours from morning to late afternoon.

The time sampled depended on a number of factors, such as; angle of the sun, pool depth and the logistics of sampling several sites in close proximity. Due to the inability to sample every site at the same time of day, a conscious effort was made to sample each site in both the morning and the afternoon. Considerable differences in river size and character between the two stream areas warranted separate analysis for the Blairmore and Coleman open-water study sections.

## 5.6 Description of the Ice-Covered Method

In January and February 1999, I tested a video camcorder in a waterproof housing and exterior mounted light in ice-covered pools of the Crowsnest River. Two V-weir and two natural high quality pools were used as study sites.

At each V-weir or natural high quality pool, four holes were drilled in the ice. Holes were staggered over the pool in a manner intended to cover the entire pool area. To cut a hole large enough to fit the housing (45 cm x 60 cm), five auger holes were drilled in a circle then the center ice piece was chipped away. Site disturbance, by the noise of ice drilling and chipping, was decreased by maintaining extensive quiet periods between ice clearing and filming. Time between ice clearing and filming generally exceeded 2 hours, with a minimum quiet period of 20 minutes for any video sample. Twenty minutes was considered a sufficient minimum quiet period because consistently low numbers of salmonids were observed in all samples.

Designed to decrease the likelihood of detection by fish, filming commenced at the downstream hole and moved upstream (assuming that the fish commonly face the current). In order to the maneuver the camcorder housing through the ice hole and within the river, a 2.03 m hollow aluminum pole was attached to a steel bracket fitted around the housing. At each hole, the camcorder was lowered to approximately 15 cm from the river bed. Testing of various pole-camera angles indicated horizontal filming (parallel to the stream bottom) resulted in the best quality video results. Due to the relatively shallow depths which characterize the Crowsnest

River (<2.0 m), this location allowed viewing of fish resting on the bottom, as well as, those individuals near the ice undersurface. The camcorder was slowly, smoothly rotated 360° twice in each hole (approximately two minutes per rotation). Each filming rotation commenced facing upstream, then briefly paused every 90° ( 90°, 180°, 270° and 360°). This definition in rotation was intended to document underwater structures (boulders, woody debris, etc.) and aid in determination of whether fish seen in the first rotation were new or duplicate individuals. Sample filming time at each site was approximately eight minutes (two minutes per hole). As was the case with open-water sampling, an automatic focus camcorder setting was the preferred setting.

Collection of video data was replicated six times at each of the two V-weir and two control ice-covered sites. Sampling times varied at each ice-covered site throughout the daylight hours from morning to late afternoon. All ice-covered samples were collected during two sampling periods: January 20$^{th}$ -24$^{th}$ and February 22$^{nd}$ - 25$^{th}$. The time/day sampled varied according to several factors, such as, ice penetration time (maintaining at least 20 minutes of quiet between ice clearing and filming) and extensive breaks in filming due to flowing water over the ice surface. Due to the inability to sample every site at the same time of day, a conscious effort was made to sample each site in both the morning and the afternoon.

## 5.7 Fish Identification and Enumeration

Accurate fish identification was accomplished with the assistance of Alberta Environment staff (fisheries technicians and biologists, Lethbridge, AB). Sport fish were categorized as trout or mountain whitefish and identified to exact trout species if possible. Fish were considered unidentifiable if it was not possible to assess whether they were trout or mountain whitefish. Due to the low number of non-sport fish observed throughout the study (none in open-water and two suckers in ice-covered conditions), unidentifiable fish were assumed to be sport fish and included in the analysis. To ensure that individual sport fish were not counted twice in the same sample, fish which were possibly duplicates were excluded from enumeration results.

## 5.8 Statistics

In order to compare the relative trout and mountain whitefish abundance between each V-weir and natural high quality pool site, a Kruskal-Wallis One Way Analysis of Variance on Ranks was conducted for site enumerations in each study reach. The Kruskal-Wallis analysis assessed whether the median number of salmonids (as a whole), trout or mountain whitefish enumerated among study sites was significantly different (Zarr 1984). A pairwise multiple comparison procedure (Student-Newman-Keuls test) was then applied to each pair of sites to identify which pools differed significantly in the mean number fish detected compared to any other pool in each study area (Zarr 1984). This non-parametric analysis was intended to address the previously outlined hypothesis that "there is no difference in the relative abundance of trout and mountain whitefish between pools (both V-weir and controls) in the Crowsnest River" and identify variation in relative abundance between individual sites. Where possible, *t*-tests were calculated to assess the difference in mean physical measurements between sites (Ambrose and Ambrose 1987).

# 6.0 RESULTS

## 6.1 Relative Abundance Between V-Weirs and Natural High Quality Open-Water Sites

During the open-water sampling period, water temperatures ranged between + 0.5°C to + 3.5 °C. Air temperatures varied from - 6 °C to + 6 °C . During this filming session, the average, maximum and minimum daily discharge rates of the Crowsnest River at the Frank flow measurement station were 0.997 $m^3$ / s, 1.02 $m^3$ / s and 0.964 $m^3$ / s, respectively. As outlined in the methods section, sample times in open-water filming varied from morning to late afternoon at open-water sites. High or low sport fish enumerations were not associated with either morning or afternoon sampling times. Poor quality video results were not included in the samples.

Over six sampling periods in the Blairmore study area, no trout or mountain whitefish were observed in V-weir Bv-N. In V-weir Bv-17, a total of 35 whitefish and 69 trout were enumerated. At control site Bc-83, no trout and 15 whitefish were observed. At the remaining Blairmore control Bc-Z, 8 trout and 16 whitefish were detected. Seventy-three percent of the total sport fish observed in this study area were recorded at V-weir Bv-17 (Table 4 and 5).

Table 4: Summary of the number of mountain whitefish detected in video observations in the Blairmore open-water study section

| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Total |
|---|---|---|---|---|---|---|---|
| V-weir Bv-17 | 12 | 4 | 3 | 8 | 4 | 4 | 35 |
| V-weir Bv-N | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Control Bc-83 | 2 | 3 | 10 | 0 | 0 | 0 | 15 |
| Control Bc-Z | 0 | 0 | 3 | 2 | 6 | 5 | 16 |
| Total | | | | | | | 66 |

**Table 5:** Summary of the number of trout detected in video observations in the Blairmore open-water study section

| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Total |
|---|---|---|---|---|---|---|---|
| V-weir Bv-17 | 12 | 15 | 6 | 12 | 13 | 11 | 69 |
| V-weir Bv-N | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Control Bc-83 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Control Bc-Z | 3 | 0 | 2 | 0 | 0 | 3 | 8 |
| Total | | | | | | | 77 |

All identifiable fish observed in video sampling appeared to be adults (visible parr marks), with the exception of three juvenile trout at V-weir site Bv-17 and two at control site Bc-Z.

In the Coleman study area, a total of 39 sport fish were enumerated (Table 6). Of those individuals which were identifiable, 31 were trout and 2 were mountain whitefish. No fish were observed at V-weir sites Cv-240 and Cv-241 over six sampling periods. At the remaining three sites, V-weir Cv-61 and controls Cc-D and Cc-226, results were inconsistent, with small numbers of lone fish observed. The highest number of sport fish detected in this study area was at control Cc-242 which averaged 4.5 fish per sample (77 % of total fish observed in the Coleman Area).

Table 6: Summary of the number of sport fish detected in video observations in the Coleman open-water study section

| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Total |
|---|---|---|---|---|---|---|---|
| V-weir Cv-61 | 1 | 1 | 3 | 0 | 0 | 0 | 5 |
| V-weir Cv-240 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| V-weir Cv-241 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Control Cc-242 | 2 | 4 | 2 | 3 | 11 | 8 | 30 |
| Control Cc-D | 2 | 0 | 1 | 0 | 0 | 0 | 3 |
| Control Cc-226 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Total | | | | | | | 39 |

Based on the absence of visible parr marks, all salmonids observed at the Coleman sites in video sampling appeared to be adults.

Whether the salmonid enumerations were considered as a whole or grouped into trout and mountain whitefish, the results of the open-water Kruskal-Wallis ANOVA on Ranks were significant. For both the Blairmore and Coleman reaches, the analysis indicated that the

difference between the median number of fish observed was significantly different between sites. As a result, the hypothesis was rejected for both of the open-water study areas.

In the Blairmore reach, the median values among treatment sites were significantly different for trout ($P < 0.001$). The Pairwise Multiple Comparison of trout numbers between sites indicated that significantly more trout were observed in V-weir site Bv-17 compared to any other site. Conversely, the number of trout detected in V-weir site Bv-N was significantly lower than any other site. There was no significant difference in the number of trout enumerated between the two control sites in this reach.

Similar to the trout analysis, the median values among treatment sites were significantly different for mountain whitefish ($P = 0.008$). Pairwise Multiple Comparison of mountain whitefish enumerations between sites indicated that V-weir Bv-17 contained significantly more whitefish than any other site in the Blairmore area. The number of mountain whitefish enumerated in V-weir site Bv-N was significantly less compared to any other Blairmore site. There was no significant difference in the number mountain whitefish between the two Blairmore control sites.

When Blairmore salmonid observations were analyzed as a group (all salmonids), the results resembled the trout and mountain whitefish statistical calculations; median values among treatment sites were significantly different ($P <0.001$). Again, the hypothesis was rejected with significant differences in the median number of sport fish between sites. Pairwise Multiple Comparison of Blairmore pools indicated that significantly more salmonids were enumerated in

V-weir Bv-17 compared to any other pool and the number of salmonids detected in V-weir Bv-N was significantly lower than any other site. As well, there was no significant difference in the number of salmonids enumerated between the two control sites in this study area.

For the Coleman study area, the number of mountain whitefish observed was insufficient to perform tests of data significance, thus the statistical analysis examined salmonid enumerations as a whole. According to the Kruskal-Wallis ANOVA, the median number of salmonids among treatment sites was significantly different ($P < 0.001$). As in the Blairmore study area, the hypothesis must again be rejected. Pairwise comparison of sport fish observations at each site indicated that significantly more salmonids were enumerated in control site Cc-242 than any other Coleman site. Comparisons of salmonid observations between all other sites revealed insignificant differences.

Evaluation of whether V-weirs may be counted towards the OMRD Fisheries Mitigation goal of "no net loss of recreational fishing opportunities" was assessed through examination of whether each V-weir contained 80 % as many sport fish as control sites. Review of the number of salmonids observed in the Blairmore V-weirs compared to control pools indicated that V-weir Bv-17 surpassed the OMRD goal while Bv-N failed. In the Coleman area, all three V-weirs contained insufficient sport fish to attain the OMRD goal. However, due to the inconsistency in structure use, small sample size and only one season of winter observations, this data was inconclusive; it was not possible to draw final conclusions about structure success or failure.

Evaluation of the hypothesis and the OMRD goal were both influenced by the congregation of a large number of sport fish in a few pools. It was evident that fish use of open-water pools was inconsistent and variation was greater between individual sites in each study area than variation between V-weir and control site types.

Groups of sport fish, containing three to eleven individuals, were documented at Coleman control site Cc-242. These groups were adult trout, congregated in sheltered resting areas. Observations of aggregations at this site was not consistent over the six filming sessions. The largest aggregations of fish recorded in open-water were in Blairmore V-weir site Bv-17. In this case, mixed species groups of four to twenty-two fish consisted of mountain whitefish and trout. Activities varied from resting to feeding among members of these groups. Gregarious behavior at this site was consistent over the six sampling periods. Many fish within groups were positioned less than a body length from each other.

In the Coleman study area, trout were more numerous in both control and V-weir sites (Table 7). Sample numbers recorded in the Blairmore sites indicated a higher proportion of mountain whitefish in controls while majority of the sport fish observed in V-weir Bv-17 were trout. However, compared to any other Blairmore site, significantly more trout and mountain whitefish were enumerated in V-weir pool Bv-17. Taking into account all trout observed in both study areas, 100 % of identifiable individuals were recognized as rainbow trout.

Table 7: Identification of trout species and mountain whitefish observed in Blairmore and Coleman sites (percent of the total fish is shown in brackets)

| | Mountain Whitefish | Trout | Unknown Salmonid Species | Total Fish |
|---|---|---|---|---|
| **Blairmore Controls** | **31 (73.8)** | **8 (19.1)** | **3 (7.1)** | **42** |
| **Blairmore V-weirs** | **34 (30)** | **70 (61)** | **10 (9)** | **114** |
| **Coleman Controls** | **2 (5.9)** | **27 (79.4)** | **5 (14.7)** | **34** |
| **Coleman V-weirs** | **0 (0)** | **4 (80)** | **1 (20)** | **5** |

In an attempt to generally characterize the physical habitat of each pool, depth, velocity and substrate measurements were collected in three stream transects at the pool head, mid-pool and pool tail (Appendix E). Statistical comparisons of physical measurements were not possible in the Blairmore study section due to deep water conditions where velocity measurements could not be collected. In addition, the total pool area ($m^2$) of each site was not measured. The lack of these measurements limits precise definition of high-use areas of pools.

Relative abundance of sport fish observed at the Blairmore sites was highly skewed towards V-weir site Bv-17 with 73 % of all fish observed in this study area. One of the stream transects, measured through the upstream portion of the pool closest to the V-weir, crossed through the area where the majority of the fish congregated. Large numbers of trout and mountain whitefish fish utilized a deep ( > 120 cm), low velocity (0 - 7.5 cm/s) area dominated by cobble-boulder substrate (Figure 12). This location was in close proximity to the high flow area, in the upstream

20 % of the pool. Few fish were observed in the middle of the pool and none were recorded in the downstream end of the pool.

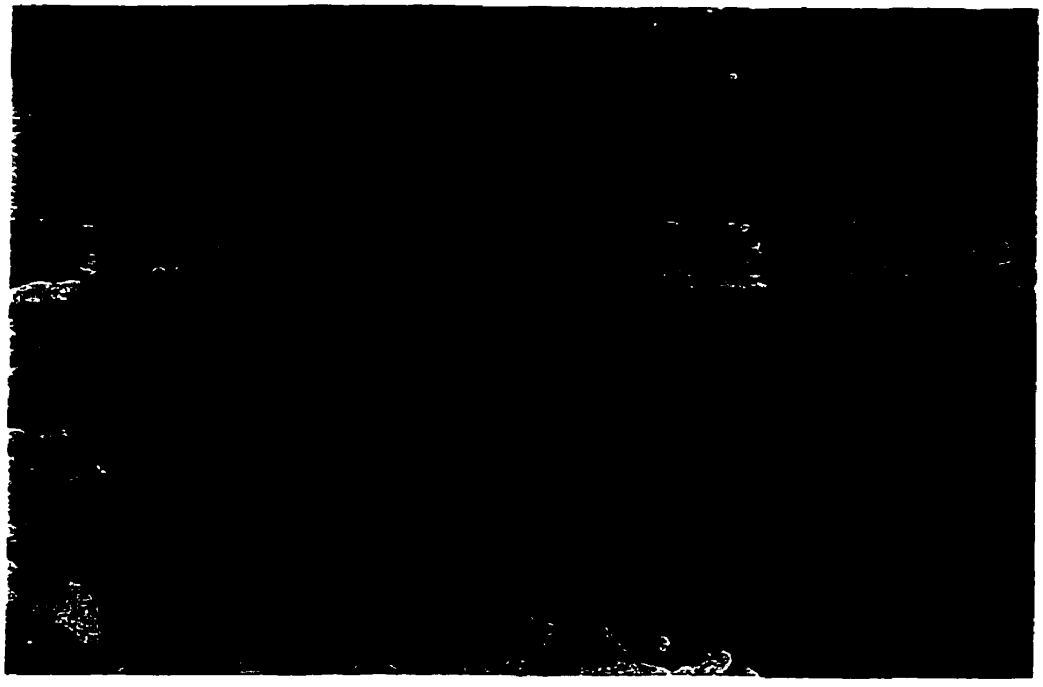

**Figure 12:** Photo of V-weir site Bv-17 filming the portion of the pool where sport fish aggregated

Located approximately 160 m further upstream from V-weir site Bv-17, no fish were observed at V-weir Bv-N. With the exception of steeper sloping banks and stream margins at site Bv-17, physical differences between these sites were not immediately apparent. Comparison of measurements collected from the upstream portion of V-weir Bv-N, similar in pool location to the high-use area of site Bv-17, do reveal some physical differences. In site Bv-17, approximately 5 m of mid-pool cross section was > 120 cm deep and channel depth was > 100

cm within 2 m from both stream banks. In site Bv-N, only 2.5 m of the river cross section was deeper than 120 cm and depth measured less than 100 cm, approximately 5 m from each river bank. The pool head of both V-weir sites were characterized by back-flow or low velocity. Substrate size was generally smaller at V-weir Bv-N, with considerable middle and downstream portions of the pool dominated by sand.

The site with the second highest fish use in the Blairmore area was control site Bc-Z. The depth characteristics and channel shape of this site bore some resemblance to site Bv-17. Comparable to site Bv-17, stream margins descended to depths in excess of 120 cm within 2 m of the land-water interface at the head of the pool. In addition, the channel shape of control Bc-Z was similar to V-weir Bv-17, in that 4 to 6 m of the mid- pool cross section was in excess of 120 cm deep. Stream margin velocity measurements were slightly higher than comparable locations in the V-weir pool; the average within 3 m of the stream bank of the control was 5.5 cm/s. One obvious difference in fish use of these two pool sites was that, as opposed to mainly congregating at the pool head in V-weir site Bv-17, fish observed in control site Bc-Z were actively swimming throughout the pool.

Differences in instream characteristics between control Bc-83, where only mountain whitefish were observed, and V-weir Bv-17, which contained 61 % trout, may be differences in winter habitat qualities used by mountain whitefish and trout. The mean depth, velocity and substrate measured at control site Bc-83 were 57.2 cm, 9.8 cm/s and cobble, respectively. In comparison, large numbers of fish were utilizing deep ( > 100 cm), low velocity (0 - 7.5 cm/s) areas

dominated by cobble-boulder substrate in V-weir Bv-17. Thus, mountain whitefish may be attracted to slightly faster velocity, shallower depth and smaller substrate than trout in winter. However, because Site Bv-17 contained significantly more trout and mountain whitefish than either control, these results do not support a difference in resource use between trout and mountain whitefish. High-use appears to be more related to individual site characteristics than whether a pool is a V-weir or control.

In an attempt to correlate high-use with instream physical characteristics in the Coleman study section, *t*-tests were calculated which compared the mean depth, velocity and substrate measurements of control Cc-242 with the other V-weir and control sites. This statistical test is intended to assess whether differences in macro-site characteristics between this highly used control and the other sites in this study section were significant (Table 8 and 9).

**Table 8:** Physical characteristics of Coleman open water sites

| Site | Total # Fish | Depth (cm) | | Velocity (cm/s) | | Substrate (see scale below) | |
|---|---|---|---|---|---|---|---|
| | | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| Cc-D | 3 | 59.08 | 29.81 | 15.32 | 24.24 | 3.22 | 1.6 |
| Cv-61 | 5 | 59.04 | 30.04 | 12.75 | 12.61 | 3.61 | 1.38 |
| Cc-226 | 1 | 44.79 | 24.46 | 16.18 | 12.12 | 3.31 | 1.23 |
| Cv-240 | 0 | 46.02 | 18.99 | 22.47 | 18.16 | 4.61 | 0.76 |
| Cv-241 | 0 | 41.41 | 19.9 | 22.22 | 13.39 | 4.3 | 0.75 |
| Cc-242 | 30 | 46.38 | 17.07 | 23.61 | 24.93 | 4.46 | 0.75 |

The substrate units of measure correspond to the following modified Wentworth categories: silt (< 0.5 mm), sand (0.5 - 2.0 mm), gravel (3-64mm), cobble (65-256mm) and boulder (>256mm) (Cummins 1962 in Brown and Mackay 1995).

**Table 9:** *T* - test results comparing mean physical measurements of control site Cc-242 with all other Coleman sites

| | Control Cc-D | Control Cc-226 | V-weir Cv-241 | V-weir Cv-240 | V-weir Cv-61 |
|---|---|---|---|---|---|
| **Depth** | N / A | 1.193 | 0.911 | 0.019 | N / A |
| **Velocity** | 11.957 | N / A | N / A | 1.707 | N / A |
| **Substrate** | 3.381 | 3.795 | 0.708 | 0.885 | 2.389 |

Measurements which possessed significantly different variances (*F*-test results) compared to site Cc-242 were not subjected to the *t*-test; these results were indicated by N / A.

Results from *t*-tests, indicated that high sport fish use of control site Cc-242 was not simply linked to mean velocity, substrate or depth measurements. At $P < .05$ and applicable degrees of freedom, the mean substrate and depth of the two V-weirs (Cv-240 and Cv-241) which possessed no fish, were not statistically different than the mean measurements for site Cc-242. In addition, the mean velocity for site Cv-240 was not significantly different than that of Cc-242. Of those sites which contained small numbers of fish inconsistently (V-weir Cv-61 and controls Cc-D and Cc-226), mean substrate size was significantly smaller than site Cc-242. Mean velocity of control site Cc-226 was significantly slower than site Cc-242, however this did not coincide with higher fish use.

It is worth noting that there were two areas of control site Cc-242 where fish congregated. These pool pockets, depicted in Figure 13, were close to the cover of boulders and sheltered from the main river flow. One of these high-use areas was a small, mid-stream pool, located at the upstream end of the site, between the two main plunge areas (242 - A). The area of 242 - A was approximately 1.0 $m^2$. The other high-use area was within the upstream portion of the pool, along the south stream bank (242 - B). In both of these areas, groups of fish were observed resting in sheltered pools, close to the cover of boulders. One of the stream transects, measured through the upstream portion of control site Cc-242, was in the vicinity of high use area 242 - B. This southern, upstream portion of the pool is characterized by lower velocities of 17.1 - 18.7 cm / s compared to the mean (23.6 cm / s) and greater depths of 67.5 - 72.5 cm compared to the mean (46.4 cm) measured at this site. Although measurements were not collected for area 242 - A, visible estimation indicates that this area is a low velocity, deep pool (> 75 cm), dominated by

boulder substrate. Since the deepest area encountered in transect measurements was 77.5 cm. these two high-use pool areas were among the deepest measured in the pool. These qualitative descriptions of specific areas of the control frequented by trout may be the best approximation of high-use habitat in this pool.

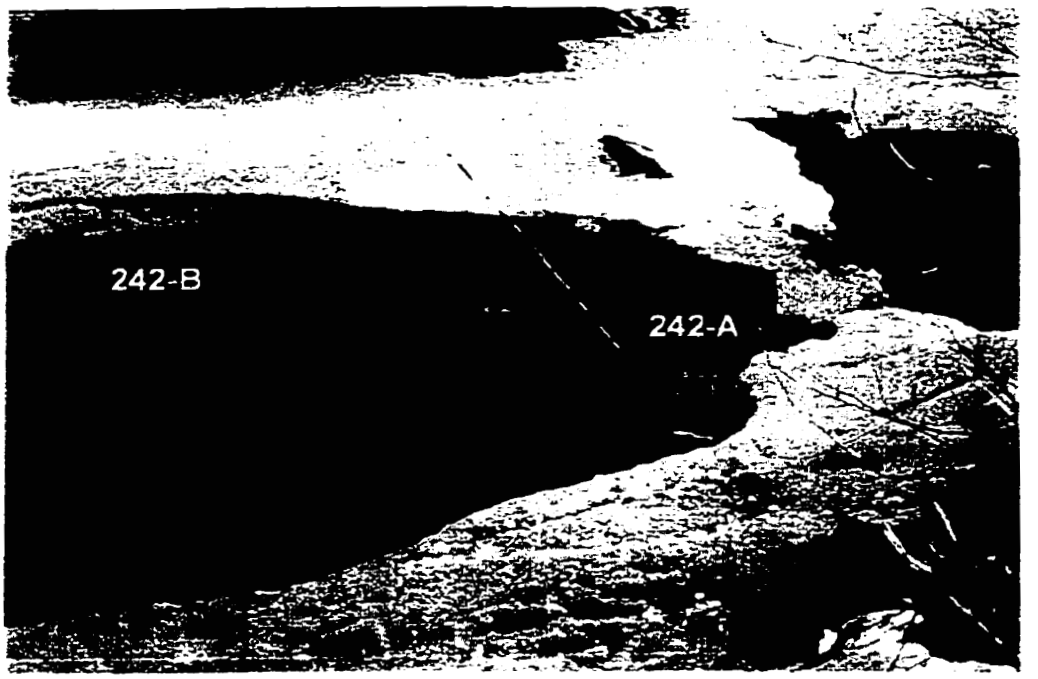


**Figure 13:** Photo of control site Cc-242 delineating the two high-use areas 242 - A and 242 - B.

### 6.1.1 Summary of Open-Water Results

**Blairmore Study Area**

- Whether salmonid enumerations were considered as a whole, or divided into trout and mountain whitefish, V-weir site Bv-17 contained significantly more salmonids, while V-weir Bv-N contained significantly fewer salmonids, than any other site.
- There was no significant difference in the number of trout, mountain whitefish or salmonids (as a group), between the two control sites.
- While proportionately more whitefish were observed in control pools and proportionately more trout in one V-weir pool (Bv-17), significantly more trout and whitefish were enumerated in V-weir pool (Bv-17).
- High-use pool areas generally exhibited low velocity (0 - 7.5 cm/s), depth (> 120 cm) and cobble-boulder substrate.
- Fish use of pools was inconsistent and variation was greater between individual sites than between V-weir and control site types.
- Majority of fish were observed in aggregations of three to twenty-two fish. Aggregations consisted of trout only, mountain whitefish only and mixed groups.
- 98 % of salmonids observed were adults.

**Coleman Study Area**

- Significantly more salmonids were observed in control pool Cc-242 compared to any other Coleman site and there was no significant difference in the number of sport fish between any of the other sites.
- No fish were observed in two of three V-weirs.
- Sport fish were observed in all three control sites.
- One control site contained 77 % of the total fish observed.
- 31 of 33 identifiable fish observed were trout (2 whitefish).
- Specific areas of high-use were deep (> 65 cm), low velocity (17.1-18.7 cm/s) pools with boulder substrate.
- Fish use of pools was inconsistent and variation was greater between individual sites than between V-weirs and control site types.
- The majority of fish were observed in aggregations of three or more.
- No juveniles were recorded in any Coleman site.

## 6.2 Relative abundance between V-weirs and natural high quality pools at Ice-covered Sites

During the ice-covered data collection dates, water and air temperatures ranged from 0 to +1°C and - 15 to +8 °C, respectively. During the study period, the average, maximum and minimum daily discharge rates of the Crowsnest River at the Frank flow measurement station were 1.08 $m^3$ / s, 1.14 $m^3$ / s 0.962 $m^3$ /s, respectively. Periods of warm weather during these sampling sessions led to ice and snow melt and breaks in filming due to flowing water over the ice surface. Melting conditions elevated the level of water turbidity.

As outlined in the methods section, sampling times varied from morning to late afternoon at each ice-covered site. Sampling days varied for each site over the January and February sampling periods. Sport fish enumerations were consistent low whether sampling occurred in the morning or afternoon.

A total of 30 fish were observed in the four ice covered sites. Of this total, 9 (30 %) were not possible to identify due to unseasonably high turbidity conditions (Table 10). Mountain whitefish and trout were observed at all four sites (Table 11 and 12). All trout identified were rainbow, with the exception of two bull trout in one V-weir pool. Two non-sport fish were observed, one longnose sucker and one white sucker, but not enumerated for the ice-covered analysis.

**Table 10:** Identification of trout and mountain whitefish observed in Lundbreck sites (Percent of the total fish is shown in brackets)

| | Mountain Whitefish | Trout Species | Unknown species | Total Fish |
|---|---|---|---|---|
| **Lundbreck Controls** | 3 (37.5) | 3 (37.5) | 2 (25) | 8 |
| **Lundbreck V-weirs** | 5 (23) | 10 (45) | 7 (32) | 22 |

**Table 11:** Summary of mountain whitefish observations during ice-covered sampling

| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Total |
|---|---|---|---|---|---|---|---|
| **V-weir Cv-77** | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| **V-weir Lv-233** | 1 | 0 | 2 | 0 | 0 | 0 | 3 |
| **Control Lc-75** | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| **Control Lc-291** | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| **Total** | | | | | | | 8 |

**Table 12:** Summary of trout observations during ice-covered sampling

| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Total |
|---|---|---|---|---|---|---|---|
| **V-weir Cv-77** | 1 | 1 | 0 | 0 | 1 | 2 | 5 |
| **V-weir Lv-233** | 2 | 2 | 1 | 0 | 0 | 0 | 5 |
| **Control Lc-75** | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| **Control Lc-291** | 1 | 0 | 0 | 1 | 0 | 0 | 2 |
| **Total** | | | | | | | 13 |

Whether the salmonid enumerations were considered as a whole or grouped into trout and mountain whitefish, the results of the Kruskal-Wallis ANOVA were the same. There was no significant difference in the median number of trout ($P = 0.285$), mountain whitefish ($P = 0.860$) or salmonids as a group ($P = 0.141$) observed among the Lundbreck sites. With no significant difference in the number of fish between ice-covered sites, the hypothesis cannot be rejected.

As was the case with examination of the OMRD goal in the open-water study sites, limited sampling sites and repetitions led to inconclusive results. However, even though the difference in the number of salmonid were not significantly different between any ice-covered sites, raw examination of the number of salmonids observed in each V-weir compared to control pools

indicated that both V-weirs surpassed the OMRD goal.

Due to ice cover, physical measurements were limited to depth and velocity. At each site, these measurements were collected through four ice holes, staggered within the pool. *T*-test calculations indicated that the difference in mean velocities approached significance (slower in V-weir pools) ($P < 0.10$, $t = 1.77$) and mean depth was significantly greater ($P < 0.05$, $t = 3.45$) in V-weir compared to control sites (Table 13 and 14).

**Table 13:** Velocity (cm/s) measurements through observation holes at ice-covered sites

| | STUDY SITES | | | |
|---|---|---|---|---|
| | **Control Lc-291** | **V-weir Lv-233** | **V-weir Lv-77** | **Control Lc-75** |
| **Hole 1** | 50.9 | 28.3 | 17.8 | 48.8 |
| **Hole 2** | 45.3 | 29.3 | 28 | 38.6 |
| **Hole 3** | 38.1 | 27.6 | 43.6 | 27.7 |
| **Hole 4** | 42.1 | 44.8 | 26.2 | 24.4 |
| **MEAN** | **44.1** | **32.5** | **28.9** | **34.9** |

**Table 14:** Depth (cm) measurements through observation holes at ice-covered sites

| | STUDY SITES | | | |
|---|---|---|---|---|
| | **Control Lc-291** | **V-weir Lv-233** | **V-weir Lv-77** | **Control Lc-75** |
| **Hole 1** | 40 | 90 | 75 | 87.5 |
| **Hole 2** | 53 | 85 | 70 | 70 |
| **Hole 3** | 60 | 85 | 80 | 60 |
| **Hole 4** | 56 | 95 | 78 | 30 |
| **Mean** | **52.25** | **88.75** | **75.75** | **61.875** |

## 6.3 Utility of Night Filming

In an attempt to assess the presence of juvenile salmonids, night filming was tested under ice-covered and ice-free conditions. In open water testing, fish were attracted to the light from stream areas several meters outside of pool boundaries and the visibility was poor. The video clarity was better in ice-covered night sampling, but limited. Fish were observed under ice, but insufficient illumination and increased particle reflection degraded the resulting video quality.

# 7.0 DISCUSSION / CONCLUSION

## 7.1 Evaluation of V-Weirs for Provision of Winter Habitat

The severity of winters in the southern foothills region of Alberta is highly variable. In extreme years, streams in this area are subjected to harsh instream conditions such as: low water flow, sub-surface ice development and shifting ice conditions (Environment Canada 1999; Jim Allan, Pisces Environmental Consulting Services, Red Deer, Alberta; personal communication). These physical limitations on habitat availability are augmented by freezing water temperatures which slows fish metabolism and reduces swimming ability and consequentially heightens the need for sheltered instream positions (Cunjak 1988; Cunjak and Power 1987; Hartman 1963). It is under these challenging seasonal conditions that the existence of low velocity, deep habitat is important (Brown and Mackay 1995; Cunjak and Power 1986; Gosse 1982; Jakober 1995; Schrader 1989). One of the purposes of V-weir installation in the Crowsnest River is to provide deep, low flow overwintering habitat (Lowe 1996).

Previous evaluations of artificially created pools have shown high use of these deep, low velocity habitats during low flow periods (i.e., Gowan and Fausch 1996; Hunt 1971; Riley and Fausch 1995; White 1975). A central purpose of this study was to assess sport fish use of V-weir pools during low flow winter conditions. Success of structures, in their provision of overwintering habitat, was evaluated in two ways. First, with respect to the OMRD goal of "no net loss of

recreational fishing opportunities". The second evaluation considered the hypothesis: There is no difference in the relative abundance of trout and mountain whitefish between pools (both V-weir and natural high quality controls) in the Crowsnest River. Given the limitations of sample size, inconsistent pool use and a single sample season, evaluation of structure success was limited.

### 7.1.1 Open-Water Sites

In the Blairmore and Coleman open-water study areas, the hypothesis was rejected because the median number of salmonids was significantly different among sites. Whether the statistics were calculated for salmonids as a group or separately for trout and mountain whitefish, one site contained a large majority of the total sport fish observed while others contained few or no fish in each open-water study area. In the Blairmore area, one V-weir (Bv-17) contained significantly more salmonids than any other site and the other V-weir (Bv-N) significantly fewer salmonids than any other site sampled. There was no significant difference in the number of sportfish between the two Blairmore control sites. In the Coleman study reach, significantly more salmonids were observed in control pool Cc-242 compared to any other site and there was no significant difference in the number of sport fish between any of the other low-use sites.

In consideration of the OMRD goal of "no net loss of recreational fishing opportunities", artificial structures must provide habitat for 80% as many sport fish as natural high quality pools to be considered successful. In the Blairmore study area, the V-weir (Bv-17) which contained significantly more sport fish than any other site surpassed the OMRD goal, while the V-weir (Bv-

N) with significantly fewer salmonids failed. All three V-weirs in the Coleman study area failed to attain the OMRD goal with few or no fish and significantly fewer fish than control pool Cc-242.

The overwhelming influence of many sport fish aggregated in a few sites influenced the evaluation of both the hypothesis and the OMRD goal. In each study area, it was evident that fish use of pools was inconsistent and variation was greater between individual sites than between V-weirs and control site types. As a result of inconsistent pool use, a control versus treatment study design cannot not fully address the large number of environmental variables that may have affected whether a fish utilized a particular pool as overwintering habitat. For this reason, a more appropriate study design may involve the use of resource selection probability functions (RSF).

A RSF approach is designed to assess the relative importance of all environmental parameters which may influence resource use (Millspaugh et al. 1998). The relative probability of resource combinations being selected is calculated by considering the total available resource units and compares the resource units used with those units not used by the target species in a particular area (Mace et al. 1996; Manly et al. 1993). Successful RSF analysis assumes that several factors are correctly identified and measured, such as; available, used and unused resource units, relevant environmental variables affecting resource-use probability are included and access to available resources is equitable (Manly et al. 1993). Clearly, RSF is a multivariate, ecological approach which may clarify the quality and quantity of resources selected by salmonids in winter and

thereby improve our definition and understanding of effective overwintering habitat.

### 7.1.1.1 Considerations in Salmonid Pool Selection

#### 7.1.1.1.1 Sheltered Overwintering Habitat

Examination of the physical commonalities between the sites with the most fish and differences reflected in the lowest use sites, may broadly define the physical characteristics commonly used by Crowsnest River sport fish in winter. In the Blairmore study area, physical factors correlated with high fish use were substantial depth (> 120 cm), low velocity (0 - 7.5 cm/s) and cobble-boulder substrate. Specific areas of high-use in the Coleman study area were characterized by low velocity (17-18 cm/s), depth (67.5 - 72.5 cm) and boulder substrate. The winter habitat with the greatest number of salmonids in both study sections is generally described as low velocity pools with considerable depth and boulder cover.

Similar winter habitat preferences have been documented by a number of other winter studies with varying degrees of subsurface ice development. The most highly utilized winter habitat of bull trout and cutthroat trout in Meadow and Daly Creeks, Montana was low velocity (< 10 cm/s), deep (>50 cm) pools (Jakober 1995). Schrader's (1989) studies in South Willow Creek, Montana, found that brook trout and rainbow trout utilized pools with depths >45cm and velocity < 30cm/s. Adult brook trout and brown trout in southern Ontario selected depths of 25 - 150 cm and velocities of 1.5 - 43 cm/s as overwintering habitat (Cunjak and Power 1986). Chishlom et al. (1987) recorded trout preference for deep (30-107 cm), low velocity (< 15 cm/s) habitat in

high elevation Wyoming streams. Cover has also been commonly cited as an important factor in salmonid overwintering habitat (Cunjak and Power 1986; Heggenes et al. 1993; Jakober 1995; Meyer and Griffith 1997). Cunjak and Power (1986) found that depth was an important selection factor for trout, but only where it is sheltered from high velocity flow and in combination with cover. The relative importance of depth, velocity and cover has been disputed and may vary from stream to stream.

Salmonid investigations have cited groundwater discharge point as an important characteristic if overwintering habitat (Cunjak and Power 1986; Smith and Griffith 1994). During previous OMRD studies, no major groundwater sources have been observed at any of these Crowsnest River sites (Rick Pattenden, R.L. & L. Environmental Services Ltd., Edmonton, Alberta; personal communication). Water temperatures measured between adjacent sites showed negligible differences with the mercury thermometer employed during this study. However, a more accurate thermometer may have been able to detect temperature differences of less than one degree.

#### 7.1.1.1.2 Aggregations

In addition to the preference for sheltered, low velocity habitat in winter, the role of aggregative behavior should be considered in salmonid overwintering in the Crowsnest River. The majority of fish recorded were in single or multi-species aggregations of 3 to 22 fish, as opposed to lone individuals. Aggregations of trout (both mixed and single species groups) have been

documented by several researchers in winter (Brown et al. 1993; Cunjak and Power 1986; Gosse 1982; Heggenes et al. 1993; Jakober 1995; Jakober et al. 1998; Riehle and Griffith 1993). Aggregations are commonly recorded in deep, low velocity pools in winter (Cunjak and Power 1986; Jakober 1995).

With the congregation of large numbers of salmonids in a few pools, it is essential to explore the behavioral influence of pool fidelity on habitat selection within and between winters. It is possible that a pool utilized by a group of fish may change from winter to winter, as well as, shift within one season. Further winter monitoring of V-weir and control pools is necessary to determine whether sport fish consistently use the same pools throughout several winters.

V-weir pool Bv-17 exemplified prime overwintering habitat described by other investigators: extensive depth, low velocity flows and proximity to cover (boulders, turbulence and depth). Due to the large number of fish observed in this pool, it is important to describe the physical habitat which characterized this pool. The majority of fish observed were aggregated in the head of pool, closest to the V-weir. This high-use area of the pool was located in close proximity to the V-weir tip where the greatest volume of water flowed over the weir. Several large trout were observed in this deep, higher velocity mid-stream portion, however, the majority were congregated in the zero flow area, within the first 4 meters from the river bank.

There are several adaptive reasons which may explain winter aggregative behavior of adult sport fish populations in deep, low velocity pools. As water temperature decreases, metabolic rates

fall and fish become less territorial (Cunjak 1988; Hartman 1963). Cunjak and Power (1986) noted that increases in this behavior during the day was correlated with decreases in water temperature and subsurface ice development. Aggregative behavior has been noted more frequently in pools which lack cover, than those with extensive instream cover (Cunjak and Power 1986; Heggenes et al 1993). The threat of predation has been cited as a potential motivation for congregation into large groups during winter (Heggenes et al 1993; Jakober 1995). The risk of predation may be augmented by reduced swimming ability in lower temperatures. Congregation into large aggregations may reduce the risk of predation for individual fish within the group.

Aggregations of trout and mountain whitefish may be explained by similar mechanisms in the Crowsnest River. On one of six sampling sessions, a river otter *Lutra canadensis* was observed at V-weir site Bv-17. This mammal is an effective predator which feeds on fish (Cunjak 1996). With low water temperatures (1 - 3.5 °C) measured at this site, fish metabolism would be slow. Thus, the occurrence of large multi-species groups of adult sport fish recorded in this pool may be related to reduced instream temperatures, risk of predation and reduced territoriality.

In colder years, a reduction of available habitat due to subsurface ice development may also stimulate aggregative behavior. Even though subsurface ice was not present in this study, extensive frazil and anchor ice has been observed in the Crowsnest River in previous video explorations (Jim Allan, Pisces Environmental Consulting Services Ltd., Red Deer, Alberta; personal communication). This indicates that, in other years, the Crowsnest River is susceptible

to habitat exclusion by subsurface ice formation.

Feeding of trout and mountain whitefish was observed within groups recorded. Jakober (1995) documented smaller groups of trout feeding during the night in winter. However, reduced metabolic rates in cold temperatures naturally reduces the winter food requirements of fish (Hartman 1963). Even though feeding was observed in aggregations during this investigation, the risk of predation may outweigh the need for defending feeding positions in winter.

#### 7.1.1.1.3 River Location

In addition to aggregative winter behaviour, the relative longitudinal (upstream / downstream) in-stream location of the open-water sites may have influenced whether a fish selected a particular pool as overwintering habitat. Concurrent with the declining water temperatures of autumn, winter studies have noted fall and winter salmonid movement until they reach appropriate habitat to overwinter (Brown and Mackay 1995; Chisholm et al.1987; Jakober 1995). Gowan and Fausch (1996) recorded immigration into treatment and control sections in the upstream direction twice as often as downstream. In the Coleman study area, 77 % of the fish observed were located at the furthest downstream site (control Cc-242). Among the Blairmore sites, the two pools (control Bc-Z and V-weir Bv-17) which contained 90 % of the fish recorded in the study area, were the furthest downstream sites. Winter movement of salmonids has been linked to the amount and timing of subsurface ice development (Brown and Mackay 1995; Chisholm et al 1987; Jakober 1995). The extent of fish movement ranges from frequent, when ice conditions

are severe and active, to remaining in a limited area throughout the winter, when suitable habitat is available (ibid). Perhaps, fish in the Crowsnest River move upstream until they find suitable winter habitat (i.e., V-weir Bv-17 and controls Bc-Z, Cc-242), and with the lack of habitat exclusion by subsurface ice in 1999, had no need to move further. Further winter monitoring is necessary to determine whether the pools preferred in this study, would provide suitable overwintering habitat in years of extensive ice development.

#### 7.1.1.1.4 Trout and Mountain Whitefish

There was no statistically significant difference in winter habitat-use between trout and mountain whitefish in any of the study areas sampled. However, in the Blairmore area, proportionately more whitefish were present in control sites compared to V-weir pools. In this area, 74 % of sport fish observed were identified as whitefish in the control sites, while trout dominated V-weir Bv-17 with 61 % of fish recorded. Control site Bc-83, where mountain whitefish was the sole salmonid species observed, was characterized by generally faster water velocity, smaller substrate and shallower depths than V-weir Bv-17. Mountain whitefish and trout (fewer) were both recorded at control Bc-Z. This site possessed similar depth and channel shape as V-weir Bv-17, but was characterized by smaller substrate and slightly faster water velocities. Regardless of differences in proportionate abundance, V-weir Bv-17 contained significantly more trout and mountain whitefish compared to either of the control sites.

#### 7.1.1.1.5 Anglers

Evaluation of winter use of V-weirs must also consider the potential influence of anglers. An angler survey conducted on the Crowsnest River found that V-weirs received a high fishability and preference rating (Hildebrand and O'Neil 1992). Hunt (1971) found that the installation of log dams increased the number and success of anglers in Lawrence Creek, Wisconsin. Higher fishing pressure on artificially created pool reaches compared to unaltered stream sections was also documented in Colorado streams (Gowan and Faush 1996; Riley and Fausch 1995). With respect to the current study, fishing regulations do not allow angling in the upper Crowsnest River (open-water study area) from Nov 1st to June 15th and prohibit fishing through river ice (ice-covered study area). Except for the possibility of final migrations to overwintering pools prior to November 1st, the influence of winter angling mortality on the study results was considered negligible.

#### 7.1.1.1.6 Small Population Size

The observation that some V-weirs possessed little or no fish may relate more to the small size of the adult salmonid population in the upper Crowsnest River. Previous investigations in the upper Crowsnest River have suggested that the amount of adult deep-water habitat may be in excess of that required by the resident population of legal-sized rainbow trout (R.L. & L Environmental Services Ltd. 1996). Thus, there may be too few adult fish in the upper Crowsnest River to utilize all of the pool habitat provided by V-weirs. If the population of adults is low, perhaps

overwintering habitat is not limiting the sport fish population size. It is possible that other factors, such as low river productivity and/or angling pressure, may be limiting the salmonid population size. Regardless, if fish do congregate in different pools each winter, the number of V-weirs in the upper Crowsnest River may be justified by intermittent fish use.

Prior to the installation of V-weirs in the Blairmore and Coleman study areas, deep, low velocity pool habitat was less abundant ( R.L. & L Environmental Services Ltd. 1989). Consequently, the presence of more deep pool habitat may increase winter survival of trout and mountain whitefish in years of extensive subsurface ice development.

#### 7.1.1.1.7 Juvenile Concealment

A total of 195 fish were observed in the open water portion of this study. Of these fish, 5 (2.6 %) were juveniles. Previous snorkel studies at these sites have reported significantly higher proportions of juvenile sport fish: out a total of 125 sport fish recorded, 21 % were juveniles (R.L. & L Environmental Services Ltd. 1992 -1994) (Appendix G). Comparison with these earlier investigations indicates a much lower proportion of juveniles were observed in winter video sampling compared to previous snorkel studies. This comparison is likely an indication that the number of juvenile salmonids was underestimated in the current study due to diurnal concealment behavior in winter. Juvenile concealment behavior has been reported to commence at water temperatures ranging from 6 - 8.5 °C (Campbell and Neuner 1985; Contor 1989; Riehle and Griffith 1993). Water temperatures in the open-water study did not rise above 3.5 °C in any of the sites investigated. The absence of a fish fright response (to the housing presence), and the

ability to clearly discern distant ( > 2 m away) gravel and small woody debris in open-water video, indicates that the lack of juveniles observed in open-water may not be explained by equipment-related limitations. Ecologically adaptive reasons for this type of juvenile behavior in winter may be energy conservation, shelter from high velocity flows and predator avoidance (Contor 1989; Hartman 1963; Heggenes et al. 1993).

Night testing of the underwater video camera and light resulted in degraded video results. Nocturnal snorkel observations have successfully recorded juveniles at night (Riele and Griffith 1993). Further experimentation with the type and power level of the illumination source may improve the quality of night filming. Furthermore, future testing under colder winter conditions would likely result in improved video quality due to lower turbidity levels.

### 7.1.2 Ice-Covered Sites

Whether the ice-covered Kruskal-Wallis statistics were calculated separately for trout and mountain whitefish or salmonids as group, the difference in the median number of sport fish in each pool was insignificant. Thus, the hypothesis could not be rejected. Nonetheless, examination of the raw enumerations indicated that there were more sport fish observed in each of the V-weir pools compared to the control sites. Therefore, even though the results were inconclusive, it could be argued that these two artificial sites surpassed the OMRD goal.

Comparisons of mean velocity and depth measurements between control and V-weir sites

indicated that the V-weirs possessed significantly deeper mean depths and near significantly slower mean velocities than control sites. The high-use V-weir habitat was characterized by mean velocity and depth measurements of 31 cm/s and 82 cm, respectively.

Previous 1995 and 1996 late summer snorkeling observations, conducted by R.L. and L. Environmental Services Ltd. (1997) below Lundbreck Falls (ice-covered sites), recorded more salmonids in both V-weir and control sites than observed during this investigation. They also documented greater numbers of sport fish at control sites than V-weirs. It is possible that the relative importance of these artificial structures compared to controls is greater in winter than summer. The lower overall number of fish recorded in winter could signify that sport fish are overwintering in the reservoir. Radiotagging studies conducted from 1993 to 1996 recorded the descent of bull trout from the Oldman River to overwinter in the Oldman River Reservoir (Golder Associates 1999). However, these results are of limited utility because it is not known if any other sport fish species besides bull trout overwinter in the reservoir.

Another potential explanation of the low numbers of fish observed in ice-covered V-weirs, is the poor choice of video filming location. The video observation holes were located midstream, at least 7.0 meters from the V-weir spillway. Results from the open-water study, conducted after ice-covered sampling, indicate that fish may have congregated between the V-weir spillway and stream bank. Another factor that may have influenced salmonid aggregations in the Lundbreck study area was the presence of large instream predators, such as the bull trout, observed in this

study reach. Additionally, a large group of sport fish may have been congregated in the adjacent V-weir, not sampled in this study. Lastly, the reduced visibility encountered in the study may have underestimated the number of salmonids recorded in all four sites. As a result, a group sport fish may have been present in these sites and not recorded.

No juvenile sport fish were observed in the ice-covered study sites. As in the open-water portion, this is likely explained by diurnal concealment behavior of juveniles in winter. However, due to the elevated turbidity conditions encountered under ice, it is also possible that juveniles may have been present but undetected.

## 7.2 Appropriateness of Methodology to Assess Effectiveness of V-Weir artificial Habitat Structures in an Open-Water River

The underwater video observation technique functioned well to answer the fundamental question of whether trout and mountain whitefish were using the V-weir created pools as much as natural high quality pools in ice-free sites. Filming from the stream bank also enabled the camcorder to record species composition, behavior and habitat-use information of fish present in the pool.

There were several factors which reduced the focal capability of the camcorder in open-water. The influence of sun rays reflecting off instream particles decreased the camcorder capabilities. Instream debris and turbulence occasionally limited visibility. The potential of salmonids utilizing these instream features as cover may influence fish detection. However, this reaction was considered inconsequential to sport fish enumerations due to the absence of a fright response (to the camcorder presence). Optimal video quality resulted on cold, cloudy days in calm portions of stream pools with little instream debris. The focal distance which the camcorder was capable of was approximately 5.5 m in open-water observations. This distance was sufficient to assess relative fish use of open-water artificial and natural pools in the Crowsnest River.

Collecting video observations in open-water in pools can be limited by the stream character. For example, pools with extensive (> 2 m) sand/silt bars along the stream margin are difficult to film

by extending the pole from shore. Wading in to access the pool results in poor visibility because of disturbed sediment. It is also difficult to film the entire area of a large pool undisturbed, if it is not possible to walk along both sides of the river bank.

The likelihood of diurnal concealment behavior in winter coupled with the lack of juvenile salmonids observed during this investigation indicates that, without further modifications, underwater video surveillance may not be an effective technique to sample juvenile salmonids in winter.

## 7.3 Appropriateness of Methodology to Assess Effectiveness of V-Weir artificial Habitat Structures in an Ice-Covered River

Underwater video observation, as a technique to assess trout and mountain whitefish use of artificial and natural high quality pools, has numerous practical applications in ice-covered river sampling. Filming through several ice holes over each pool enables the camcorder to record species composition, relative abundance, behavior and habitat-use information of fish present in the pool. Successful collection of the above mentioned data in ice-covered artificial and natural pools is possible in part because the cold-water conditions. These environmental factors cause salmonid metabolism to slow, reduced activity levels and a preference for deep, low velocity pools (Baltz et al.1991; Brunnell et al. 1998; Chisholm et al.1987; Cunjak 1988; Cunjak and Power 1986; Heggenes et al. 1993; Jakober 1995; Jakober et al.1998). These physiological and behavioral changes in winter increase the likelihood of capturing fish with a stationary filming device. Enumeration and positive identification of fish observed is dependent on the distance from the camcorder, fish activity and water visibility. Due to stationary nature of the observation technique and limited filming area, underwater video observation records the relative abundance, but is not functional for population or density estimates.

Fright responses to the presence of the camcorder and light were rare. An aversion was observed only when the housing was moved into close proximity with resting individuals. In a few cases,

fish exhibited a positive phototactic response. This reaction was problematic in that it complicated observation results. For example, when collecting observations in a pool. A trout swims toward the camera when filming through hole A, and another similar size trout swims by the camera in hole C. Positive determination that the fish observed in holes A and C are the same or different individuals is difficult.

The exterior mounted light was beneficial in other ways. It's artificial illumination expanded the focal distance, allowed viewing into dark crevices of rock and organic debris, and increased the detail of information collected.

Similar to open-water results, the focal capability of the camcorder was influenced by several factors under ice. On chinook days (air temperature > 0° C), elevated run-off conditions increased the water turbidity. A warmer than average winter led to a considerable reduction in visibility in the current study, resulting in 30 % identification difficulties; high turbidity levels reduced the ability to clearly identify fish species. Cloud cover increased the visibility by reducing the sun rays reflecting off instream particles through the ice. Instream debris and turbulence also decreased the focal distance. The potential of salmonids utilizing these instream features as cover may also decrease the likelihood of fish detection. However, since fright responses were uncommon, it is unlikely that the quality of observation results was greatly reduced. Thus, optimal video quality resulted on cold, cloudy days in calm portions of stream pools with little instream debris. Accounting for the factors which influence visibility, the maximum under- ice focal distance was approximately 4.5 m. With several filming holes and

consideration of technique limitations in high turbidity, this field of view is sufficient to assess relative fish use of ice-covered artificial and natural pools in the Crowsnest River.

This technique does not involve any direct contact with fish, thus, there is little possibility of injury or stress. The unobtrusive nature of this technique is beneficial when dealing with an important river like the Crowsnest River. The sport fishery in this river is not only ecologically valuable, but vital for the recreational opportunities it provides. Limiting fish injury or stress avoids the potential of impacting the population of "catchable size" sport fish and protects "species of concern" such as bull trout.

Several problems associated with the extreme environmental conditions of winter were encountered, but most were possible to adapt to or overcome. A couple of difficulties were directly related to water freezing immediately upon bringing the housing out of the water. For example, a wind chill of - 20°C resulted in housing control seizure and development of a layer of ice over the housing lens. These conditions caused operation difficulties and blurred video results. The situation was remedied with a modest amount of alcohol applied with a mist bottle.

In addition to the logistical difficulties which are unavoidable in winter, there are hazards which can make this work uncomfortable and dangerous. The risk of hypothermia and falling though the river ice are ever-present. Due to frequent chinook winds during sampling periods, this study was particularly at risk from the latter. Precautions to deal with these risks involved developing a risk management plan which included using a belay system, wearing life jackets, preparation for

and awareness of hypothermia, and ensuring that all field personnel are aware of the emergency equipment on hand and the appropriate emergency response.

Ice penetration proved to be challenging. The hole dimensions required for the housing to pass freely into flowing water was approximately 60 cm x 40 cm. Ice thickness encountered measured up to 46 cm, thus, efficient methods to open and maintain the hole were vital. The hand auger proved to be inappropriate for the ice conditions experienced in this study. High levels of sediment throughout the ice layers posed difficulties for the hand auger, resulting in almost immediate blade dulling. In January, the entire layer of river ice dropped and up to 40 cm of water flowed over the ice surface. This blanket of flowing water immobilized the hand auger. Another method of ice penetration tested was the gasoline-powered chainsaw. Success with this equipment was limited. The last method attempted was a 20.3 centimeter (8 inch) industrial strength gasoline-powered auger. Generating rapid penetration of ice layers with minimal effort, this technique was the most efficient. This equipment was essential to carrying out underwater video sampling through river ice.

## 7.4 Fisheries Management

Long term monitoring is essential to effectively evaluate artificial structure success or failure. To date, there are very few evaluations of artificial pools which have been long term, (i.e., Hunt 1971; Riley and Fausch 1995; White 1975) and no long term studies which have examined salmonid occupation of artificial pools during low flow winter periods. The insufficiency of monitoring programs is often linked to budget constraints, design flaws, lack of comparable controls, an inexperienced management team and a short term time frame (Noss and Cooperrider 1994, Reeves et al. 1991).

Underwater video surveillance monitoring of V-weir pools in the Crowsnest River should be continued for several reasons. To begin with, the mild winter conditions which dominated this study did not allow exploration of V-weir effectiveness during periods of extensive subsurface ice development. Repeated monitoring over several winters would increase the validity of the results of this study. Considering the congregations of adult sport fish documented in this study, continued winter monitoring could also determine whether adult sport fish return to the same overwintering habitat year after year and whether they remain in one pool throughout the winter. Finally, further monitoring would clarify whether there are differences in winter habitat-use between mountain whitefish and trout.

In addition to a need for continued winter monitoring, alteration of the research design may be

warranted. The observations collected in this investigation showed inconsistent pool use and greater variation between individual sites in each study area than variation between V-weir and control sites. Previous OMRD fisheries evaluations, which have compared population estimates between artificial and control sites, have also been plagued with inconsistencies in biological performance within and between treatment and control sites (R. L. and L Environmental Services Ltd. 1993; 1997). As a result of these inconsistencies, a control versus treatment study design may be inappropriate for the evaluation of fisheries management programs. The control versus treatment approach may overlook characteristics of an individual high-use site and fail to define the relative importance all relevant environmental variables affecting fish selection of overwintering pools. A shift to a Multivariate approach, such as RSF, may be a more comprehensive, ecologically-based framework to assess the relative importance of all environmental parameters influencing habitat selection. From a broader management perspective, RSF fosters a basic understanding of the combination of biotic and abiotic factors which influence the distribution and abundance of populations (Boyce and MacDonald 1999).

## 7.5 Recommendations

Recommendations resulting from this study are directed at the OMRD Fisheries Mitigation Program, underwater video investigations and fisheries management in general.

### 7.5.1 OMRD Fisheries Mitigation Program

A. There is a need for long term monitoring of artificially created deep-water habitat in the Crowsnest River to assess structure effectiveness in winter. Results from a small number of V-weirs, in one sampling season, cannot effectively evaluate overall structure success or failure. Further underwater video surveillance studies, incorporating Resource Selection Probability Functions, may more precisely define the relative importance of high-use site characteristics, assess pool fidelity, describe specific characteristics required to attract and hold sport fish and clarify whether there are differences in habitat selection between trout and mountain whitefish. Continued winter monitoring may also define the number of seasons and sample sites required to effectively assess structure performance.

B. Due to the mild winter conditions which characterized this study, the effects of subsurface ice development on artificial habitat effectiveness could not be evaluated. Continuation of data collection for RSF analysis would evaluate the influence of extreme subsurface ice development on winter habitat selection.

C. There is a need for nocturnal evaluation of artificial habitat structures to assess overwintering habitat for juvenile salmonids. The low number of juveniles observed in this investigation compared to previous studies, coupled with the likelihood of diurnal concealment behavior in winter, indicates that the number of juveniles utilizing V-weirs in winter has potentially been underestimated. Future winter monitoring should include nocturnal sampling to effectively assess winter habitat use by juvenile sport fish. The utility of underwater video surveillance to accomplish this goal should be investigated.

### 7.5.2 Underwater Video

A. Further experimentation to assess the utility and effectiveness of underwater video in winter should be conducted. Comparing camcorder results with similar open-water snorkeling observations may further define the capabilities and weaknesses of this technique.

B. The strength of underwater video observation may be improved if used in conjunction with other technologies. For instance, the addition of radiotelemetry studies could determine movement patterns to answer the question of whether these structures are increasing the stream's carrying capacity or simply causing movement from pool to pool. The partnership of underwater observation (snorkel/scuba) and telemetry has been successfully used in previous ice-covered winter studies to collect information on micro- and macro-habitat use and movement (Emmett and Convey 1990; Jakober 1995; Jakober

et al. 1998).

C. Modification and experimentation with underwater video equipment could improve the quality of video results. Future ice-covered studies could experiment with the number and position of lights (e.g., placement through another ice hole, variation in filming depths, alteration of light angle, several lights at different locations). Other possibilities not tested in this research are polarized lenses and light filters, which may increase the video quality. Exploration in these areas may also lead to improvements in the quality of nocturnal observations.

D. The inability to observe video while filming decreased the potential quality of results. This problem was evident in both the open-water and ice-covered portions of this research. Connection of a monitor to an underwater video / housing has been successfully used to survey salmonid redds and spawning habitat in a large ice-free river (Groves and Garcia 1998). This capability could improve fish quantification and identification in future research projects.

E. The extension device used in this research could be lengthened to accommodate deeper and/or wider river studies. The 2.03 m (ice-covered) and 3.11 m (open-water) poles tested in this study were sufficiently long and functioned well. This was the case because the Crowsnest River is relatively small; the maximum channel width sampled was 15.8 m (open-water) and the maximum confirmed depth was 1.63 m (ice-covered).

The maximum functional extension would be approximately 1.5 m. This extension would require greater reliance on the upstream rope for leverage and a strong, agile camera operator. Testing with a 1.3 cm and 2.5 cm pole widths in this research indicate that a 1.9 cm (0.75 inch) diameter would likely be the optimal pole size, possessing both strength and relative light-weight.

F. Design modifications of the open-water pole mechanism could also be explored to increase it's maneuverability and alter the weight of the camera. For example, use of a waist harness and a front pole pocket (similar to a flag carrier) may be adaptable.

### 7.5.3 General Fisheries Management

A. Fisheries management plans and objectives must be based in a thorough understanding of critical habitat requirements throughout the year. There is a need for more research to define critical habitat requirements of salmonids throughout the year, especially in winter. Information pertaining to mountain whitefish is particularly sparse. Increased research efforts in winter would improve our understanding of critical overwintering habitat needs and inform future fisheries conservation and restoration efforts.

B. As opposed to the commonly used control versus treatment monitoring study design, an RSF analysis may more effectively define the relative importance of all environmental parameters influencing resource selection. The definition of more precise environmental

characteristics of high-use habitat, may inform future guidelines for the construction of high quality artificial habitat.

C. Research effort should be directed towards assessment of the nature and degree of subsurface ice development associated with instream structures. Jakober (1995) suggested that comprehension of stream specific subsurface ice conditions is vital to predict winter habitat requirements of trout. Assessment of the ice conditions which sport fish may endure in the Crowsnest River is necessary to define and evaluate effective overwintering habitat. On a broader scale, development of modeling to predict instream ice conditions would be an invaluable tool. If possible, such a tool should be designed to assess a variety of individual stream characteristics (riparian character, channel shape, hydrology, etc.), as well as, regional factors (climate, basin character, elevation, etc.).

D. Development of alternative methods to effectively sample streams under ice is an important research need. Underwater video observation is useful for sampling limited areas within small river systems, but its utility is restricted for large scale surveys of small and large ice-covered rivers.

E. With the growing Canadian population and rising human demands, the popularity of in-stream habitat alteration may continue to rise. The 1986 DFO stipulation of "no net loss" of productive fish habitat ensures the continuance of stream alteration activities in Canada. Therefore, it is essential that fisheries compensation and restoration programs be

physically and biologically evaluated.

F. Successes and failures in fisheries management should be meticulously documented. In addition to recording the general evaluation results of restoration and compensation monitoring programs, complete documentation of all associated activities and definitions is essential. For example, physical definitions and evaluation criteria of control habitat, structure maintenance history and baseline habitat definitions, must be recorded and available for review. Efforts could also be directed at some degree of standardization of definitions and evaluation criteria of management activities.

G. Increased availability of published and unpublished in-stream structure evaluations is critical. Attempts have been made to compile stream mitigation literature in bibliographies (e.g., Duff and Banks 1988) and evaluation reviews (e.g., Hartman and Miles 1995; White 1996). Development of a comprehensive database which organizes and categorizes all existing literature would increase the likelihood of access to past habitat alterations. In order to actually view the documents, a fee-based internet access system may be required. Without these essential steps, it is not possible for fisheries managers to learn from past successes or failures.

H. There is a need for the publication of guideline documents for effective construction and maintenance of instream habitat alteration (e.g., Lowe 1996). To be useful, instruction documents must outline specific guidelines for a variety of stream conditions, as well as,

outline river characteristics which are prone to structure failure. Structures which are successful in some streams may not function well in streams with different climate, geography, stream character or fish species (Hartman and Miles 1995; Allan and Lowe 1997).

I. To minimize damage inflicted on aquatic systems, a higher priority must be placed on watershed protection in fisheries management. Riparian protection should be at the forefront of these efforts. When conservation goals are not attainable, compensation and restoration efforts should focus on the rehabilitation of healthy riparian communities and the natural fluvial processes. This "renaturalization" approach may be more successful in the long term reestablishment and maintenance of high quality fish habitat (Pattenden et al 1998).

# 8.0 SUMMARY

Assessment of the effectiveness of V-weirs for over-wintering salmonids is only one of the challenges in evaluating the success or failure of fish habitat compensation program. The analysis is complicated by the myriad of factors within the watershed which may influence fish population size and structure at various spatial and temporal scales, such as; riparian deforestation, instream habitat degradation, predation, movement, river productivity, reproductive success; overwintering mortality; natural population cycles, angling pressure and other population limiting factors (Cunjak 1996; Gowan and Fausch 1996; Hunt 1971; 1976; Riley and Fausch 1995; White 1996 ).

Some V-weir pools provided overwintering habitat for adult salmonids in upper and lower Crowsnest River. In each of the open-water study areas, pool use was inconsistent and variation was greater between individual sites than between V-weir and control sites. There were significant differences in the median number of salmonids enumerated in both open-water study areas. In the Blairmore open-water study area, significantly more salmonids were enumerated in one V-weir than any other site. Conversely, significantly fewer were observed in the other Blairmore V-weir compared to than any other site. In the Coleman open-water study area, one control pool contained significantly more fish than any other pool. In the ice-covered study reach, there was no significant difference in the median number of sport fish observed in any of the pools. Conclusions of this investigation were limited due to small sample size, single season of data collection and inconsistent use of V-weir pools.

It is possible that a control versus treatment study design is inappropriate for the evaluation of fisheries management programs. This commonly used comparison may overlook characteristics of high-use habitat which influence pool selection. Alternatively, Resource Selection Probability Functions is an ecologically-based analysis which may define the relative importance all relevant environmental variables affecting fish selection of overwintering pools. Further winter monitoring using underwater video surveillance and RSF may clarify pool fidelity between and within winters, evaluate sport fish use of V-weirs as overwintering habitat and define winter habitat selection variables.

Underwater video observation was useful in determining whether adult salmonids use V-weirs during winter. With an understanding of technique limitations under elevated turbidity conditions, the method is appropriate to sample pools in shallow, ice-covered and open-water river systems in winter. The utility of this sampling method is greater in areas which are subject to consistently cold winter temperatures. There are few effective alternatives to assess the success of fisheries mitigation structures under river ice. Use of underwater video equipment should be considered an affordable option which takes little time and personnel to operate. The findings of this methodological exploration are preliminary and should be expanded by long term assessment of the capabilities of underwater video observation.

Due to the inherent complexity of natural communities and processes, creating effective artificial habitat is no easy task. Future effort and consideration should be directed towards a shift in the focus of fisheries management, from fish habitat manipulation and watershed restoration to

watershed protection and prevention of habitat degradation. Watershed management efforts, such as maintaining healthy riparian forests and natural fluvial processes, are essential to healthy river systems. This approach may aid in the long term maintenance of natural processes and native species diversity, and reduce the need for habitat compensation and restoration in the future.

# LITERATURE CITED


Allan, J.H. and S. Lowe. 1997. *Rehabilitating mainstem holding and rearing habitat.* Chapter 11 in Fish Habitat Rehabilitation Procedures. Edited by P.A. Slaney and D. Zaldokas.. **Watershed Restoration Technical Circular No. 9**. Ministry of Environment, Lands and Parks, Vancouver, BC.

Alaska Department of Fish and Game. 1976. *De-watering effects of industrial development on Arctic fish stocks*: 50-55. **A special report to the Alaska Board of Fisheries, Sport Fish Division, Alaska Department of Fish and Game.**

Ambrose, H.W. III and K.P. Ambrose. 1987. **A handbook of biological investigation**. 4th edition. Hunter Textbooks Inc. Knoxville, Tennessee.

Ash G.R., L. Hildebrand and J. O'Neil 1987. **Oldman River Dam project, fisheries mitigation pre-engineering studies - Crowsnest River fish population studies, data summary**. Prepared for Alberta Environment, Planning Division. November 30, 1987. Prepared by R.L.& L. Environmental Services Ltd. Edmonton, Alberta.

Baltz, D. M., B. Vondracek, L.R. Brown and P.B. Moyle. 1991. *Seasonal changes in microhabitat selection by rainbow trout in a small stream.* **Transactions of the American Fisheries Society** 120: 166-176.

Berg, N.H. 1994. *Ice in stream pools in California's Sierra Nevada: spatial and temporal variability and reduction in trout habitat availability.* **North American Journal of Fisheries Management** 14:372-384.

Berry, D. K. 1997. *Sportfishing in Alberta 1995.* In **The Fifth survey of recreational fishing in Canada, summary report.** Alberta Environment. Fisheries and Wildlife Management Division. Edmonton, Alberta.

Boyce, M.S. and L.L. McDonald. 1999. *Relating populations to habitat using resource selection functions.* **Trends in Ecology and Evolution** 14(7): 268-272. July 1999.

Brewin, M.K. et al. unpublished. **Review of the winter ecology of non-anadromous salmonids**. Trout Unlimited Canada, Calgary, Alberta.

Brown, R.S. 1994. **Spawning and overwintering movements and Habitat Use by cutthroat trout (*Oncorhynchus clarki*) in the Ram River, Alberta**. M.Sc. Thesis, University of Alberta, Edmonton, Alberta.

Brown, R.S., S.S. Stanislawski and W.C. Mackay. 1993. *Effects of frazil ice on fish.* In

**Proceedings of Environmental Aspects of River Ice Workshop.** Edited by Prowse, T.D. and N.C. Gridley. National Hydrology Research Institute, Sci. Rep.#5. Saskatoon, Saskatchewan.

Brown, R.S. and W. C. Mackay. 1995. *Fall and winter movements of and habitat use by cutthroat trout in the Ram River, Alberta.* **Transactions of the American Fisheries Society** 124: 873-885.

Brunnell, D.B.jr, J.J. Isely, K.H. Burrel and D.H. Van Lear. 1998. *Diel movement of brown trout in a southern Appalachian river.* **Transactions of the American Fisheries Society** 127: 630-636.

Bustard, D. R. and D.W. Narver. 1975. *Aspects of winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri).* **Journal of the Fisheries Research Board of Canada** 32: 667-680.

Calkins, D. J.; Gatto, L. W., and Brockett, B. E. 1989. *Field assessment of fisheries habitat enhancement structures in Bingo Brook, Vermont, after the spring 1989 ice run.*.In **Proceedings of the XXII IAHR Congress**. Ottawa, ON.

Campbell, R. F. and J.H. Neuner. 1985. **Development of seasonal habitat preference criteria for rainbow trout (Salmo gairdneri) in western Washington Cascade Mountain streams.** Bellevue, Washington: Puget Sound Power and Light Company Volume II (Draft).

Chapman, D.W. 1966. *Food and space as regulators of salmonid populations in streams.* **The American Naturalist** 100(913): 345-357.

Chapman, D. W. and T.C. Bjornn. 1969. *Distribution of salmonids in streams, with special reference to food and feeding.* Fisheries Symposium on Salmon and Trout in Streams. In **H. R. MacMillan Lectures**. Institute of Fisheries, University of British Columbia.153-176. Vancouver, B. C.

Chisholm, I. M. W.A. Hubert, and T.A. Wesche. 1987. *Winter stream conditions and use of habitat by brook trout in high-elevation Wyoming streams.* **Transactions of the American Fisheries Society** 116: 176-184.

Contor, C. R. 1989. **Diurnal and nocturnal winter habitat utilization by juvenile rainbow trout in the Henry's Fork of the Snake River, Idaho.** M.Sc. Thesis. Idaho State University, Pocatello, Idaho.

Contor, C.R. and J.S. Griffith. 1995. *Nocturnal emergence of juvenile rainbow trout from winter concealment relative to light intensity.* **Hydrobiologia** 299: 179-183.

Cummins, K.W. 1962. *An evaluation of some techniques for the collection and analysis of benthic samples with some emphasis on lotic waters.* **American Midland Naturalist** 67: 477-504.

Cunjak. R.A. 1988. *Physiological consequences of overwintering in streams: the cost of acclimitization.* **Canadian Journal of Fisheries and Aquatic Sciences.** 45(443-452).

Cunjak, R.A. 1996. *Winter habitat of selected stream fishes and potential impacts from land-use activity.* **Canadian Journal of Fisheries and Aquatic. Science** 53(Suppl. 1): 267-282.

Cunjak, R.A. and G. Power.1986. *Winter habitat utilization by stream resident brook trout (Salvilinus fontinalis) and brown trout (Salmo trutta).* **Canadian Journal of Fisheries and Aquatic Sciences.** 43: 1970-1981.

Cunjak, R.A. and G. Power. 1987. *The feeding and energetics of stream-resident trout in winter.* **Journal of Fish Biology** 31: 493-511.

Davis C. L., Carl, L. M. and D. O. Evans. 1997. *Use of a remotely operated vehicle to study habitat and population density of juvenile lake trout.* **Transactions of the American Fisheries Society** 126: 871-875.

Dolloff, A., Kershner, J and R. Thurow. 1996. *Underwater surveillance.* In **Fisheries Techniques.** 2nd edition. Edited by B.R.Murphy and D.W. Willis. American Fisheries Society, Southern Printing Company.

Dominion Ecological Consulting Ltd.1988. **A strategy for fisheries mtigation in the Oldman River Basin, volume I, upstream component.** Prepared for Alberta Environment Planning Division and Alberta Forestry, Lands and Wildlife, Fish and Wildlife Division. April 1988. Edmonton, Alberta.

Doppelt, B., Scurlock, M., Frissell, C. and J. Karr. 1993. **Entering the Watershed: A New Approach To Save America's River Ecosystems.** Island Press, Washington, D.C.

Duff, D.A. and N. Banks 1988. **Indexed bibliography on stream improvement.** USDA Forest Service, Intermountain Region, Logan, Utah.

Emmett, B. 1989. **Overwintering of juvenile chinook salmon in the Nechako River, 1988-89 studies. 1989.** Prepared by Archipelago Marine Research Ltd. Victoria, British Columbia for the Salmonid Habitat Division of Department of Fisheries and Oceans. Vancouver, British Columbia.

Emmett, B. and Convey, L. 1990. **Overwintering of juvenile chinook salmon in the Nechako River, 1989-90 studies.** Prepared by Archipelago Marine Research Ltd. Victoria, British

Columbia for the Salmonid Habitat Division of Department of Fisheries and Oceans. Vancouver, British Columbia.

Emmett, B.; Levings, C. D.; Kerfoot, P., and Lauzier, R. B. 1992. *A prototype submersible electrofisher: design and user manual.* **Canadian Manuscript Report of Fisheries Aquatic Science. No. 2143.**

Environment Canada. Unpublished Data. *Flow measurement at the Frank flow station.* **Water Survey of Canada**

Fitch, L.A. 1978. **A report on the biological inventories of 11 Streams in the Crowsnest drainage district of Alberta** ARPW, Fish and Wildlife Division, Lethbridge, Alberta.

Fitch, L.A. 1997. *Bull trout in southwestern Alberta: notes on historical and current distribution.* In **Friends of the Bull Trout Conference Proceedings**. Edited by Mackay, W.C., M.K. Brewin and M Monita 147-160. Calgary, AB, 5-7 May 1994. Bull Trout Task Force, Alberta.

Giger, R.D. 1973. *Stream flow requirements of salmonids.* **Anadromous fish project**. Job Final report, Project AFS 62-1. Oregon Wildlife Corporation.

Golder Associates. 1999. **Oldman River bull trout radiotelemetry studies 1993 - 1996, Draft.** Prepared for Alberta Public Works, Supply and Service. February 1995. Edmonton, Alberta.

Gosse, J. C. 1982. **Microhabitat of rainbow and cutthroat trout in the Green River below Flaming Gorge Dam.** Utah Division of Wildlife Resources, Salt Lake City.

Gowan, C. and K.D Fausch. 1996. *Long-term demographic responses of trout populations to habitat manipulation in six Colorado streams.* **Ecological Applications** 6(3): 931-946.

Gregory, S.V., F.J. Swanson, W.A. McKee and K.W. Cummins. 1991. *An ecosystem perspective of riparian zones: focus on links between land and water.* **Bioscience** 41(8): 540-551.

Griffith J.S. and R.W. Smith. 1995. *Failure of submersed macrophytes to provide cover for rainbow trout throughout their first winter in the Henry Forks of the Snake River, Idaho.* **North American Journal of Fisheries Management** 15: 42-48.

Groves P.A. and A.P. Garcia. 1998. *Two carriers used to suspend an underwater video camera from a boat.* **North American Journal of Fisheries Management** 18:1004-1007.

Grumbine, R.E. 1997. *Reflections on "What is ecosystem management?".* **Conservation Biology** 11(1): 41-47.

Hartman, G.F. 1963. *Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring.* **Journal of the Fisheries Research Board of Canada.** 20:769-788.

Hartman G.F. and M. Miles, 1995. **Evaluation of fish habitat improvement projects in BC and recommendations on the developments of guidelines for future work.** Prepared for Fisheries Branch, B.C. Ministry of Environment, Lands and Parks. January 1995. Victoria, British Columbia.

Hauck, F.R. 1949. *Some harmful effects of the electric shocker on large rainbow trout.* **Transactions of the North American Fisheries Society** 77: 61-64.

Heggenes J. and R. Borgstrom. 1988. *Effect of mink Mustala vison Schreber, predation on cohorts of juvenile Atlantic salmon, Salmo salar L and brown trout S.trutta L. in three small streams.* **Journal of Fish Biology** 33:885-894.

Heggenes, J, O.M. Krog, O.R. Lindas, J.G. Dokk and T. Bremnes. 1993. *Homeostatic behavioral responses in a changing environment: brown trout (Salmo trutta) become nocturnal during winter.* **Journal of Animal Ecology** 62: 295-308.

Heggenes, J., T.G. Northcote and A Peter. 1991. *Seasonal habitat selection and preferences by cutthroat trout (Oncorhynchus mykiss) in a small, coastal stream.* **Canadian Journal of fisheries and Aquatic Sciences** 48:1364-1370.

Heifetz, J.; Murphy, M. L., and Koski, K. V. 1986. *Effects of logging on winter habitat of juvenile salmonids in Alaskan streams.* **North American Journal of Fisheries Management** 6: 52-58.

Hill, T.D., S.T. Lynott, S.D. Bryan and W.G. Duffy. 1996. *An efficient method for setting gill nets under ice.* **North American Journal of Fisheries Management** 16: 960-962.

Hunt, R.L. 1971. *Responses of a brook trout population to habitat development in Lawrence Creek.* **Technical bulletin 48.** Department of Natural Resources, Madison, Wisconsin.

Hunt R.L. 1976. *A long-term evaluation of trout habitat development and its relation to improving management-related research.* **Transactions of the American Fisheries Society** 105:361-364.

Jakober, M.J. 1995. **Autumn and winter movements and habitat use of resident bull trout and westslope cutthroat trout in Montana.** M. Sc. Thesis, Montana State University, Bozeman, Montana.

Jakober, M.J., T.E. McMahon, T.F. Thurow and C.G. Clancy. 1998. *Role of stream ice on fall*

*and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams.* **Transactions of the American Fisheries Society** 127: 223-235.

James P.W., Leon S.C. , Zale A.V. and O.E. Maughan. 1987. *Diver-operated electrofishing device.* **North American Journal of Fisheries Management** 7: 597-598.

Kondolf, G,M. And E.R. Micheli. 1995. *Evaluating stream restoration projects.* **Environmental Management** 19(1):1-15.

Long, J. 1993. **How to rock climb!** Chockstone Press, Evergreen, Colorado.

Lowe S. 1996. **Fish habitat enhancement designs: typical structures.** Water Resources Management Services, Technical Services and Monitoring division, River Engineering Branch. Alberta Environmental Protection. January 1996. Edmonton, Alberta.

Maciolek, J. A. and P.R. Needham. 1952. *Ecological effects of winter conditions on trout and trout foods in Convict Creek, California, 1951.* **Transactions of the American Fisheries Society** 81: 202-217.

Mace, R.D., Waller, J.S., Manley, T.L., Lyon, L.T. and H. Zuuring. 1996. *Relationships among grizzly bears, roads and habitat in the Swan Mountains, Montana.* **Journal of Applied Ecology** 33(6): 1395-1404.

Manly, B., L. McDonald and D. Thomas. 1993. **Resource selection by animals.** Chapman and Hall. London, England.

Marcus M.D., L.E. Noel and M.K. Young. 1990. *Rating salmonid research needs in the central rocky mountains.* **Fisheries.** 15(3):14-18.

McMichael, G.A., Fritts, A.L. and T.N. Pearsons. 1998. *Electrofishing injury to stream salmonids; injury assessment at the sample, reach and stream scales.* **North American Journal of Fisheries Management** 18: 894-904.

Meyer, K.A. and J.S. Griffith. 1997. *Effects of cobble-boulder substrate configuration on winter residency of juvenile rainbow trout.* **North American Journal of Fisheries Management** 17(1): 77-84.

Millspaugh J.J., J.R. Skulski, B.J. Kernahan, K.J. Raedeke, G.C. Brundige and A.B. Cooper. 1998. *Some comments on spatial independence in studies of resource selection.* **Wildlife Society Bulletin** 26(2):232-236.

Minns, C.K., J.R.M. Kelso and R.H. Randall. 1996. *Detecting the response of fish to habitat alterations in freshwater ecosystems.* **Canadian Journal of fisheries and Aquatic**

**Sciences** 53(suppl. 1): 403-414.

Moyle, P.B. and J.J. Cech jr. 1988. **Fishes: an introduction to ichthyology**. 2nd edition. Prentice Hall, Englewood Cliffs, New Jersey.

Noss. R.F. and A.Y. Cooperrider. 1994. **Saving nature's legacy: protecting and restoring biodiversity. Island Press, Washington, DC.**

Page, L.M. and B.M. Burr. 1991. **A field guide to freshwater fishes. North American north of Mexico.** The Peterson Field Guide Series. Houghton Mifflin Company, Boston, New York.

Petts, G.E. 1984. **Impounded rivers: perspectives for ecological management**. Wiley-Interscience Publication. Chichester, England.

Platts, W.S. and R.L. Nelson. 1988. *Fluctuations in trout populations and their implications for land-use evaluation.* **North American Journal of Fisheries Management** 8:333-345.

Prowse T.D. 1993. *Environmental significance of river ice to stream flow in cold regions.* **Freshwater Biology** 32: 241-259.

Prowse, T.D. and N.C Gridley. 1993. **Environmental aspects of river ice workshop.** Editors. National Hydrology Research Institute, Sci. Rep.#5. Saskatoon, Saskatchewan.

Reeves G.H., Hall J.D., Roelofs T.D., Hickman T.L. and C.O. Baker 1991. *Rehabilitating and modifying stream habitats.* In **American Fisheries Society Symposium: Proceedings, Volume 19(special publication)** pp 519-558.

Reynolds, J.B. 1996. *Electrofishing.* In **Fisheries Techniques.** 2nd edition. Edited by B.R.Murphy and D.W. Willis. American Fisheries Society, Southern Printing Company..

Riehle, M. D. and Griffith, J. S. 1993. *Changes in habitat utilization and feeding chronology of juvenile rainbow trout at the onset of winter in Silver Creek, Idaho.* **Canadian Journal of Fisheries and Aquatic Sciences** 50: 2119-2128.

Riley, S.C. and K.D. Fausch. 1995. *Trout population response to habitat enhancement in six northern Colorado streams.* **Canadian Journal of fisheries and Aquatic Sciences** 52:34-53.

R.L. & L Environmental Services Limited. Unpublished. **Raw data collected by R.L. & L Environmental Services Limited in the Crowsnest River from 1992 to 1994.** Prepared for Alberta Public Works Supply and Services. Edmonton, Alberta.

R.L. & L. Environmental Services Limited. 1992. **Angler creel and opinion survey Crowsnest River, 1990.** Prepared for Alberta Public Works Supply and Services. November 1992. Edmonton, Alberta.

R.L. & L. Environmental Services Limited. 1993. **Fish population responses in Crowsnest River to OMRD mitigation program, 1987 - 1991 .** (draft report) Prepared for Alberta Public Works Supply and Services. May 1993. Edmonton, Alberta.

R.L. & L. Environmental Services Limited.1994. **Fisheries evaluation program - 1992 annual report- Crowsnest River.** Prepared for Alberta Public Works Supply and Services. November 1994. R.L. & L. Environmental Services Ltd. November 1994. Edmonton, Alberta.

R.L. & L. Environmental Services Limited. 1997. **Fisheries evaluation program, 1996 annual report, Crowsnest River.** Prepared for Alberta Public Works Supply and Services. May 1997. Edmonton, Alberta.

Schill, D.J. and K.F. Beland. 1995. *Electrofishing injury studies*. **Fisheries** 20(6): 28-29.

Schmidt, D.R. , Griffiths, W.B. and L.R. Martin. 1989. *Overwintering biology of anadromous fish in the Sagavanirktok River Delta, Alaska.* **Biological Papers of the University of Alaska.** 1989. 24: 55-74.

Scott W.B. and E.J. Crossman. 1973. **Freshwater fishes of Canada**. Fisheries Research Board of Canada. Bulletin 84. Minister of Supply and Services Canada, Ottawa, Ontario.

Sharber, N.G., Carothers, S.W., Sharber, J.P. de Vos, J.C. and D.A. House. 1994. *Reducing electrofishing-induced injury of rainbow trout.* **North American Journal of Fisheries Management** 14: 340-346.

Smith, R.L. 1986. **Elements of ecology**. 2nd edition. Harper and Row Publishers, New York.

Smith R.W. and J.S. Griffith. 1994. *Survival of rainbow trout during their first winter in the Henry Forks of the Snake River, Idaho.* **Transactions of the American Fisheries Society** 123: 747-756.

Smith, J. J. and Hiram, W. L. 1983. **Energetic factors influencing foraging tactics of juvenile steelhead trout, *Salmo gairdneri*.** Dr. W. Junk Publishers, The Hague, Netherlands. 173-180.

Sparks, R.E. 1995. *Need for ecosystem management of large rivers and their flood plains.* **Bioscience** 45(3): 168-182.

Strange, R.J., Schreck C.B and R.D. Ewing. 1978. *Cortisol concentrations in confined juvenile chinook salmon (Oncorhynchus tshawytscha).* **Transactions of the North American Fisheries Society** 107: 812-819.

Stassman, M. A. 1989. **The basic essentials of rock climbing.** ICS Books, Merriville, Indiana.

Stromberg J.C., Tiller, R. and B. Richter, 1996. *Effects of Groundwater Decline on Riparian Vegetation of Semi-Arid Regions: The San Pedro, Arizona.* **Ecological Applications** 6(1):113-131.

Swales, S, Lauzier, R.B. and C.D. Levings. 1986. *Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia.* **Canadian Journal of Zoology** 64: 1506-1514.

Underwood, A.J. 1991. *Beyond BACI: experimental designs for detecting human environmental impacts on temporal variations of natural populations.* **Australian Journal of Marine and Freshwater Research**. 42: 569-587.

U.S. department of Agriculture. 1985. *Fish habitat enhancement handbook.* Forest Service Southern Region. **Technical Publication R8-TP7**. January 1985.

Van Eimeren, P. 1996. **Westslope cutthroat trout *Oncorhynchus clarki Lewsi.* Chapter 1 in Conservation and Assessment For Inland Cutthroat Trout: Distribution, Status and Habitat Management Implications.** U.S. Department of Agriculture, Forest Service. Northern, Rocky Mountain, Intermountain and Southwestern Regions. June 1996. p 1-9.

Walker, B. 1995. *Conserving biological diversity through ecosystem resilience.* **Conservation Biology** 9(4): 747-752.

Ward, J.V., and J.A. Stanford. 1989. *Riverine ecosystems; the influence of man on catchment dynamics and fish ecology.* in **Proceeding of the International Large River Symposium** (LARS). Edited by Douglas P. Dodge, Department of Fisheries and Oceans, Ottawa.

Wessels, N.K. and J.L. Hopson. 1988. **Biology**. Random House Inc., New York.

White, R.J. 1975. *Trout population responses to streamflow fluctuation and habitat management in Big Roche-a-Cri Creek, Wisconsin.* **Verb. Internat.Verein. Limnol.**19: 2469-2477.

White, R.J. 1996. *Growth and development of North American stream habitat management for fish.* **Canadian Journal of Fisheries and Aquatic Science** 53 (Supplemental 1): 342-363.

Winter, J. 1996. *Underwater biotelemetry.* in **Fisheries Techniques.** 2nd edition. Chapter 8. Edited by B.R. Murphy and D.W. Willis. 555-590.

Zarr, J.H. 1984. **Biostatistical Analysis.** 2nd edition. Prentice-Hall Inc. Englewood Cliffs, N.J.

# APPENDIX A

## Glossary

# Glossary

**Abiotic** - Non-living part of an environment, such as water, rock, light, elements, etc.

**Backwater area** - An area which is part of the wetted area of a stream, but is separated from the main channel.

**Biotic** - A living component of the environment, including fish, plants, insects and the like.

**Catchable-sized** - The terms 'legal-sized' and 'catchable-sized' are used interchangeably within this document. They refer to a sport fish measuring at least 254 mm.

**Electrofishing** - A fish sampling technique which involves sending an electric shock through the water. Fish stunned from the shock are collected in a net.

**Habitat Compensation** - Habitat compensation involves modifying existing habitat (not necessarily the area directly impacted), with the intention of enhancing habitat quality. In other words, in exchange for losses ensued in one area, there may be compensation in another. For the purposes of this document, the terms compensation and mitigation are used interchangeably.

**Habitat Mitigation** - Habitat mitigation involves modifying existing habitat (not necessarily the area directly impacted), with the intention of enhancing habitat quality. In other words, in exchange for losses ensued in one area, there may be compensation in another. For the purposes of this document, the terms compensation and mitigation are used interchangeably.

**Habitat Restoration** - The goal of habitat restoration is to reestablish the pre-disturbance structure and function through activities, such as, the rehabilitation of fish habitat or riparian forest.

**Homeostatic** - Maintenance of equilibrium within an environment.

**Inter and intra specific** - Between and within species.

**Legal-sized** - The terms 'legal-sized' and 'catchable-sized' are used interchangeably within this document. They refer to a sport fish measuring at least 254 mm.

**Lotic** - Referring to a flowing water body or stream.

**Mark-recapture** - A technique which involves capturing, tagging and recapturing individuals for the purposes of growth and / or population estimates.

**Native species** - A species which is naturally located in a particular area, native to the region.

**Population density** - The number of individuals within a population per unit area.

**Redd** - A nest of fish eggs.

**Salmonid** - Fish species categorized (by evolutionary) within the family Salmonidae, including salmon, trout and whitefish species.

**Stream order** - Terminology to describe stream size. Accordingly, a headwater stream which has no other streams flowing into it, is a first order stream. When two first order streams join, the resulting stream is a second order stream and so on.

**Stream transect** - A series of depth, velocity and substrate measurements collected across a stream cross-section. Measurements are generally collected every meter (or other defined equidistant measurement) across the stream, from the high water mark on each bank.

**Substrate** - A term which describes the stream bottom composition, such as bedrock, sand, boulder, etc.

**Turbidity** - The presence of instream particles which reduce the water clarity. The higher the turbidity, the shorter the under water observation distance

**Undercut bank** - A stream bank which has been eroded away so that a portion of the bank hangs over the stream.

The following references aided in the definition of glossary terms: Moyle and Cech 1988; R.L. & L Environmental Services Ltd. 1997; Smith 1986; Wessells and Hopson 1988.

# APPENDIX B

# OMRD Artificial Habitat Structures

# OMRD Artificial Habitat Structures

## B-1 Opposing Wing Deflectors

The purpose of these structures is to " provide a stable, high quality, self-maintaining feeding, resting and escape cover for adult trout consisting of depth, surface turbulence and instream cover. The habitat should be effective during all seasons and flow conditions, including overwintering periods. Rocks and tree cover in the run/pool will provide shelter from the current and predators and visual isolation from other fish. Rock clusters in the side pools and tail out of the run will provide feeding opportunities. The opposing wing deflectors are more aesthetically pleasing to fishermen, natural looking than groynes and can be used as an alternate design for a V-weir" (Lowe 1996, 15). The structure consists on a triangular revegetated spoil area bordered by rocks. The largest rocks are placed on the upstream side of the each wing deflector and the structure gradually tapers from the bank into the stream channel.

## B-2 Groynes

The purpose of groynes is "to deflect the main current in the stream to another location and/or provide economical bank protection. Feeding, resting and potential spawning areas may be located off the tips of the groynes" (Lowe 1996, 18). There are three central types of groynes:

a) Attracting groynes are rock clusters which are angled downstream at 45 ° from the stream bank. These are intended to deflect the flow to the middle half of the river. When several of these groynes are staggered on opposite banks and combined with an excavated run and rock clusters, they are intended to provide a "deep meandering channel pattern in a previously straight reach"(Lowe 1996, 18).

b) Repelling groynes are rock structures which are angled upstream at 30 ° from the stream bank. They are designed to deflect flow towards the opposite bank, thus bank protection is necessary where erosion is directed. Generally, this structure would be installed on an outside bank to redirect the current away from the naturally eroding bank. This measure protects the bank from extreme erosion, especially in the case of unstable banks and high flows.

b) Deflecting groynes are rock clusters which are constructed at a 90 ° angle with the stream bank. The positioning of this structure diverts stream flow away from the bank towards the stream center. When the structure protrudes close to fifty percent of stream width, bank armour is required on the opposite bank. This type of groyne is generally built on outside of a wide river bend, with the intention to constrict the reach width. Several deflecting groynes are often installed

consecutively (10 m apart) providing feeding habitat and a pool excavated directly out from each groyne .

## B-3 Excavated Fish Runs

The purpose of this mitigative measure is " to provide a section of deeper, fast moving flow for high quality feeding and resting habitat for adult trout. When combined with deflecting or attracting groynes and rock clusters, shallow riffles with little cover can be converted into resting, feeding and shelter areas"(Lowe, 1996, 20). The run is excavated in straight sections which are angled from side to side within the middle half of the river. These runs may be constructed amongst groynes and rock clusters changing a shallow, straight river section into a deep, meandering reach. Bank erosion, due to meandering flows, can result and may require protection. Excavated fish runs performed poorly in the OMRD Fisheries Mitigation program in that they filled with sediment, especially in flooding and high flow periods.

## B-4 Rock Clusters

These instream structures are intended " to provide sheltered feeding and resting habitat in relatively shallow riffle and run habitats. In deeper sections, during higher flow events, this habitat will support adult trout. Rock clusters will support juvenile and young-of-the-year life stages under a wide range of conditions. These structures will aided in trout winter survival also provide minor mid-stream current deflection and resting areas to aid in migration" (Lowe 1996, 16). Clusters of rocks vary in number from 2 to 5 and are positioned in the central 3/4 of the river channel. Rocks are placed in excavated holes. usually from 0.8 to 1.5 m apart, protruding not more than 0.3 m above the stream surface. Rock size varies with river size ranging from .02 m diameter in small creeks to 3.0 m in large rivers.

# APPENDIX C

## Open-Water Study Sites

## Open-Water Blairmore Sites

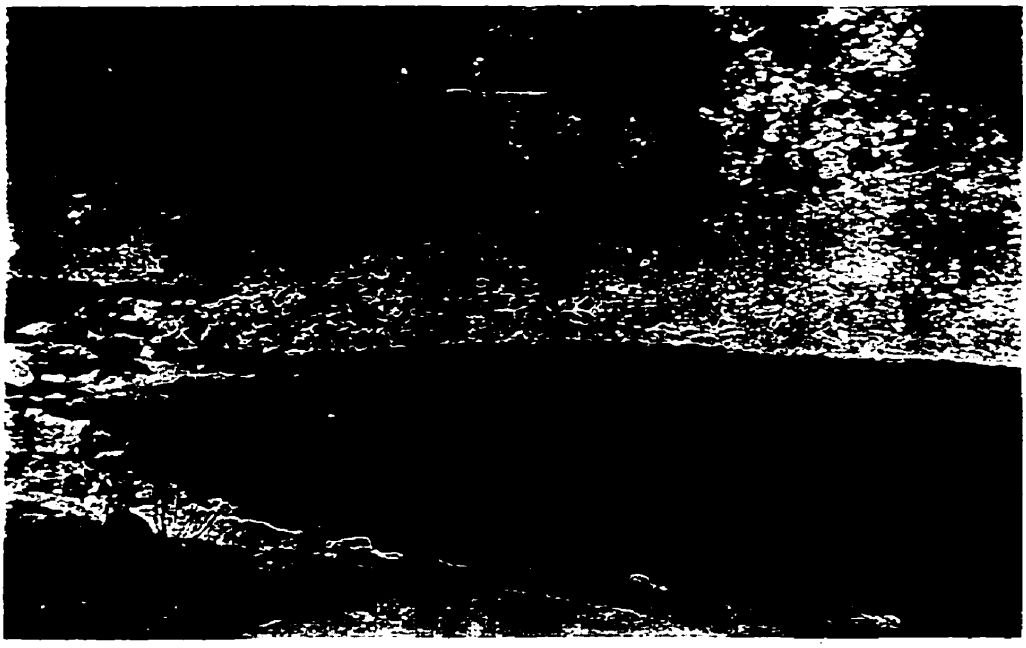

Figure C-1 V-weir Site Bv-17

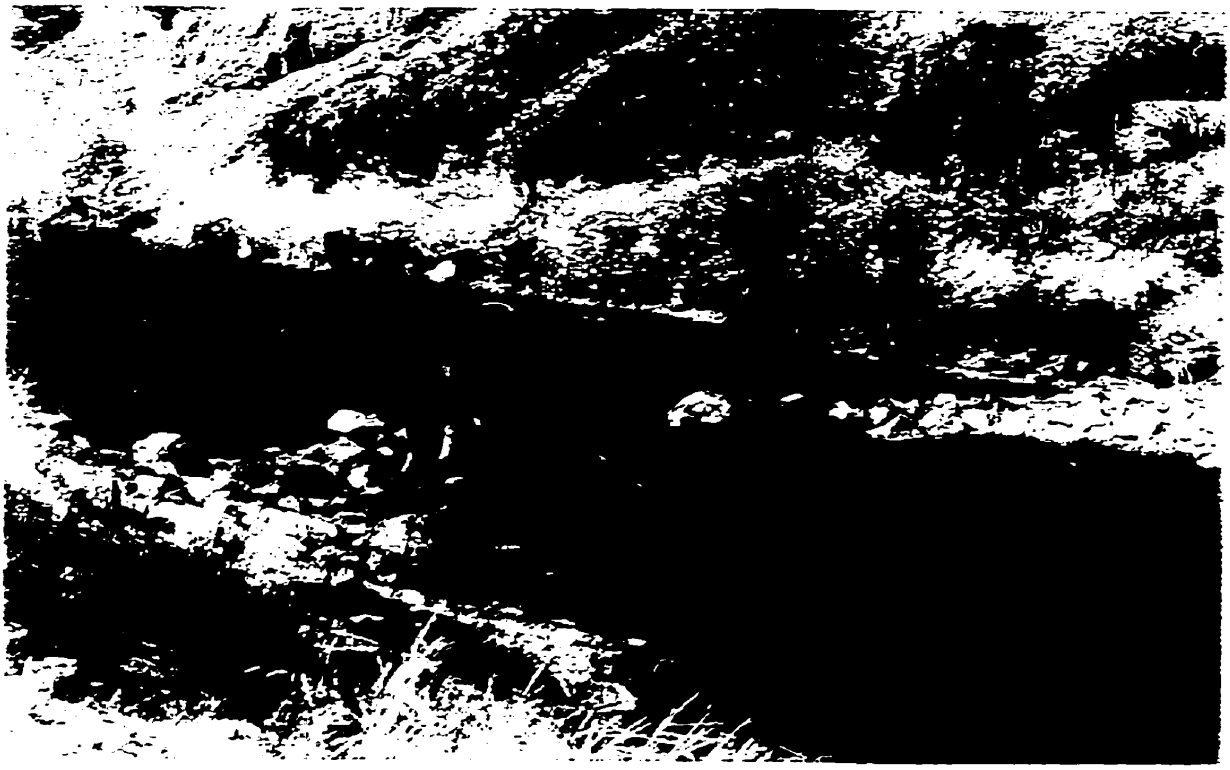

Figure C-2 V-weir Site Bv-N

Figure C-3 **Control Site Bc-83**

Figure C-4 **Control Site Bc-Z**

## Coleman Open-Water Sites

**Figure C-5 Control Site Cc-242**

**Figure C-6 V-Weir Site Cv-241**

**Figure C-7 V-Weir Ste Cv-240**

**Figure C-8 V-Weir Site Cv-61**

Figure C-9 **Control Site Cc-226**

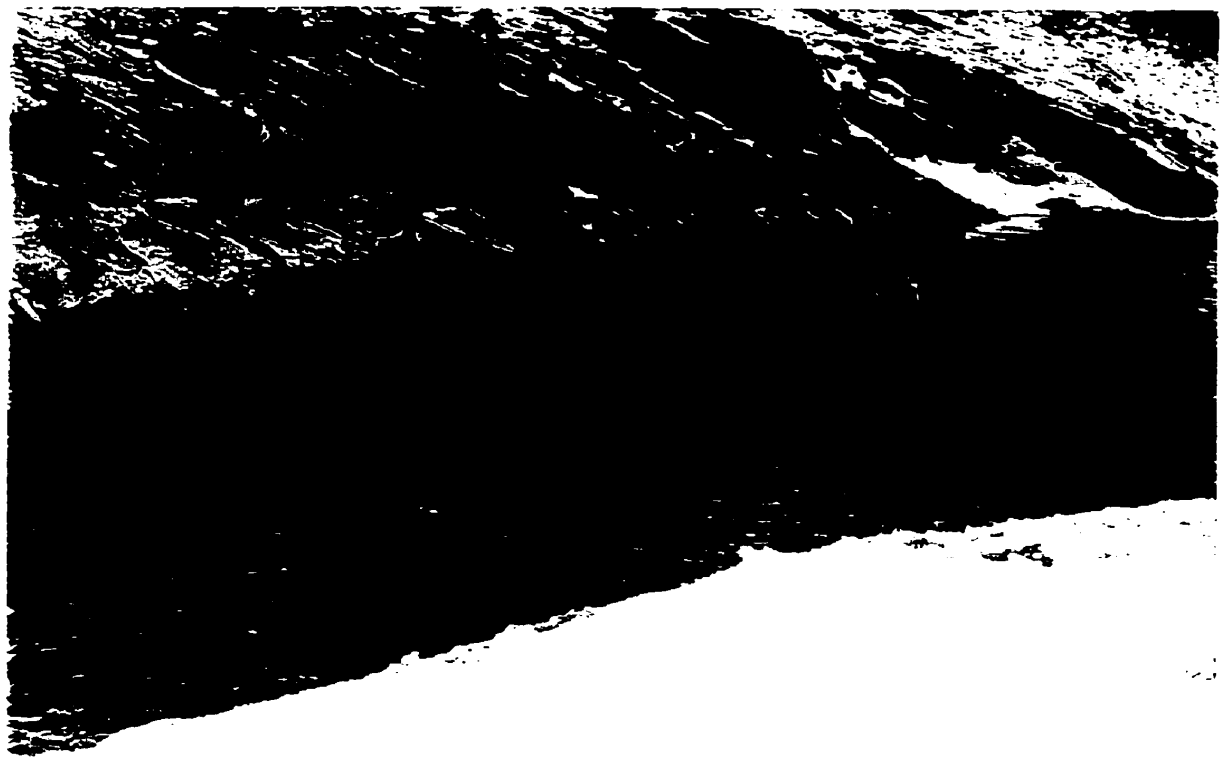

Figure C-10 **Control Site Cc-D**

# APPENDIX D

## Ice-Covered Study Sites

# Ice-Covered Lundbreck Sites

Figure D-1 **A March 1998 Photo of the Lundbreck Reach Showing the Landuse of Sites Lv-77, Lc-291 and Lv-233 (photo courtesy of Alberta Environment).**

**Figure D-2** **V-weir Site Lv-77**

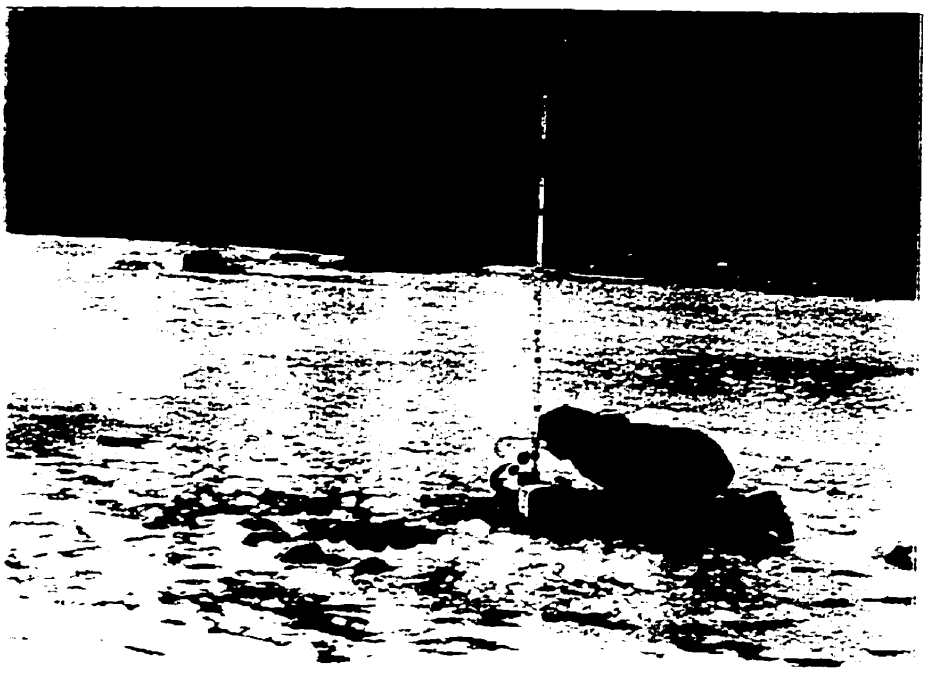

**Figure D-3** **V-weir Site Lv-233**

Figure D-4 **Control Site Lc-75**

Figure D-5 **Control Site Lc-291**

# APPENDIX E

# Physical Measurements

## V-Weir Site Bv-17 Pool Tail

| Width (m) | Depth (cm) | elocity (cm/sec) | Substrate |
|---|---|---|---|
| 0.5 | 38.8 | 0 | 4 |
| 1.5 | 58.8 | 0 | 4 |
| 2.5 | 87.5 | 0 | 4 |
| 3.5 | 102.5 | 0 | 5 4 |
| 4.5 | 117.5 | 3.85 | 5 |
| 5.5 | 120 | 11.13 | 5 4 |
| 6.5 | 127.5 | 2.83 | 5 2 |
| 7.5 | 130 | 10.53 | 2 5 |
| 8.5 | 127.5 | 9.38 | 5 4 |
| 9.5 | 100 | 2.53 | 5 4 |
| 10.5 | 75 | 0 | 4 |
| 11.5 | 50 | 0 | 4 2 |
| 12.5 | 40 | 0 | 4 |
| 13.5 | 31 | 0 | 4 |

## V-Weir Site Bv-17 Mid-Pool

| Width (cm) | Depth (cm) | elocity (cm/sec) | Substrate |
|---|---|---|---|
| 0.5 | 30 | 0 | 4 |
| 1.5 | 60 | 0 | 4 |
| 2.5 | 90 | 0 | 5 4 |
| 3.5 | 100 | 0.041 | 4 5 |
| 4.5 | 115 | 0.0848 | 4 5 |
| 5.5 | 115 | 0.1203 | 4 5 |
| 6.5 | 125 | 0.195 | 4 2 |
| 7.5 | > 120 | | |
| 8.5 | > 120 | | |
| 9.4 | 130 | 0.0763 | 4 |
| 10.4 | 130 | 0 | 5 4 |
| 11.4 | 97 | 0 | 2 |
| 12.4 | 67.5 | 0 | 4 |
| 13.4 | 42.5 | 0 | 4 |

## V-Weir Site Bv-17 Pool Head

| Width (cm) | Depth (cm) | elocity (cm/sec) | Substrate |
|---|---|---|---|
| 0.5 | 27.5 | 0 | 4 |
| 1.5 | 57.5 | 0 | 4 |
| 2.5 | 106 | 7.45 | 5 |
| 3.5 | > 120 | | |
| 4.5 | > 120 | | |
| 5.5 | > 120 | | |
| 6.5 | > 120 | | |
| 7.5 | > 120 | | |
| 8.8 | 132.5 | 13.63 | 4 |
| 9.8 | 90 | 0 | 2 |
| 10.8 | 77.5 | 0 | 4 |
| 11.8 | 27.5 | 0 | 4 |

## V-Weir Site Bv-N Pool Tail

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 6 | 0 | 2 3 4 |
| 1.5 | 17 | 0 | 2 |
| 2.5 | 45 | 0 | 2 |
| 3.5 | 67.5 | 0 | 3 4 |
| 4.5 | 75 | 0 | 3 4 |
| 5.5 | 90 | 0 | 1 |
| 6.5 | 95 | 0 | 1 5 |
| 7.5 | 110 | 3.65 | 1 5 |
| 8.5 | 115 | 7.78 | 2 5 |
| 9.5 | 97.5 | 35.73 | 4 5 |
| 10.5 | 80 | 47.03 | 4 2 |
| 11.5 | 62.5 | 66.3 | 4 2 |
| 12.5 | 37.5 | 20.05 | 3 2 |
| 13.5 | 20 | 14.18 | 3 2 |
| 14.5 | 7.5 | 0 | 2 |

## V-Weir Site Bv-N Mid-Pool

| Width (cm) | Depth (cm) | elocity (cm/sec) | Substrate |
|---|---|---|---|
| 0.2 | 7.5 | 0 | 2 |
| 1.2 | 15 | 0 | 2 |
| 2.2 | 25 | 0 | 2 |
| 3.2 | 42.5 | 0 | 2 |
| 4.2 | 50 | 0 | 2 |
| 5.2 | 60 | 0 | 2 |
| 6.2 | 75 | 0 | 2 |
| 7.2 | 82.5 | 0 | 2 |
| 8.2 | 87.5 | 0 | 3 2 |
| 9.2 | 80 | 11.58 | 5 |
| 10.2 | 102 | 43.65 | 5 |
| 11.2 | 100 | 42.2 | 4 |
| 12.2 | 82.5 | 15.45 | 4 |
| 13.2 | 45 | 0 | 2 3 4 |
| 13.7 | 17.5 | 0 | 2 3 4 |

## V-Weir Site Bv-N Pool Head

| Width (cm) | Depth (cm) | elocity (cm/sec) | Substrate |
|---|---|---|---|
| 0.5 | 17.5 | 0 | 4 |
| 1.5 | 20 | 0 | 4 |
| 2.5 | 22.5 | 0 | 4 |
| 3.5 | 55 | 0 | 5 4 |
| 4.5 | 80 | 0 | 5 4 |
| 5.5 | 107.5 | 17.35 | 5 4 |
| 6.5 | 115 | 35.18 | 5 |
| 7.5 | >120 | | |
| 8.5 | >120 | | |
| 9.55 | 97.5 | 47 | 5 |
| 10.55 | 112.5 | 12.63 | 2 5 |
| 11.55 | 82.5 | 0 | 2 |
| 12.55 | 55 | 0 | 2 |
| 13.55 | 32.5 | 0 | 2 |
| 14.55 | 27.5 | 0 | 2 |

## Control Site Bc-83 Pool Tail

| Width (m) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 13.8 | 0 | 4 |
| 1.5 | 22.5 | 0 | 5 |
| 2.5 | 50 | 6.23 | 4 |
| 3.5 | 70 | 0 | 4 |
| 4.5 | 67.5 | 0 | 5 |
| 5.5 | 12.7 | 7.3 | 5 |
| 6.5 | 85 | 6.78 | 4 |
| 7.5 | 75 | 14.9 | 5 2 4 |
| 8.5 | 82.5 | 4.18 | 2 |
| 9.5 | 97.5 | 0 | 2 |
| 10.5 | 71.3 | 10.43 | 5 4 |
| 11.5 | 60 | 13.25 | 2 |
| 12.5 | 52 | 8.3 | 2 |
| 13.5 | 40 | 4.25 | 4 |
| 14.5 | 50 | 0 | 2 4 |
| 15.5 | 17.5 | 0 | 4 |

## Control Site Bc-83 Mid-Pool

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 17.5 | 0 | 4 |
| 1.5 | 40 | 17.35 | 4 |
| 2.5 | 62.5 | 9.38 | 2 |
| 3.5 | 72.5 | 0 | 5 2 |
| 4.5 | 92.5 | 5.25 | 4 |
| 5.5 | 85 | 21.85 | 4 |
| 6.5 | 65 | 14.18 | 4 2 |
| 7.5 | 60 | 10.2 | 4 |
| 8.5 | 65 | 9.1 | 2 4 |
| 9.5 | 55 | 10.43 | 2 4 |
| 10.5 | 55 | 10.65 | 2 4 |
| 11.5 | 50 | 16.48 | 2 |
| 12.5 | 45 | 16.15 | 2 5 4 |
| 13.5 | 30 | 17.68 | 2 |
| 14.5 | 20 | 11.9 | 2 |

## Control Site Bc-83 Pool Head

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 40 | 0 | 4 |
| 1.1 | 57.5 | 10.38 | 4 |
| 2.1 | 55 | 16.4 | 4 |
| 3.1 | 57.5 | 14.8 | 4 |
| 4.1 | 70 | 25.68 | 4 |
| 5.1 | 75 | 26.95 | 2 4 |
| 6.1 | 92.5 | 22.93 | 5 2 |
| 7.1 | 80 | 2.6 | 5 2 |
| 8.1 | 77.5 | 5.73 | 2 |
| 9.1 | 85 | 14.18 | 2 4 |
| 10.1 | 72.5 | 20.13 | 2 4 |
| 11.1 | 60 | 13.78 | 2 4 |
| 12.1 | 47.5 | 15.93 | 2 4 |
| 13.1 | 40 | 14.45 | 2 |
| 14.1 | 50 | 8.2 | 2 4 5 |
| 15.1 | 45 | 2.53 | 4 |

## Control Site Bc-Z Pool Tail

| Width (m) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 9 | 0 | 1 |
| 1.5 | 17 | 7.15 | 1 |
| 2.5 | 30 | 3.5 | 1 |
| 3.5 | 48.8 | 10.65 | 4 |
| 4.5 | 62.5 | 12.13 | 4 |
| 5.5 | 77.5 | 16.6 | 4 |
| 6.5 | 87.5 | 17.68 | 5 4 |
| 7.5 | 90 | 20.28 | 5 4 |
| 8.5 | 67.5 | 17.9 | 4 |
| 9.5 | 47.5 | 20.13 | 4 |
| 10.5 | 32.5 | 16.38 | 4 |
| 11.5 | 20 | 14.45 | 1 |

## Control Site Bc-Z Mid-Pool

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 18.8 | 0 | 4 |
| 1.5 | 52.5 | 0 | 4 |
| 2.5 | 110 | 0 | 4 |
| 3.4 | 145 | 0 | 4 |
| 4.5 | > 120 | | |
| 5.5 | > 120 | | |
| 6.5 | > 120 | | |
| 7.6 | 142.5 | 33.98 | 4 |
| 8.6 | 105 | 15.55 | 4 |
| 9.6 | 87.5 | 14.15 | 2 4 |
| 10.6 | 27.5 | 0 | 4 |

## Control Site Bc-Z Pool Head

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 12 | 0 | 4 |
| 1.5 | 95 | 0 | 4 |
| 2.5 | > 120 | | |
| 3.5 | > 120 | | |
| 4.5 | > 120 | | |
| 5.5 | > 120 | | |
| 6.5 | > 120 | | |
| 7.9 | 142 | 8.7 | 1 |
| 8.63 | 100 | 0 | 1 |
| 9.63 | 92.5 | 0 | 1 |

## Control Site Cc-226 Pool Tail

| Width (m) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 12.5 | 6.1 | 2 3 |
| 1.5 | 22.5 | 30.8 | 2 3 |
| 2.5 | 35 | 26.28 | 2 |
| 3.5 | 47.5 | 21.15 | 2 |
| 4.5 | 65 | 22.65 | 2 |
| 5.5 | 67.5 | 20.03 | 2 1 |
| 6.5 | 75 | 18.13 | 5 |
| 7.5 | 55 | 6.33 | 5 |
| 8.5 | 45 | 2.98 | 5 |
| 9.5 | 17.5 | 0 | 5 |

## Control Site Cc-226 Mid-Pool

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 7.5 | 0 | 2 |
| 1.5 | 7.5 | 0 | 3 |
| 2.5 | 22.5 | 21.8 | 2 3 |
| 3.5 | 35 | 16.95 | 2 |
| 4.5 | 55 | 22.65 | 2 3 |
| 5.5 | 77.5 | 22.93 | 2 3 |
| 6.5 | 85 | 25.45 | 5 2 |
| 7.5 | 77.5 | 12.33 | 5 |
| 8.5 | 62 | 0 | 5 |

## Control Site Cc-226 Pool Head

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 13 | 0 | 3 4 |
| 1.5 | 32.5 | 0 | 3 4 |
| 2.5 | 52.5 | 27.65 | 2 1 3 |
| 3.5 | 60 | 31.08 | 3 4 |
| 4.5 | 57.5 | 15.25 | 5 3 |
| 5.5 | 65 | 39.58 | 2 5 3 |
| 6.5 | 12 | 30.5 | 5 |

## V-Weir Site Cv-240 Pool Tail

| Width (m) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | under ice | | |
| 1.5 | 40 | 12.8 | 4 5 |
| 2.5 | 67.5 | 19.48 | 5 |
| 3.5 | 65 | 20.48 | 5 |
| 4.5 | 70 | 26.98 | 5 4 |
| 5.5 | 14 | 37.4 | 5 |
| 6.5 | 16 | 29.9 | 5 |

## V-Weir Site Cv-240 Mid-Pool

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 35 | 4.1 | 2 |
| 1.5 | 40 | 10.35 | 5 |
| 2.5 | 70 | 7.45 | 5 |
| 3.5 | 72.5 | 17.8 | 5 |
| 4.5 | 60 | 18.45 | 5 |
| 5.5 | 70 | 33 | 5 |
| 6.5 | 57.5 | 18.9 | 5 4 |
| 7.5 | 35 | 0 | 5 |

## V-Weir Site Cv-240 Pool-Head

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 17.5 | 8.5 | 3 4 |
| 1.5 | 45 | 11.65 | 2 5 |
| 2.5 | 40 | 33.43 | 5 |
| 3.5 | 55 | 28.85 | 5 |
| 4.5 | 20 | 88.4 | 5 |
| 5.5 | 37.5 | 34.58 | 5 |
| 6.5 | 47.5 | 22.85 | 5 |
| 7.5 | 37.5 | 9.03 | 5 |

## V-weir Site Cv-61 Pool Tail

| Width (m) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 25 | 0.221 | 4 |
| 1.5 | 65 | 0.2248 | 4 |
| 2.5 | 77.5 | 0.2318 | 5 |
| 3.5 | 72.5 | 0.1715 | 5 |
| 4.5 | 72.5 | 0.1425 | 5 4 |
| 5.5 | 75 | 0.0885 | 4 1 |
| 6.5 | 62.5 | 0.035 | 4 1 |
| 7.5 | 15 | 0 | 4 |

## V-weir Site Cv-61 Mid-Pool

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 35 | 15.38 | 4 |
| 1.5 | 82.5 | 29.4 | 5 |
| 2.5 | 85 | 25.9 | 5 |
| 3.5 | 87.5 | 15.45 | 5 |
| 4.5 | 85 | 11.1 | 5 |
| 5.5 | 70 | 2.68 | 1 |
| 6.5 | 50 | 0 | 1 |
| 7.5 | 27.5 | 0 | 1 3 |
| 8.5 | 13 | 0 | 1 3 |

## V-weir Site Cv-61 Pool-Head

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 7 | 0 | 3 1 |
| 1.5 | 20 | 0 | 3 1 |
| 2.5 | 60 | 4.8 | 3 1 |
| 3.5 | 90 | 37.18 | 5 |
| 4.5 | 100 | 21.75 | 5 2 |
| 5.5 | 40 | 45.25 | 5 |
| 6.5 | 97.5 | 17 | 5 |
| 7.5 | 95 | 6.93 | 5 4 |
| 8.5 | 75 | 0 | 4 1 |
| 9.5 | 9 | 0 | 4 |

## V-Weir Site Cv-241 Pool Tail

| Width (m) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 17 | 0 | 1 4 |
| 1.5 | 32.5 | 2.75 | 4 |
| 2.5 | 30 | 6.03 | 4 |
| 3.5 | 40 | 21.03 | 5 4 |
| 4.5 | 50 | 38.4 | 5 |
| 5.5 | 37.5 | 63.93 | 5 |
| 6.5 | 45 | 33.3 | 5 |
| 7.5 | 40 | 13.5 | 5 4 |
| 8.5 | 25 | 12.15 | 3 4 |

## V-Weir Site Cv-241 Mid-Pool

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | under ice | | |
| 1.5 | 37.5 | 0 | 3 4 |
| 2.5 | 40 | 5.8 | 3 4 |
| 3.5 | 47.5 | 14.38 | 5 4 |
| 4.5 | 62.5 | 43.2 | 5 |
| 5.5 | 62.5 | 69.9 | 5 |
| 6.5 | 65 | 25.5 | 5 4 |
| 7.5 | 42.5 | 25.08 | 4 |
| 8.5 | 22.5 | 0 | 3 4 |
| 9.5 | 22.5 | 0 | 3 4 |

## V-Weir Site Cv-241 Pool-Head

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | under ice | | |
| 1.5 | 50 | 13.4 | 5 |
| 2.5 | 70 | 29.63 | 5 |
| 3.5 | 80 | 94.93 | 5 |
| 4.5 | 70 | 34.45 | 5 |
| 5.5 | 70 | 42.83 | 5 |
| 6.5 | 55 | 0 | 5 2 |
| 7.5 | 45 | 0 | 5 |

## Control Site Cc-242 Pool-Tail

| Width (m) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 20 | 0 | 4 5 |
| 1.5 | 20 | 32.3 | 5 |
| 2.5 | 42.5 | 36.55 | 4 5 |
| 3.5 | 25 | 45.7 | 5 |
| 4.5 | 50 | 36.63 | 4 |
| 5.5 | 47.5 | 25.9 | 4 |
| 6.5 | 42.5 | 16 | 4 |
| 7.5 | 17.5 | 17.1 | 3 4 |

## Control Site Cc-242 Mid-Pool

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 10 | 0 | 5 |
| 1.5 | 52.5 | 22.48 | 5 |
| 2.5 | 32.5 | 34.28 | 5 |
| 3.5 | 50 | 37.13 | 5 |
| 4.5 | 42.5 | 27.63 | 5 |
| 5.5 | 57.5 | 20.13 | 5 |
| 6.5 | 57.5 | 12.35 | 4 5 |
| 7.5 | 27.5 | 6.7 | 4 1 |

## Control Site Cc-242 Pool-Head

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | under ice | | |
| 1.5 | 0 | 0 | 5 |
| 2.5 | 55 | 33.5 | 5 |
| 3.5 | 77.5 | 36.95 | 5 |
| 4.5 | 40 | 25.2 | 5 |
| 5.5 | 72.5 | 18.73 | 5 |
| 6.5 | 67.5 | 17.13 | 4 |
| 7.5 | 45 | 8.6 | 4 |

## Control Site Cc-D Pool Tail

| Width (m) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 25 | 0 | 1 |
| 1.5 | 47.5 | 0 | 1 |
| 2.5 | 65 | 0 | 4 |
| 3.5 | 87.5 | 0 | 1 |
| 4.5 | 107.5 | 13.25 | 5 |
| 5.5 | 95 | 18.65 | 5 |
| 6.5 | 87.5 | 17.03 | 5 |
| 7.5 | 92.5 | 21.2 | 5 |
| 8.5 | 52.5 | 36.35 | 5 |

## Control Site Cc-D Mid-Pool

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 12.5 | 0 | 1 |
| 1.5 | 27.5 | 0 | 1 |
| 2.5 | 52.5 | 0 | 1 |
| 3.5 | 100 | 6.9 | 1 5 |
| 4.5 | 112.5 | 11.93 | 1 5 |
| 5.5 | 100 | 16.08 | 5 |
| 6.5 | 80 | 29.73 | 5 |
| 7.5 | 55 | 32.23 | 5 |
| 8.5 | 11 | 0 | 5 |

## Control Site Cc-D Pool-Head

| Width (cm) | Depth (cm) | Velocity (cm/s) | Substrate |
|---|---|---|---|
| 0.5 | 14 | 0 | 4 |
| 1.5 | 20 | 91.6 | 4 |
| 2.5 | 35 | 83.65 | 5 4 |
| 3.5 | 52.5 | 55.6 | 5 |
| 4.5 | 75 | 25.28 | 4 2 |
| 5.5 | 60 | 0 | 4 3 1 |
| 6.5 | 60 | 0 | 3 1 |
| 7.5 | 60 | 0 | 3 1 |
| 8.5 | 62.5 | 0 | 3 1 |
| 9.5 | 52.5 | 0 | 3 1 |
| 10.5 | 45 | 0 | 3 1 |
| 11.5 | 25 | 0 | 3 1 |

# APPENDIX F

# Risk Management Plan

# Risk Management Plan

**Purposes:**

To be generally prepared for minor and major emergencies which may occur while working on the ice-covered Crowsnest River. To prevent and/or deal effectively with the ever-present risk of someone falling through the river ice and hypothermia.

**General briefing for a new assistant**

- Location of the Blairmore Hospital
- Assistant stays off the ice as much as possible
- Utilize a belay technique[1] with the assistant as belayer, and a nearby rock or tree as an anchor
- Maintain zero slack in the rope
- Constant alertness of the belayer is essential
- Both wear life jackets at all times
- Assistant retains pole, cell phone, first aid kit and compass at all times
- In the event that the ice breaks, effective use of the belay technique will prevent the individual from being swept under the ice and allow swift rescue to shore

**Someone falls through the ice, steps of action:**

- Do not run onto the ice
- If already on the ice, slowly lay down and crawl towards shore
- Secure your position on shore
- Talk to the person who has fallen at all times
- Pull fallen person out of the water and onto the shore by rope, or by pole if rope is not possible
- Transport person by sled to the truck
- Remove wet clothes and wrap person in wool blankets and a dry hat
- Go straight to the Blairmore Hospital

**Hypothermia:**

- Signs to watch for: constant shivering, confusion, disorientation, lethargy and decreased consciousness.
- Early recognition of the signs of hypothermia may be facilitated by maintaining an ongoing conversation to assess on another's condition.
- Treatment: bundle up, warm liquids(tea with jello powder) and keep the conversation going and seek medical assistance

---

[1]Belaying in the incorporation and manning of a separate safety line connected to a rescuer via an independent anchor

**Spare Equipment (in the truck):**

- 2 wool blankets
- spare boots
- spare coat, socks, hat
- thermos of hot tea
- simplified map of the area ( major towns, Blairmore Hospital, cabin)
- highway reflectors
- first aid kit
- waterproof matches
- spare tire
- jello powder and candies
- candles
- flashlight

**Equipment on hand:**

- cell phone
- climbing rope
- harness
- compact first aid kit
- 25 foot pole
- life jackets
- compass

# APPENDIX G

# Previous Snorkel Observations

## Previous Snorkel Observations

Table G-1 Snorkel surveys conducted by R.L. & L. Environmental Services Ltd. from 1992 - 1996. Video Average is the average of all six video observations collected in the Blairmore study area. Mountain whitefish (MW), rainbow trout (RB), trout species (TR) adults (ad), juveniles (juv)

| | Date Snorkeled | Snorkel Numbers | Video Average |
|---|---|---|---|
| **V-weir Site 17** | 06/14/92<br>06/30/93<br>11/14/93<br>08/23/94<br>09/02/95<br>09/05/96 | 7ad MW, 4ad 2juv RB<br>3ad MW, 1juv RB<br>1ad MW, 3ad RB<br>13ad 1juv MW, 19juv 4adRB<br>15ad MW, 1ad RB<br>1 ad RB | |
| **Average** | | 12.5 | 19 |
| **V-weir Site N** | 11/14/93<br>08/31/95<br>09/05/96 | 5ad MW<br>6ad MW<br>1ad RB | |
| **Average** | | 4 | 0 |
| **Control Site 83** | 08/31/95<br>09/05/96 | 2ad MW, 1ad RB<br>2ad RB | |
| **Average** | | 2.5 | 2.5 |
| **Control Site Z** | Not sampled by R.L. & L. | N/A | |
| **Average** | | | 4.5 |

Table G-2 Snorkel surveys conducted by R.L. & L. Environmental Services Ltd. from 1992 - 1996 . Video Average is the average of all six video observations collected in the Coleman study area. Mountain whitefish (MW), rainbow trout (RB), trout species (TR) adults (ad), juveniles (juv).

| | Date Snorkeled | Snorkel Numbers | Video Average |
|---|---|---|---|
| V-weir Site 241 | 08/30/95<br>09/04/96 | 1ad RB<br>0 | |
| Average | | 0.5 | 0 |
| V-weir Site 240 | 08/30/95<br>09/04/96 | 2ad RB<br>1ad RB | |
| Average | | 1.5 | 0 |
| V-weir Site 61 | 08/30/95<br>09/04/96 | 10ad MW, 2ad RB<br>3ad RB | |
| Average | | 7.5 | 0.7 |
| Control Site 242 | 08/30/95<br>09/04/96 | 2ad RB<br>5ad RB | |
| Average | | 3.5 | 4.7 |
| Control Site D | 08/29/95<br>09/04/96 | 0<br>4ad RB | |
| Average | | 2 | 0.5 |
| Control Site 226 | 08/29/95<br>09/04/96 | 3juv RB<br>0 | |
| Average | | 1.5 | 0.16 |