Physical Stream Feature Assessments Using Aerial Videographic Surveys

by

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THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE

REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

in

NATURAL RESOURCE MANAGEMENT

THE UNIVERSITY OF NORTHERN BRITISH COLUMBIA

April, 2000

Abstract

The accuracy of aerial videographic surveys to identify and locate physical stream features was compared to ground-identified physical stream features. A portion of the Mackenzie Timber Supply Area, in northern British Columbia, was surveyed using aerial videographic survey techniques to identify selected stream features. The features were identified visually and recorded on a computer with their corresponding GPS locational positions. In addition, a super VHS video recording was made using a camera mounted to the undercarriage of the helicopter. A Watershed Restoration Program Level 1 fish habitat assessment was developed using this video recording to investigate the information that may be collected using a video-only approach. The accuracy of identification and location of both the visual and video-only survey data were determined by conducting ground stream assessments on a stratified random sampling of aerial surveyed stream segments.

The visual aerial stream feature information had an overall accuracy of less than eight percent with an average locational error of ± 37 metres for each stream feature. Aerial identification accuracy was affected significantly by the type of stream feature identified and the order of the stream surveyed. Larger, easily interpreted features such as "Bridges" or "Culverts" that were associated with openings in the crown closure were successfully identified with 100% accuracy, while smaller, more complex features such as "Backwater Channels" were not successfully identified during the course of the aerial survey. The identification of detailed stream features from the air was not possible on any size of stream using the current aerial videographic methodology and therefore the technique should not be used for gathering detailed stream habitat information. However, aerial videographic surveys appear to be a cost-effective tool for assessing overview information such as large, easily interpreted features and general stream descriptions. The preliminary investigation of a video-only approach indicated that qualitative stream habitat assessments may be performed with a high success rate on streams larger than 4^{th}-order. However, the successful identification of quantitative stream parameters might decrease as stream complexity increases. Detailed physical information on larger streams might be obtainable visually and recorded with higher resolution video with changes to the aerial videographic survey technique.

Master's Thesis (MSc) in the Faculty of Natural Resources and Environmental Studies

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Acknowledgement

I would like to express my gratitude to my supervisor, Dr. Alex Hawley, and committee members, Don Caddon, Dr. Steve Dewhurst, and Dr. Roger Wheate, for their invaluable input and patience. I would also like to thank Slocan Forest Products in Mackenzie for their financial support of the ground survey program, Terra•Pro GPS Surveys Inc. and their Prince George staff for the technical support, donation of time, and resources, as well as White Pine Environmental Resources Inc. for their cooperation. I would like to acknowledge Environmental Dynamics Inc. for providing an efficient and professional ground survey crew and thank my family and friends for general love and support.

Chapter One:

Introduction

Fisheries resources are integral to the provincial economy and important for the livelihood and enjoyment of many British Columbians. In 1996, seafood was the province's number one food export, generating export sales in excess of $858 million while the commercial and aquaculture industry supported 20, 000 employees (MOELP, 2000). Approximately 700, 000 British Columbia residents and 100, 000 visitors use British Columbia waterways for recreational fishing in freshwater and tidal areas, creating associated provincial revenues of just under one billion dollars from fishing gear purchases, lodging, guides, and boat rentals (DFO and MOELP, 1994). Furthermore, fishing occupies a unique place in the culture and social system of the First Nations people and supplies Band members with a source of commercial income (DFO and MOELP, 1994).

Inventories of aquatic habitat and fish populations are the primary source of information for the evaluation of watershed conditions and the management of fishery resources (Dolloff et al. 1993). Stream inventories are performed for the conservation and management of fish and fish habitat, compliance with legislation, work creation, and community education. The identification of factors impacting on, or limiting, fish populations and production, such as habitat and nutrient deficiencies, is a primary reason for performing a habitat inventory (Osborne et al. 1991). This inventory information is then used to plan habitat restoration and improvement programs (Dolloff et al. 1997).

Habitat inventories also help land developers comply with federal and provincial regulations, such as the *Forest Practices Code of British Columbia Act*, and provide resource agencies with information for monitoring, auditing, and enforcing these regulations (DFO 1986 and MOF 1995a). Inventories also provide community-based training and employment and help promote stream habitat conservation around the province (Johnston and Slaney 1996). Fishery managers select areas in which habitat inventories will be conducted based on these inventory objectives, the spatial scale of the stream information required, and the associated time and cost required to effectively gather the inventory information (Beechie and Sibley 1990; Washington Forest Practices Board 1993).

Aerial videography is currently used as an overview stream habitat inventory method in British Columbia for collecting watershed and channel-level physical stream information (T. Zimmerman, MOELP, personal communication). This inventory technique is specifically used in remote areas where mapping and aerial photographic coverage is outdated or nonexistent and to help supplement maps and photographic information which may be unreliable at the channel level (MOF 1995a; MOF 1996; MOELP 1997; W.Cooper, MOELP, personal communication). There has been no quantitative information gathered to evaluate whether aerial videographic surveys can effectively record physical stream information. In addition, recent technological advancements, such as higher resolution video equipment and GPS "position-tagging" software, have potentially increased the accuracy of feature identification, the accuracy of feature location, and the size of stream features that can be surveyed using aerial videography.

An assessment is required to evaluate the accuracy of stream feature identification, the accuracy of stream feature location, and associated costs of an aerial videographic survey to gather stream features.

I evaluated aerial videographic surveys for stream feature inventory in four ways to determine whether this inventory technique could provide effective stream feature information. I performed a comparison of visual aerial-inventoried stream feature data and ground-inventoried stream data to evaluate accuracy of aerial feature identification. I also evaluated the accuracy of stream feature location by comparing the GPS location of aerial-inventoried stream features to the GPS location of ground-inventoried stream features. In addition, I performed a video-only fish habitat assessment and compared it to a ground assessment as a preliminary investigation of whether only the video portion of the aerial videographic survey (without aerial survey commentary) could be used to assess stream features. Finally, the costs of aerial videographic surveys were compared to the costs of ground surveys.

Chapter Two:

Literature Review

Fish in the Study Area

In the Mackenzie area of British Columbia, forty-three salmonid and non-salmonid fish species utilize freshwater lakes and streams to obtain the physical and biological requirements for specific life stages and successful reproduction (McPhail and Carveth 1993). Twenty-two of these species are located in the Upper Peace River drainage above the W.A.C. Bennett Dam (Appendix 1). I focussed on salmonids in this study because of the emphasis that regulatory agencies have in the Mackenzie region and throughout British Columbia on stream features important to salmonids (D.Cadden, MOELP, personal communication).

Most stream-living salmonids begin life as incubating eggs which are buried in the streambed and which hatch into alevins among the gravel (Allan 1969). After a period of weeks to months, alevins mature to juveniles and emerge out of the gravel to rear in streams for a period of less than a year to more than eight years, depending on species and location (Butler 1991). Anadromous juveniles, such as Dolly Varden and steelhead, migrate downstream to the ocean while non-anadromous species remain in lakes and streams. Most trout species become adults after two to four years, and subsequently mature after a period of one to thirteen years depending on species and location (Butler 1991). Mature adults of trout and char return to spawn in their natal streams (Bjornn 1991; Bjornn and Reiser 1991).

Fish usually respond to the combined effect of two or more of the physical, chemical, and biological variables in their environment. The fish may respond physiologically, as indicated by altered growth or health, or behaviorally, as indicated by rearing and spawning site selections (Bjornn and Reiser 1991). The mix of environmental factors in any stream determines the carrying capacity of that stream for fish, and the capacity can change if one or more of the factors are altered (Toews and Brownlee 1981; Bjornn and Reiser 1991). The physical, chemical, and biological factors that affect the populations of salmonids in streams are generalized below.

Physical Factors That Influence Salmonids and Salmonid Distribution

Water is continuously cycled from the atmosphere to the earth and oceans through evaporation, condensation, precipitation, and runoff. The portion of that cycle important to freshwater salmonids is runoff, or the movement of water downhill by various routes (Allan 1995). Climate, vegetation, topography, geology, land use, and soil characteristics of a watershed determine the physical nature and chemical composition of the surface runoff and channel morphology (Allan 1995; Hogan and Ward 1997). Streams and rivers are in dynamic equilibrium between erosion and deposition of largely inorganic materials (Toews and Brownlee 1981; Allan 1995). In addition, they transport organic matter, including vegetation and animal material, from the land to the oceans (Toews and Brownlee 1981).

Stream fish habitat is defined as the "…spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly to carry out their life processes…"(PFRCC 2000). There are six general physical stream factors that impact the distribution of freshwater salmonid species: stream flow, stream temperature, salmonid access to habitat, stream clarity, substrate, and cover (Vannote et al 1980; Toews and Brownlee 1981; Bjornn and Reiser 1991). Cover is defined as the protection against predation and stream flow offered by physical habitat (Bjornn and Reiser 1991).

Stream flow

Stream flow is determined by a combination of stream width, depth, gradient, and water velocity. It is perhaps the most important environmental factor affecting fish and all other organisms of running waters, and influences other important physical stream attributes (Allan 1995). Stream flow is closely tied to stream fish-carrying capacity, as the amount of stream flow determines the space available to salmonids (Bjornn and Reiser 1991). In general, when there is no flow under natural conditions, there are no salmonids. As flow increases up to a point fish numbers increase, perhaps not linearly. Above a certain stream flow, fish numbers level off or decline (Bjornn and Reiser 1991).

Fish require a relatively stable stream flow without extreme freshets and droughts. Extreme freshets (i.e. high flows) tend to scour away benthos, developing salmonid eggs, and alevins in the substrate, and facilitate bedload transport and bank instability (Toews and Brownlee 1981; Fausch et al. 1988). Conversely, low flow periods in the winter are associated with freezing causing embryo and alevin mortality. In the summer, a minimum amount of flow is required for salmonid rearing (Toews and Brownlee 1981; Fausch et al. 1988).

Stream velocity influences the particle size of the substrate within the stream channel, and can indirectly influence fish cover. Baxter and McPhail (1996) recorded that water depth is an important habitat attribute for juvenile bull trout *(Salvelinus confluentus)* especially when associated with good cover. Finally, high stream flows can serve as physical fish migration barriers and can impact water quality by increasing dissolved oxygen concentrations, which are harmful at very low and very high concentrations. High flows can also increase suspended sediments, which in high concentrations become detrimental to fish (Bjornn and Reiser 1991; Allan 1995).

Stream Temperature

Stream temperature influences all life stages of salmonids. Unusually high temperatures can lead to disease outbreaks in migrating and spawning fish, and unsuitable temperatures altered timing of migration, and accelerated maturation (Bjornn and Reiser 1991). During incubation, water temperature affects the rate of embryo and alevin development and the capacity of water to dissolve oxygen. Finally, most salmonids have lower and upper lethal temperature limits during all life stages (Bjornn and Reiser 1991; Behnke 1991).

Salmonid Access to Habitat

Access of fish to habitat at specific times of the year is another key physical requirement of freshwater fishes. Salmonid fry, juveniles, and adults must have physical access to rearing areas and overwintering habitat, and adults must have access to spawning grounds (Bjornn and Reiser 1991). Typical impediments to access include waterfalls, debris jams, excessive stream velocities, and low stream flows (Toews and Brownlee 1981; Bjornn and Reiser 1991).

Stream Clarity

Stream water must be clear enough to permit sunlight to reach the stream bottom and the algal community, where most of the primary production of the stream occurs (Toews and Brownlee 1981). In addition, salmonids feed by sight, and enough light must also penetrate the stream water to allow them to see their prey (Toews and Brownlee 1981). Elevated suspended inorganic or organic solids can increase the turbidity of the stream water and impair salmonid foraging and limit primary production (Vannote et al. 1980).

Substrate

Salmonids require different substrates for spawning, cover from predators, and shelter from stream current (Fausch et al. 1988; Bjornn and Reiser 1991). The substrates of salmonid streams are also important habitats for incubating embryos and aquatic invertebrates, the primary prey of salmonids in streams (Bjornn and Reiser 1991). For successful spawning, salmonids require clean, stable gravel that ranges from 0.2 to 15 centimetres in diameter (depending on adult fish size) and which will remain clean throughout incubation and alevin emergence. The gravel should permit intergravel water flow to provide adequate dissolved oxygen to eggs and alevins and to remove metabolic wastes such as carbon dioxide and ammonia (Toews and Brownlee 1981; Bjornn and Reiser 1991; Bjornn 1991). Cobble and boulder substrate ranging from 15 to 400 centimetres in diameter provides cover from strong currents and predators for fish in summer and in winter. Silt and sand substrates less than 0.2 centimetres in diameter have little or no value as cover for fish (Bjornn and Reiser 1991; Johnston and Slaney 1996).

Cover

The cover provided by undercut banks, logs, cobble and boulder substrate, turbulence, overhanging vegetation, and deep pools is also critical to salmonids (Fausch et al. 1988; Flebbe and Dolloff 1995). This physical stream attribute provides juvenile feeding areas, refuges from strong currents, escape from predators, and overwintering areas (Toews and Brownlee 1981).

Chemical Factors That Influence Salmonids and Salmonid Distribution

The materials transported in streams can be subdivided according to whether they are dissolved or suspended, organic or inorganic, and by chemical description (Allan 1995). A useful breakdown of materials in streams includes: suspended inorganic matter, dissolved major ions, dissolved nutrients, suspended and dissolved organic matter, gases, and trace metals (Behnke 1991; Allan 1995). These materials affect stream production and can directly impact salmonids (Toews and Brownlee 1981).

Stream Production

Salmonid populations in streams are usually limited by two factors: the abundance of salmonid prey, comprised primarily of aquatic invertebrates (a biological factor), and the rearing space available (a physical factor) (Bjornn and Reiser 1991). The abundance of salmonid prey is dependent on aquatic stream production that is, in turn, based on a combination of internal and external nutrient and energy pathways (Vannote et al. 1980; Toews and Brownlee 1981; Allan 1995). The internal nutrient and energy pathway is dependent on primary production by aquatic autotrophic organisms, which derive their energy from sunlight and their materials from non-living sources (Toews and Brownlee 1981; Allan 1995). Primary producers include mainly high productivity plants such as periphyton and bryophytes and some chemosynthetic bacteria that produce organic compounds from hydrogen sulphide and carbon dioxide (Giller and Malmqvist. 1998).

The external nutrient and energy pathway is dependent on plant material entering the stream from streamside vegetation as well as salmonid and mammal carcasses that provide nutrients to heterotrophic organisms (Toews and Brownlee 1981; Allan 1995). Plant material can enter the stream as coarse particulate organic matter (CPOM) and is either consumed by invertebrates or broken into fine particulate organic matter (FPOM) by invertebrate shredders, microbial processes, and physical abrasion (Giller and Malmqvist. 1998). The majority of all organic material transported in streams, however, is in the form of dissolved organic matter (DOM). This DOM is comprised of a heterogenous mixture of small organic molecules such as sugars, lipids, amino acids, and proteins to large humic molecules. It originates directly from terrestrial runoff or from instream sources such as detrital leaching, exudates from algae, higher plants, heterotrophs that breakdown FPOM, and animal excretions (Allan 1995; Giller and Malmqvist. 1998). The incorporation of DOM into food webs is largely the result of microbial uptake and subsequent transfer to invertebrate consumers (Giller and Malmqvist. 1998).

These internal and external nutrient pathways result in autotrophic and heterotrophic organisms that are preyed upon by micro- and macro-invertebrates (primarily insects). These invertebrates comprise a large portion of the diet of stream-dwelling salmonids for example FPOM provides food for invertebrates such as caddis and blackfly larvae, mayflies, and chironomids that are in turn consumed by fish (Toews and Brownlee 1981; Bjornn and Reiser 1991; Giller and Malmqvist. 1998). Positive correlations have been observed between stream primary productivity and trout production, trout standing crop, and growth (Bjornn and Reiser 1991).

Dissolved Oxygen

Dissolved oxygen is essential to the respiration of fish (Behnke 1991). Most natural streams have enough dissolved oxygen for salmonids, although oxygen concentrations in some small streams may be reduced by large amounts of organic debris, when temperatures are high, and when flows are low (Bjornn and Reiser 1991). The minimum concentration of dissolved oxygen in streams should not fall below 5-6 mg/L although growth, food conversion efficiency, and swimming performance may be impaired at this level (Bjornn and Reiser 1991).

Other chemical factors such as dissolved ions and trace metals can also influence fish and other stream biota. The deleterious effects of acid stream water are well documented, primarily in terms of reduced numbers of species and individuals, but also altered ecosystem processes (Allan 1995). Fish generally require stream pH (a measure of the hydrogen ion concentration and therefore water acidity) to be in the range of 6.5-9.0 (MOELP 2000). Salmonid mortality has been documented at pH 5.0 and the toxicity of acid waters can vary with the concentration of metals such as aluminum. Studies have indicated that the mortality of salmon and trout was dramatically increased in the presence of 0.35mg/l aluminum at pH 5.0, but mortality was relatively low at pH 4.3 with no aluminum (Giller and Malmqvist 1998).

Biological Factors That Influence Salmonids and Salmonid Distribution

Salmonid species share similar general biological factors that impact spawning, incubation, rearing, foraging, and migration (Allan 1969). These biological factors, which include stream production (mentioned above), competition, predation, and disease, are often closely associated with physical stream attributes.

Competition

Competition is defined as an interaction between individuals, brought about by a shared requirement for a resource, leading to a reduction in the survivorship, growth, and/or reproduction of the competing individuals concerned (Begon et al. 1990; Allan 1995).

These resources may be in short supply, thereby limiting availability to competing species, or organisms may harm each other in the process of seeking the same resource (Allan 1995).

Predation

Predation is the consumption of one organism by another organism, in which the prey is alive when the predator first attacks it (Begon et al. 1990). As soon as young fish begin rearing in the stream, their numbers continually decrease, due partly to predation by other fish, birds, and mammals (Allan 1969; Bjornn and Reiser 1991). Predation is probably the most important cause of salmonid mortality during downstream migration (Allan 1969).

Disease

Most diseases in fish are related to stresses such as low levels of dissolved oxygen, extremes in water temperature, and physical crowding. Individual fish resistance to disease drops in stressful situations and disease organisms can more readily establish themselves (Moring 1991). The common diseases affecting freshwater salmonids are caused by bacteria, fungi (which is a secondary invader after an initial wound or lesion), viruses, protozoa, parasitic worms, and fish lice (Moring 1991).

Fish Habitat Inventories

A fish habitat inventory (or habitat assessment) records biophysical information about a stream (MOELP 1997). Habitat inventories can be used to evaluate the capability of the stream for fish production, as the basis for stream classifications, and as the basis for predictive physical and biological modeling such as standing crop estimates (Fausch et al. 1988; Hawkins et al. 1993). These inventories are recognized as a snapshot of physical or biological stream features at the time of the inventory, for field-collected data, or at the time the area was remotely sensed (i.e. aerial photographs) (Allan 1995).

A number of studies indicate that the characteristics of physical habitat influence the density and survival of salmonids during the freshwater phases of their life history (Fausch et al. 1988). Most fisheries managers, therefore, assume that fish distribution and abundance are limited by the quality and quantity of physical habitats present within a watershed (Pokrant and Hildebrand 1984; Washington Forest Practices Board 1993; Johnston and Slaney 1996).

Reasons for Conducting a Habitat Inventory

There are four reasons for performing fish habitat inventories: fish conservation, habitat management, compliance with legislation, and work creation/community education.

Conservation

The primary reason for performing habitat inventories is to maintain and protect fisheries, aquatic, and forest resources (Johnston and Slaney 1996; MOELP 1997). To this end, biological inventories provide baseline assessment information such as fish species characteristics, distributions, and relative abundance of salmonid populations (Osborne et al. 1991; Simonson et al. 1994; MOELP 1997). Physical inventories help identify factors limiting fish populations and production, such as habitat and nutrient deficiencies (Osborne et al. 1991; Simonson et al. 1994; MOELP 1997).

Habitat Management

Fish habitat management, a tool of fish conservation, involves maintaining and improving aquatic habitat and mitigating habitat damage due to anthropogenic or natural occurrences (Johnston and Slaney 1996). An inventory of factors limiting the production of salmonids in streams must be completed before any habitat-enhancement program is undertaken (Reeves et al. 1989; Hawkins et al. 1993). Fisheries biologists must also identify critical stream reaches for spawning, rearing, and overwintering, as well as stream reaches vulnerable to impacts from logging and other developments (Oswood and Barber 1982). Habitat inventories help identify these limiting factors and vulnerable areas. The data are then used to evaluate habitat restoration and improvement programs (Dolloff et al. 1997). These inventories also form the building blocks for developing management plans, facilitating basin planning, and monitoring environmental change (Osborne et al. 1991; Simonson et al. 1994; Dolloff et al. 1997).

In British Columbia, habitat assessments are used "to restore fisheries, aquatic, and forest resources" the primary goal of the WRP (Johnston and Slaney 1996). Identifying areas for habitat improvement and the assessment of habitat conditions after project completion are recognized as integral components of determining the effectiveness of habitat restoration projects (Osborne et al. 1991; Simonson et al. 1994).

Compliance with Legislation

In British Columbia there is a complex matrix of legislation at the federal, provincial, and municipal levels for fish habitat protection and management. There are two pieces of legislation that are specifically designed to protect fish habitat, the federal *Fisheries Act*, the new provincial *Fish Protection Act* (PFRCC 2000). There are also a number of pieces of legislation not specifically targeting fish that empower provincial and municipal agencies to restrict land development and activities that can impact fish habitat. Some examples are the *Forest Practices Code of British Columbia Act* that is designed to preserve stream riparian areas, the *British Columbia Water Act* that enables the province to regulate water diversion and storage, the *Land Title Act* designed to minimize flood plain development and damage, *the Agricultural Land Reserve Act* designed to protect farmland from conversion to non-agricultural use, and the *Waste Management Act* for the management of solid waste, storm water, and sewage (PFRCC 2000).

Habitat inventories help developers comply with these local regulations and assist resource agencies in enforcing provincial and federal legislation. For example, these habitat assessments can specifically provide information for riparian management areas and lake classification by measuring stream/lake dimensions and fish presence (MOF 1995a; MOF 1996; MOELP 1997). This information allows forest company managers, planners, and field personnel to develop forest development plans in compliance with the *Forest Practices Code of British Columbia Act* (MOF 1995a; MOF 1996; MOELP 1997). Conversely, these same habitat assessments allow resource agency personnel to monitor, audit, and enforce provincial and federal regulations such as the *Provincial Forest*

Practices Code of British Columbia Act (FPC) and the *Federal Fisheries Act* (DFO 1986; MOF 1995a; MOF 1996).

Work Creation/Community Education

Habitat inventories provide employment, community training, and community education. The FPC provides value-added jobs for consulting companies through the inventory requirements written into the FPC (MOF 1995a; MOF 1996). Habitat inventories also provide community-based training and employment through the WRP (Johnston and Slaney 1996).

Physical Habitat Inventory Methods

The methodology for physical habitat inventories is well-established and can range in scale from a watershed perspective over a broad temporal range to a micro-level scale such as an individual species' instream flow requirements (Osborne et al. 1991; Allan 1995; Dolloff et al. 1997). Numerous stream habitat survey systems have been designed to provide information on salmonid habitat quality (Oswood and Barber 1982). The most accurate way to inventory stream habitat is to visit and measure all habitats over a wide temporal range but, because of time, expense, and logistical constraints, stream assessments generally involve a subset of all physical stream features (Oswood and Barber 1982; Dolloff et al. 1993).

Streams can be broadly described on three spatial scales: the watershed level, the channel level, and the habitat unit level (Toews and Brownlee 1981; Fausch et al. 1988; Allan

1995; Dolloff et al 1997). In British Columbia, there are a series of fish and fish habitat inventory methods used that provide information about fish distribution, population status, habitat condition, and the capability of habitat to support fish (MOELP 1997). Many of the inventories gather information using two or more of the spatial scales mentioned above. Appendix 2 lists the habitat features that are generally measured at each stream inventory scale/level (i.e. Watershed, Channel, or Habitat Unit). A list of the fish habitat inventories commonly performed in British Columbia along with a summary of the data collection techniques used and the relative scale of the information gathered is presented in Figure 1.

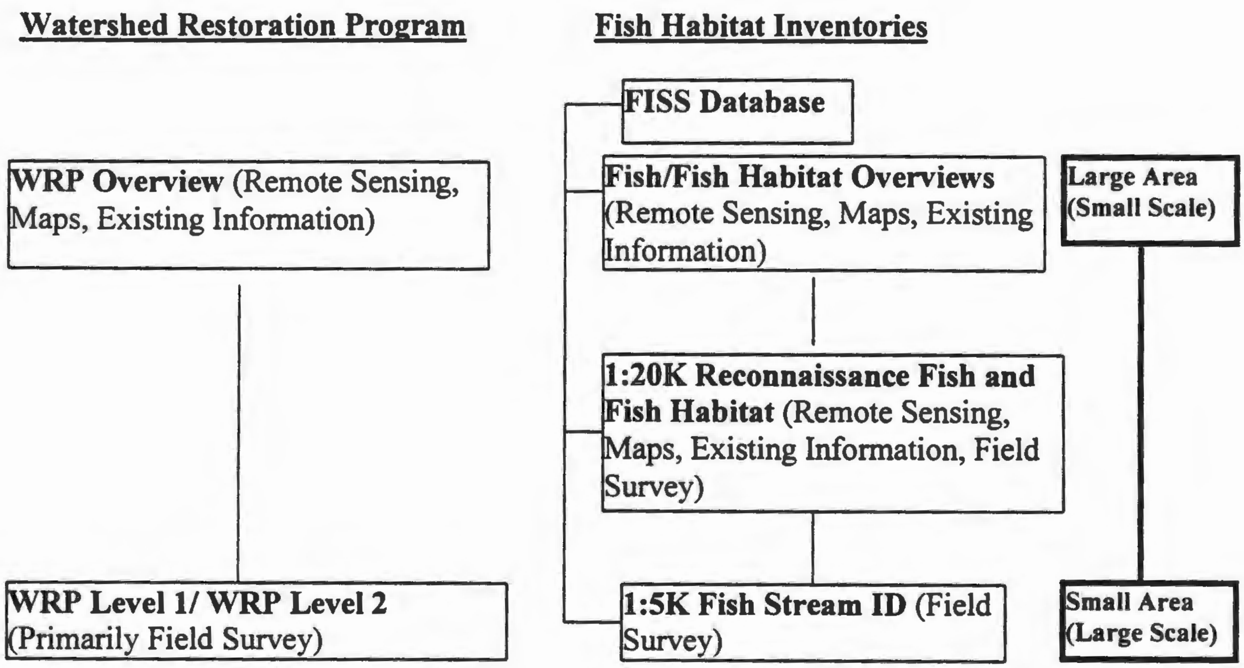

Figure 1: Physical fish-stream habitat inventories performed in British Columbia, their relative spatial scales, and inventory methodology (in parentheses). The Fisheries Information Summary System (FISS) is a provincial database and the Watershed Restoration Program (WRP) is a province-wide directive focussing on stream rehabilitation.

Watershed Level (Overview Surveys)

Physical information gathered at the watershed level consists of factors that impact the entire drainage such as flow stability, geology, and soil characteristics, and other anthropogenic factors such as land use and man-made dams (Osborne et al. 1991; MOELP 1997). These inventories typically indicate whether more intensive levels of assessment are required, and in which reaches or stream segments these more intensive assessments should occur (Johnston and Slaney 1996).

The primary information sources and inventory tools for these inventories are fisheries databases (Fisheries Information Summary System or FISS), remote sensing (aerial photographs/aerial videography), large scale maps (i.e., 1:20, 000 to 1:50 000), previous inventories, and literature surveys (Meidinger and Pojar 1991; McPhail and Carveth 1993; MOELP 1997). In British Columbia two inventories which examine streams at the watershed scale are the Fish and Fish Habitat Overview Inventory and the WRP Overview Assessment (Johnston and Slaney 1996; MOELP 1997).

Fish and fish habitat overview inventories are required primarily for prioritizing watersheds for more detailed inventories and for gathering cursory field information in geographical areas where very little is known (Johnston and Slaney 1996; MOELP 1997). Information gathered in these inventories generally covers very large areas (i.e., multiple watersheds) and is important in defining variables such as field crew access, preliminary reach delineation, general morphological features, and fisheries-sensitive zones (MOELP 1997).

Overview assessments performed by the WRP of British Columbia focus on altered stream segments and potential fish enhancement locations (Johnson and Slaney 1996). The gathered information is used to identify watersheds of interest, to assemble existing information about streams within each watershed, to identify stream reaches, to determine habitat conditions at an overview level, to identify areas of concern, and to aid in the generation of rehabilitation strategies (Johnson and Slaney 1996).

Channel Level (Reconnaissance surveys)

Physical information gathered at the channel level consists of information on channel morphology, riparian zone vegetation and width, and stream reach summary information, such as percent pools and percent fish cover (Osborne et al. 1991; MOF 1995a; MOF 1996; MOELP 1997).

The primary information sources and inventory tools for these inventories are fisheries databases (i.e. FISS), remote sensing (aerial photographs/aerial videography), large scale maps (i.e. 1:20, 000 to 1:50, 000), previous inventories, literature, and field assessments. In British Columbia two inventories which examine streams at this scale are the channel assessment procedure and the 1:20, 000 reconnaissance fish and fish habitat inventory (MOF 1996; MOELP 1997).

Both the Forest Practices Code and WRP require channel assessments to be completed to identify disturbed stream channels (MOF 1996). Information gathered in this assessment includes specific reach delineation, classification of channel reaches, channel width and length, channel morphology, and general watershed level characteristics such as channel coupling (MOF 1996).

The 1:20, 000 reconnaissance fish and fish habitat inventory is intended to provide general information on fish populations and habitat that is required for planning more intensive inventories and for resource planning at the individual watershed level (i.e. Forest Development Planning) (MOELP 1997). The information is gathered at all scales and includes the review of existing information and overview inventory data, the identification and location of stream reaches and lakes via maps, air photos, and aerial videos, the development and completion of a field inventory program to gather channel and habitat level information, and the entry of data onto a FISS database (MOELP 1997).

Habitat Unit Level (Detailed surveys)

Detailed inventories are performed at the habitat and microhabitat scale, and are derived primarily from the collection of field data. The type of information gathered at this scale is very detailed and includes such variables as the dimensions of each habitat unit (i.e., pools), stream discharge, and bank height, and includes collection of information at the channel level such as riparian vegetation, crown closure, and total cover provided (Johnston and Slaney 1996). The traditional methodology for gathering this field level information requires visual estimation and equipment such as an eschelon tape, stadia rod, and flow meter (Johnston and Slaney 1996).

One inventory that uses information gathered at this level of detail is the WRP level 1 fish habitat assessment (FHAP) which provides further information on selected stream reaches (Johnston and Slaney 1996). This inventory is comprised primarily of field sampling at the stream reach level, dividing each reach into distinct, naturally-occurring habitat units such as pools, glides, riffles, and cascades, and recording other features such as wetlands (Hawkins et al. 1993; Johnston and Slaney 1996).

Selection of a Habitat Inventory

Spatial scale, temporal scale, species distribution, features to inventory, the time available for the inventory, and cost should be considered when choosing a particular fish habitat inventory (Washington Forest Practices Board 1993; Johnston and Slaney 1996).

The spatial scale at which the analysis is focused is the initial consideration in choosing an appropriate habitat assessment (Washington Forest Practices Board 1993). Classification systems derived from inventories, for example, are frequently used to aid in describing habitat conditions and channel response at the reach scale, whereas limiting factors are more appropriately approached at the watershed scale (Reeves et al 1989; Beechie and Sibley 1990; Washington Forest Practices Board 1993).

The temporal scale of the inventory is an important consideration for fish habitat inventory (Osborne et al. 1991). Most inventory programs generally restrict sampling to warm months of low stream flow. This may limit the successful identification of a limiting habitat variable if it is temporally out of phase with the sampling time (Osborne et al. 1991).

Multiple species management should also be considered in inventory methodology (Washington Forest Practices Board 1993). In many habitat assessments, the efficiency of the inventory can be increased by focusing the analyses on the particular habitats of identified target species (Johnston and Slaney 1996).

Selection of an appropriate subset of stream features to survey must be based upon logistical constraints, empirical determination of the critical stream features for that region, and intended uses of the survey data (Oswood and Barber 1982). At one extreme, the most accurate and reliable inventory is a complete count and measurement of all habitat units in a watershed. This is impractical for all but very small or experimental streams (Dolloff et al 1997). Fisheries managers in each region must balance the costs of obtaining data on various stream features and the time needed to obtain the data, against the predictive capabilities required of that data (Oswood and Barber 1982).

A common method of obtaining a subset of physical stream habitat data is to sub-sample sections of a stream. Stream reaches, defined as a "homogeneous segment of a drainage network, characterized by uniform channel pattern, gradient, substrate, and channel confinement" (Johnston and Slaney 1996), within a watershed are identified using overview assessments. Ground sample sites are then randomly selected using the formula $y = 500\ (x^{-0.8})$, where x is the number of reaches of a certain group, and y is the sampling proportion (MOELP 1997). Typical errors for estimation of total fish abundance arise mainly from extrapolation from a small number of sampled stream sections to an entire stream reach. These errors can be reduced through choice of sampling design. For example, Hankin and Reeves (1988) recommend visually estimating all habitat units within a reach and systematically (e.g. 1 in 6) sampling habitat units from this stratum to correct visual survey bias.

Inventory Location

Fish habitat inventories are performed on streams in areas of proposed development or forest harvesting, in areas that have been damaged or altered due to anthropogenic or natural causes, in locations proposed for enhancement, in areas with sensitive/endangered species, and in remote locations where resource information is inadequate or unknown (MOF 1995a; MOF 1996; MOELP 1997).

Effective Inventories

Habitat models and stream classifications based on inventory data are only as good as the inventory information gathered. If the inventory data are incomplete or inaccurate, the model or classification will undoubtedly be incomplete or inaccurate (Reeves et al 1989). Conversely when sampling methods are applied carefully, consistently, and to the full extent of their capabilities, maximum precision is achieved (Hamilton and Bergersen 1984).

An effective fish habitat inventory must contain the following four features.

1. **The accurate identification of habitat features**. Many habitat features are visually estimated or interpreted in a habitat inventory, since more accurate methods are unavailable or too time consuming and expensive (Oswood and Barber 1982). Examples of visually estimated features include habitat units (e.g. pools and riffles), substrate composition, percent fish cover, and percent crown closure (Anon. 1995; Roper and Scarnecchia 1995; Wang et al. 1996). The accuracy and precision of visual habitat estimation, recorded by surveyors on stream banks or by aerial photographs, have not been extensively investigated but can be expected to vary with investigator experience, with the inventory technique, and with the number of habitat types (Hankin and Reeves 1988; Oswood and Barber 1982; Osborne et al. 1991; Hawkins et al 1993; Roper and Scarnecchia 1995). Inventory techniques must be repeatable over time and in relation to other survey teams (Oswood and Barber 1982; Simonson et al. 1994).

2. **Accurate georeferencing of the stream, stream reach (segment), and/or significant morphological features**. Georeferencing facilitates a return to the site at a later date, documents the habitat frequency and location in relation to other habitat features, and facilitates the monitoring of morphological changes over time due to anthropogenic or natural disturbances (Anon. 1995; MOELP

3. **Accurate and reliable habitat feature recording methods**. This is usually comprised of a table of features or feature description software (Anon. 1995; MOELP 1997). One of the most important roles in habitat assessments is that of the recorder, which may be synonymous with crew chief. This person must understand the data organization and is responsible for efficient, complete data collection (Hamilton and Bergersen 1984).

4. **A data storage mechanism**. The ability of fisheries managers to easily access and extrapolate inventory information is essential in all fisheries inventories. This inventory data can provide information on the relative quality and quantity of habitat available for fish within a stream or serve as an information base for further analysis facilitating communication amongst researchers and managers (e.g. classifications, modeling) (Hawkins et al 1993; Simonson et al. 1994).

Remote Sensing

Remote sensing is a technique for obtaining information about objects by analyzing data collected from instruments which are not in direct physical contact with the objects under study (Lillesand and Kiefer 1987; Ham 1996). The measurement of electromagnetic reflectance from airborne platforms is a widely accepted technique for mapping, inventorying, and monitoring earth resources (Lillesand and Kiefer 1987; Ham 1996). Measurement devices for this work include satellites (electro-optical scanners), radar, and film exposed with video recorders or still-frame cameras (Greer 1993).

Remote Sensing and Fish Habitat Inventories

Field techniques are the most widely recognized method for collecting stream channel and habitat data, and are frequently the only choice available for the collection of data that require in situ measurements such as water chemistry (Ham 1996). There are numerous techniques for habitat feature measurement, interpretation, and classification that do not require in situ measurements (Anon. 1995; Ham 1996; MOELP 1997). Remote sensing can increase the efficiency of fieldwork, can be relatively inexpensive and easy to conduct, and can provide data in a shorter time period than ground assessments (Bobbe et al. 1993; Greer 1993; Ham 1996).

British Columbia habitat inventories use two forms of remotely-sensed information, aerial photographs and aerial videography (MOF 1995a; Johnston and Slaney 1996; MOF 1996; MOELP 1997). Aerial photography is currently used for fish habitat inventories in conjunction with topographic and forest cover maps. Information on watershed boundaries, stream order, reach delineation, stream access points, and forest cutblock location is gathered at both the watershed and channel level (MOF 1995a; Ham 1996; MOF 1996; MOELP 1997). Some resource biologists do not feel comfortable with the channel level information gathered using aerial photography due to the height of the survey platform (e.g. 15, 000 feet) (W. Cooper, Ministry of Environment, Lands, and Parks, personal communication). Aerial videography is used to help supplement this watershed and channel level information, especially in remote areas where mapping and aerial photography information is outdated or nonexistent (Myhre et al.1990; MOF

1995a; MOF 1996; MOELP 1997; T. Zimmerman, Ministry of Environment, Lands, and Parks, personal communication).

Satellite imagery is generally not used in fish habitat inventories because of the relatively small scale and low resolution of the image data. The maximum image resolution for the Canadian Radarsat and SPOT satellite series, for example, is 10m, while LANDSAT satellites can at best achieve 15m image resolution (Lillesand and Kieffer 1987; Um and Wright 1998). Conversely, aerial photographs can achieve resolutions of less than one metre with 1:20, 000 scale photography (Lillesand and Kieffer 1987). In addition, satellite imagery is most often two-dimensional, whereas aerial photographs and aerial videography reveal relief information through the use of stereoscopes and oblique camera angles, respectively (Lillesand and Kieffer 1987). Furthermore, most of the available satellites with reasonable spatial resolution have been designed with land surveys in mind, so that the number and distribution of spectral channels and the range of brightness are not optimal for water studies (Hilton 1984).

Aerial Videography as a Fisheries Inventory Tool

A variety of video systems have been developed to collect natural resource data including multi-band video, colour infrared, and other modifications to video cameras (Sidle and Ziewitz 1990). Aerial videography applications in British Columbia include biophysical inventories in support of oil spill contingency planning, stream inventory surveys in support of habitat characterization, forest cut-block planning, forest health surveys, shellfish habitat inventories, powerline surveys, and coastal charting (Harper and Reimer 1995).

Aerial videography involves taking continuous overlapping frames of an area from an airborne platform and recording the image data on videotape (Ham 1996). This technique has gained in popularity over the past ten years due primarily to recent innovations which have resulted in more compact and inexpensive cameras, recorders, and monitors with higher resolution, making them more practical for use in resource management (Sidle and Ziewitz 1990; Harper and Reimer 1995).

Aerial video data can be broadly classified into three groups that are similar to the aquatic survey standards for fisheries inventory: overview surveys (watershed level), reconnaissance surveys (channel level), and detailed inventory surveys (channel and possibly habitat unit level) (Ham 1996).

Overview surveys are based on images which have no scaling or georeferencing and therefore cannot be used to make spatial measurements such as distance or area (Harper and Reimer 1995; Ham 1996). Reconnaissance surveys are based on images that can be scaled, but generally have no georeferencing (Harper and Reimer 1995; Ham 1996). If the scale of the image can be determined, reconnaissance surveys may be used to obtain planimetric data such as reach length and channel width, but this procedure has not been tested or evaluated (Ham 1996). Detailed inventory information can in theory be used for planimetric mapping because both scaling and georeferencing of the image is known.

This detailed information may be accurate for recording channel features and habitat unit level mapping, but this procedure has not been tested or evaluated (Harper and Reimer 1995; Ham 1996).

Advantages and Disadvantages of Aerial Videography

There are three main advantages of aerial videography over ground techniques: the ability to provide information in a short period of time compared to labour- and time-intensive ground survey techniques; the ability to record a permanent visual image of the stream that can be analyzed later with optical, mechanical, or electronic devices not available in the field; and the low cost per survey kilometre for an aerial survey compared to ground surveys (Mussakowski 1984; Greer 1993; Ham 1996). Additional advantages associated with aerial videography include the flexibility to use a wide variety of aircraft, the ability to view images in real-time, the relatively cheap image acquisition compared to other survey techniques (such as aerial photography), the ease of processing the video in foreign countries where aerial film processing may be difficult to obtain, the ability to include audio narration and GPS positions on the videotape which enhance the interpretive quality of the imagery, and the ability to tailor imagery to a particular application (Everitt et al 1988; Ham 1996; Harper and Reimer 1995; Myhre et al 1990). Furthermore, the video output can be viewed on a video monitor, an ordinary television, or can be converted to digital form. These images can be easily interpreted by the lay-person, because the oblique video image provides a three dimensional image that is similar to the view from the window of an aircraft (Ham 1996; Harper and Reimer 1995; Sidle and Ziewitz 1990)

Current disadvantages of aerial videography include the relatively low image resolution (1-2 metres with a camera height of 1000 metres) compared to aerial photography (0.08 metres with a camera height of 1000 metres), the narrow ground area covered which can limit the utility of the technique on larger rivers, the initial capital expense of the survey equipment, and the need for specialized equipment to provide accurate scaling, georeferencing, and measurement (Mussakowski 1984; Everitt et al 1988; Harper and Reimer 1995; Ham 1996; Seibert et al 1996). The lack of scaling, georeferencing, and measurement at the overview level and in some reconnaissance level aerial surveys means that these data cannot be measured or digitized at all, and users may have difficulty in the future tying images together or locating previously surveyed areas (Harper and Reimer 1995; Ham 1996). Two disadvantages that are often overlooked when considering aerial imaging of streams are the restricted ability to interpret stream habitat through dense crown closure and the interpretive error associated with the surveyor.

The Information Gap

One historical disadvantage of all visual inventory techniques is the interpretive error and bias associated with the surveyor (Osborne et al. 1991; Hawkins et al 1993). This issue has not been a significant problem with aerial videography in the past because only major, easily interpreted stream features that could be verified by viewing the videotape in an office setting were surveyed (Harper and Reimer 1995; T. Zimmerman, Ministry of Environment, Lands, and Parks, personal communication). Quantitative information pertaining to the accuracy of aerial videographic surveys to record stream fish habitat information has not been gathered to date. In addition, recent technological advancements, specifically higher resolution video equipment and GPS "position-tagging" software enabling the georeferencing of specific features, have potentially increased the accuracy of identification and location, and increased the scale of stream features that can be surveyed using aerial videography. An assessment is required to evaluate the accuracy of identification and location, and associated costs of an aerial videographic survey to gather stream features.

Hypotheses

This study evaluated the accuracy of identification and locational accuracy of an aerial videographic survey to identify stream features by addressing nine hypotheses. I also investigated uses of the video portion of the aerial videographic survey and tracked the aerial survey costs compared to ground survey costs.

Assessment of Accuracy of Stream Feature Identification

Ho1 - The *identification* of stream features is not different for unmodified and modified aerial surveys than the *identification* of stream features from the ground.

Ho2 – The modification (i.e. the data obtained visually from the helicopter are reviewed and corrected on the basis of a post collection review of the video images) of an unmodified aerial survey does not change the *identification* of stream features compared to the *identification* of stream features from the ground.

Ho3 - Watershed does not influence the accuracy of *identification* (i.e. the percentage of stream features correctly identified) of stream features from a modified aerial survey compared to the *identification* of stream features from the ground.

Ho4 - Stream order does not influence the accuracy of *identification* of stream features from a modified aerial survey compared to the *identification* of stream features from the ground.

Ho5 - The type (and scale) of stream features does not influence the accuracy of *identification* of stream features from a modified aerial survey compared to *identification* of stream features from the ground.

Locational Accuracy

Ho6 - The *location* of stream features identified from a modified aerial survey is not different than the *location* of stream features from the ground.

Ho7 - Watershed does not influence the differences between the *location* of stream features from a modified aerial survey compared to the *location* of stream features from the ground.

Ho8 - Stream order does not influence the differences between the *location* of stream features from a modified aerial survey compared to the *location* of stream features from the ground.

Ho9 - The type (and scale) of stream features does not influence the differences between the *location* of stream features from an aerial survey compared to *location* of stream features from the ground.

Preliminary Evaluation of Video to Make a WRP Level 1 Fish Habitat Assessment

In addition to the nine hypotheses above, I performed a preliminary evaluation to determine whether fish habitat characteristics identified using only the aerial video can be used as the basis for a Watershed Restoration Program Level 1 Fish Habitat Assessment.

Cost Comparison

I tracked the cost to perform an aerial videographic survey per kilometre of stream and the cost to perform a ground survey per kilometre of stream to investigate whether differences existed between these two survey techniques.

Chapter Three:

Methods

Study Areas

The present research was conducted as part of a larger 900-kilometre stream inventory of the Mackenzie Timber Supply Area (TSA). In this larger inventory, all watersheds in the Mackenzie TSA were aerial surveyed with a helicopter in 1998 as part of an aerial inventory contract for Slocan Forest Products, with funding from Forest Renewal British Columbia. This 900-kilometre area within the Mackenzie TSA can be generally divided into a northern and a southern region based upon geographical location. The northern area has generally higher stream elevations above sea level, well-confined rivers and streams, and steeper stream gradients. The southern area is generally characterized by lower stream elevations, less-confined rivers and streams, and lower stream gradient (Figure 2).

The three largest aerial surveyed watersheds within the northern and southern survey areas were selected for comparison: the Del Creek, Paul River, and Pack River watersheds. These particular watersheds were selected because each watershed was completely surveyed from the air, each offered vehicular access for the ground survey crew, and collectively they represented the diversity of watersheds and habitat types in both the northern and southern survey areas.

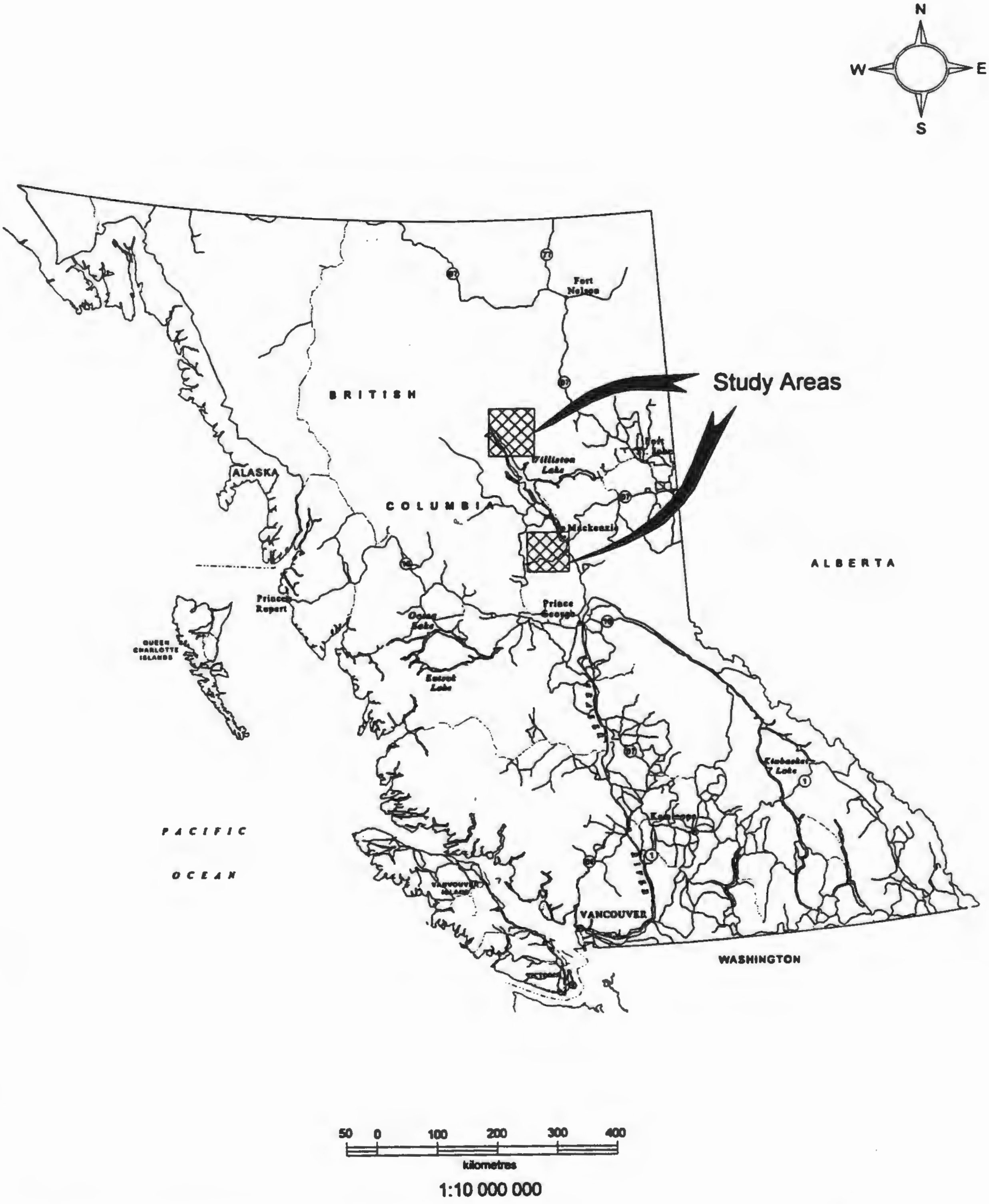

Figure 2: Location of northern and southern study areas for ground survey in British Columbia.

Del Creek is located in the Lower Akie landscape unit of the Mackenzie TSA, south of Buffalo Head camp and the community of Fort Ware (Figure 3). This 4^{th}-order drainage, at the 1:50, 000 scale, flows south through the Muskwa Ranges of the Rocky Mountains into the Finlay River. The 375 square kilometre drainage is characterized by confined, high gradient tributaries flowing into a low gradient, occasionally confined, valley with numerous wetlands. The maximum elevation in the Del Creek watershed is 2, 000 metres above sea level, draining to the confluence with the Finlay River at 700 metres above sea level.

The Paul River watershed is located in the Paul landscape unit of the Mackenzie TSA, between the Del Creek and Buffalo Head camp (Figure 3). This 5^{th}-order system, with a drainage area of 1, 125 square kilometres, is also located in the Muskwa Ranges of the Rocky Mountains and is characterized by high gradient streams and steep topography with elevations exceeding 2, 100 metres above sea level.

The Pack River is located in the Tudyah landscape unit of the Mackenzie TSA, between the communities of McLeod Lake to the south and Mackenzie to the north (Figure 3). This 6^{th}-order drainage is relatively unconfined and drains the interior plateau of the Rocky Mountain Trench north into the Parsnip Reach of the Williston Reservoir. Note that only the 1^{st}-5^{th}-order streams were used for data comparison. The 6, 500 square kilometre area, characterized by low gradient streams and numerous lakes, has a range of elevation from approximately 670 metres at the river confluence with Williston Reservoir to 1, 300 metres above sea level. Major sub-basins of the Pack River include the McLeod

River, McDougall River, and Crooked River as well as August, Des, Holder, and Reed creeks.

A stratified random sampling of the aerial surveyed streams was used to select sites for ground surveys. Site selection was designed to maximize survey crew efficiency and to include replicates for each stream order within each watershed. To select ground sample sites, an independent biologist used 1:50, 000 topographic maps to initially delineate the survey area into watershed boundaries and stream orders. Stream segments that were further than 500 metres from road access were excluded from the sampling to ensure reasonable ground access to sample sites. On the remaining streams, potential sample site locations were labeled as 500 metre segments on the 1:50, 000 topographic map and numbered. Two sample sites per stream order per watershed were then randomly chosen. This stratified random sampling procedure was modified in the following way. If a selected stream segment was within 100 metres of a "Bridge" or "Culvert" then the selected stream segment was shifted to include this feature at one end of the segment. This modification was considered not to seriously impact the evaluation of the survey technique and provided an easily identified feature for matching between air and ground surveys. A total of four sample stream segments were modified in this way. Each ground survey sample site was 500 metres long as measured on the ground by hip chain. The resulting 28 sample sites chosen for ground assessment were the experimental sites for this study and are represented in Figure 3.

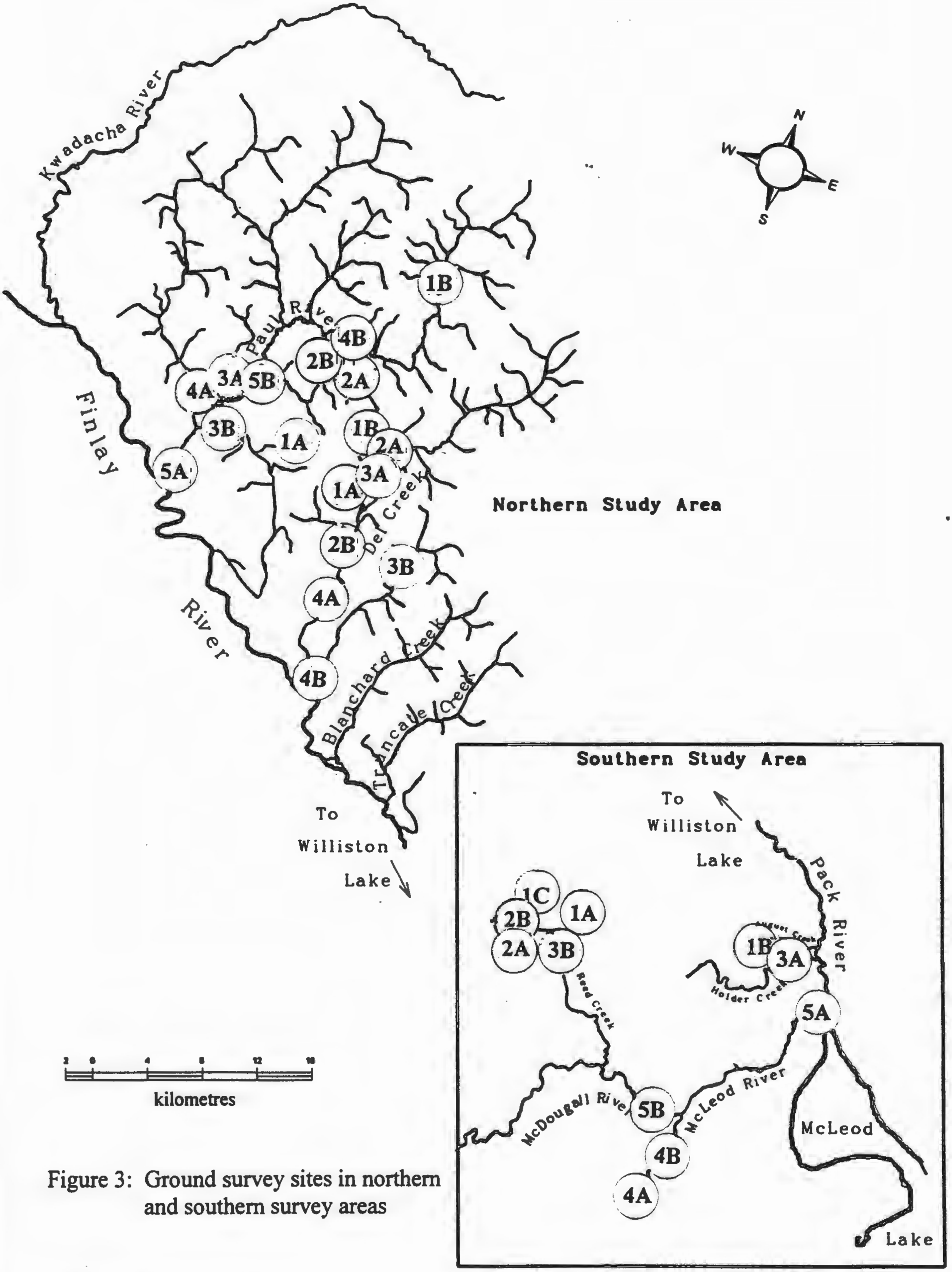

Figure 3: Ground survey sites in northern and southern survey areas

Survey Methodology

Aerial Survey

The aerial videographic survey technique to identify stream features was based on the "Aerial Photography and Videography Standards for Fish Habitat Channel Assessment" (Ham 1996) with some modification. In this process, an R44 Astro helicopter was equipped with a Global Positioning (GPS) video system for Hi-8 video capture. This system used an electronically stabilized video camera that was externally mounted on the helicopter, and was equipped with remote focus, iris, and zoom controls that were located in the helicopter cabin. A video recorder located in the rear seat of the helicopter was installed in an aluminum bracket equipped with rubber mounts to eliminate blurring effects or shudder due to aircraft vibration (S. Hills, Terra•Pro GPS Surveys Inc., personal communication; Sidle and Ziewitz 1990). GPS coordinates were captured with an eight channel Trimble Pro-XL GPS receiver capable of 30 metre accuracy (prior to differential correction) mounted to the boom of the helicopter.

The survey crew consisted of the aerial stream surveyor and pilot in the front seats of the helicopter and a technician in a rear seat. Stream features from a predetermined list, as specified by a Ministry of Environment contract monitor prior to the inventory, were identified by the aerial surveyor as the pilot flew over streams in the Mackenzie TSA watersheds. This stream feature list included habitat features important to fish such as "Pools", "Riffles", and "Large Organic Debris", and other stream features important to habitat inventories such as "Culverts" and "Bridges" (Table 1). The survey crew worked in an upstream direction 30-50 metres above the ground at 50-70 kilometres per hour.

Table 1: Stream features identified at each inventory scale. Table excerpted from Osborne et al. 1991.

Features	Watershed	Channel	Habitat Unit
Length			Yes
Width			Yes
Depth			Yes
Discharge			Yes
D_{90}			Yes
Compaction			Yes
Bank Height			Yes
Bank Texture			Yes
Habitat Unit			Yes
Substrate Type		Yes	Yes
Substrate Size		Yes	Yes
Undercut Banks		Yes	Yes
Unstable Banks		Yes	Yes
Stream Cover		Yes	Yes
Reach Delineation		Yes	
Channel Morphology		Yes	
Percent Pools		Yes	
Large Woody Debris Abundance and Distribution		Yes	
Riparian Vegetation		Yes	
Width of Riparian Zone		Yes	
Crown Closure		Yes	
Channel Gradient		Yes	
Channel Confinement		Yes	
Valley: Channel Ratio		Yes	
Aspect	Yes	Yes	
Watershed Boundary	Yes		
Watershed Land Use	Yes		
Watershed Geology	Yes		
Watershed Soils	Yes		
Flow Stability	Yes		

Rudder turns were employed on stream bends to maintain a horizontal aspect over the stream and to keep the stream in view at all times. It was not always possible to keep a level picture due to extreme river meandering, tail winds, and a lack of aircraft power.

The GPS coordinates of the helicopter were superimposed onto the video image continuously during the inventory. The surveyor's audible identification of the stream features was recorded onto the videotape using the helicopter headset microphone with a feed to the video recorder. The technician, equipped with a headset to hear the audible feature identifications, used a touch-pad notebook computer with "Aspen Field Inventory" software to record the stream feature and GPS position (S. Hills, Terra•Pro GPS Surveys Inc., personal communication). The data recording software permitted ten stream features to be present on the computer screen viewed by the technician. The survey team selected the ten features that were they thought would be frequently encountered within the survey such as "Large Organic Debris", "Pools", and "Riffles". One of these features was designated as "X" points, used when stream features were identified by the surveyor but entered as an "X" in the database. In such instances, the technician was unable to keep up with the rate of the data flow due to the frequency of the stream features or other reasons such as air sickness. These ten features were easily "quick-marked" to the survey database with one touch of the computer touch-pad. The remaining features, which included the less frequent, larger features (e.g. "Bridges") required the technician to scroll the feature library for the feature of interest and then perform a "quick-mark" with the touch-pad.

The aerial survey was performed in the summer from August 7th, 1998 to September 1st, 1998, during low stream flows, in order to maximize the ability of the aerial surveyor to distinguish stream features that would be obscured by high water. The Hi-8 video produced by the survey was edited to remove extraneous video segments such as recordings of the ground as the crew flew to a fuel cache. The edited video was then copied to Super VHS video tapes for user convenience and future interpretation.

This aerial videographic survey methodology produced two products: a database of GPS-positioned stream features resulting from the surveyor's visual assessment and the corresponding data recording by the technician, and video images of the over-flown streams. The GPS positions of the stream features were differentially corrected and used to produce stream plot maps. These maps contained stream names, symbols identifying each stream feature, and "X" points. This database of stream features, "X" points, and associated GPS spatial positioning comprised the "unmodified" aerial data set. A "modified" aerial data set was produced by reviewing the video at a later date and replacing the "X" points on the stream plot map with the corresponding audio call of the surveyor on the video recording and correcting obvious surveyor mistakes. An example of an obvious mistake made during the survey that would be "corrected" during this modification was a mistaken call of "tributary left" when the tributary was actually on the right stream bank. This modification process was also used to provide a final quality assurance of the survey maps produced to ensure that streams were labeled correctly and that video time tags were inserted. Video time tags are small information symbols placed directly on the maps produced of the aerial surveyed watersheds to help resource managers match the map to a corresponding video segment (S. Hills, Terra•Pro GPS Surveys Inc., personal communication). After data modification using the video, both unmodified and modified aerial databases were converted into Microsoft Excel spreadsheet format.

Ground Survey

A ground survey crew, professionally trained and not affiliated with the aerial survey, conducted a ground survey of the stream features at each sample site. The ground survey was conducted within three weeks of the aerial survey (August 25, 1998 to September 21, 1998) to ensure that the stream features were not altered from the time of the aerial survey by high stream flows or anthropogenic activities. The ground crew recorded the stream features in each sample site using the same feature list specified in the aerial survey (Appendix 2). In addition, the feature GPS position was recorded using an eight channel Trimble Pro-XL GPS receiver capable of an accuracy of ± one metre (after differential correction). In larger streams that could not be traversed, the ground crew recorded stream feature GPS positioning from the stream bank and estimated the distance from the bank to the central point of the stream feature, called an "offset". This "offset" was recorded and used to adjust the GPS position during data processing.

The ground crew misidentified the location of one 1^{rst}-order stream sample site in the Paul River watershed and surveyed an adjacent stream that was not aerial surveyed. This error was detected after the ground crew demobilized from the area and the site was not surveyed. This stream was dropped from all subsequent analyses, resulting in 27 sites for data comparison.

Data Analysis

Comparison of Aerial Identified and Ground Identified Stream Features

The unmodified aerial survey, modified aerial survey, and ground survey data sets were plotted using the GPS coordinates associated with each stream feature. Feature symbols were used to visually distinguish stream features from one another (e.g. "Riffle" from "Pool Class 1") such that the unmodified aerial survey, modified aerial survey, and ground survey data were represented as a series of feature symbols along each stream sample site (Appendix 3). The unmodified and modified aerial survey data, plotted on mylar sheets, were then overlaid onto corresponding ground survey data plots for each sample site to match correctly identified aerial survey stream features with the ground survey stream features. The number of unmodified and modified stream features correctly "matching" ground stream features were then summarized for each sample site and each feature. The maximum distance between the aerial and ground surveyed features over which the features could be considered to be the same feature was set at 120 metres. For example, a "Pool Class 1" identified in the aerial survey that was greater than 120 metres from a corresponding ground "Pool Class 1" feature was deemed to be out of the "line-of-sight" for the aerial surveyor and was not classified as a correct identification. This 120 metre limit was chosen because it was the maximum locational error found for easily identified stream features such as "Bridges" or "Culverts" when comparing the aerial and ground data.

Initial Data Interpretation

Consistent discrepancies, that did not relate to the correct identification of the type of feature, existed between the modified aerial stream feature interpretation and ground crew stream feature interpretation of four types of features: "Bedrocks", "Riffles", "Slumping Banks", and "Wetlands". For "Bedrock", on three occasions, the aerial crew recorded "Bedrock Confinement" in the exact position that the ground crew recorded "Bedrock Outcrop" indicating that the same feature was recognized but identified slightly differently. For "Riffle", on three occasions, the aerial crew identified "Riffle Start" and "Riffle End" over the course of an extended riffle stream surface, while the ground crew recorded two or more distinct riffles over this same section. Similarly, on four occasions, the aerial crew documented "Slumping Bank Start" and "Slumping Bank End" that may have been recorded as multiple discrete "Slumping Bank" sections by the ground crew. In addition, in four instances, the aerial surveyor recorded "Wetlands Left" when the wetland was recorded on the right bank of the stream by the ground crew.

The interpretation of these differences affects the comparison of the accuracy of the two aerial survey methods and the reasons for inaccurate identifications. For example, one evaluation could reasonably be that it was not that the aerial surveyor failed to correctly identify the "Riffle" or "Slumping Bank", but rather the aerial surveyor did not enjoy the same degree of resolution needed to identify the less turbulent or non-slumping sections. In such instances, the identification of the feature could be considered "correct" because the physical type of feature was identified and only the structural details of the feature were in error. For the purposes of preliminary analysis, therefore, the comparison between the modified aerial data set and ground data was calculated in two ways using a "Definitive" data set in which the above examples *were not* recorded as correct identifications and an "Interpretive" data set in which the above examples *were* recorded as correct identifications. The number of stream features correctly identified for unmodified and modified aerial surveys were summarized for each of the 22 stream features in the survey. The entire data set consisted of 2,945 cases that were comparisons of a ground stream feature and corresponding aerial stream feature. Of these 2,945 cases, there were fourteen cases in which the "Interpretive" aerial data set recorded a correct identification and the "Definitive" data set recorded an incorrect identification. A Chi-Squared Goodness of Fit test was used to evaluate whether the correction of the data from "Definitive" to "Interpretive" significantly affected the frequency of stream features correctly identified. This discrepancy between data sets did not effect the evaluation of the percentage of correctly identified stream features for each aerial survey (Appendix 4.1). Therefore, the "Interpretive" data set was used for the remainder of the analysis.

Assessment of Accuracy of Stream Feature Identification

Accuracy was defined as the number of times a stream feature identified on the ground was identified as the same feature from the air, expressed as a percentage. The number of stream features identified correctly was summarized for each type of feature in each sample site for the unmodified and modified aerial survey data compared to the ground data. These percentages were then used to determine whether the aerial videographic survey accuracy to identify stream features was significantly affected by video modification, stream factors (i.e. watershed, stream order, and type of stream feature), or aerial surveyor training.

Video Modification

The significance of the effect of video modification on the accuracy of aerial stream surveys was determined by performing a 2 x 16 Chi-Squared Goodness-of-Fit Test comparing the frequency of unmodified and modified features correctly identified across the 22 feature types identified in the survey. Notice that for six of the stream features the unmodified and modified features correctly identified were zero and therefore could not be included in the analysis because the Chi-Squared statistic for these features would have been calculated by dividing by zero. The video-unmodified features correctly identified were treated as expected values and the video-modified features correctly identified were treated as observed values. The modified data set was used for the subsequent statistical analyses because this modified data set was the final digital product submitted to the Ministry of Environment, Lands and Parks and Slocan Forest Products as part of the aerial inventory contract requirements and is the normal product of similar surveys.

Stream Factors

To identify whether the accuracy of aerial stream feature identification was statistically influenced by watershed, stream order, or the type of stream feature, the data were summarized into the mean proportion of stream features correctly identified by each feature within each stream order and watershed. The proportional data were transformed using the formula $\sqrt{(\ln(\text{proportion correct} + 1)}$ to normalize proportional data (Menard 1996) and subjected to an analysis of variance (ANOVA) with watershed, stream order, and stream feature as main effects (Appendix 4.3). Examination of the data revealed that this full ANOVA resulted in a number of empty cells because of a failure of some stream features to appear in some stream orders (e.g. "Bridges" do not appear in lower stream orders) resulting in lost degrees of freedom during the analysis. Thus, only stream features with 26 or more occurrences or identifications by the ground survey crew over the entire survey were included in the analysis. This number of occurrences was chosen to include the maximum number of stream feature types (levels) in the analysis and to select those features that were represented in most stream sample sites. The nine stream features thereby included in the ANOVA were "Beaver Dam", "Gravel Bar", "Large Organic Debris Class 1", "Large Organic Debris Class 2", "Pool Class 1", "Pool Class 2", "Pool Class 3", "Riffle", and "Slumping Bank" features.

The Pack River and Paul River watersheds contained 5th-order or higher stream segments, but the Del Creek watershed did not contain streams higher than 4th-order. Therefore, the analysis was conducted with only 1st- to 4th-order stream segments. The resulting model was a completely randomized factorial design with the factors watershed, stream order, and stream feature and three levels, four levels, and nine levels, respectively.

Aerial Surveyor Evaluation

Training Effect on Accuracy

The effect of observer training on aerial survey accuracy was examined by evaluating the percentage of stream features correctly identified across inventory day using a linear regression with inventory day as the explanatory variable and the percentage of stream features correctly identified as the response variable. Other factors that were significant in the accuracy of stream feature identification, such as stream order and feature, were not included in the analysis because inventory day was nested across stream orders and stream features.

Variation Among Aerial Surveyors

To evaluate the adequacy of the main aerial surveyor for this study three sample sites in the Pack River watershed were subjected to a second aerial survey using a second experienced aerial surveyor. The accuracy of stream feature identification for this second survey was calculated as before and compared to the values obtained by the main study aerial surveyor using a 2 x 3 Chi-Squared Goodness-of–Fit test using accuracy results from the two aerial surveyors as the two rows and the three sample sites as columns. The number of stream features correctly identified by the second aerial surveyor were treated as expected values and the number of features correctly identified by the main aerial surveyor were treated as observed values.

Locational Accuracy

The aerial locational accuracy of each stream feature based on aerial GPS was calculated, initially, by separating correctly identified aerial features into two categories: aerial features which had precisely known corresponding ground features and those features for which there were two or more possible corresponding ground features. The locational error of aerial stream features which had precisely known corresponding ground features was calculated by subtracting the aerial GPS position from the ground GPS position using the formula: Locational Error (in metres) = $\sqrt{((X_{air} - X_{ground})^2 + (Y_{air} - Y_{ground})^2)}$

where “X” was the Universal Transverse Mercator easting value for each aerial feature and the corresponding ground feature and “Y” was the northing value for each aerial feature and the corresponding ground feature.

An ANOVA was conducted with these values to determine the effects of watershed and stream order on locational error. Fifteen stream features were summarized with precisely known locational errors: “Beaver Dams”, “Bedrocks”, “Boulder Clusters”, “Bridges”, “Culvert Crossings”, “Gravel Bars”, “Islands”, “Large Organic Debris Classes 1 and 2”, “Pool Classes 2 and 3”, “Riffles”, “Slumping Banks”, “Tributary Left”, and “Wetlands”. However, there was insufficient representation of each of the stream features in each of the stream orders to include feature as a factor in this analysis. As with previous analyses using watersheds, the levels of stream order was restricted to four to reduce the empty cells in the analysis because the Del Creek watershed did not contain streams higher than 4^{th}-order. The resulting model was a completely randomized factorial design with two factors, watershed and stream order, with three levels, and four levels respectively.

The minimum locational error for stream features for which the precise ground feature was unknown (i.e. there were two or more possible corresponding ground features) was determined by calculating the distance from the aerial feature location to all possible ground features within the 120 metre limit and selecting the minimum of these values. These minimum locational errors were averaged to yield the mean minimum locational errors for these types of features.

Preliminary Evaluation of Video to Make a WRP Level 1 Fish Habitat Assessment

A single 5th-order stream sample site on the Paul River (Paul 5a) was chosen to assess the potential for using only the aerial video to conduct a WRP Level 1 fish habitat assessment. This segment was selected for assessment in this way because it was representative of the type of stream on which a WRP level 1 assessment would be performed, and because larger streams in the Mackenzie TSA have less relative crown closure and therefore stream habitat is less obscured from the air. In order to conduct a WRP level 1 fish habitat assessment using only a video image, the assessment procedures described in the Fish Habitat Assessment Procedures (FHAP) by Johnston and Slaney (1996) were slightly modified. Initially, a schematic of the stream sample site was drawn including major features and habitat units (Figure 5.A, Appendix 5). Each of the habitat variables were subsequently calculated as described below.

Aerial WRP Level 1 Fish Habitat Assessment Methodology

Percentage Pools

Pools identified using the video were marked on the sample site schematic and the area of each pool was estimated (Table 5.A, Appendix 5). For this particular sample site, the wetted width of the stream was estimated to be 15 metres by the aerial surveyor (recorded on the audio track of the video). The wetted area was calculated by multiplying this width by the sample site length of 500 metres. The percentage of pool area within the sample site was calculated by totaling the pool area for the sample site and dividing by the total area of the sample site (multiplied by 100%). The wetted width of the stream as estimated above, combined with a visual approximation (from the video) of a stream gradient of less than 2%, allowed the pool quality to be predicted from Table 5.A as identified in the FHAP procedures (Appendix 5).

Pool Frequency

The pool frequency (expressed as the mean pool spacing) was calculated by initially estimating the linear distance between each pool and dividing by the wetted stream width (15 metres). The stream was then rated for pool frequency quality using the guidelines from Table 5.A (Appendix 5), for a stream with less than a 2% gradient and 15 metre width.

Large Woody Debris Pieces per Channel Width (for entire sample site)

The number of large woody debris pieces were marked on the schematic drawing of the stream sample site (Figure 5.A, Appendix 5). Debris pieces were also labeled as *functional* if they influenced the channel geomorphology by causing channel scour or impoundment (Johnston and Slaney 1996). The total number of pieces divided by the sample site length divided by the estimated width was calculated and compared to the rating guidelines provided in Table 5.A (Appendix 5). For this large woody debris pieces per channel width calculation the wetted width was used instead of the channel width.

Percent Wood Cover in Pools and Holding Pools

The percent wood cover in pools was estimated by reviewing the video and by visually determining whether large woody debris was present in each pool. In addition, the presence of large pools was recorded.

Dominant Substrates and Gravel Quality

The dominant substrates and presence of gravel within the stream channel were estimated visually noting the substrate on the stream banks and attempting to view the substrate through the water surface.

Off-channel Habitat and Other Variables

The presence of off-channel habitat such as side channels, wetlands, sloughs (if present), and other characteristics such as canopy closure and canopy composition were subjectively estimated and recorded according to the percentage divisions provided in the FHAP procedures (Table 5.A, Appendix 5).

Ground WRP Level 1 Fish Habitat Assessment Methodology

To evaluate the aerial FHAP assessment, the ground crew performed an FHAP level 1 assessment on the 5^{th}-order Paul River (Paul 5a) sample site using the procedures specified in the FHAP technical circular to quantify the habitat characteristics and rate the quality of the sample site. The results of the aerial and ground FHAP assessments were compared as a preliminary evaluation of the ability to perform a WRP level 1 fish habitat assessment using only the video portion of these aerial surveys.

Cost Comparison

All costs associated with each phase of the aerial survey were documented during the course of the survey, summarized, and compared to the corresponding costs for each phase of the ground inventory. In addition, the total cost for each survey was divided by the corresponding kilometres of streams surveyed to compare the survey cost per kilometre of stream inventories.

Chapter Four:

Results

Assessment of Accuracy of Stream Feature Identification

Only 22 of the possible 35 stream features were observed in the present study and recall that "Bedrock", "Riffle", "Slumping Bank", and "Wetland" features were truncated (see *Initial Data Interpretation* pg. 46) (Table 2). The overall mean accuracy of aerial videographic surveys in recording stream features was under 8% and ranged from 0% to 100%.

Table 2: The number and mean percentage (± SD) of stream features correctly identified by unmodified and modified aerial surveys for the entire aerial data set.

Stream Feature	**Number of Features Identified by Ground Crew**	**Number of Correctly Identified Features (Unmodified)**	**Number of Correctly Identified Features (Modified)**	**Percent Improved**	**Mean Accuracy (Modified Data; all Stream Orders)**
Backwater channel	23	0	0	0	----
Beaver dam	27	8	12	50.0	44.4 ± 50.63
Bedrock	13	5	5	0	38.5 ± 50.63
Boulder clusters	3	1	1	0	33.3 ± 57.74
Bridge	11	9	11	22.2	100 ± 0
Culvert crossing	5	5	5	0	100 ± 0
Fish barrier (probable)	1	0	0	0	----
Gravel bar	59	3	5	66.7	8.5 ± 28.09
Island	22	1	1	0	4.5 ± 21.32
LOD_class_1	1194	87	91	4.6	7.6 ± 26.55
LOD_class_2	217	17	17	0	7.8 ± 26.93
LOD_class_3	19	0	0	0	----
Pool class 1	173	8	8	0	4.6 ± 21.06
Pool class 2	513	21	21	0	4.1 ± 19.83
Pool class 3	103	8	9	12.5	8.73 ± 28.38
Reach break	17	0	5	**	29.4 ± 46.97
Riffle	465	12	14	16.7	3.01 ± 17.11
Side channel	20	0	0	0	----
Slumping bank	43	6	9	50.0	20.9 ± 41.16
Tributary left	3	1	1	0	33.3 ± 57.73
Tributary right	2	0	0	0	----
Wetland	12	4	7	75.0	58.3 ± 51.49
Overall	**2945**	**196**	**222**	**13.3**	**7.5 ± 26.41**

** The initial value was zero, therefore the percent improvement could not be calculated

Video Modification

The number of stream features correctly identified were as much as 75% higher for video- modified aerial survey data than video-unmodified aerial survey data, depending on the stream feature (Table 2). However, the frequency[1] of correctly identified stream features for video-unmodified and video-modified aerial survey data was not statistically different overall ($\chi^2 = 6.670$; $p > 0.05$).

Stream Factors

The mean percentage of stream features identified correctly varied significantly across the type of stream feature ($p = 0.0002$) and across stream order ($p < 0.0001$) for aerial surveys (Table 3). Watershed, however, was not a significant factor in the aerial identification of stream features. The effect size for this statistical analysis was 0.507, a large effect size according to Kirk 1996, and therefore statistical results should be detected with this analysis.

Table 3: Significant effects for the percentage of stream features correctly identified using an aerial survey. An ANOVA with watershed (3 levels), order (4 levels), and stream feature (9 levels) as factors respectively. (NS = Not Significant. ** = Significant; $p < 0.01$). The three-way interaction was pooled with the residual due to the empty cells in the ANOVA.

Effect	Degrees of Freedom	F-Ratio
Watershed	2	0.7782 (NS)
Order	3	**10.9215 (**)**
Feature	8	**3.8768 (**)**
Watershed*Order	6	**2.7997 (**)**
Watershed*Feature	16	**1.9983 (**)**
Order*Feature	24	**2.0671 (**)**

A Tukey-Kramer HSD post hoc test did not reveal significant differences ($p > 0.05$) between the stream features included in the statistical model (Figure 4).

[1] The frequency is stated here instead of percentage because the Chi-Squared Goodness-of-Fit test was performed on frequencies.

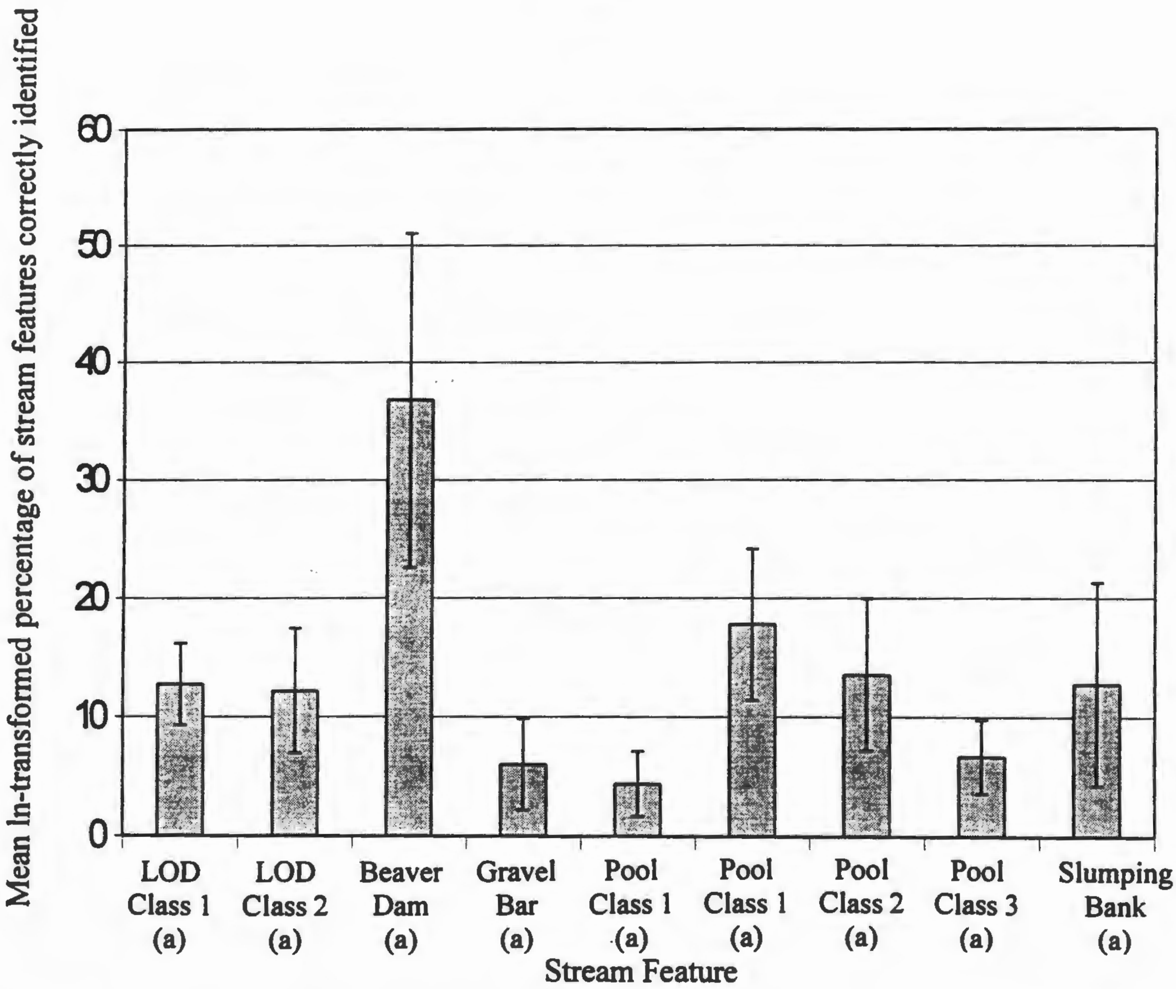

Figure 4: Mean ln-transformed percentage of stream features correctly identified for features used as levels in a 3 x 4 x 9 analysis of variance with watershed, stream order, and stream feature as main effects. Means designated with the same letter were not significantly different (Tukey-Kramer HSD post-hoc range test, p>0.05).

A summary of the entire data set revealed that the stream features identified in the aerial survey can be arbitrarily segregated into four groups based on the percentage of correct aerial identification. These four groups are: features not identified correctly (0%), features occasionally identified correctly (1% to 20%), features frequently identified correctly (21% to 60%), and features always identified correctly (100%) (Figure 5).

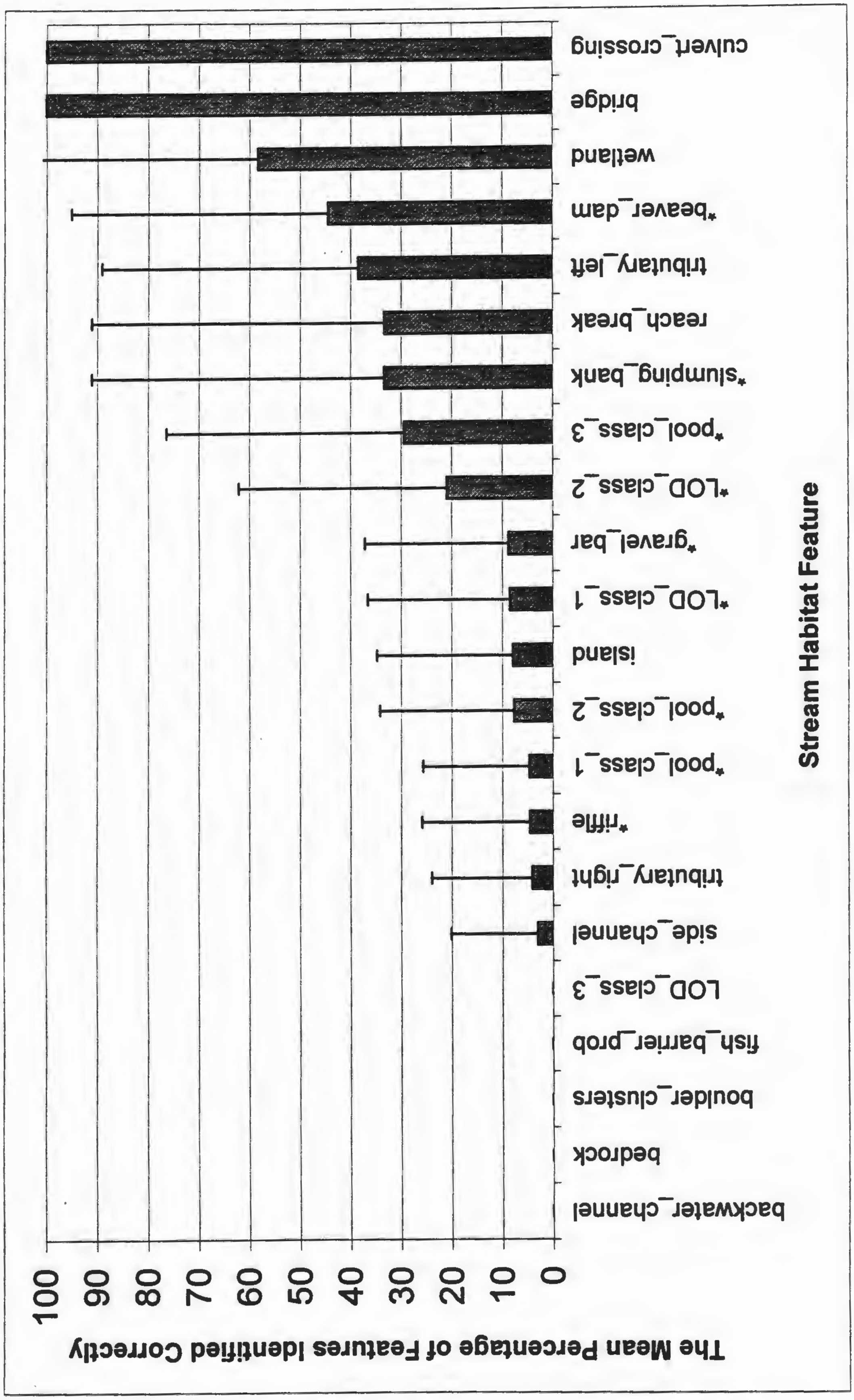

Figure 5: The mean percentage of stream features identified correctly for 1rst - 4th -order sample sites (+/- SD). Features with (*) were included in the 3 x 4 x 9 analysis of variance.

A Tukey-Kramer HSD post hoc range test revealed that the mean percentage of stream features correctly identified was significantly higher for 4th-order streams compared to 1st- and 2nd-order streams and higher for 3rd-order streams compared to 2nd-order streams (Figure 6).

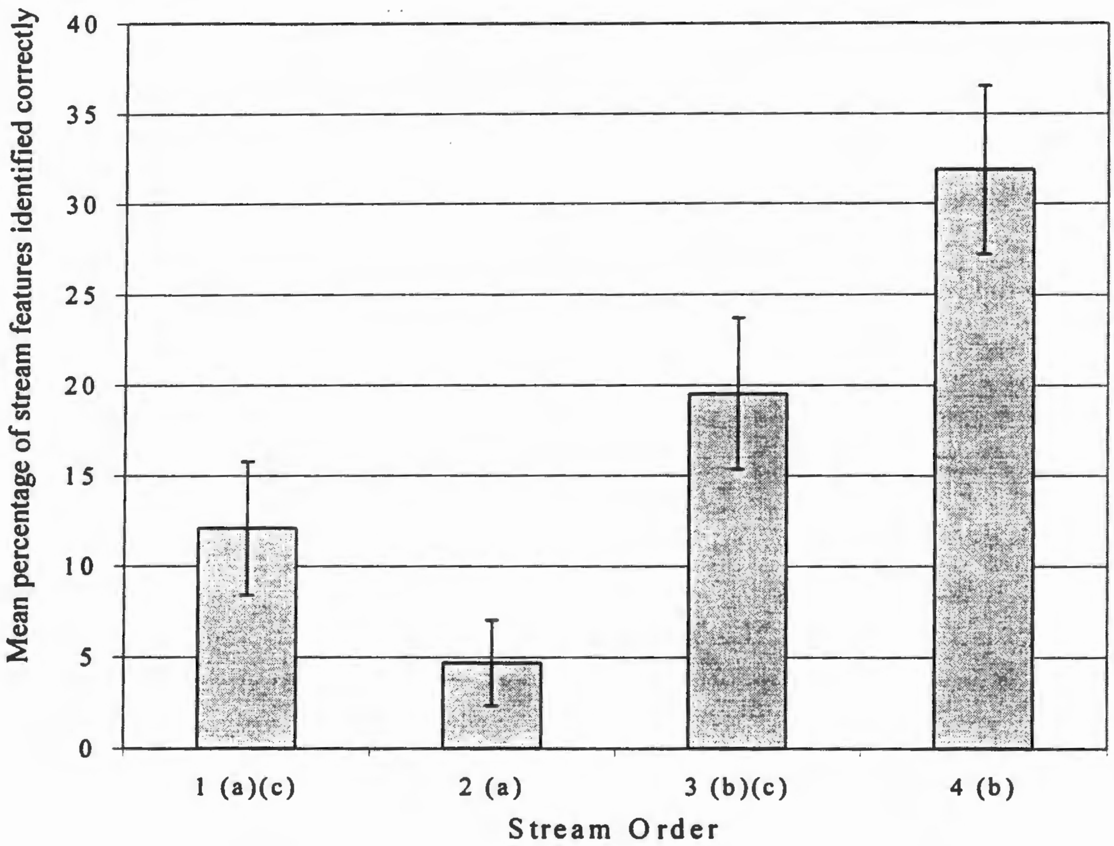

Figure 6: Mean ln-transformed percentage of stream features correctly identified for stream orders used as levels in a 3 x 4 x 9 analysis of variance with watershed, stream order, and stream feature as main effects. Means designated with different letters were significantly different (Tukey-Kramer HSD post-hoc range test, $p<0.05$).

The distribution of stream features identified by the ground crew across each watershed and stream order revealed that the total number of stream features generally decreased with increasing stream order (Table 4).

Table 4: The number and mean percentage (± SD) of stream features correctly identified by unmodified and modified aerial surveys for each sample site. Sample sites are defined by watershed, stream order, and replicate. For example 'DEL 1A' is a sample site located in the Del Creek watershed on a 1st-order stream, replicate 'A'.

Sample Site	Number of Features Identified by Ground Crew	Number of Correctly Identified Features (Unmodified)	Number of Correctly Identified Features (Modified)	Mean Percentage of Correctly Identified Features (Unmodified)	Mean Percentage of Correctly Identified Features (Modified)
DEL 1A	231	0	1	0.0 ± 0.00	0.4 ± 6.58
DEL 1B	348	1	2	0.3 ± 5.36	0.6 ± 7.57
DEL 2A	254	1	2	0.4 ± 6.27	0.8 ± 8.86
DEL 2B	5	2	3	40.0 ± 54.77	60.0 ± 54.77
DEL 3A	177	2	2	1.1 ± 10.60	1.1 ± 10.60
DEL 3B	147	2	2	1.4 ± 11.62	1.4 ± 11.62
DEL 4A	55	5	6	9.1 ± 29.01	10.9 ± 31.46
DEL 4B	67	14	15	20.9 ± 40.96	22.4 ± 42.00
PACK 1B	95	21	23	22.1 ± 41.71	24.21 ± 43.06
PACK 1C	215	6	6	2.8 ± 16.51	2.8 ± 16.51
PACK 2A	175	7	7	4.0 ± 19.65	4.0 ± 19.65
PACK 2B	193	1	2	0.5 ± 7.20	1.0 ± 10.15
PACK 3A	97	18	21	18.6 ± 39.08	21.6 ± 41.40
PACK 3B	40	8	8	20.0 ± 40.51	20.0 ± 40.51
PACK 4A	42	14	17	33.3 ± 47.71	40.5 ± 49.68
PACK 4B	34	7	7	20.6 ± 41.04	20.6 ± 41.04
PACK 5A	36	13	14	36.1 ± 48.71	38.9 ± 49.44
PACK 5B	16	9	9	56.3 ± 51.23	56.3 ± 51.23
PAUL 1B	83	4	4	4.8 ± 21.55	4.8 ± 21.55
PAUL 2A	106	1	1	0.9 ± 9.71	0.9 ± 9.71
PAUL 2B	198	3	4	1.5 ± 12.25	2.0 ± 14.10
PAUL 3A	118	9	12	7.6 ± 26.66	10.2 ± 30.35
PAUL 3B	30	6	6	20.0 ± 40.68	20.0 ± 40.68
PAUL 4A	41	13	15	31.7 ± 47.11	36.6 ± 48.77
PAUL 4B	79	11	13	13.9 ± 34.84	16.5 ± 37.31
PAUL 5A	31	5	7	16.1 ± 37.39	22.6 ± 42.50
PAUL 5B	32	13	13	40.6 ± 49.90	40.6 ± 49.90
Overall	2945	196	222	6.7 ± 24.93	7.5 ± 26.41

In addition, two 1st- and 2nd-order sample sites (DEL 2B and PACK 1B) had higher mean percentages of correctly identified features (60% and 24%, respectively) than other sample sites of the same stream order. The Del Creek 2nd-order site contained a total of only five stream features consisting of two "Beaver Dams", two "Wetlands", and one

"Backwater Channel". The Pack River 1st-order site contained a total of 95 stream features; six of these features were "Beaver Dams".

"Culvert Crossing" features only appeared in 1st- and 2nd-order streams while "Bridge" features appeared only in 3rd-, 4th-, and 5th -order streams. Features that were frequently identified correctly by the aerial survey (21% to 60% accuracy) were evenly distributed across stream order, while features occasionally identified correctly (1% to 20%) were the most numerous features identified (Table 5).

Table 5: The distribution of stream features identified by the ground crew in each watershed and stream order

Stream Feature	Watershed	Stream Order					Overall Features by Watershed	Overall Features Identified
		1rst	2nd	3rd	4th	5th		
Backwater Channel	DEL	4	2	0	0	---	6	
	PACK	3	1	3	1	1	9	
	PAUL	3	4	1	0	0	8	23
**Beaver Dam	DEL	0	2	0	0	---	2	
	PACK	6	1	1	1	0	9	
	PAUL	5	1	9	1	0	16	27
Bedrock	DEL	0	0	0	0	---	0	
	PACK	0	2	0	3	4	9	
	PAUL	0	0	0	0	4	4	13
Boulder Cluster	DEL	0	0	0	0	---	0	
	PACK	0	0	0	2	1	3	
	PAUL	0	0	0	0	0	0	3
Bridge	DEL	0	0	2	2	---	4	
	PACK	0	0	2	1	1	4	
	PAUL	0	0	1	1	1	3	11
Culvert Crossing	DEL	0	1	0	0	---	1	
	PACK	2	0	0	0	0	2	
	PAUL	1	1	0	0	0	2	5
Fish Barrier	DEL	0	0	0	0	0	0	
	PACK	1	0	0	0	0	1	
	PAUL	0	0	0	0	0	0	1
**Gravel Bar	DEL	1	1	6	1	---	9	
	PACK	4	20	12	1	2	39	
	PAUL	0	3	0	8	0	11	59
Island	DEL	0	0	0	1	---	1	
	PACK	3	2	2	1	0	8	
	PAUL	3	8	2	0	0	13	22

** Features included in analysis of variance

Table 5 (Continued): The distribution of stream features identified by the ground crew in each watershed and stream order

Stream Feature	Watershed	Stream Order					Overall Features by Watershed	Overall Features Identified
		1rst	2nd	3rd	4^{th}	5th		
**LOD Class 1	DEL	243	127	162	76	----	608	
	PACK	125	115	52	32	19	343	
	PAUL	1	80	78	47	37	243	1194
**LOD Class 2	DEL	16	7	30	18	----	71	
	PACK	46	37	7	8	3	101	
	PAUL	1	20	10	12	2	45	217
LOD Class 3	DEL	3	0	2	1	----	6	
	PACK	0	9	1	0	0	10	
	PAUL	0	2	0	1	0	3	19
**Pool Class 1	DEL	26	4	17	5	----	52	
	PACK	13	46	6	2	2	69	
	PAUL	3	15	9	19	6	52	173
**Pool Class 2	DEL	156	56	46	8	----	266	
	PACK	58	66	12	4	4	144	
	PAUL	20	68	8	4	3	103	513
**Pool Class 3	DEL	5	2	4	4	----	15	
	PACK	9	11	4	3	0	27	
	PAUL	27	21	10	3	0	61	103
Reach Break	DEL	3	1	1	0	----	5	
	PACK	2	2	2	0	0	6	
	PAUL	1	1	1	1	2	6	17
**Riffle	DEL	118	54	51	5	----	228	
	PACK	38	50	16	13	9	126	
	PAUL	17	68	12	10	4	111	465
Side Channel	DEL	0	0	0	0	----	0	
	PACK	0	0	2	4	0	6	
	PAUL	0	1	11	2	0	14	20
**Slumping Bank	DEL	3	0	1	1	----	5	
	PACK	0	2	5	2	6	15	
	PAUL	0	12	0	7	4	23	43
Tributary Left	DEL	0	0	1	0	----	1	
	PACK	0	1	0	0	0	1	
	PAUL	0	0	1	0	0	1	3
Tributary Right	DEL	0	0	1	0	0	1	
	PACK	0	0	0	0	0	0	
	PAUL	0	0	0	1	0	1	2
Wetland	DEL	1	2	0	0	----	3	
	PACK	0	2	1	0	0	3	
	PAUL	1	0	4	1	0	6	12
Overall		972	931	609	318	115	2945	2945

** Features included in analysis of variance

There were significant interactions for the percentage of stream features identified correctly across watershed and stream order ($p = 0.0147$), across watershed and stream feature ($p = 0.0201$), and across order and stream feature ($p = 0.0067$) (Figures 7, 8, & 9).

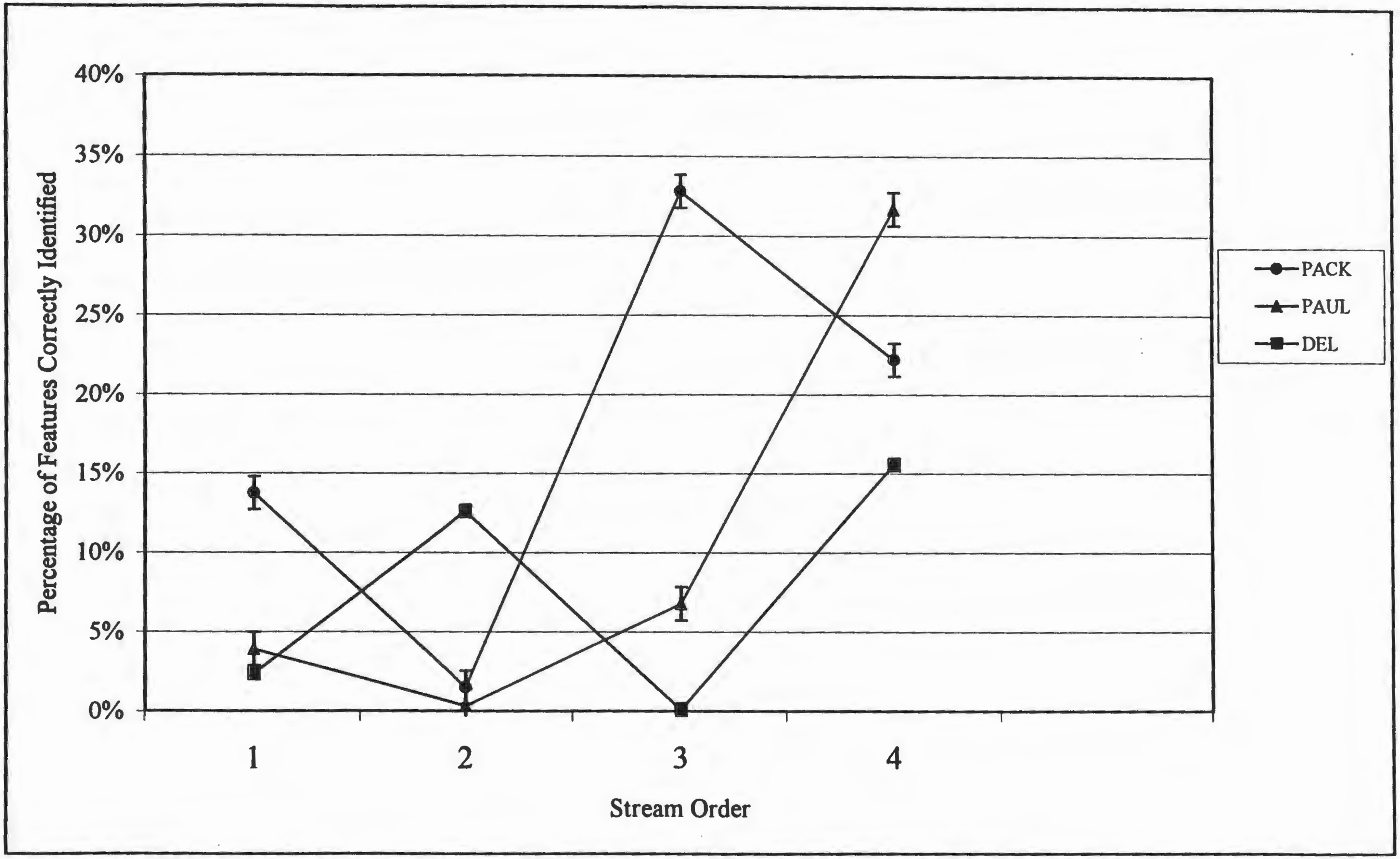

Figure 7: Percentage of stream features correctly identified by watershed and stream order (+/- SE). Data summarized using nine stream features included in analysis of variance.

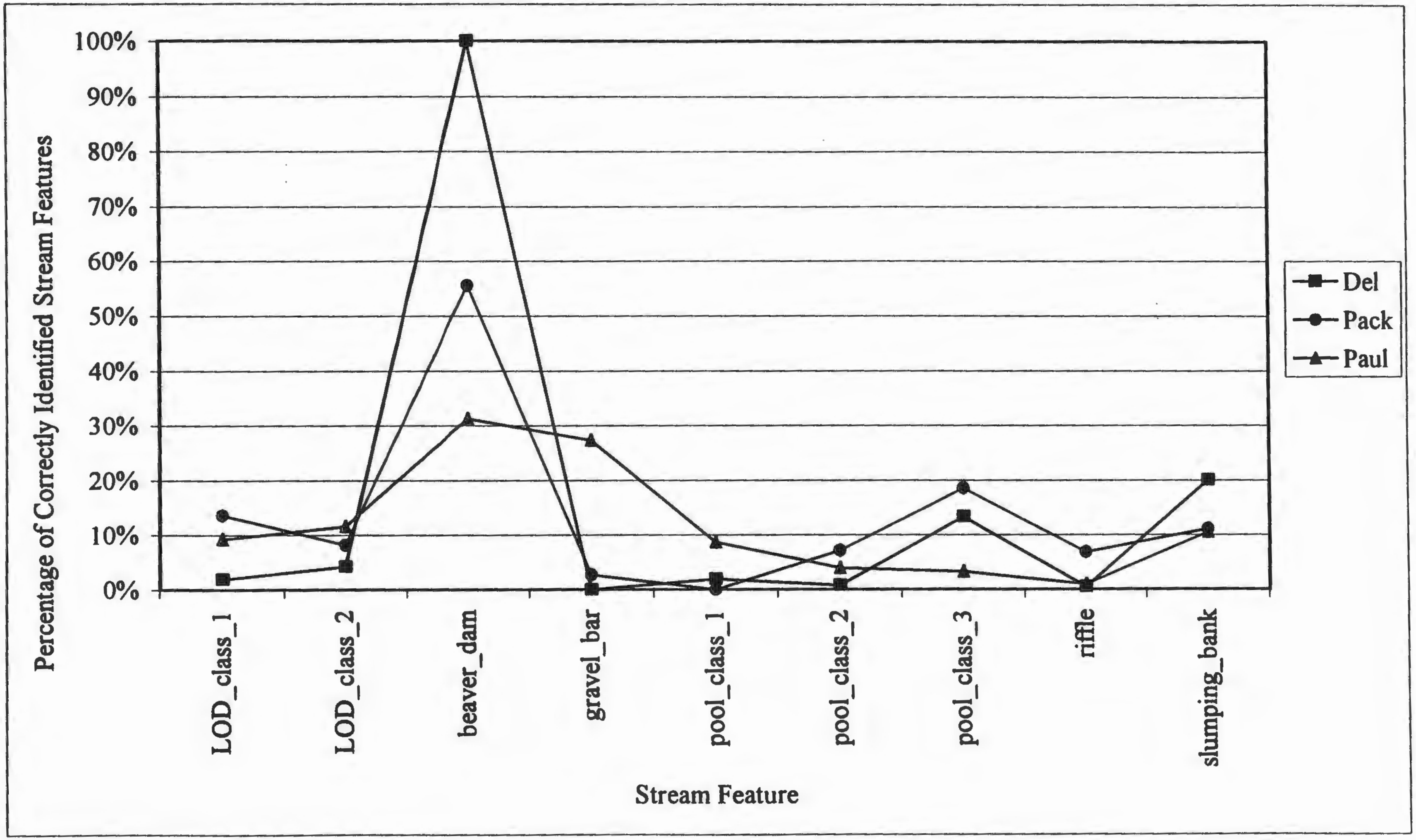

Figure 8: Percentage of stream features correctly identified by watershed (+/- SE). Data summarized using only 1st-4th-order streams.

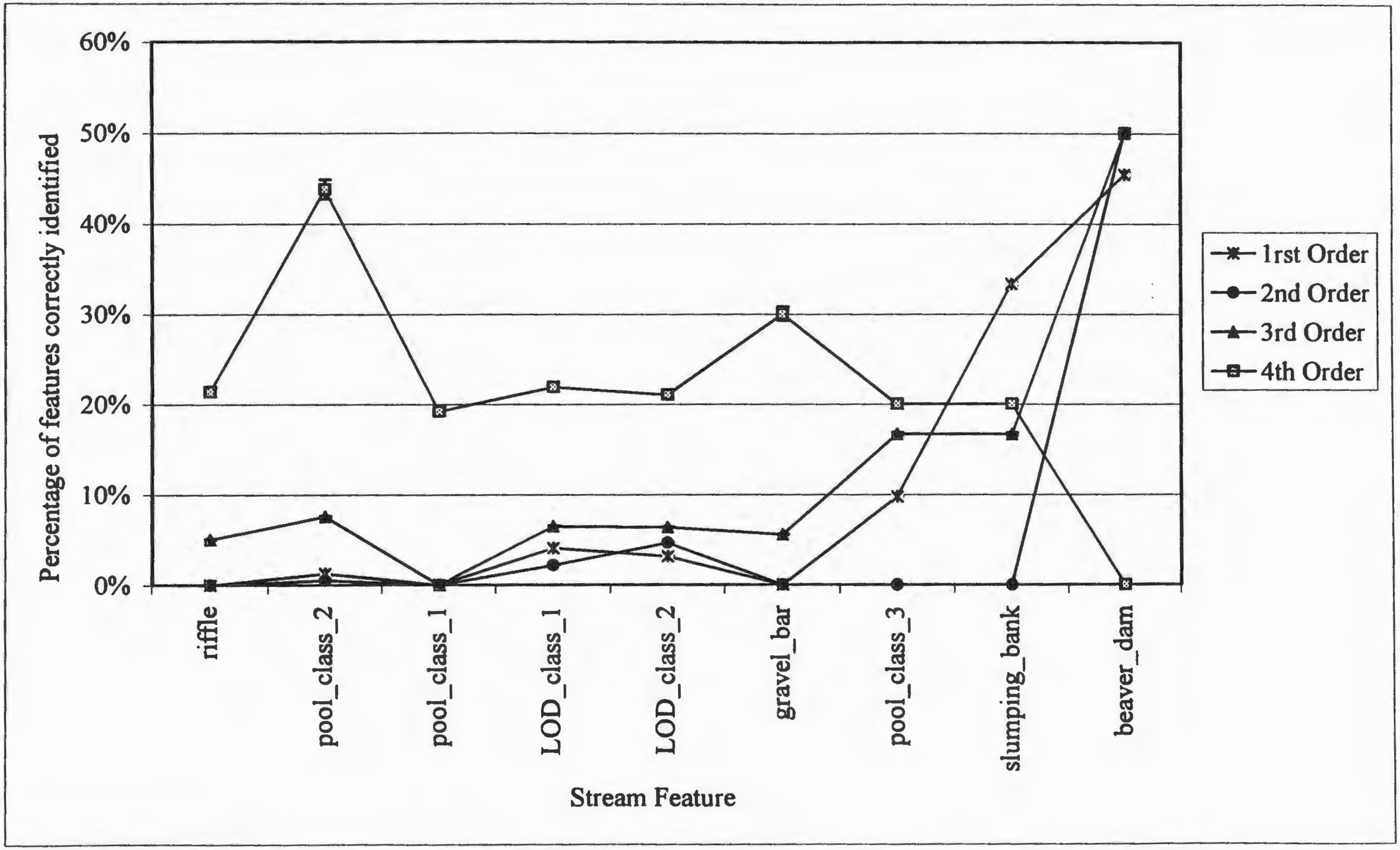

Figure 9: Percentage of stream features correctly identified by stream order (+/- SE). Data summarized using nine features in analysis of variance and 1st - 4th-order streams.

Aerial Surveyor Evaluation

Training Effect on Accuracy

The percentage of stream features identified correctly was not significantly correlated with the day of the survey ($F_{(1,4)} = 2.318$; $p = 0.1976$).

Variation Among Aerial Surveyors

The frequency[2] of stream features correctly identified was significantly higher for both unmodified ($\chi^2 = 11.47$; $p < 0.05$) and modified ($\chi^2 = 7.39$; $p < 0.05$) surveys for the main aerial surveyor compared to the second aerial surveyor over the PACK 4A, PACK 4B, and PACK 5A sites. The main aerial surveyor was more accurate in the successful identification of "Large Organic Debris Class 1", "Pool Class 1", and "Riffle" features compared to the second aerial surveyor. The second aerial surveyor, however, was more accurate in the successful identification of "Boulder Cluster", "Gravel Bar", "Large Organic Debris Class 2", and "Pool Class 3" features (Table 6).

[2] The frequency is stated here instead of percentage because the Chi-Squared Goodness-of-Fit test is performed on frequencies

Table 9: Comparison of aerial video and ground FHAP level 1 assessment summary. For dominant substrate, off-channel habitat, gravel quantity, and holding pool variables, values are not applicable (N/A) to achieve a rating.

Habitat Variable	**Ground Assessment**		**Video Assessment**		**Correct Video Assessment**
	Value	**Rating**	**Value**	**Rating**	
Percent Pools	0.0	Poor	0.3	Poor	Yes
Pool Frequency	No Pools	Poor	0.7	Good	No
Large Woody Debris per Channel Width	1.3	Fair	0.5	Poor	No
Percent Wood Cover in Pools	No Pools	Poor	0.0	Poor	Yes
Dominant Substrates	N/A	Poor	N/A	Poor	Yes
Off-Channel Habitat	N/A	Poor	N/A	Poor	Yes
Gravel Quantity	N/A	Poor	N/A	Poor	Yes
Holding Pools	N/A	Poor	N/A	Poor	Yes

Cost Comparison

The percentage of costs that were associated with each task of the aerial and ground surveys performed for this study were similar. The total percent cost in the pre-planning phase and field component of the aerial videographic survey was slightly lower than that for the ground survey while the total percent of aerial cost for the post processing phase was higher (Table 10).

Table 6: The mean percentage (± SD) of stream features correctly identified by stream feature for the study main aerial surveyor and a second aerial surveyor over the replicated sample sites (PACK 4A, PACK 4B, PACK 5A). The standard deviation was presented because the summary was taken directly from the raw data.

Stream Feature	n	Mean Percentage of Correctly Identified Stream Features by the Main Aerial Surveyor		Mean Percentage of Correctly Identified Stream Features by the Second Aerial Surveyor	
		Video Unmodified	Video Modified	Video Unmodified	Video Modified
Backwater Channel	2	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00
Beaver Dam	1	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00
Bedrock Outcrops	3	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00
Boulder Clusters	2	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	100.0 ± 0.00
Bridge	2	0.0 ± 0.00	100.0 ± 0.00	50.0 ± 70.71	100.0 ± 0.00
Gravel Bar	2	50.0 ± 70.71	50.0 ± 70.71	0.0 ± 0.00	0.0 ± 0.00
Island	1	*100.00	*100.00	*0.00	*100.00
LOD Class 1	49	38.8 ± 49.23	40.8 ± 49.65	12.2 ± 33.12	22.4 ± 42.16
LOD Class 2	11	18.2 ± 40.45	18.2 ± 40.45	54.5 ± 52.22	54.5 ± 52.22
Pool Class 1	3	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00
Pool Class 2	7	57.1 ± 53.45	57.1 ± 53.45	0.0 ± 0.00	0.0 ± 0.00
Pool Class 3	3	0.0 ± 0.00	0.0 ± 0.00	33.3 ± 57.74	33.3 ± 57.74
Riffle	17	41.2 ± 50.73	47.1 ± 51.45	17.6 ± 39.30	17.6 ± 39.30
Side Channel	2	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00
Slumping Bank	7	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00	0.0 ± 0.00

* Standard Deviation could not be calculated

Locational Accuracy

The mean locational error for precisely known stream features, defined as those features for which there was only one possible corresponding ground stream feature, was 37 ± 27.58 metres.

Stream Factors

There was not a significant effect ($p > 0.05$) of stream factors on the mean locational error for precisely known stream features across watershed and stream order. The effect size for this analysis was 0.2071, however, the data could not be normally distributed

(Figure 4C, Appendix 4.5). The locational error of precisely known features did appear to vary widely across stream feature (Table 7).

Table 7: The mean locational error (± SD) of precisely known modified aerial surveyed stream features. The standard deviation was presented because the summary was taken directly from the raw data.

Stream Feature	n	Minimum Linear Positional Error (m)	Maximum Linear Positional Error (m)	Average Linear Positional Error (m)
Beaver dam	3	7.2	19.4	13.1 ± 6.11
Bedrock	2	53.8	78.7	66.3 ± 17.64
Boulder clusters	1	59.3	59.3	59.3
Bridge	11	11.5	101.5	32.7 ± 26.58
Culvert crossing	5	10.5	46.4	31.3 ± 15.38
Gravel bar	2	35.9	38.0	37.0 ± 1.51
Island	1	53.4	53.4	53.4
LOD class 1	2	20.3	36.6	28.4 ± 11.55
LOD class 2	1	96.5	96.5	96.5
Pool class 2	6	2.1	29.2	17.5 ± 12.61
Pool class 3	5	7.0	54.9	28.6 ± 17.07
Riffle	9	10.0	109.9	41.1 ± 30.57
Slump bank	8	13.37	64.9	32.8 ± 20.48
Tributary left	1	108.0	108.0	108.0
Wetlands	2	34.3	120.7	77.5 ± 61.08
Overall	59	2.1	120.7	36.8 ± 27.58

Therefore, a specific precisely known stream feature identified by the aerial survey was, on average, approximately 37 metres from the true GPS location. Unfortunately there were not enough samples of precisely known features to include stream feature as a factor in the locational accuracy statistical model.

The minimum value for features that could not be associated with a specific feature identified on the ground was 1.2 metres. The minimum locational error for these features was lowest for "Large Organic Debris Classes 1" and "2" and highest for "Beaver Dam", "Gravel Bar", and "Pool Class 1" stream features (Table 8).

Table 8: The minimum locational error for aerial surveyed stream features that could not be associated with a specific ground feature.

"Unknown" Stream Feature	**N**	**Minimum Possible Locational Error (m)**
Beaver Dam	59	12.83
Boulder Clusters	1	146.82
Gravel Bar	25	12.38
LOD Class 1	3390	1.20
LOD Class 2	230	1.69
Pool Class 1	103	13.20
Pool Class 2	194	4.70
Pool Class 3	62	3.50
Reach Break	1	89.96
Riffle	18	5.40

Preliminary Evaluation of Video to Make a WRP Level 1 Fish Habitat Assessment

Fish habitat level 1 assessment values and ratings, calculated using only the video produced during the aerial survey, were correctly assessed for six out of eight habitat variables (Table 9). In addition to the assessment habitat variables, two isolated pools and one glide, 500 metres in length, were identified as habitat features by the video assessment. Conversely, no pools and one riffle habitat feature, 500 metres in length, were identified in the ground assessment. Furthermore, 16 pieces of large woody debris were identified by the video compared to 39 pieces identified in the ground assessment.

Table 10: Cost comparison for the aerial videographic survey and ground survey.

Task	**Cost Breakdown**		**Percentage of Total Cost**	
	Ground Inventory	**Aerial Inventory**	**Ground Inventory**	**Aerial Inventory**
Pre-Planning	\$495	\$1,840	3.0%	2.2%
Field Work	\$15,387	\$64,425	93.1%	76.2%
Post-Processing	\$640	\$5,570	3.9%	6.6%
Video Modification	—	\$12,640	—	15.0%
Total Survey Cost	**\$16,522**	**\$84 475**	—	—
Kilometres Surveyed	14.5 kms	916 kms	—	—
Total Cost per Kilometre	**\$1,140**	**\$92**	—	—

The total cost for the aerial videographic survey *without* video modification would decrease to \$71,835 with a respective decrease in the cost per kilometre to \$78.

Chapter Five:

Discussion

Assessment of Accuracy of Stream Feature Identification

The overall mean accuracy of the aerial videographic survey technique compared to a ground survey was below 8%. This is unacceptably low to consider this technology as a method to inventory stream features from the air. There was, however, great variation in the accuracy of feature identification. It is useful to examine the specifics of that variability in order to improve the survey technique and to assess its utility for other applications.

Video Modification

In order to correctly identify a stream feature from the air, the surveyor must have initially viewed the feature, interpreted the feature correctly, and verbally identified the correct feature into the helicopter head set. The technician must also have heard the call and entered it correctly into the digital database. The video modification process was intended to ensure that the technician performed this last step in successful identification of a stream feature correctly. Video modification was also intended to ensure that "X" points, features that could not be "quick-marked" during the survey, were replaced with the corresponding stream feature described by the aerial surveyor.

The ability of the aerial survey technician to correctly "quick-mark" 196 of the 222 stream features identified by the aerial surveyor indicates that the "quick-marking" procedure was an effective survey recording mechanism. This "quick-marking" data recording technique and digital data storage mechanism appear to be accurate and reliable, two qualities essential in effective inventories (Hamilton and Bergersen 1984; Anon. 1995; MOELP 1997).

A large discrepancy between the video-unmodified and video-modified features would have indicated that the procedure of "quick-marking" stream features during the aerial survey was not effective. Video modification, however, did not substantially increase the accuracy of the aerial survey and the expense and effort of modification is not justified on the basis of its contribution to increasing the accuracy of the aerial stream feature identification. The occasional misidentification of "Wetland Right" as "Wetland Left" in the modified aerial data set also suggests that all obvious aerial surveyor mistakes were not corrected during modification. This modification process, however, was *not* designed to be a thorough examination of the stream features recorded on the video portion of the aerial survey by an experienced biologist and one could not expect dramatic increases in the accuracy of stream feature identification during the modification of aerial survey data. Video modification does appear to be a necessary quality assurance procedure to ensure important stream features such as "Beaver Dams", "Bridges", and "Wetlands" were not omitted from the modified data base (Table 2). This modification can cost effectively be performed by an office technician, instead of a more expensive biologist, to ensure that the verbal calls of the aerial surveyor were correctly recorded into the database. Video modification was also used to ensure that the 1:20, 000 maps produced from this digital survey data were labeled properly with video time tags and stream names.

The fact that video modification dramatically improved (up to 75%) the accuracy of identification of some stream features identified by the aerial surveyor was most likely due to the nature of the data recording software. The "Aspen Field Inventory" software permitted only ten features to be present on the technician's computer screen at one time. Prior to the aerial inventory, the survey team selected the ten stream features that would be most frequently encountered during the aerial stream survey (i.e. "X" points, "Large Organic Debris", "Pools", and "Riffles"). These ten features were easily "quick-marked" to the survey database with one touch of the computer touch-pad. The remaining stream features, which included the less frequent features such as "Beaver Dams", "Bridges", "Gravel Bars", "Reach Breaks", "Slumping Banks", and "Wetlands", required the technician to scroll the stream feature library for the feature of interest and then perform a "quick-mark" with the computer touch-pad. This two-step procedure was likely the cause of the large discrepancy between the unmodified and modified accuracy for these particular stream features. In the future, during an overview assessment to identify major morphological stream features, the ten "quick-mark" features on the technician's computer could contain these *major* features and would likely result in less disparity between the video-unmodified and video-modified data.

Video modification appears to have been useful for general aerial survey quality assurance and, despite the fact that the accuracy of aerial stream feature identification was not significantly increased during modification, the process should remain as a quality assurance tool. In addition, video modification can be used to add specific map features such as video time tags to facilitate the use of aerial video and associated maps, derived from the digital aerial data, by resource managers.

Factors Affecting the Accuracy of Identification of Stream Feature

Based on the results of this study, there were three factors that appeared to influence the accuracy of stream feature identification: relative crown closure, helicopter flight characteristics, and stream feature characteristics. These three factors affect the first steps in the aerial identification process of viewing the feature by the aerial surveyor, interpreting the feature correctly, and verbally identifying the correct feature into the helicopter head set. Furthermore, specific aerial survey procedures may have combined with the physical attributes of each stream feature to reduce the accuracy of feature identification.

Relative Crown Closure

The relative stream crown closure was an important factor in the successful aerial identification of stream feature. This particular variable inhibited the identification of stream features from the air by impairing the surveyor's view of the stream. The fact that stream order was a significant factor in the accuracy of stream feature identification was likely due to a decrease in the percentage of relative crown closure with increasing stream order, resulting in less obstructed views of the stream (Vannote et al 1980). Therefore, the relatively dense crown closure associated with 1^{st}- and 2^{nd}-order streams impeded the view of the aerial surveyor resulting in lower accuracies of identification compared to 3^{rd}- and 4^{th}-order streams.

The interaction between watershed and stream order can be explained by examining the widths of the stream orders. The bankfull width data, a physical stream variable collected during the ground WRP level 1 fish habitat assessment and defined as the distance between channel banks, for 3rd- to 5th-order streams indicated that stream width may have been a more appropriate factor in this analysis rather than stream order. Replicate 3rd-order stream segments in the Paul River watershed were 1.0 and 2.8 metres wide, while in the Pack River watershed streams of the same order were 5.7 and 8.0 metres wide. The relative crown closure for the Paul River streams was likely greater than the Pack River streams and, subsequently, the accuracy of identification on Paul River 3rd-order streams was below 8% compared to above 30% on Pack River 3rd-order streams (Figure 7). Unfortunately, stream width data was not gathered on lower order streams and an analysis could not be performed with stream width as a factor instead of stream order.

Two stream sample sites, Del 2B, and Pack 1B, appear to have elevated accuracies for stream feature identification compared to other sample sites of the same order (Table 4). The corresponding modified aerial survey accuracy for these two sites was 60.0% and 24.2%, respectively, compared to all other 1rst- and 2nd-order stream sites in this study that had aerial survey accuracies below 5%. There may have been a decrease in crown closure at these two sites likely as a result of beaver dams and associated flooding that subsequently leads to a decrease in canopy closure and the presence of low growing hydrophytic vegetation (MOF 1995b). The distribution of stream features at these two sample sites support this conclusion in that the Del Creek 2nd-order sample site contained two “Beaver Dam” features and two “Wetland” stream features as identified by the ground crew while the Pack River 1st-order site contained six “Beaver Dams” over the 500 metre sample site.

The relatively high accuracies of “Bridge”, “Culvert Crossing”, “Beaver Dam”, and “Wetland” stream features may have been partially attributed to a lack of crown closure specifically associated with each of features. “Bridge” and “Culvert Crossing” features were associated with roads and subsequently surrounded by open areas that resulted in a relatively clear view of the feature by the surveyor, affording a greater opportunity for the successful aerial identification. Furthermore, “Beaver Dam” and “Wetland” features were associated with flooding and subsequent decreases in canopy closure (MOF 1995b). The resulting clearings enabled the aerial surveyor to successfully complete the first step in the aerial identification process, viewing the stream feature. Other stream features identified in this survey such as the “Large Organic Debris” classes, “Pool” classes, and “Riffles” were not consistently associated with reductions in crown closure, and this may have hindered the aerial surveyor in performing the initial aerial identification step of viewing the feature.

Helicopter flight characteristics

The successful identification of each stream feature depended on one or a combination of helicopter flight characteristics and stream feature characteristics (Somers et al 1991).

Certain helicopter flight characteristics including survey height, survey speed, and ability to perform "rudder turns" may have influenced the interpretive ability of the aerial surveyor and, therefore, impacted the accuracy of the aerial survey. The height of the survey platform affects the correct identification of stream features, as it does with other remote sensing applications such as satellite imagery and aerial photography (Sidle and Ziewitz 1990; Ham 1996). Helicopters are chosen for stream aerial videographic surveys (over fixed wing aircraft) because their high maneuverability and slow flying speeds allow the helicopter to fly slower and lower over highly crenulated streams (Harper and Reimer 1995). This ability improves the detail that can be viewed by the aerial surveyor and the video image resolution, however, it does not sufficiently increase the accuracy of identification of small features (e.g. "LOD Class 1").

In addition to the survey height, the velocity or speed of the helicopter may have resulted in less accurate stream feature identification. The surveyor may have required a certain amount of viewing time to successfully identify a stream feature and certain stream features combined with a helicopter velocity of 30-50 kilometres per hour did not allow the surveyor enough time to identify these features. Higher stream gradients that required the pilot to increase the survey velocity of the helicopter may result in a decrease in the accuracy of stream feature identification by reducing the viewing time of the aerial surveyor.

The ability to perform slow, steady rudder turns over sinuous portions of streams may also have impacted the ability of the surveyor to correctly identify stream features. To view and capture a video image of the entire stream around a stream bend the survey pilot attempted a rudder turn that involved slowing the helicopter down and performing a slow turn without allowing the aircraft to pitch or roll. These turns could not always be performed due to a combination of tail winds, tortuous stream meanders, and a lack of helicopter power. A post-survey visual evaluation of the aerial video confirmed that, during the inventory, the video camera recorded one of the stream banks instead of the stream itself on some of the stream bends on the Paul River (T. Zimmerman, Ministry of Environment, Lands, and Parks, personal communication). During these turns, the surveyor sitting on the left side of the aircraft may have had an obstructed view of sections of the stream beneath the right side of the helicopter. Thus, one could postulate that stream features with right-bank stream designation (recall that the stream were flown in an upstream direction yet the right and left bank designations were defined as if one were looking downstream) would be more accurately identified than stream features with left-bank stream designation. Unfortunately, small sample sizes for "Tributary-Right" and "Tributary-Left" do not allow for further investigation of this occurrence.

Stream feature characteristics

Stream feature characteristics such as size, level of definition, and physical complexity may also have influenced the interpretive ability of the aerial surveyor and subsequent accuracy of identification. A combination of the stream feature size and the height of the helicopter above the stream may have influenced the ability of the aerial surveyor to successfully interpret the stream feature and therefore successfully identify certain features (Hilton 1984). For example, relatively small stream features such as "LOD Class 1" may have been more difficult to interpret for the aerial surveyor compared to a larger stream feature such as a "Bridge" which may have been reflected by the corresponding accuracies of these two features (Figure 5).

Stream feature level of definition (size and left or right designation) may have contributed to some of the disparity between the successful identification of stream features. The aerial surveyor may have been able to more rapidly define, and therefore identify accurately, features with lower levels of definition (i.e. "Culvert") compared to features with higher levels of definition such as "Tributary Right" and "Tributary Left". Roper and Scarnecchia (1995) found that as the number and complexity of feature types used in a stream evaluation increased, the consistency among the multiple surveyors used in the study decreased. The stream features in this study more likely to be identified correctly, such as "Bridge" and "Culvert" features, did not involve any size estimation or left or right designation. These higher accuracy features may have been easier for the aerial surveyor to interpret in the brief time the helicopter was over a feature, resulting in higher identification success than for features with higher levels of definition.

Another factor that may have influenced the accuracy of aerial stream assessments may have been the physical nature of each stream feature. Wang et al. (1996) stated that features with greater morphological complexity may be more difficult to define. "Bridge", "Culvert Crossing", "Wetland", and "Beaver Dam" stream features were relatively easy to identify having clearly defined feature boundaries compared to a "Riffle" feature for example. "Riffles" have a more convoluted definition being defined as a "habitat unit with fast, turbulent, white water…(with)…broken (surface water) but the habitat unit is not falls, cascades, or chutes" (Appendix 2). In addition, the boundaries of a riffle segment were not as clearly defined other features (e.g. a "Bridge" feature). Furthermore, the physical size of a stream feature may also have influenced the accuracy of feature identification as the aerial surveyor may have been able to distinguish larger features more clearly than smaller features. Interestingly, as stream order increased, the size of each stream feature within the stream increased and the relative number of features per 500-metre sample site decreased. This is consistent with previous observations (Hankin and Reeves 1988; Hawkins et al. 1993; Hogan and Ward 1997). Therefore, not only was the aerial view of the stream and subsequent stream feature identification improved as stream order increased, but there were also fewer features to identify in the limited time the surveyor was allotted to successfully identify stream features from the air. These three physical stream feature variables, physical complexity, defined boundaries and feature size, accompanied by the time constraint placed on the aerial surveyor may have resulted in a decrease in accuracy for features that were complex for the aerial surveyor to interpret, small in size, and that had undefined boundaries.

The three factors that can be specifically attributed to each stream feature, size, level of definition, and physical complexity, along with the relative crown closure, may explain the four categories of stream feature identification accuracy (Figure 5). Stream features that were not identified successfully from the air were not associated with a decrease in crown closure, were complex in definition, and were generally smaller in relative size. Features that were accurate between 1% and 20% were attributed with one or two factors favorable for successful aerial identification such as a decrease in the crown closure (i.e. "Tributary Right"). Features that were accurate between 21% and 60% and features with 100% accuracy were attributed with at least three of the factors favorable for successful aerial identification. For example "Bridges" were associated with a relative decrease in crown closure, were large in size and easily interpreted.

The interactions of stream feature across watershed and stream feature across stream order may be explained by interacting factors that influence the accuracy of identification. For example, the width of stream order appears to fluctuate across watershed and, therefore, a lower accuracy stream feature not specifically associated with a decrease in crown closure, such as a "Riffle", would have been more visible on the Pack Watershed with larger stream widths (and relative crown closure) per stream order than on the Del Creek watershed with smaller widths per stream order (and relative crown closure) (Figures 8 and 9). Conversely, stream features specifically associated with a decrease in crown closure (e.g. "Beaver Dam"), do not appear to be more accurately identified with increase in stream order. Perhaps the larger widths attributed to the streams in the Pack River watershed and larger order streams in general actually decreased the ability of the aerial surveyor to identify "Beaver Dams". A reasonable explanation could be that "Beaver Dams" did not span the entire width of the stream or were not associated with a decrease in crown closure in larger streams. Therefore, some stream features (e.g. "Riffles") were more successfully identified with increasing stream orders and the greater relative stream widths per order associated with the watershed while other features (e.g. "Beaver Dams") did not show increases in accuracy with increasing stream order and across watershed due to characteristics specific to the feature.

Watershed

Despite the fact that watershed characteristics did not significantly effect the accuracy of aerial surveys in the identification of stream features, these characteristics are still important to consider during an aerial survey. The size of the survey area, stream gradient, channel confinement, and elevation above sea level are significant when planning aerial inventories. These factors assist the pilot when considering potential fuel cache sites, the size and power of the helicopter required, and the time required to survey a watershed. High elevation, steep gradient, deeply incised streams made surveying more difficult because even moderate winds resulted in the suspension of the aerial survey due to safety considerations. Even during calm winds, the pilot was challenged with trying to keep the video camera steady while negotiating steep climbs (R. Buchannan, Terra•Pro GPS Surveys Inc. personal communication). In addition, these deeply-incised channels were more prone to shading in the morning and afternoon resulting, in shortened aerial survey days.

Low gradient watersheds pose a different problem for aerial surveyors. The survey could generally be performed in stronger winds and for longer periods during the day compared to higher gradient watersheds, but the streams to be surveyed were more difficult to locate. In fact the aerial crew mistakenly surveyed one 1^{st}-order stream adjacent to the stream targeted for this survey. As a consequence the ground crew was required to mobilize back into this low gradient area to survey the additional 1rst-order stream segment.

Aerial Surveyor Evaluation

Training Effect

The purpose of evaluating the accuracy of stream feature identification across the eight inventory days was to determine whether the accuracy of the aerial surveyor improved as more time was spent surveying (self-training). Test surveys were run prior to the commencement of this study as recommended in the literature, in order to remove the training effect as a variable (Roper and Scarnecchia 1995; Wang et al 1996). The finding that accuracy was not affected with increasing aerial surveyor self-training supports the procedure of training surveyors (including aerial surveyors) prior to the commencement of a stream survey to ensure consistency over the course of an inventory.

Variation Among Aerial Surveyors

The statistical difference between the two aerial surveyors likely resulted from a lack of aerial surveyor training for the second aerial surveyor as recommended by Roper and Scarnecchia (1995) and Wang et al. (1996). A pre-survey training session could not be incorporated into this study design for the second aerial surveyor due to time, logistics, and the extra cost associated with training. This lack of training probably resulted in a decrease in stream feature identification accuracy for the second aerial surveyor over the replicated sample sections. Importantly, previous studies have shown that observer experience does not necessarily improve the precision and accuracy of stream surveys

(Roper and Scarnecchia 1995; Wang et al. 1996). These studies instead indicated that consistent, uniform training was important especially when multiple surveyors are used.

The difference between the stream features correctly identified by each aerial surveyor was probably a result of consistent surveyor bias attributed to all visual estimates of stream features. Hankin and Reeves (1988) suggest that it is unlikely that "different experienced observers will share the same … bias of visual estimation". One surveyor, for example, may be consistently higher in the estimation of one survey variable while a second surveyor may be consistently higher in a different variable (Hankin and Reeves 1988).

As identified in the initial data interpretation with the identification of "Interpretive" and "Definitive" data sets, there appeared to be some consistent bias between the aerial and ground surveyor that can be expected in all stream assessments (Hankin and Reeves 1988). This bias was the reason for using only one aerial surveyor and one ground surveyor in this study. However, there may have been undetected surveyor bias and subsequent discrepancy relating to stream feature interpretation between the aerial and ground surveyors. This may have translated into lower accuracy for some of the stream features. This bias was not believed to have compromised the findings within the study because of the measures taken to minimize this influence. As mentioned in the methodology, both the aerial and ground surveyors were experienced and were thoroughly trained prior to the commencement of the study in the assessment of the particular stream feature list used.

Locational Accuracy

The locational accuracy of aerial survey stream feature identification was affected by the position of the helicopter and the timing of the last two steps in the identification process, the audible call of the aerial surveyor and the "quick-mark" by the GPS technician. The Trimble Pro-XL GPS unit has a rated spatial accuracy of about a metre after differential correction. As both the aerial and ground surveyors utilized these particular GPS units, the minimum spatial error for each stream feature recorded during the aerial survey would be two metres. The procedure of gathering a GPS feature position during the aerial survey may account for the majority of spatial error over this two metres.

When identifying stream features from the air, the surveyor looked upstream or off to the side of the helicopter to view the stream features. The GPS receiver for recording the positional information for aerial surveyed stream features was located on the tail boom of the helicopter behind the aerial surveyor. This most likely created a spatial disparity between the stream feature and GPS receiver. In addition, the delay between when the call was made by the aerial surveyor and the time the stream feature position was entered into the database by the technician would also have caused spatial disparity between the aerial GPS receiver and the ground location of the stream feature. For example, in the identification of a stream feature that was not readily on the aerial technicians' computer screen, such as "Bridge" or "Wetland" features, the technician was required to scroll the stream feature library for the feature of interest and then perform a "quick-mark" with the touch-pad. The time-delay during this process may have resulted in a large spatial disparity between the actual GPS position of the stream feature and the position of the aerial receiver on the helicopter boom.

Stream Factors

Watershed and stream order did not have a significant effect on the locational accuracy of aerial stream feature identification. Specific watershed characteristics, stream characteristics, and weather factors such as stream gradient, channel meander, channel confinement, and wind were likely more influential on the locational accuracy than the general watershed or stream order surveyed.

Steep stream gradients may have adversely impacted the GPS position of stream features on these steep streams as the pilot would usually require more speed to gain the altitude required to continue the survey over steep streams or stream segments (R. Buchannan, Terra•Pro GPS Surveys Inc., personal communication). This may have resulted in a greater spatial disparity between the position of the stream feature and the position recorded on the data set by the technician.

Stream meander may also have contributed to spatial positioning errors as the helicopter occasionally failed to negotiate "rudder turns". Stream features on the bends of these meandering streams may have higher locational errors than stream features on relatively straight stream sections. In addition, high winds during the aerial survey would occasionally displace the helicopter off the centre-line or thalweg of the stream. This displacement may have created a greater spatial disparity between the actual stream feature position and the recorded position. In fact, extreme winds periodically resulted in the cessation of the aerial survey for the safety of the crew and to ensure the survey quality was maintained.

Higher order streams are generally located closer to the main valley bottom. This may have allowed the aerial crew to fly slower on these streams, leading to a higher locational accuracy in the acquisition of stream features from the air. The data, however, does not support this hypothesis and indicates that other factors were probably more significant, or that there were not enough data points to detect any significant trends. Stream meander, for example, may have been more significant in the acquisition of spatial data from the air. As previously mentioned, an increase in stream meander likely results in an increase in stream feature locational error. An aerial crew may be able to increase locational accuracy in higher order streams by flying slower and negotiating "rudder turns". Flying slower may also lead to an increase in the accuracy of aerial stream feature identification by allowing the aerial crew and specifically the aerial surveyor the time to view and interpret stream features correctly.

The locational accuracy appears to vary widely for the stream features identified in this study. Unfortunately there were not enough samples to draw any significant trends for the locational error by precisely known stream features. Locational accuracy may increase for certain easily identified stream features such as "Bridge" features. However, as with watershed and stream order, other factors such as stream gradient and stream meander may be more significant to the spatial positioning of stream features.

Interestingly, the minimum positional error for features that could not be associated with a specific feature identified on the ground during the aerial survey was generally lower than the positional error for precisely known stream features. This can be explained by the high frequency of occurrence of some of these ground stream features that increased the probability that a "like" feature would be identified closer to the aerial feature location (Table 8). For example, suppose that the ground crew identified and GPS-positioned four "Large Organic Debris Class 1" stream features on a stream segment and that the aerial surveyor identified and positioned one "Large Organic Debris Class 1" feature. The positional error for features that could not be associated with a specific feature identified on the ground would be calculated four times and the corresponding minimum locational error would be the smallest of these four calculations. However, there would be no way of knowing which one of the four ground "Large Organic Debris Class 1" stream features the aerial surveyor had actually identified.

Resource managers should consider the value of spatial positioning when considering the precision of aerial videographic surveys. If the objective of the aerial survey is to identify overview information such as stream network, fish barriers, access locations, and other major morphological features, then ± 37 metres would probably be sufficient. If, however, the purpose of the survey is to sequentially identify detailed stream information at the habitat unit level then more locational accuracy would probably be required than this aerial videographic survey could provide using the current survey methodology.

Preliminary Evaluation of Video to Make a WRP Level 1 Fish Habitat Assessment

Overall, the video-only FHAP assessment was 75% accurate in the identification of the stream habitat variables compared to a ground FHAP assessment. This result can be interpreted as a very useful product for resource managers. However, the two variables incorrectly rated by the video assessment, pool frequency and large woody debris per channel width, were quantitative variables. This indicates that the collection of quantitative variables (such as the percentage of pools) using a video-only approach may not be appropriate. The eight habitat variable values and ratings are compared, evaluated, and discussed separately below:

Percent Pools and Pool Frequency

The percentage of pools over the sample stream section was correctly rated by the video-only assessment. However two pool habitat units were mistakenly recorded in the aerial assessment. This inaccuracy resulted in the incorrect value and rating for the pool frequency over the sample stream section and can be explained by either the lack of video resolution or the inaccurate pool area assessment.

Poor video resolution, video colour, or low lighting may have contributed to the incorrect identification of two pools in the sample stream. Pools were identified during the video assessment as darker coloured portions of water that signify deeper, slower flowing areas in the stream and corresponding pool habitat. While viewing the video, darker sections of the stream may have been incorrectly assessed as pools due perhaps to low video resolution, poor video colour definition, or low lighting.

Unidentified woody debris may have been associated with other *identified* pieces of woody debris but, due to poor video resolution, the video surveyor failed to distinguish the *additional* pieces. In addition, the unidentified pieces may have been close to stream banks partially concealed by canopy closure. Submerged pieces of woody debris would also have been difficult to identify from the video due to a general inability to discern objects below the water surface. Subsequently, reduced water clarity may be a factor in the successful identification of large woody debris.

Percent Wood Cover in Pools

The value and rating of the percentage of wood cover in pools was identified correctly. However there were few, if any, pools in this sample site. The large woody debris tally recorded using the video identified less than half of the actual debris in the stream. Therefore, the correct assessment for the percentage of wood cover in pools might have been more difficult had the stream segment contained more pool habitat. With an increase in pool habitat in a surveyed stream, the canopy closure, video resolution (that reduce the visibility of the video surveyor), and water clarity may be limiting factors in the identification of partially submerged large woody debris.

Dominant Substrates and Gravel Quantity

The dominant substrate and gravel quantity assessment required that the surveyor correctly identify the stream substrate. For this particular assessment the video surveyor noted the dominance of cobble substrate on the exposed stream banks and minimal boulder substrate within the mainstem, on the stream banks, or in scour pools resulting from such boulders. The video surveyor also concluded that the relatively high water velocities and channelization of this sample stream segment would limit the amount of gravel retention in this area. This resulted in a correct assessment of a cobble-dominated substrate in the sample site. The assessment of substrate type and quantity would be more difficult without the substrate exposure on the stream banks, increased canopy closure, poor stream clarity, and low video resolution.

Off-Channel Habitat

Off-channel habitat was easily identified and interpreted using the aerial video, due primarily to the aerial survey standard of including both stream banks in the video image. Furthermore side channels, sloughs, wetlands and other off-channel habitat areas were relatively large features and were interpreted readily from aerial video.

Holding Pools

The successful assessment of holding pools was due to the absence of pools in the sample site. This variable may be reliably interpreted from aerial video given the size of the habitat unit and provided the stream was visible from the air. Smaller pools, however, were difficult to assess accurately from the air. More research would be needed to evaluate the reliability of identifying holding pools during a video-only aerial survey. Factors that limit the successful identification of this variable were similar to previous stream variables including increased canopy closure, reduced video resolution, and water clarity.

Possible Other Identifiable Features

Riparian structural stage and the percentage of canopy closure were relatively easy to assess using this video-only stream habitat inventory technique. The classification of riparian vegetation has been effectively performed in previous studies by Everitt et al (1988) and Courtney et al (1997). The ability to review the stream segment numerous times and the low resolution required to successfully identify stream riparian vegetation, especially large classifications such as deciduous and coniferous trees, contributed to a successful estimation of these variables.

In summary, the aerial video image appeared to be useful in the qualitative assessment of stream habitat for this particular stream segment. Quantitative variables such as pool area, pool frequency, large woody debris per channel width, and percent wood cover in pools were less accurate. This video-only assessment would not be applicable to streams with dense crown closure because variables important to an FHAP assessment such as the dominant substrate, off-channel habitat, holding pools, and other features could not be identified. The estimation of quantitative variables would probably be more difficult with increasing habitat unit complexity. In addition, low video resolution and water clarity may limit the estimation of some variables during a video-only assessment.

Cost Comparison

The cost of the aerial videographic survey per kilometre was less than 1/10th the cost of a ground survey. This aerial survey also produced information 50 times more efficiently than a ground survey averaging over 100 kilometres of aerial inventoried stream per day compared to two kilometres per day with the ground survey. Comparisons between aerial and ground surveys are not logical, however, because, as revealed in our accuracy assessment, detailed habitat information similar to that gathered by a ground survey cannot be gathered accurately using an aerial survey.

The cost of the video modification process was approximately 15% of the total cost of the aerial survey. The accuracy of the aerial survey was not significantly increased during the modification process and, therefore, it may be removed from the survey or partially reduced, in order to incorporate only a brief quality assurance to minimize the cost per kilometre surveyed. Aerial surveyors and resource managers, however, must ensure that the reduction or elimination of the modification process does not compromise the identification of key overview information such as "Bridge" and "Culvert" stream features. Conversely, video modification could be expanded to include an assessment procedure to identify qualitative information such as off-channel habitat.

Resource Management Implications

Fisheries

Aerial surveys as described in this study cannot be used to gather all of the detailed information on streams, such as that gathered during ground surveys. However, such detailed information is not generally obtained on entire streams due to the time and cost constraints associated with ground surveys. Consequently, resource managers must optimize other inventory techniques or ground survey representative stream segments (Oswood and Barber 1982; Dolloff et al. 1997; MOELP 1997). Therefore, these aerial surveys may be useful for the cost-effective assessment of overview information and qualitative channel level habitat variables on all streams prior to more detailed ground surveys. In addition, some detailed information may be attainable on larger-order (i.e. 4^{th}-and 5^{th}-order) streams with modifications to the aerial survey techniques.

Detailed stream features such as “Pool”, “Riffle”, and “Large Organic Debris” were difficult to accurately assess from the air. However, larger features associated with low canopy closure such as “Bridge”, “Culvert” and, to a lesser extent “Beaver Dam” and “Wetland” features were effectively identified. Fisheries surveyors and resource managers may be able to reliably obtain these overview features on all streams with some modification to the aerial survey methodology such as reducing the aerial inventory speed. In addition, watershed level information such as general aspect, watershed boundary, stream access locations, land use information, and general channel morphology (e.g. step-pool habitat), and the relative abundance of variables such as “Large Organic Debris” may be also be accurately obtained. Furthermore, as indicated by the preliminary video-only analysis, a post-aerial survey review of the videotape may identify qualitative information such as off-channel habitat, riparian structural stage, and the percentage of canopy closure. On larger streams (e.g. 5^{th}-order in northern British Columbia), the assessment of a truncated list of detailed information may be obtainable with modifications to the aerial survey methodology such as reducing the aerial inventory speed.

This aerial video technology should not be viewed as a replacement for other resource inventory practices such as aerial photography but Myhre et al. (1990) suggest it may be substituted where the needs do not demand the quality and cost of photography. Jennings et al (1992) and Mussakowski (1984) appear to disagree on the applicable size of inventory area for aerial videographic surveys. Jennings et al. (1992) felt that aerial videography would be suitable for the quick assessment of large areas while Mussakowski (1984) felt that the larger the area the less cost-efficient the video technique. There may be an optimum area for this aerial application, perhaps 2-10 watersheds for fisheries overview and channel level assessments. Areas larger than 10 watersheds could be assessed using maps and aerial photos.

The exact application of aerial videography and variables for accurate and reliable identification in the fisheries field may take some time and experimentation as has taken place with other resource survey techniques. For example aerial photography had been used for more than forty years and they were still discovering new applications in the late 1970s (Langley 1978).

Other uses of aerial videography

Aerial surveys have been useful for cost-effectively gathering of larger scale information for various resource applications. Previous studies have successfully recorded meso-scale resource information using aerial videography such as bird nesting habitat, wetland classification, and vegetation mapping (Everitt et al 1988; Sidle and Ziewitz 1990; Jennings et al. 1992; Courtney et al 1994; Seibert et al 1996). In addition, video remote sensing may be highly useful for monitoring linear corridors with low crown closure, such as gas pipelines and transmission rights-of-way (Mussakowski 1984).

For the moment, analog video recording is the only available remote system offering dynamic stereo coverage as a hard product of the inventory (Um and Wright 1998). This aerial video technology is progressively becoming more cost effective given higher resolution S-VHS video recording equipment. In addition, the "digital revolution" may lead to significant benefits for the routine use of operational digital remote sensing. For example, there may be significant advantages to digitizing images of larger-order fish streams (with little crown closure) and other resource images to enable computer classification (Um and Wright 1999). Presently, it is cost prohibitive to purchase equipment such as digital cameras and recorders, to use techniques for compensating for the tip and roll of the aerial platform, and to use automated video mosaicking software to match video images (Pokrant and Hildebrand 1984; Um and Wright 1999).

Chapter Six:

Summary and Recommendations

Aerial videographic surveys as described in this study cannot accurately record detailed habitat unit information and should, therefore, only be used to gather watershed level and channel level overview stream information to help focus more detailed ground surveys. This aerial survey failed to provide a key requirement of an effective stream inventory at the habitat unit level: the accurate identification of the stream features measured. In addition, the locational accuracy of this aerial survey, while adequate for the location of overview information, was not adequate for a detailed 1:20, 000 reconnaissance survey and subsequent sequential identification of stream features.

The accuracy of identification and locational accuracy of aerial videographic surveys could be improved by altering the survey protocol. The stream feature list used by the aerial surveyor could be truncated to include only large features that can be reliably assessed using aerial surveys. These would include such features as "Bridges", "Culvert Crossings", "Falls", and "Fish Barriers". Information on other stream features such as "Large Organic Debris", "Riffles", and "Pools" may be obtained, but resource managers must realize that the accuracy of these features may not be reliable.

Truncating the stream feature list to approximately ten features would allow the aerial technician to have all features easily accessible in the "quick-mark" software. This may reduce the number of "X" points (features missed by the technician during the inventory) thereby reducing the video modification process. In addition, this would allow the surveyor to concentrate on fewer stream features without the interpretive difficulties associated with designating the relative size of the stream feature and the stream bank designation (e.g. "Tributary Left"). More detailed information such as the stream bank designation could be assigned later, if desired, during the video modification process.

To further increase the accuracy of identification and locational accuracy of aerial videographic surveys, the helicopter velocity could be reduced and the survey could be restricted to wider, larger-order streams such as 4^{th}- and 5^{th}-order streams in northern British Columbia. This reduction in velocity may increase the accuracy of the surveyor in identifying stream features in a number of ways. A lower survey velocity on larger streams would provide the surveyor with more interpretive time for each stream feature and theoretically increase the accuracy of feature identification. A lower survey velocity would also increase the ability of the helicopter pilot to capture the entire stream around stream bends and reduce the pitch and roll of the helicopter. In addition, lower survey velocities may also increase locational accuracy by decreasing the spatial disparity between the actual stream feature GPS position and the position of the GPS receiver in the tail boom of the helicopter. This decrease in helicopter velocity on larger-order streams may be offset by surveying 1^{st}- and 2^{nd}-order streams at higher velocities gathering only overview information.

The importance of pre-survey training was illustrated during a comparison of aerial surveyors. The lack of a pre-survey training session likely influenced the accuracy of stream feature identification for the second aerial surveyor, despite extensive aerial survey experience (Roper and Scarnecchia 1995; Wang et al 1996). This pre-survey training must be incorporated into any aerial videographic survey and for any resource management survey, regardless of the survey medium. Furthermore, it may be valuable to incorporate a ground assessment in aerial videographic survey planning, to ensure survey quality and to compensate for consistent surveyor bias such as consistently interpreting “Bedrock Outcrop” as “Bedrock Confinement” (Hankin and Reeves 1988).

The preliminary aerial video assessment of stream habitat variables was 75% accurate in the identification of habitat variables on a 5th-order sample stream segment. The sample site analyzed, however, was relatively channelized and did not have complex habitat numbers or structure. The success of stream habitat variable estimation may decline with increasing channel and habitat complexity, especially for quantitative variables such as percent pool, pool frequency, large woody debris per channel width, and percent large woody debris cover in pools. In addition, dense crown closure appears to reduce the ability of the aerial video to identify stream habitat and thus reduces the accuracy of video assessment. To help ensure that factors such as crown closure and video resolution do not impact similar video surveys in the future, the aerial surveys should be performed on 4th-order streams or larger or on streams with limited crown closure (less than 20%). To help improve video resolution, these streams should be flown as low and slow as economically possible, recording with the highest resolution tapes and the highest resolution cameras and recorders practically available (Ham 1996).

Stream clarity may also affect the successful identification of pool habitat units, large woody debris (especially submerged debris), and the identification of stream substrate during video analysis. These video surveys should take place in optimum lighting conditions and during low flow periods to ensure maximum stream clarity (Ham 1996).

To further understand the practical application and stream information that can be gathered from the video portion of aerial videographic surveys, a thorough sampling of stream sample sites across stream orders and watersheds should be undertaken.

Aerial videographic surveys can be an effective fisheries inventory tool for collecting meso-scale watershed and channel level information prior to more detailed ground surveys. However, further research will be required to determine whether the aerial videographic survey information gathered on larger order streams is more cost effective and detailed than existing survey techniques such as aerial photography. Aerial videographic surveys will most likely develop with technological advances in digital recording equipment, computer power and software, time, and experimentation in the fisheries field and other resource applications.

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Appendix 1:

Fish Species in the Upper Peace River Drainage

Common Name	Family (Subfamily)	Specific Name
1. Salmonids, Whitefish, and Graylings		
Kokanee	*Salmonidae (Salmoninae)*	*Oncorhynchus nerka*
Rainbow trout	*Salmonidae (Salmoninae)*	*Oncorhynchus mykiss*
Brook trout	*Salmonidae (Salmoninae)*	*Salvelinus fontinalis*
Lake trout	*Salmonidae (Salmoninae)*	*Salvelinus namaycush*
Dolly varden	*Salmonidae (Salmoninae)*	*Salvelinus malma*
Bull trout	*Salmonidae (Salmoninae)*	*Salvelinus confluentus*
Lake whitefish	*Salmonidae (Coregoninae)*	*Coregonus clupeaformis*
Pygmy whitefish	*Salmonidae (Coregoninae)*	*Prosopium coulteri*
Mountain whitefish	*Salmonidae (Coregoninae)*	*Prosopium williamsoni*
Arctic grayling	*Salmonidae (Thymallinae)*	*Thymallus arcticus*
2. Non-Salmonids		
Redside shiner	*Cyprinidae*	*Richardsonius balteatus*
Northern squawfish	*Cyprinidae*	*Ptychocheilus oregonensis*
Peamouth	*Cyprinidae*	*Mylocheilus caurinus*
Brassy minnow	*Cyprinidae*	*Hybognathus hankinsoni*
Longnose dace	*Cyprinidae*	*Rhinichthys cataractae*
Lake chub	*Cyprinidae*	*Couesius plumbeus*
Longnose sucker	*Catostomidae*	*Catastomus catastomus*
Largescale sucker	*Catostomidae*	*Catastomus macrocheilus*
White sucker	*Catostomidae*	*Catastomus commersoni*
Burbot	*Gadidae*	*Lota lota*
Prickly sculpin	*Cottidae*	*Cottus asper*
Slimy sculpin	*Cottidae*	*Cottis cognatus*

Appendix 2:

Definition of Stream Features

Reconnaisance Level Stream Inventory - Aerial GPS/videography 1998

Notes:

1. Aerial GPS video survey procedure usually entails mapping from the stream confluence upstream to the headwaters. All left and right features are described in relation to downstream flow (therefore the left bank is viewed on the right of the video screen when flying upstream) (T.Zimmerman MOELP, personal communication).

2. (W) Indicates features normally described at the watershed scale; (C) Indicates features normally described at the channel scale; (H) Indicates features normally described at the habitat unit scale (Osborne et al. 1991).

"x" point – a stream feature that could not be mapped by video/GPS technician during survey. The correct feature is to be added during video modification process.

backwater channel (C) - side channel of stream/creek with no noticeable flow; usually inlet and outlet are the same.

beaver dam (H) - beaver dam partially or totally blocking the stream.

bedrock confinement start (C) - upstream point on stream where bedrock confines the channel on either side; commentary and video will clarify location.

bedrock confinement end (C) - downstream point on stream where bedrock confines the channel on either side; commentary and video will clarify location.

bedrock outcrop (H) - point where bedrock overhangs or protrudes into the stream on either bank; commentary and video will clarify location. Bedrock is classified as <4000 mm (larger than a car).

boulder cluster (H) - point where two or more boulders are clustered in the stream providing usable fish habitat; boulders are classified as 256-4000 mm (basketball to car in size).

braided channel (C) - low gradient area of a stream having two or more flow branches (anastomosing islands).

bridge (H) - bridge (logging or other) over stream - includes culvert crossings.

cascade (H) - a series of two or more consecutive drops structures/steps approximately 0.5-2.0m in height each.

chute (H) - all/most of the stream flows through a narrow, confined feature caused by bedrock confinement or large boulders.

F1 - falls class 1 (H) - waterfalls/drops that are possible fish barriers to some fish species.

F2 - falls class 2 (H) - probable fish barrier to most fish species - greater than two meters in height.

fish barrier (probable) (H) - probable barrier to fish migration upstream.

islands vegetated (H) - instream island or gravel bar that has growing (green) vegetation over one meter tall.

islands non-vegetated (H) - instream island or gravel bar that does not having growing (green) vegetation over one meter tall.

LOD 1 - large organic debris class 1 (H) - relatively stable woody material having a minimum diameter greater than 10 cm and a length greater than one meter that lies within the stream channel but ***does not*** noticeably alter the stream flow. Consists of 1-3 pieces of debris and cover less than 50% of the stream channel.

LOD 2 - large organic debris class 2 (H) - relatively stable woody material having a minimum diameter greater than 10 cm and a length greater than one meter that lies within the stream channel and noticeably alters the stream flow. Consists of greater than 3 pieces of debris and covers more than 50% of the stream channel.

LOD 3 - large organic debris class 3 (H) - relatively stable woody material having a minimum diameter greater than 10 cm and a length greater than one meter that lies within the stream channel and spans the entire channel width (large debris jam)

P1 - pool class 1 (H) - a portion of the stream with reduced velocity, deeper than the surrounding area, and useable by fish for resting or cover (contains some surface cover or flow turbulance) that comprises less than 50% of the wetted stream width.

P2 - pool class 2 (H) - a portion of the stream with reduced velocity, deeper than the surrounding area, and useable by fish for resting or cover (contains some surface cover or flow turbulance) that comprises 50% or more of the wetted stream width.

P3 - pool class 3 (H) - a portion of the stream with reduced velocity, deeper than the surrounding area, and useable by fish for resting or cover (contains some surface cover or flow turbulance) that comprises the entire wetted stream width. For most class 3 pools the channel width is enlarged compared to areas upstream and downstream.

reach break (potential) (C) - boundary between two reaches (reach being defined as a segment of stream with relatively homogenous gradient, flow, cover and habitat features).

riffle start (H) - upstream point on stream where riffle habitat unit begins. Used when riffle areas are more than 100 metres in length.

riffle end (H) - downstream point on stream where riffle habitat unit ends. Used when riffle areas are more than 100 metres in length

riffle (H) - habitat unit with fast, turbulent, white water. Surface of the water is broken but habitat unit is not falls, cascades or chutes. Used when riffle areas are less than 100m in length.

side channel start (H) - upstream point on stream where lateral channel, parallel to mainstream, begins.

side channel end (H) - downstream point on stream where lateral channel, parallel to mainstem, ends.

slumping bank left (H/C) - area where left bank has/is eroding into stream.

slumping bank right (H/C) - area where right bank has/is eroding into stream.

tributary right (H/C) - confluence point where tributary flows into the stream (being surveyed) from the right bank.

tributary left (H/C) - confluence point where tributary flows into the stream (being surveyed) from the right bank.

wetlands left (H/C) - wetland area adjacent to or incorporating the left bank of the stream. Wetlands areas can be marshes, swamps or other areas of standing water.

wetlands right (H/C) - wetlands area adjacent to or incorporating the right bank of the stream. Wetlands areas can be marshes, swamps or other areas of standing water.

wetted channel width (C) - the estimated wetted channel width as estimated from the air. This is a very important feature if trying to calculate feature areas from the air

Appendix 3:

An Example of the Aerial and Ground Data Matching Procedures

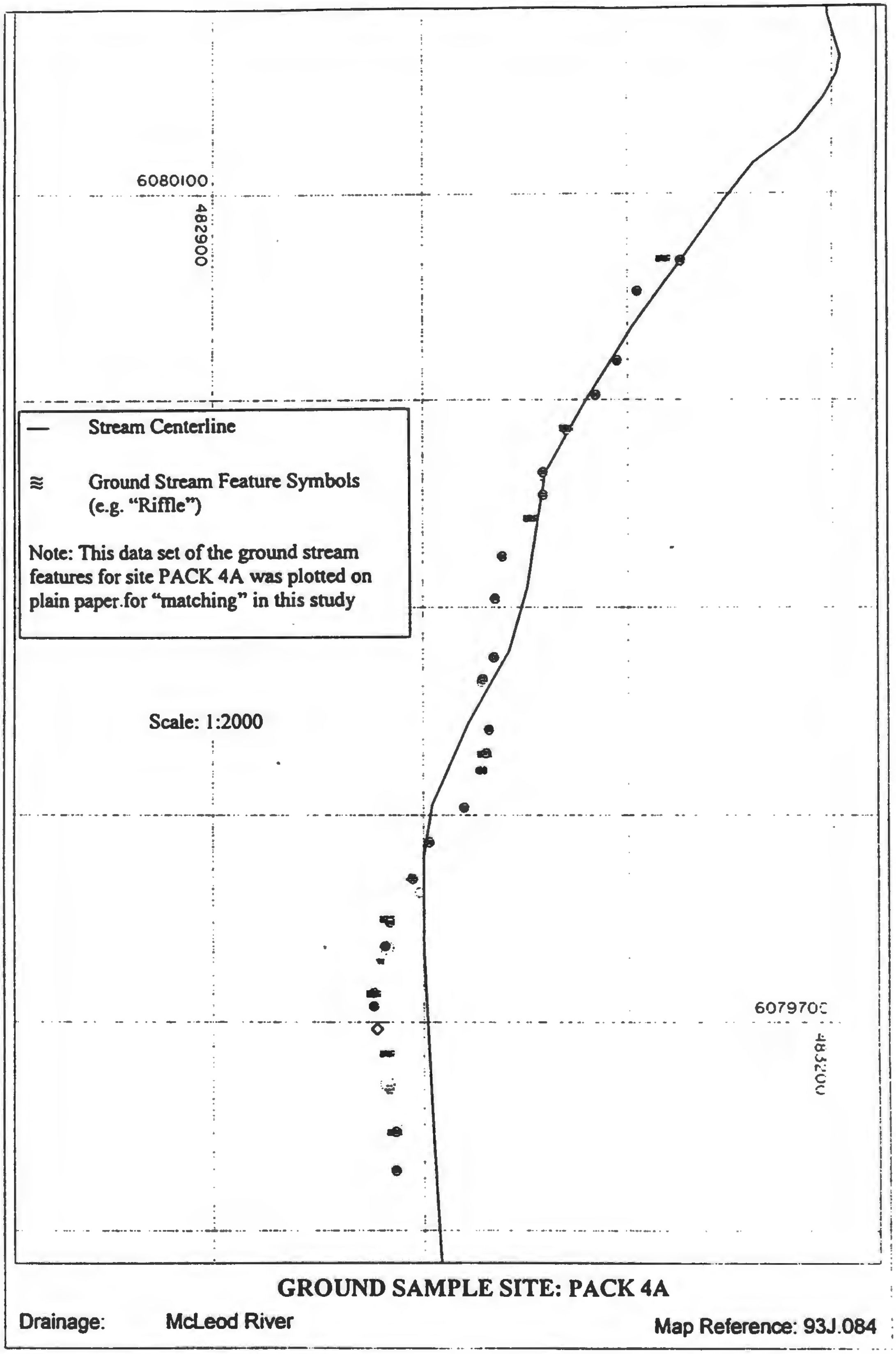
An example of sample site stream feature plots in the Pack River watershed to illustrate the "matching" technique to determine the proportion of stream features correctly identified. An accompanying list of stream features and their associated symbols is also provided.

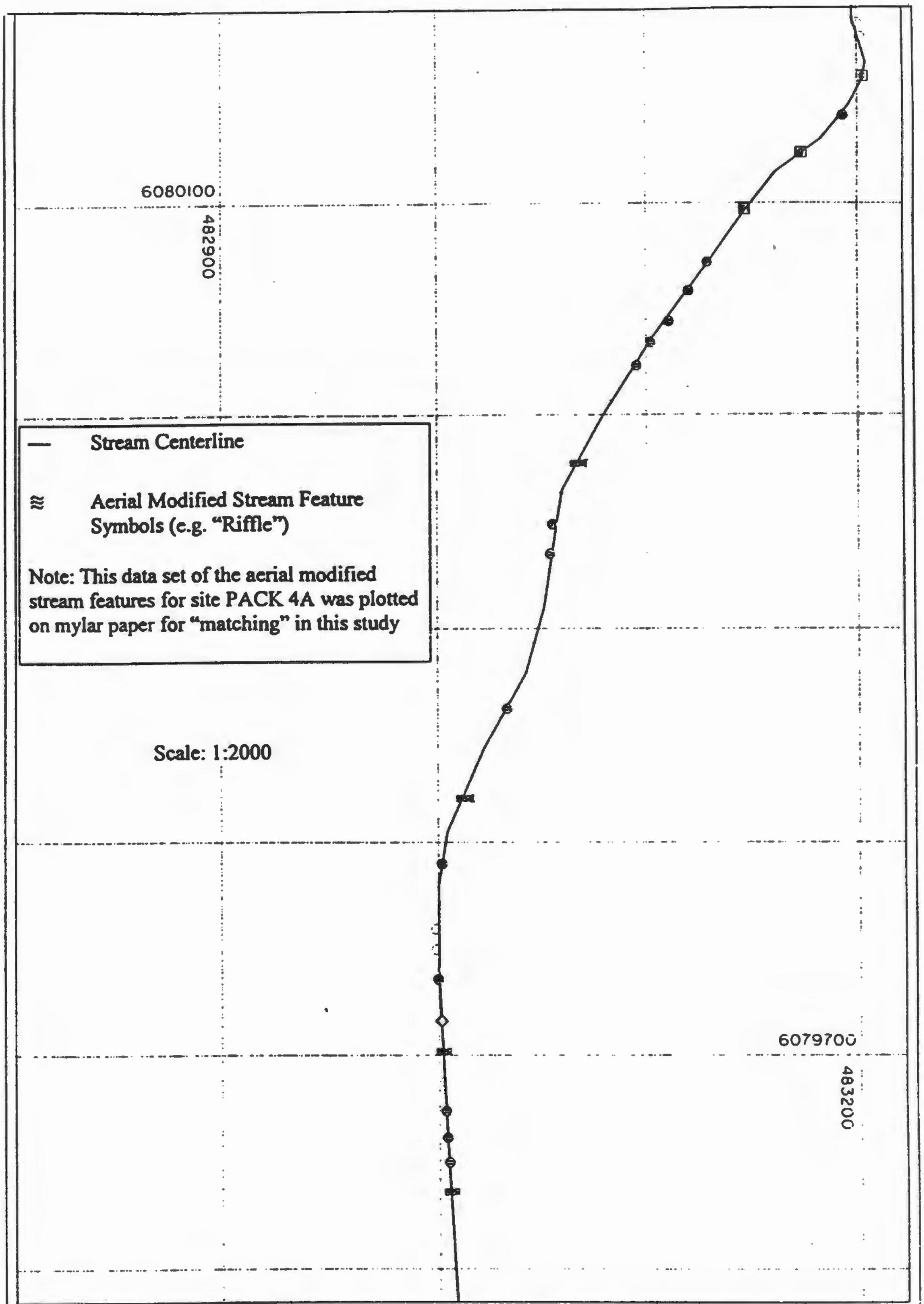
The "matching" technique involved:

1. Plotting the unmodified aerial survey, modified aerial survey, and ground survey data sets using the GPS coordinates associated with each stream feature. Feature symbols were used to visually distinguish stream features from one another (e.g. "Riffle" from "Pool Class 1") such that the unmodified aerial survey, modified aerial survey, and ground survey data were represented as a series of feature symbols along each stream sample site.

2. The unmodified and modified aerial survey data, plotted on mylar sheets, were then overlaid onto corresponding ground survey data plots for each sample site to match correctly identified aerial survey stream features with the ground survey stream features.

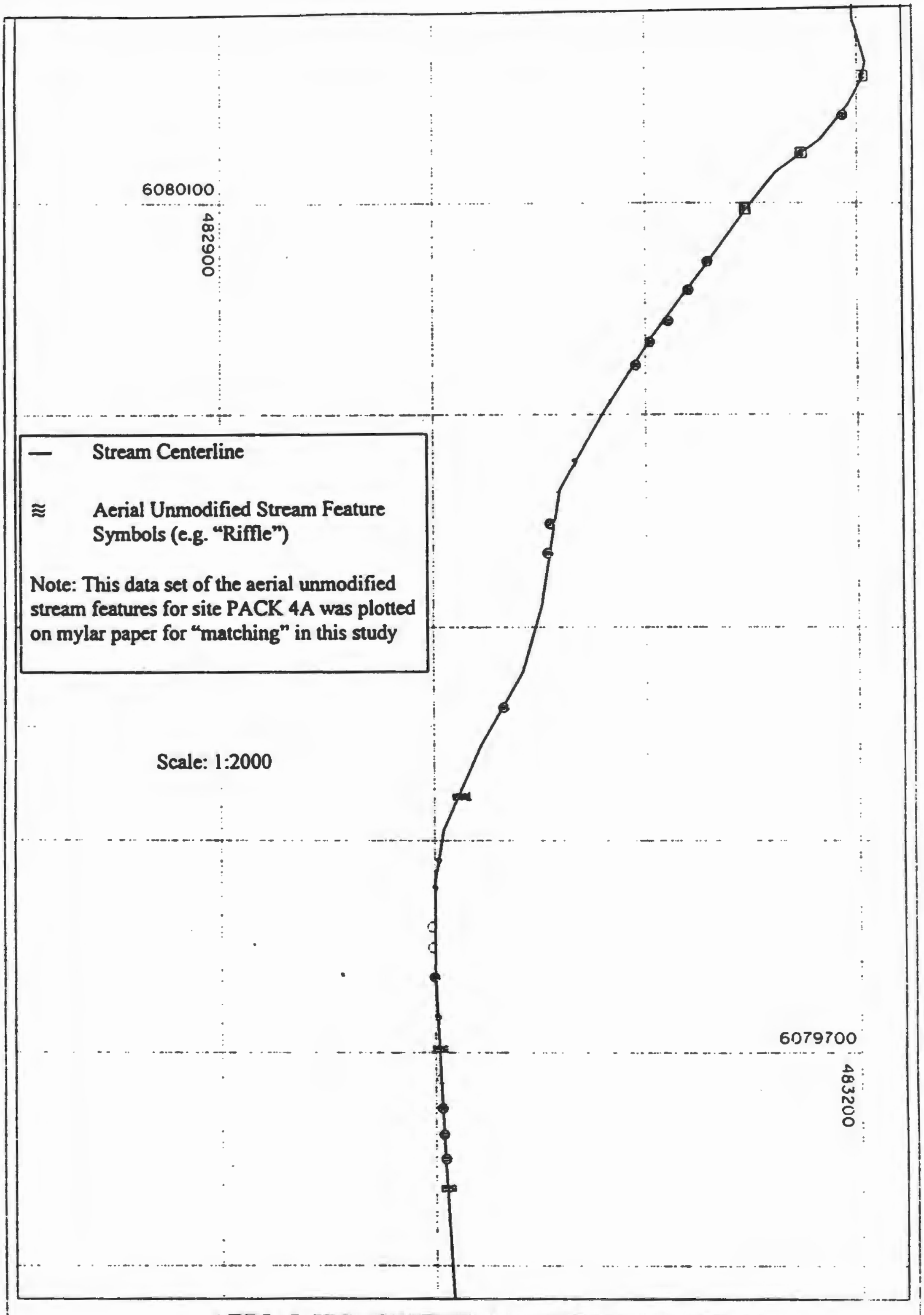
3. The number of unmodified and modified stream features correctly "matching" ground stream features were then summarized for each sample site and each feature. The maximum distance between the aerial and ground surveyed features over which the features could be considered to be the same feature was set at 120 metres.


6080100
482900
Stream Centerline
Ground Stream Feature Symbols
(e.g. "Riffle")
Note: This data set of the ground stream features for site PACK 4A was plotted on plain paper for "matching" in this study
Scale: 1:2000
6079700
483200
GROUND SAMPLE SITE: PACK 4A
Drainage: McLeod River
Map Reference: 93J.084



AERIAL MODIFIED SAMPLE SITE: PACK 4A

Drainage: McLeod River | Map Reference: 93J.084



AERIAL UNMODIFIED SAMPLE SITE: PACK 4A

Drainage: McLeod River Map Reference: 93J.084

SYMBOL	DESCRIPTION
	Backwater channel- side channel of stream with no noticeable flow; usually inlet and outlet are the same.
	Backwater channel(left bank)- side channel of stream with no noticeable flow; usually inlet and outlet are the same.
	Backwater channel(right bank)- side channel of stream with no noticeable flow; usually inlet and outlet are the same.
	Beaver dam - blocking the stream. A beaver dam partially blocking stream will be classified as LOD.
	Braided channel- low gradient area of a stream having two or more flow branches (anastomosing islands)
X	Fish barrier - impassable obstruction in stream; usually in conjunction with waterfalls.
X	Fish barrier (possible) - barrier other than falls which represents a possible barrier to fish migration upstream.
C	Cascade - a series of two or more consecutive drops, structures or steps approximately 0.5-2.0m in height each.
	Chute - all/most of the stream flows through a narrow confined feature caused by bedrock confinement or boulders.
	Bedrock confinement - bedrock which confines the channel of a stream on either side; commentary on video will clarify.
	Bedrock confinement (left bank)
	Bedrock confinement (right bank)
	Bedrock confinement start - upstream point of bedrock confinement.
	Bedrock confinement end - downstream point of bedrock confinement.
	Culvert crossing - all stream flow passes through a culvert beneath a loggin road or other.
F1	Falls class 1- waterfall which represents a possible barrier to fish migration; falls height should be estimated on video.
F2	Falls class 2 - waterfall which represents a definite barrier to fish migration; height should be estimated on video.
	Boulder cluster/garden - point where two or more boulders (250-4000mm) are clustered providing useable fish habitat.
GB	Gravelbar - gravelbar that does not have growing (rooted) vegetation.
+	Islands - instream island that has growing (rooted) vegetation.
+	Islands (non-vegetated) - instream island that does not have growing (rooted) vegetation
	Large organic debris (LOD) class 1- isolated log, blowdown tree or swamp.
	Large organic debris (LOD) class 2 - clump of logs, blowdown trees or stumps.
	Large organic debris (LOD) class 3 - large logjam, blowdown or stumps across most of the stream significantly altering flow.
	Logging area - cut block present or logging activity in the area.
	Logging (downstream extent) - downstream point or end of logging area or cut block.
	Logging (left bank) - logging activity or cut block river-left.
	Logging (right bank) - logging activity or cut block river-right.
	Logging (upstream extent) - upstream point or start of logging area or cut block.

	Bedrock outcrop - point where bedrock (>4000mm) overhangs or protrudes into the stream on either bank.
	Slide area - slide present on either bank.
	Slumping bank start - upstream point on stream where bank is eroding into stream, affecting water quality, begins.
	Slumping bank (left bank) - point on stream where left bank is eroding into stream, affecting water quality.
	Slumping bank (right bank) - point on stream where right bank is eroding into stream, affecting water quality.
	Slumping bank end - downstream point on stream where bank is eroding into stream, affecting water quality, ends.
	Poolclass 1 - useable rest area for fish that is isolated behind a boulder, LOD or other feature.
	Poolclass 2 - useable rest area for fish that is intermediate in size (between 1 and 3).
	Poolclass 3 - useable rest area for fish that spans the width of the stream channel.
	Reach Break (potential) - boundary between two reaches (reach is a segment of stream with homogenous characteristics).
	Riffle - habitat unit with fast, turbulent, white water. Used in riffle areas less than 100m in length.
	Riffle start - upstream point on stream where riffle habitat unit begins.
	Riffle end - downstream point on stream where riffle habitat unit ends.
Rd	Road present - road(s) in area which are not represented in background TRIM data.
Rd	Road present (left bank) - road(s) river-left which are not represented in background TRIM data.
Rd	Road present (right bank) - road(s) river-right which are not represented in background TRIM data.
SC	Side channel - area on stream where a lateral channel, parallel to mainstem, is present; video commentary will specify bank.
SC	Side channel end - downstream point on stream where lateral channel, parallel to mainstem, begins.
SC	Side channel end - downstream point on stream where lateral channel, parallel to mainstem, ends.
	Wetlands - areas of marshes, swamps or other areas of standing water.
	Wetlands left - wetland area adjacent to or incorporating the left bank of the stream.
	Wetlands right - wetland area adjacent to or incorporating the right bank of the stream.
TRIBS	Area of drainage - area on mainstem which has several tributaries flowing into it.
	Tributary left - confluence point where tributary flows into the stream (being surveyed) from the left bank.
	Tributary right - confluence point where tributary flows into the stream (being surveyed) from the right bank.
	Ford - non-constructed creek crossing (i.e. vehicles drive through creek bed).
	Bridge - bridge (logging or other) over stream.
	Kilometer marker
SUB	Sub-Surface Flow - indicates area in drainage where normal river flow is underground.

Appendix 4:

Detailed Statistical Information

4.1 Preliminary Data Analysis: A 2 x 22 Chi-Square Goodness of Fit test comparing the "Definitive" and "Interpretive" data sets

This analysis was used to investigate whether there was a statistical difference between a "Definitive" data set and an "Interpretive" data set. The "Definitive" data set was created by matching the aerial and ground stream features using the strict feature definitions. Therefore, a "Slumping Bank End" identified by the aerial surveyor was not counted as a correct match to a "Slumping Bank" identified on the ground. The "Interpretive" data set was created by matching the aerial and ground stream features using truncated aerial and ground feature definitions. Therefore, features with many levels such as "Slumping Bank End" and "Slumping Bank Start" would all be truncated to just "Slumping Bank".

The null hypothesis (Ho) used for this analysis was that "there is not a statistical difference between the observed (Interpretive) and expected (Definitive) data sets".

The degrees of freedom = n (features identified in aerial survey) – 1
= 16 – 1
= 15

Notice that for six of the stream features the definitive and interpretive features correctly identified were zero and therefore could not be included in the analysis because the Chi-Squared statistic for these features would have been calculated by dividing by zero.

$$\chi^2 = \sum_{i=1}^{15} = (Fi - fi)^2/fi$$

$\chi^2 = 13.853$

The critical value for the $\chi^2_{0.05}$ distribution = 24.996 (Zar 1996 Table B1). Therefore we cannot reject Ho and conclude that the two data sets are not statistically different.

The above analysis evaluated the effect of the different interpretations of the correct identification of stream features overall. Another question is whether there was an effect of the different interpretation of the correct identification of stream features for only features that were corrected. We repeated the analysis using the number of features correct for only the features that were truncated ("Bedrock", "Riffle", "Slumping Bank", and "Wetland" features) and found that:

$\chi^2 = 13.853$

The critical value for the $\chi^2_{0.05}$ distribution = 7.815 so we can reject Ho and there was a statistical difference between the Interpretive and Definitive data sets when only the four feature are included in the analysis.

4.2 A 2 x 22 Chi-Square comparing the Modified and Unmodified numbers of habitat features identified correctly.

The null hypothesis (Ho) used for this analysis was that "there is not a statistical difference between the observed (Modified) and expected (Unmodified) data sets".

The degrees of freedom	=	n (stream feature identified in aerial survey) – 1
	=	16 – 1
	=	15

Notice that for six of the stream features the unmodified and modified features correctly identified were zero and therefore could not be included in the analysis because the Chi-Squared statistic for these features would have been calculated by dividing by zero.

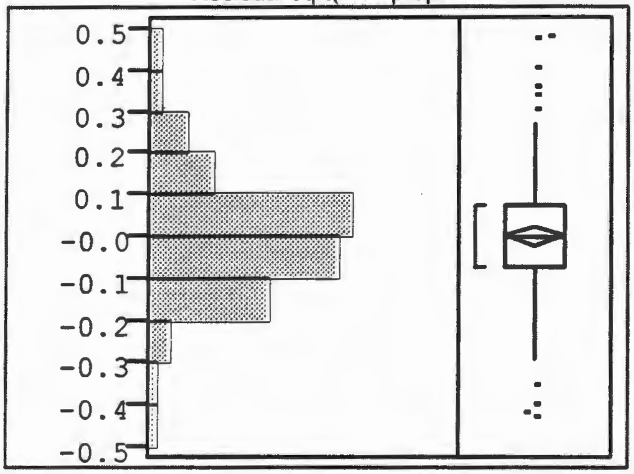
$$\chi^2 = \sum_{i=1}^{15} = (Fi - fi)^2/fi$$

$\chi^2 = 6.670$

The critical value for the $\chi^2_{0.05}$ distribution = 24.996 (Zar 1996 Table B1). Therefore we cannot reject Ho and the two data sets are not statistically different.

4.3 Test for data normality and figures of interactions for 3x4x9 analysis of variance with Watershed, Order and Feature as factors.

Residual sqrt(ln1+ prop.



Quantiles

maximum	100.0%	0.48819
	99.5%	0.48819
	97.5%	0.36807
	90.0%	0.19184
quartile	75.0%	0.07306
median	50.0%	-0.0048
quartile	25.0%	-0.075
	10.0%	-0.1707
	2.5%	-0.3431
	0.5%	-0.42
minimum	0.0%	-0.42

Moments

Mean	0.0000
Std Dev	0.1525
Std Error Mean	0.0121
Upper 95% Mean	0.0238
Lower 95% Mean	-0.0238
N	160.0000
Sum Weights	160.0000

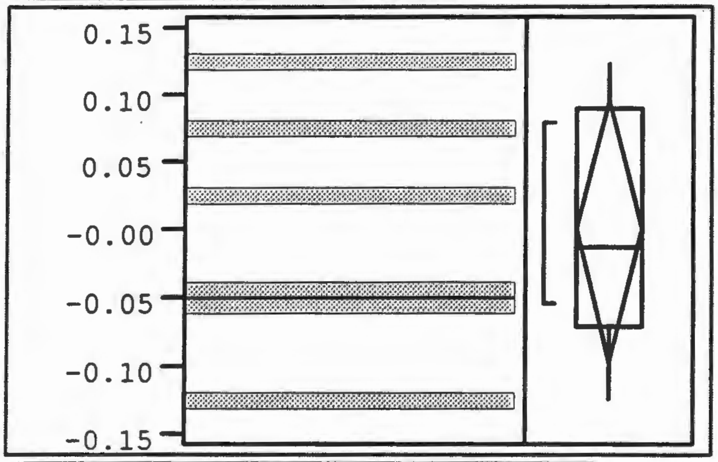
Test for Normality
Shapiro-Wilk W Test

W	Prob<W
0.971278	0.0614

Figure 4A: Test for data normality and box plot of residuals for the aerial data $\sqrt{\ln(1+ \text{proportion of aerial stream features correctly identified})}$

4.4 Test of data normality for linear regression of percentage of stream features correctly identified by inventory day.

Residual Mean(CORR(M))



Quantiles

maximum	100.0%	0.12286
	99.5%	0.12286
	97.5%	0.12286
	90.0%	0.12286
quartile	75.0%	0.09025
median	50.0%	-0.0126
quartile	25.0%	-0.071
	10.0%	-0.1235
	2.5%	-0.1235
	0.5%	-0.1235
minimum	0.0%	-0.1235

Moments

Mean	0.000000
Std Dev	0.091893
Std Error Mean	0.037515
Upper 95% Mean	0.096434
Lower 95% Mean	-0.096434
N	6.000000
Sum Weights	6.000000

Test for Normality

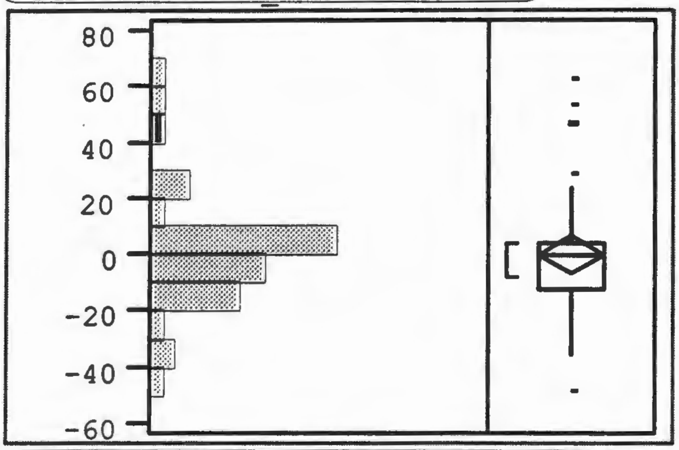
Shapiro-Wilk W Test

W	Prob<W
0.964261	0.8542

Figure 4B: Test for data normality for the proportion of stream features correctly identified by inventory day

4.5 Test for data normality for "known" stream feature locational accuracy using Watershed, Stream Order and Stream Feature as factors

Residual KNOWN_DISTANCE



Quantiles

maximum	100.0%	63.423
	99.5%	63.423
	97.5%	62.753
	90.0%	28.078
quartile	75.0%	3.973
median	50.0%	-0.000
quartile	25.0%	-12.585
	10.0%	-26.400
	2.5%	-46.663
	0.5%	-47.563
minimum	0.0%	-47.563

Moments

Mean	0.00000
Std Dev	21.23241
Std Error Mean	3.27623
Upper 95% Mean	6.61646
Lower 95% Mean	-6.61646
N	42.00000
Sum Weights	42.00000

Test for Normality

Shapiro-Wilk W Test

W	Prob<W
0.899000	0.0010

Figure 4C: Test for data normality for the "known" stream feature locational accuracy

Appendix 5:

An FHAP assessment table and aerial video FHAP results and ground survey FHAP results

Table 5A: Diagnostics Table of Salmonid habitat condition (from Johnston and Slaney 1996)

Habitat Parameter	Gradient or W_b Class	Use	Quality		
			Poor	Fair	Good
Percent pool (by area)	<2 %, < 15 m wide	Summer/winter rearing habitat	< 40 %	40 - 55%	> 55 %
Percent pool (by area)	2-5 % , < 15 m wide	Summer/winter rearing habitat	< 30 %	30 - 40 %	> 40 %
Percent pool (by area)	>5 % , < 15 m wide	Summer/winter rearing habitat	< 20 %	20 - 30 %	> 30 %
Pool frequency (mean pool spacing)	<2 %, < 15 m wide	Summer/winter rearing habitat	> 4 channel widths per pool	2 - 4 channel widths per pool	< 2 channel widths per pool
Pool frequency (mean pool spacing)	2-5 % , < 15 m wide	Summer/winter rearing habitat	> 4 channel widths per pool	2 - 4 channel widths per pool	< 2 channel widths per pool
Pool frequency (mean pool spacing)	>5 % , < 15 m wide	Summer/winter rearing habitat	> 4 channel widths per pool	2 - 4 channel widths per pool	< 2 channel widths per pool
LWD pieces per bankfull channel width	all	Summer/winter rearing habitat	< 1	1 - 2	> 2
% wood cover in pools	< 5 %, < 15 m wide	Summer/winter rearing habitat	most pools in low category 0 - 5 %	most pools in moderate category 6 - 20 %	most pools in high category > 20 %
Boulder cover in gravel-cobble riffles	all	Summer/winter rearing habitat	< 10 %	10 - 30 %	> 30 %
Overhead cover	all	Summer/winter rearing habitat	< 10 %	10 - 20 %	> 20 %
Substrate	all	Winter rearing habitat	interstices filled: sand or small gravel subdominant in cobble or boulder dominant	interstices reduced: sand subdominant in some units with cobble or boulder dominant	interstices clear: sand or small gravel rarely subdominant in any habitat unit

Table 5A: Diagnostics Table of Salmonid habitat condition (from Johnston and Slaney 1996)

Habitat Parameter	Gradient or W_b Class	Use	Quality: Poor	Quality: Fair	Quality: Good
Off-channel habitat	< 3 %, all widths	Winter rearing habitat	few or no backwaters, no off-channel ponds	some backwaters	backwaters with cover and pond, oxbows and other low energy off-channel areas
Holding pools	all	Adult migration	few pools/km > 1 m deep with good cover, cool		adequate pools/km, > 1 m deep with good cover, cool
Access to spawning areas	all	Adult migration	access blocked by low water, culvert, falls, temperature		no blockages
Gravel quantity	all	Spawning and incubation	absent or little		Frequent spawning areas
Gravel quality	all	Spawning and incubation	sand is dominant substrate at some sites	sand is subdominant substrate at some sites	sand is never dominant or subdominant substrate
Redd scour	all	Spawning and incubation	evidence of extensive redd scour	some scour or potential for scour	stable with low potential for scour
Inorganic nutrients	all	Summer rearing habitat	spawner numbers depressed <u>and</u> NO_3-N < 20 $\mu g \cdot L^{-1}$ <u>and / or</u> SRP < 1 $\mu g \cdot L^{-1}$	spawner numbers normal; NO_3-N from 20-40 $\mu g \cdot L^{-1}$ and SRP from 1-2 $\mu g \cdot L^{-1}$	NO_3-N > 60 $\mu g \cdot L^{-1}$ and SRP >3 $\mu g \cdot L^{-1}$

Notes:

1. Use this table when regional standards are not available.
2. We currently lack standards for channels with W_b > 15 m. Be cautious in the application of the above diagnostics to such channels.

Video Only Watershed Restoration Program FHAP Assessment Results

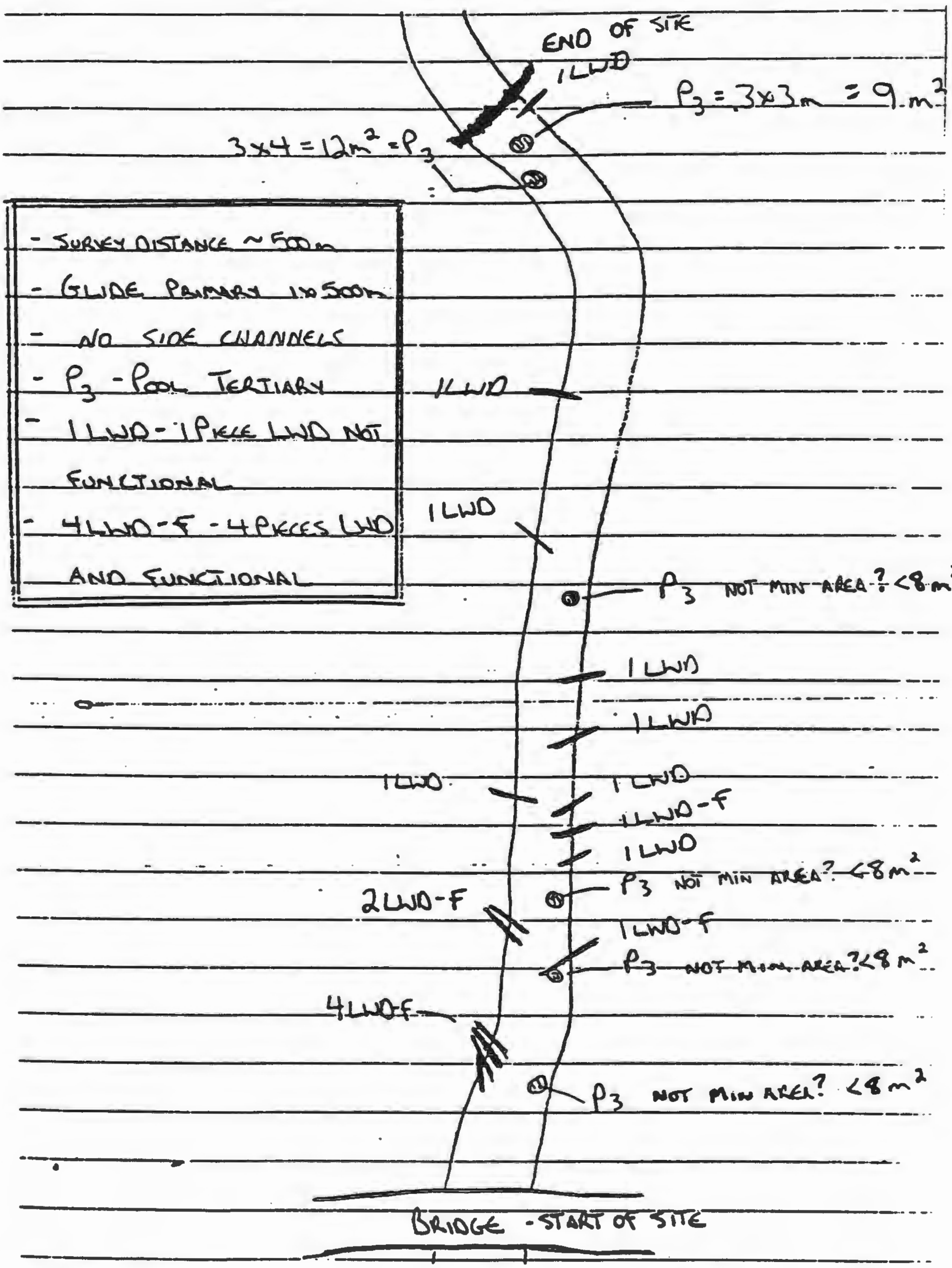


Figure 5A: Schematic of the video only FHAP for sample site Paul 5a

Video-only Level 1 FHAP assessment results for sample site Paul 5A. Detailed procedures describing the evaluation of each variable is described in the methodology (Pages 51-53).

Variable 1. Percentage Pools (Pool Area/Total Area)

Wetted Width	=	estimated at 15 metres		
Gradient	=	estimated at less than 2%		
Pool Area	=	addition of all pool areas in the sample site		
	=	$9\ m^2 + 12\ m^2$	=	$19\ m^2$
Total Area	=	15m (wetted width) x 500m	=	$7500\ m^2$
Percentage Pools	=	$19\ m^2 / 7500\ m^2$	=	0.25%

0.25 % is less than 40% (Table 5A) so condition is POOR

Variable 2. Frequency of Pools (estimated as the average wetted width between pools)

Two pools identified at the site and 10m estimated between the pools
Wetted Width/Pool = 10m/15m (average wetted width) = 0.67

0.67 is less than 2 channel widths per pools and therefore the condition (Table 5A) is rated as GOOD.

Variable 3. Large Woody Debris Pieces/Wetted Width

Total LWD Pieces = 16
Length of Sample Sites = 500
Wetted Width = 15

LWD Pieces/Wetted Width = 16/(500/15) = 0.48

0.48 is less than 1 (Table 5A) so the condition is POOR.

Variable 4. Percent Wood Cover in Pools

Pool 1 0% cover visually estimated
Pool 2 0% cover visually estimated

0% is a POOR condition (Table 5A)

Video-only Level 1 FHAP assessment results for sample site Paul 5A Continued. Detailed procedures describing the evaluation of each variable is described in the methodology (Pages 51-53).

Variable 5. Substrates

Visually assessed substrate as predominantly cobble. This condition resulted in a POOR rating because cover was minimal and overwintering habitat was absent (Table 5A).

Variable 6. Off-Channel Habitat

Visually assessed no off-channel habitat. No off-channel habitat results in a POOR rating (Table 5A).

Variable 7. Gravel Quanity

Visually assessed minimal gravel by evaluating bare sections of stream bank. These banks contained mainly cobble and thus I assumed the stream substrate was similar. No gravel results in a POOR rating (Table 5A).

Variable 8. Holding Pools

Two small pools were identified in the sample site and no larger holding pools. No holding pools results in a POOR rating (Table 5A).

Ground WRP FHAP Level 1 Assessment Results (Site Paul 5A)

orm 4 5A - Paul River 5a . 104 1 Fish Habitat Assessment

Level 1 - Habitat Survey Data Form

orest District: Mackenzie
TS map sheet:
urvey Date: 16 / 09 / 98 (d / m / y)

Watershed: Paul River
Weather: 10% cloud, sunny
Survey Crew: KBC, DSH

Sub-Basin:
Discharge ($m^3 \cdot s^{-1}$):
Subsampling Fractions: 1 (R / P / G / C / O)

Reach Number	Distance (m)	Habitat Unit Type	Habitat Unit Cat	Length (m)	Gradient (%)	Mean Depth Bankfull (m)	Mean Depth Water (m)	Mean Width Bankfull (m)	Mean Width Wetted (m)	Pools Only Max. Depth (m)	Pools Only Crest (m)	Pools Only Residual (m)	Pools Only Pool Type	Bed Material Type Dom.	Bed Material Type Sub-Dom.	Bed Material Type Spawning Gravel?
	0-500	R	1	500	0.5	.055	.50 .40 .45 .50	18.9	17.3	—	—	—	—	G	C	N A112

Total LWD Tally	Functional LWD Tally 10 - 20 cm	Functional LWD Tally 20 - 50 cm	Functional LWD Tally > 50 cm	Cover Type	%	Cover Type	%	Offchannel Habitat Type	Offchannel Habitat Access	Offchannel Habitat Length (m)	Disturbance Indicators			Riparian Vegetation Type	Riparian Vegetation Structure	Riparian Vegetation Canopy Closure	Barriers	Comments
39	21	13	0	LWD	5	OV	5	—	—	—	EB	BD		M	ME	1	N	—

April 1996 Level 1 Habitat Survey Form

1 start @ D/S end of bridge note not start of little habitat unit
OR end of habitat unit

Ground WRP FHAP Level 1 Assessment Results (Site Paul 5A)

5A - PAUL RIVER Pg 1 of 2

Sept 24, 98

A - % Pool by Wetted Area

	Habitat Unit	Cat	L(m) x	W(m)	= Total Area
Pools	∅				
Riffle	1	1	500 x	17.3	= 8650 m²
Glide	∅				

No Pools = POOR

B POOL FREQUENCY

NO POOLS = POOR

C LWD/W = Tot (reach length/W)

∅ = 39 / (500/17.3) = 1.34

FAIR

D - % Wood Cover in Pools

POOR NO pools

E Substrate

Substrate was found to be G, C with very little cover in riffle habitat unit. This riffle was also fairly fast flowing.
∴ I would say POOR [illegible] rearing habitat

Ground WRP FHAP Level 1 Assessment Results (Site Paul 5A)

PAUL 4A. Pg 2 of 2

$\boxed{F}$ - Off Channel habitat

None found ∴ POOR

$\boxed{G}$ - Gravel Quantity

No spawning availability : POOR

$\boxed{H}$ Holding Pools

None : POOR