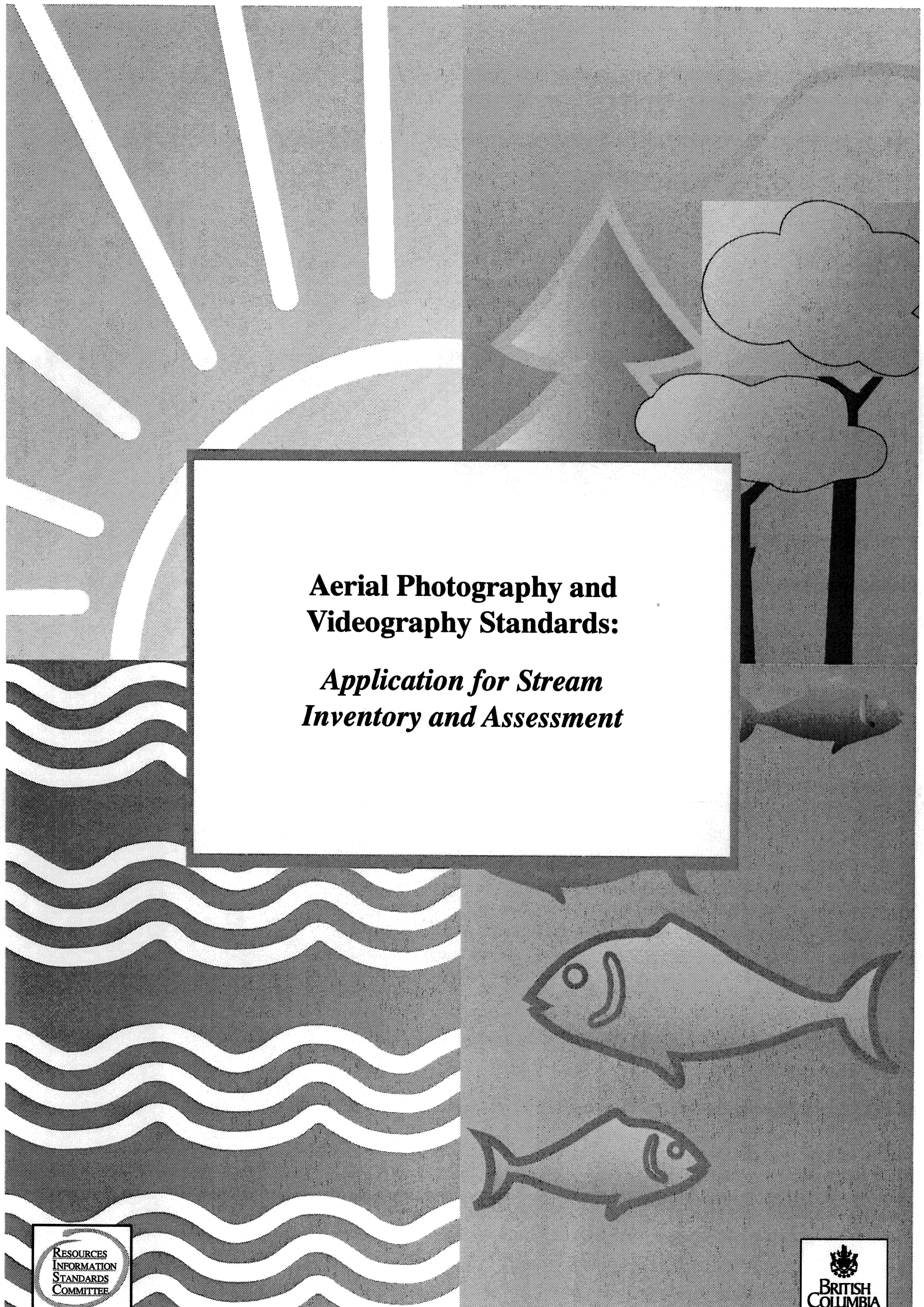

Aerial Photography and Videography Standards:

Application for Stream Inventory and Assessment

Resources Information Standards Committee

British Columbia

BRITISH COLUMBIA

RESOURCES INFORMATION STANDARDS COMMITTEE

Resources Inventory Standards Committee

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Aerial Photography and Videography Standards:

Application for Stream Inventory and Assessment

Prepared by Darren Ham (Department of Geography, UBC)
on behalf of the
B.C. Ministry of Environment, Lands and Parks,
Fisheries Branch
for the Aquatic Ecosystems Task Force,
Resources Inventory Committee

MARCH 1996

National Library of Canada Cataloguing in Publication Data
Ham, Darren.
Aerial photography and videography standards : applications for stream inventory and assessment (computer file)

"March 1996"
Variant title: Aerial photography and videography standards for fish habitat channel assessment.
Includes bibliographical references : p.
Available on the Internet.
Issued also in printed format on demand.
ISBN 0-7726-3294-4

1. Fishes – Habitat – Aerial photographs – Standards – British Columbia. 2. Aerial photography – British Columbia – Handbooks, manuals, etc. 3. Video recording - British Columbia – Handbooks, manuals, etc. I. BC Environment. Fisheries Branch. II. Resources Inventory Committee (Canada). Aquatic Ecosystems Task Force. III. Title. IV. Title: Aerial photography and videography standards for fish habitat channel assessment.

TR810.H35 1997 778.3'5 C97-960186-X

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PREFACE

The Resources Inventory Committee consists of representatives from various ministries and agencies of the Canadian and British Columbia governments. First Nations peoples are represented in the Committee. RIC objectives are to develop a common set of standards and procedures for the provincial resources inventories, as recommended by the Forest Resources Comission in its report "The Future of Our Forests".

Funding of the Resources Inventory Committee work, including the preparation of this document, is provided by the Canada-British Columbia Partnership Agreement on Forest Resources Development: FRDA II – a five year (1991-1996) $200 million program cost-shared equally by the federal and provincial governments.

Contents of this report are presented for discussion purposes only. A formal technical review of this document has not yet been undertaken. Funding from the partnership agreement does not imply acceptance or approval of any statements or information contained herein by either government. This document is not official policy of the Canadian Forest Service nor of any British Columbia Government ministry or agency.

ACKNOWLEDGEMENTS

Funding of the Resources Inventory Committee work, including the preparation of this document, is provided by the Corporate Resource Inventory Initiative (CRII) and by Forest Renewal BC (FRBC). Preliminary work of the Resources Inventory Committee was funded by the Canada-British Columbia Partnership Agreement of Forest Resource Development FRDA II.

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Terrestrial Ecosystems Task Force – Aquatic Ecosystems

This document was prepared byDarren Ham, Department of Geography, University of B.C. Preparation of this document was initiated by Anthony Cheong, Fisheries Branch (Victoria), Ministry of Environment, Lands and Parks. Funding for this work was provided by the Resources Inventory Commission. This document is largely based on similar work completed in 1995 for Tom Johnston at the Fisheries Research Centre (UBC), Ministry of Environment, Lands and Parks. This document could not have been completed without this previous funding under a grant provided through the Watershed Restoration Program.

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1.0 INTRODUCTION

This manual presents a set of standards and procedures for collecting remotely-sensed[1] data for the inventory, maintenance and enhancement of fisheries streams throughout British Columbia. This manual is directed at environmental scientists and resource managers working on behalf of the province, but should not be limited to those groups only. The impetus for this work is the recent proliferation of remote sensing techniques, but especially aerial videography, for use in inventory applications. As well, recent initiatives such as the Forest Renewal Inventory Program and the Watershed Restoration Program require that systematic resource assessments of streams be made. These surveys must be completed in a standardized way, especially if the data are to be used for mapping and archival purposes as part of province-wide databases.

Depending upon the scale of study and the detail of information required for channel and habitat assessment, a variety of surveying techniques can be employed. For detailed site-specific data, an extensive field-based survey may be required if these data have not been previously collected. For less intensive habitat assessment surveys, aerial remote sensing techniques may be more appropriate. Standard aerial photographs are generally available for most areas of British Columbia, but recent photographs (i.e., less than 2 years old) may not exist. If the only available photography is considered too old, there are several options to obtain current imagery using various aerial photographic and video platforms. These options will be discussed.

The main objectives of this project are:

- to provide an overview of aerial photography andvideography techniques;
- to discuss the appropriate technique(s) to be used for habitat and channel morphology surveys with particular reference to:
  1. the features of interest to be recorded or measured,
  2. how the required imagery can be obtained,
  3. collecting usable data from the imagery in the form of maps and tables, and
  4. associated costs, accuracy and limitations of the different techniques;
- and finally, to provide some recommendations for systematic data collection surveys.

For additional information onvideography standards and techniques, readers are directed to "Review of Aerial Video Survey Techniques and Recommendations of Survey Standards" (Harper & Reimer, 1995). For a critical review of a wide variety of remote sensing techniques for channel assessments, see "A Comparison of Methods to Monitor Stream Channel Morphology" (Ham, 1995).

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1 Remote sensing is defined as the technique of obtaining information about objects by analyzing data collected using instruments which are not in direct physical contact with the objects under study (Avery & Berlin, 1992).

2.0 PROJECT SCOPE

Conventional survey techniques are labour intensive, generally requiring extensive field work. Alternative (remote sensing) techniques have been used in experimental work as part of different research programs documenting changes in stream channel conditions (Bird & Hale, 1982; Hogan, 1989, *unpub.*). Many remote sensing techniques are widely accepted for mapping and inventory purposes, especially at smaller scales. Aerial photographs in particular are commonly used to collect data (sampling technique) for channel monitoring and assessments. They are also a primary source of data to complete Aquatic Biophysical Mapping for all but the most detailed surveys. The goal of alternative channel monitoring is to describe and evaluate simple and cost effective techniques which can be used to collect basic geomorphic data (e.g., gradient, stream width, pool:riffle spacing) and habitat information (e.g., Large Woody Debris distribution, habitat barriers, site disturbances) for a range of stream and river sizes. Some commonly used remote sensing platforms are given in Figure 1.

Ground surveys (also called intensive studies) are the most widely recognized method of collecting channel and habitat data in the field and are frequently the only choice available for in-situ data collection; measurements of streamflow, turbidity and water chemistry for example, can not normally be made from secondary sources, though exceptions are noted. Similarly, fish distribution and population counts are most accurately determined from direct field surveys or on-site measurements. There are numerous techniques, however, for feature interpretation, classification andmensuration which do not involve direct field studies. In these cases, remotely sensed data can increase the efficiency of fieldwork or provide equivalent data (van Zuidam, 1986). These data can be broadly classified into three groups, according to the level of information required. For consistency with aquatic survey standards for fisheries inventory, these are defined as:

1. overview surveys
2. reconnaissance surveys and
3. detailed inventory surveys

Overview surveys are based on images which have no scaling orgeoreferencing. A typical example would be 35-mm photographs or portable camcorder footage taken from a helicopter. Although this type of imagery can be used to document subjective channel conditions (e.g., channel type, disturbances), it can not be used to make direct measurements such as distance or area. However, this information may be transferable to a large scale map of the study area. Reconnaissance surveys are based on images which can be scaled, but have nogeoreferencing. As these images are taken vertically, the user is able to calculate a rough scale and apply that to the entire image frame (assuming camera lens length and flying height are known). If the scale of the image can be determined, reconnaissance surveys can be used to obtain planimetric data such as reach length and channel width. Most channel parameters that must be examined in an assessment project can be obtained from reconnaissance level imagery. However, this level of survey is not an acceptable standard for map production or GIS data acquisition because there is no associated georeferencing.

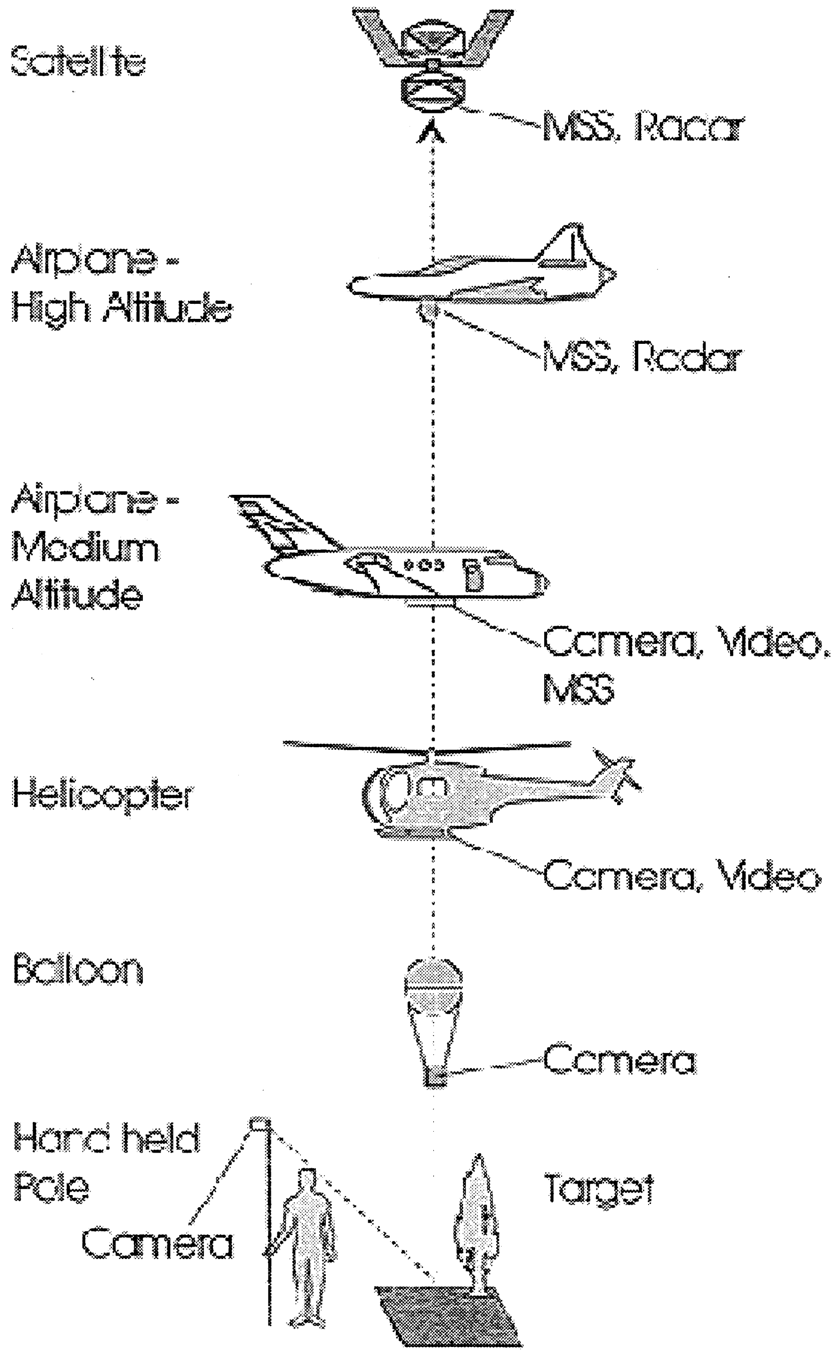


Figure 1 Common remote-sensing platforms

Detailed inventory surveys are suitable for examining channel features and for map production. This level of survey can be completed if both the scaling and georeferencing of the images is known. There are two levels of detailed survey that can be defined. The first (designated D1) does not account for aircraft yaw, pitch or roll so there may be some error in the image scaling. The second level (D2) accounts for aircraft motion and is the minimum standard that should be accepted for more precise GIS data acquisition and provincial mapping standards. Standard 9"×9" aerial photographs fall into a grey area because while they are obtained according to a strict set of procedures and guidelines established by the Surveys and Resource Mapping Branch, they are not directlygeoreferenced. However, aerial photos can be georeferenced using TRIM specification survey points and are the only accepted standard for updating provincial map databases and are always acceptable for D2 surveys. Aerial videography can be used for D2 surveys only when certain guidelines are followed.

This manual will describe the types of acquisition techniques and data collection tools required to collect data at each level of survey intensity. For each level of survey, the volume, accuracy and reliability of the data increases, but cost and effort similarly rises. The most appropriate technique to be used for different channel and habitat parameters will be emphasized. The main questions to keep in mind are "what type of data is to be collected," "what is the scale of the study" and "what is the appropriate technique to provide these data at a reasonable cost and level of accuracy." This project is intended to guide the field scientist through these problems. Further, the emphasis will be on techniques that are neither cost prohibitive nor beyond the technical expertise of anyone with basic mathematical, computer or field skills.

Prior to choosing an aerial platform to assess a particular stream channel, a basic understanding of aerial photography and video principles is required. Following this, readers should be aware of the actual stream parameters they are interested in studying and subsequently, select the most appropriate technique to acquire this information. An appropriate technique will depend upon the scale of the channel features to be measured and the type of data capture and analysis required. Options for collecting and analyzing data for fish habitat channel assessments both in-house and from external suppliers are presented. The relative advantages and limitations of each technique will be discussed.

3.0 OVERVIEW OF AERIAL PHOTOGRAPHY

3.1 Camera Formats

The range of cameras used for aerial photography worldwide is very large. Lillesand and Kiefer (1994) point out that aerial photos can be made with virtually any type of camera; however, there are clear differences between types that relate to the quality of the lens, basic camera geometry and their application in mapping. Cameras which take single instantaneous exposures recorded on film are termed frame cameras. These can be further classified by several general characteristics including type, angular field, focal length and primary use (Slama, 1980). Cameras with high resolution and low lens distortion are known as mapping cameras and are used to take the standard 9"x9" airphotos from which maps are traditionally made; for example, provincial and federal topographic maps are made from these photos. Smaller, lighter cameras with greater lens distortion are known as reconnaissance cameras (Avery & Berlin, 1992). They are mainly designed to take photos for interpretation and inventory, not mapping. This group includes 35-mm, 70-mm and multispectral cameras. However, these cameras are suitable for more general mapping (and certainly mensuration) where the very high accuracy standards required by professional mapping agencies are not needed. This finding is supported by Warner (1990) who shows that 35-mm photography provides acceptable errors for most resource surveys; at 1:10000, planimetric lengths can be measured to ±28 cm and heights to ±55 cm using a stereoplotter. Note, however, that these are relative errors based upon measurements taken with a single stereo model. Absolute errors, which compare photo measurements and locations to real world coordinates may be up to an order of magnitude (10×) greater. In general, large format cameras are thought to provide a maximum vertical precision of 1/10000 flying height (though its usually less in practice; see Fryer *et. al.*, 1994) and small format cameras are typically about half as accurate as this.

3.2 Camera lenses

The camera lens gathers light reflected from objects and transmits this light to the film. The shutter regulates the duration andaperature the amount of this light. When a camera lens is focussed at infinity (∞), the distance between the film and the lens is termed the camera focal length (Avery & Berlin, 1985). The ratio of focal length to lens diameter is the F/stop or aperture setting, and is used to designate the speed of a particular lens. The largest or fastest opening for a lens is F/1, with increments every$\sqrt{2}$; standard values may range from F/1 to F/1.4, F/2, F/2.8, F/4, F/5.6, F/8 ... F/32 and so on. Each increment (eg. F/2.8 to F/4) indicates half as much light entering the lens. A fast lens is good for use in low light conditions. However, to maintain the amount of light that reaches the film to provide correct exposure, the shutter speed must decrease along with the lens opening (to increase exposure time). For example, moving from a setting of F/4 which is correctly exposed at 1/500 seconds to F/5.6, the shutter speed would decrease to 1/250 seconds (increments of 2x). Depending on the platform used, this becomes a concern; exposure times can be low (ie. 1/60 s) for photos taken on the ground, but on moving aerial platforms, should be at least 1/250 and preferably faster to avoid blurriness.

The aperture setting also affects the depth of field and depth of focus for any photograph. Depth of field defines the plane of focus for an object where points in front of and beyond are blurred. The depth of field increases with aperture setting (smaller opening) and is greater for short focal lengths than long. For aerial photography, depth of field considerations are not important because object distance (ground) is much greater than variations in elevation of the object being photographed (Moffit & Mikhail, 1980). It is, however, critical in close range photogrammetry. When photographing bed material, for example, a smaller aperture setting should be used to maintain focus. This will cause pictures to be dark on cloudy days, so this application should only be performed under bright conditions. By comparison, the depth of focus describes the distance through which the film plane can be moved while maintaining focus (Dorrell, 1989). Depth of focus can also be extended by reducing the aperture size, but this causes object focus to decrease with distance (Moffit & Mikhail, 1980). Though not important for true vertical photographs, but affects oblique images taken near the ground; for example, the edges of the photograph will be out of focus if the depth of focus is too small. A good overview of these principles is presented in Davis (1975) and a brief summary is given in Table 1.

Table 1 Example camera settings for correct 35-mm exposures

F/STOP	SHUTTER SPEED	FILM	NOTES
f/2	1/1000 sec	400ASA	can use in low light; produces slightly grainy prints
f/2.8	1/500	400ASA	good for close-range photographs
f/4	1/250	200ASA	good combination for most aerial applications
f/5.6	1/125	200ASA	film too slow for most aerial applications
f/8	1/60	100ASA	requires good natural light; slow or stable platform
f/11	1/30	100ASA	use on stable platform (no motion) in bright light

Under cloudy conditions, use a wide aperture setting with the fast shutter speed to provide the best pictures. However, under the brighter conditions which are generally preferred for aerial photography, the F/stop of the lens and subsequent shutter speed must be decreased. The correct settings for good exposures will ultimately be determined by the speed of the film used. Typical film speeds for 35-mm cameras range from 100ASA to 400ASA (American Standards Association rating system). The speed of the film is critical to good quality results; faster film will allow one to reduce the aperture setting (and increase shutter speed) decreasing the odds of blurry photos. In general, slower film (e.g., 100ASA) takes sharper pictures because it is fine-grained, but requires good natural light. This is important for photographing in late fall and winter conditions as natural light levels are lower than in summer. During winter, for example, one should shoot with 400ASA film because of its high light sensitivity, although photos will not be as clear or sharp as with 200ASA film of the same make. 200ASA film is characterized by fine grains, meaning this is high resolution film suitable for enlargements. The use of faster film allows one to maintain fast shutter speeds and wide aperture settings for use in low light conditions, but the resultant prints aregrainier and far less suitable for enlargements. Note that the aerial film used in mapping cameras is not available in the same range of ASA settings as 35-mm and 70-mm film; aerial film speed is defined and determined in different ways and classified using a special index. To properly expose aerial film, an aerial exposure computer is used rather than a light meter that relates the film's speed index to aircraft speed, time of year, latitude, sun angle and several additional factors (Avery & Berlin, 1992).

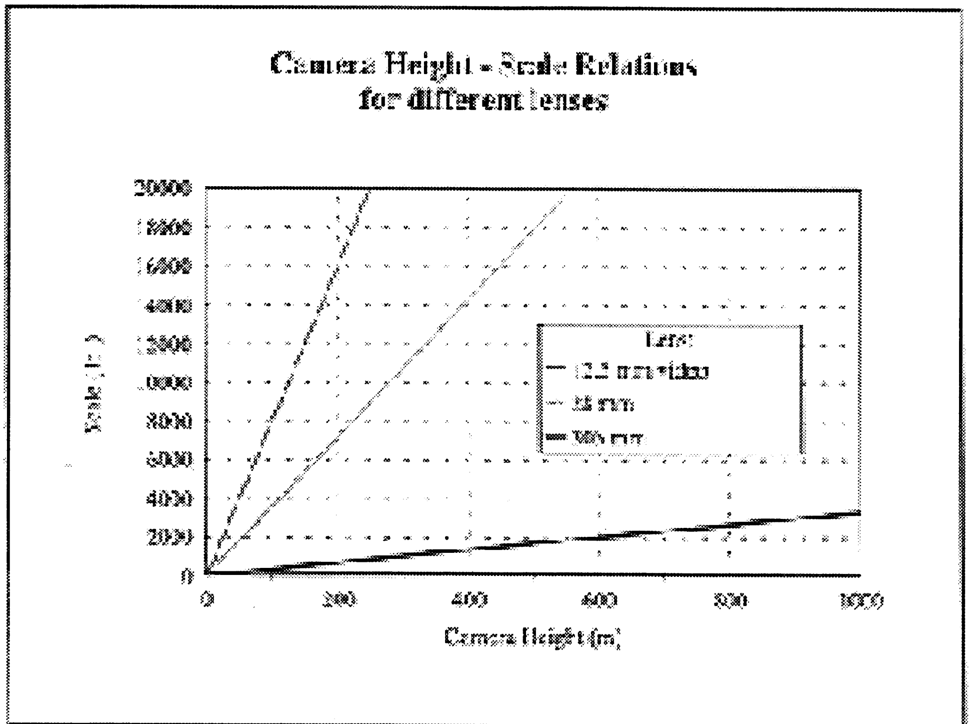
The focal length and width of the lens determines the ground coverage and field of view. The ground coverage on a photograph is a function of both the format size (scale x film width) and the viewing angle. With a given camera at a given flying height, decreasing the focal length will result in greater ground coverage, but a smaller image scale (thereby decreasing resolution). However, this is not true for different cameras at the same flying height. Although the scale will still be reduced as the focal length is shortened (see Figure 2a) the corresponding ground coverage will not increase (see Figure 2b). This is a result of the different film formats used for different camera types – wider films always provide greater ground coverage at a given scale than narrow film widths. The width of the study area, including adjacent riparian zone and total study length will determine the appropriate lens and camera combination. An alternative solution to this problem is to produce enlarged prints of small scale negatives - ground coverage will not change, but the scale will increase, allowing smaller features to become visible provided the film resolution is good. For further discussion on this topic, see section 5.0.

The relation between the focal length and diagonal film (negative) width also defines the field of view for cameras. When these distances are roughly equal, the field of view angle is roughly 45° and is commonly referred as a normal angle. For aerial cameras, angles between 60 ° and 75° are considered normal, while angles to 100° are considered wide angle (Avery & Berlin, 1985). Wide angle lenses introduce distortion, an effect that increases with decreasing lens length. Dorrell (1989) reports that the angle of view should not exceed 70 to 80° to prevent unwanted distortion, which is of particular importance for mapping. Field of view angles (measured on the diagonal) for common film bases are given in Table 2.

Specific project requirements will dictate the best choice of lens to use, though there are certain limitations of choice. For example, the Hasselblad 70-mm cameras are presently only functional with the 100-mm F/3.5 lens (41° FOV) though a 60-mm F/5.6 (62°) is available (Hasselblad guide), while standard mapping cameras are only available with 6" and more commonly used 12" lenses. The most freedom of lens type involves 35-mm cameras where there is a large selection of lens lengths and angles, particularly with zoom lenses.

Table 2 Field of view angles (FOV) for common photographic platforms

FILM TYPE	FILM LENGTH	FILM WIDTH	FOCAL LENGTH	FOV ANGLE
35 mm	24 mm	36 mm	28 mm	75.4°
35 mm	24 mm	36 mm	50 mm	46.8
35 mm	24 mm	36 mm	110 mm	22.3
70 mm	53 mm	53 mm	60 mm	64.0
70 mm	53 mm	53 mm	100 mm	41.1
9" x 9"	230 mm	230 mm	153 mm (6")	93.5
9" x 9"	230 mm	230 mm	305 mm (12")	56.1



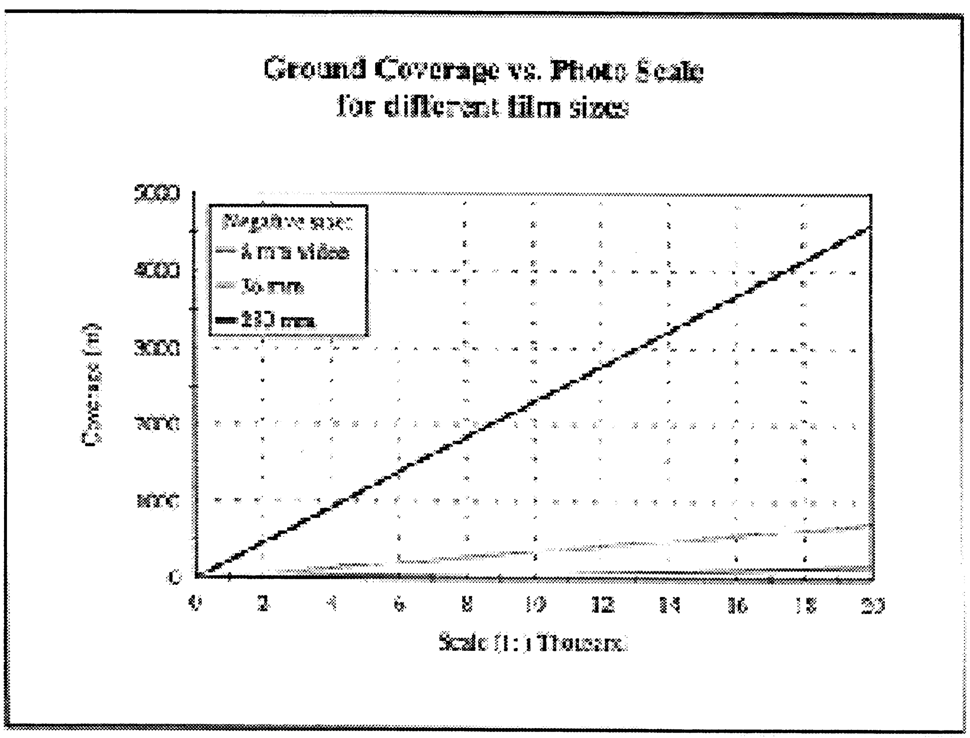


Figure 2a, 2b Camera height vs. scale and scale vs. ground coverage

3.3 Types of film

The type of film that is chosen for a particular project depends on several factors including its availability, film speed and lighting conditions. Perhaps the most important consideration is choosing a type of film most appropriate for illustrating the subject. Different film types have different spectral sensitivities which will respond differently to soil, water and vegetation, each of which typically has unique spectral reflectance curves. For example, water reflects higher in the near-infrared visible light wavelengths than at lower ultraviolet wavelengths and will therefore be more distinct and easily identifiable on infrared films. This means that water will show as very dark blue or black on colour infrared photography but clear or transparent on normal colour prints. Depending on the channel features that must be examined, the choice of an appropriate film is obviously very important for interpretation.

All photographic film can be broadly grouped into two categories; black-and-white or colour[2] Black-and white film is commonly referred as panchromatic film, which means sensitive to light of all colours (Avery & Berlin, 1992). These films have a single light-sensitive emulsion layer which is sensitive to the ultraviolet and visible wavelengths. This 'photographic' spectrum is greater than the visible light spectrum of human vision. Colour films (commonly known as natural colour) use three light-sensitive emulsion layers which but do not have as wide a photogaphic spectrum (basically the same as human vision). However, black-and-white and colour infrared films are also available which extends sensitivity beyond human vision to near-infrared wavelengths. All films are further available in two formats known as terrestrial and aerial films. Terrestrial films are designed for indoor and outdoor photography using 35-mm and 70-mm cameras but they can be used for taking aerial photographs as well. Aerial films are available in both 70-mm and 9" formats and are designed exclusively for aerial photography. The main difference is that aerial films have higher resolution and provide greater contrast (range of light intensity between lightest and darkest objects). In general, aerial films are always used with fast moving platforms (airplane, helicopter) and terrestrial film are always used with 35-mm cameras.

Panchromatic films are the most common aerial film used for general interpretation and mapping. This film is sensitive to wavelengths between 0.25 and 0.7 μm. At higher elevations, this film is used in conjunction with a yellow filter to reduce atmospheric haze. When flown at lower elevations, the yellow filter is not required. The result of this is that shadows appear lighter in tone on the print, and allows for greater clear water penetration. Good water penetration is useful for estimating water depths or examining stream bed composition. This film type (without yellow filter) can be recommended for low level aerial photography of streams and is particularly suited for lower light levels. By comparison, standard colour photography is sensitive to wavelengths between 0.4 and 0.7 μm which provides a colour rendition similar to the naked eye when a clear (UV blocking) lens is used. Colour film has the additional properties of hue (dominant wavelengths), chroma (colour strength) and value (colour lightness) for aid in object recognition. This makes colour photography particularly valuable for interpretation of channel features because people can discriminate between tens of thousands of colours, but only about 100 shades of grey (Avery & Berlin, 1992). When properly exposed, colour film also has excellent clear water penetration but this requires better light conditions than with panchromatic film.

Infrared films operate in the 0.25 to 0.9 μm wavelengths for panchromatic and 0.7 to 0.9 μm wavelengths for colour photos. Colour infrared is taken with a yellow filter to absorb UV and

---

2 Note: this discussion also applies to aerial video as videotape has roughly the same spectral response as conventional film

blue light, extending the lower spectral sensitivity to 0.5 μm (Lillesand & Kiefer, 1994). Infrared films capture that portion of the spectral range just beyond human vision, which is extremely useful for examining water and vegetation. Water appears as very dark tones on infrared photos, in sharp contrast to land and vegetation, making these photos useful for mapping drainage patterns, swamps and marshes, backchannels and flooded regions. Colour infrared is further useful for differentiating between vegetation types, detecting algae and highlighting suspended sediments in rivers. Some further examples of different film types for applications in fluvial environments are given in Table 3.

For standard 35-mm print film, ASA ratings from 100 to 400 are widely available at most retail outlets. Higher ASA values (to 1000 for B&W; 1600 for colour) should be available from some specialty shops, but would probably be too grainy to detect small details such as sediment texture when enlarged (e.g. 10x) and are best suited for indoor use. Similarly, specialty outlets should be able to provide infrared films. However, for most projects using 35-mm photography, conventional black-and-white panchromatic and colour positive films should be adequate. For 70-mm photography, there are only a few readily available types of aerial film.

Table 3 Feature identification comparison for film types

FILM TYPE	FLOODPLAIN EXAMPLE	INSTREAM EXAMPLE
panchromatic	Combination of physiographic features, surficial deposits, past floods using stereoscopic techniques. High water marks appear darker.	Channel type, site disturbances, barriers, riffles and pools, large woody debris.
normal colour	Same as above. River alluvium appears as darker tone areas than surrounding light tone sandy areas.	Best overall choice. Same as above, but also good for substrate texture and vegetation discrimination.
colour infrared	Vegetation within floodplain zone appears as various textured red colours. Good for identifying extent of flooding and offchannel habitats.	Vegetation discrimination, turbidity sources and routing.

Source: modified from Bird & Hale, 1982

For prints, there are only two choices; 160ASA Varicolour produced by Kodak and Agfa Avichrome 200 colour positive film. Cost for this film is about $150 Canadian per 100-foot roll. Agfa and Kodak also produce 200ASA colour and B&W diapositive film. Conventional prints can also be reproduced from diapositives, but at a greater cost than if done directly. Further information on 70-mm films can be obtained by contacting the above companies directly, or the commercial section of any major camera dealer or print shop.

For standard 9"×9" aerial photography, the Surveys and Resource Mapping Branch will provide details on the availability of different film and filter combinations. Generally, contact prints are produced from colour, black and white or colour infrared film, though diapositives (positive images printed on transparent plastic film, not paper) are also available upon request. For the Ministry of Forests, black and white contact prints are often printed with higher contrast than for other clients while colour prints usually have enhanced reds to aid in distinguishing tree types. Requests for special print requirements (vegetation mapping, water penetration, presence of shadows, etc.) should be made prior to the project being flown.

4.0 OVERVIEW OF AERIAL VIDEO (VIDEOGRAPHY)

4.1 Background

Videography, in the simplest sense, involves taking continuous overlapping frames of an area to record image data in analogue form on magnetic videotape. Videography is a fairly recent development in remote sensing, dating back only to the early 1970's. In the last decade, videography has become an increasingly popular tool for mapping of linear features such as roads, pipelines, powerlines and even coastlines – about 25% of the B.C. coastline has been surveyed by aerial video (Harper & Reimer, 1995). Video is an ideal image capture tool for this type of mapping because there is no need for extensive lateral ground coverage or high spatial resolution. Broader application in recent years has resulted from an increase in the quality and availability of video equipment, the advent of video analysis techniques and Global Positioning Systems (GPS) which permit multiple flightlines to be georeferenced. As a result of these developments, current applications are quite diverse in a variety ofgeneralized land-use inventory, monitoring and environmental studies. One of the largest growth areas has been in forest applications. Fong (1989) summarizes studies that have used video for timber classification, regeneration assessment, fire detection and impacts and insect and disease assessment. Graham (1993) reports on the use of video integrated with GPS to collect base data for vegetation mapping throughout Arizona. Data collected from the video were used to calibrate Landsat TM satellite imagery for map production throughout the state.

There are fewer examples of studies within fluvial environments. Harper and Reimer (1995) point out that about 20 stream classification inventories have been completed in B.C.; these have mainly been pilot projects or for general inventory of large areas. Sidle and Ziewitz (1990) discuss a recent project using standard colour video to map bird nesting habitats along 400 km of the Platte River, Nebraska. The video images were captured using a frame grabber, processed, and mapped in an image analysis program. Bobbe *et. al.* (1993) discuss the use of videography to monitor riparian areas, examine cumulative watershed effects and update GIS databases in the Tongass National Forest, Alaska. Part of the project involved mapping LOD distributions and mosaicing video imagery with historical airphotos to examine the downstream effects (changing channel morphology) caused by a massive sediment input from a debris torrent in the North Fork Bradfield River. Although use of the video was successful, 70-mm photographs taken at the same time were used for verification during image analysis. Snider *et. al.* (1994) used aerial multispectral video to classify vegetation and water areas along 160 km of the Green River, Utah over four distinct [controlled release] flow periods. Images were captured and overlaid using image analysis software to map total water area, channel bars, backchannel numbers and areal extent and riparian zone vegetation. The researchers were then able to determine relationships between water flow and various ecological parameters. It is valuable to note that these projects all covered large ground areas (small scale) such that video resolution was not critical and digitizing of images was economical.

4.2 Camera Types

The most common aerial video platforms use standard, Super-VHS or Hi-8 formats to capture data as standard RGB colour images, though multispectral cameras capable of capturing infrared bands are also available. Video provides a resolution of about 240 lines for standard colour (Mausel *et al.,* 1992) to a maximum resolution of about 400 pixels per line, and up to 485 lines per image frame for the other formats (Lillesand and Kiefer, 1994). An example of a S-VHS video image is shown in Figure 3. The use of television production quality S-VHS cameras increases resolution to about 700 lines per frame. Note, however, that the quality of the television or monitor used to display the video may further inhibit resolution, hence interpretation of the image. The development of high-definition television and recorders should double the resolution currently available. For comparison, a 35mm slide offers about 1500 lines resolution (Mausel *et al.,* 1992) and further, covers a larger spatial area at the same flying height since video frames are only 8mm wide.

Video cameras may have either a plastic (consumer video) or glass (professional video) lens. The glass lens is more expensive but provides better light transmission and convergence (Harper & Reimer, 1995). Lenses on most consumer cameras have a 12.5-mm focal length, but more expensive models may have zoom lenses providing an effective focal length of 10 to 100-mm. Some cameras still use from 1 to 3 tubes to convert the image to videotape, but most modern cameras use a CCD (charge coupled device) sensor with 1 composite or 3 individual chips for each primary colour. A shuttered three chip CCD sensor will provide the highest image resolution and has short exposure times (small as 1/10000 sec) which virtually eliminates image motion. CCD sensors also have a slightly greater spectral response than conventional film which makes them potentially useful for remote sensing / image analysis applications. For further description on different camera types and features, refer to Harper and Reimer, 1995.

4.3 Recorder Types

Consumer camcorders integrate the camera and video recorder in a single unit. Although inexpensive and simple to operate, these systems do not offer as many features and offer lower resolution compared to separate camera recorder systems. If a standard camcorder unit is used, the minimum features that should be available are a separate audio channel with microphone for recording voice commentary while in flight. Although Harper and Reimer (1995) do not recommend camcorder systems for aerial video surveying, they are reasonable for overview flights. Aerial survey systems should preferably have a separate camera and recorder that can be interfaced with other peripheral devices.

When choosing a camera/recorder platform, the main considerations are compatability with in-house viewing capabilities and recording features. For example, a professional Betacam system is of little value if there is no method of viewing the tape in the office once the survey is complete. As well, it is important to match the system components as best as possible to take advantage of higher resolution. A high resolution 700+ lines Betacam played back on a 230 line television will have an effective resolution of only 230 lines! Commercial survey companies may aquire video on a higher resolution camera/recorder system than can be played back on most VCR's. In this case, copies of the original high resolution tape can be made on a lower quality tape format which is more common (e.g., standard VHS format). This will produce a better quality final image than if originally recorded with a VHS camera and tape. Harper and Reimer (1995) further recommend that the camera have higher resolution than the recorder. This is because image quality is degraded from the camera to the tape because of signal noise and other factors. However, it may not be worth paying a significantly higher acquisition fee for video quality that you can not play back. Both the S-VHS and Hi-8 formats offer the best overall compromise in terms of resolution, features, availability and compatibility.

fig 5 2 pictures
fig 6 1 picture.
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viewed in stereo, though video should generally be considered a 2-D product only. As video images captured on the computer are in a digital format, they can be further analysed using image processing or GIS software. Increasing attention has focused on calibration, where the spectral reflectance of objects is analysed from the video using standard image processing software and techniques (Mausel *et. al.*, 1992). In general, image quality is inadequate for image analysis techniques, especially compared to other platforms and is not recommended for that specific purpose.

More advanced systems will allow the video image to be digitized directly on the computer screen. In effect, this is accomplished using 'GIS' software that is developed in-house by the different survey companies. More widely available commercial GIS packages are not easily integrated with video, GPS, laser altimeter and attitude data. Although most GIS and image analysis packages will allow you to georeference individual video frames (or any type of image), this presumes that you are able to locate at least 3 known control points on each frame. It is unlikely that this is possible, especially given the small physical ground area that each frame covers. The in-house programs are therefore simpler, more accurate and faster to use. They should, however, be capable of exporting data in a useful format such as Arc/Info, IGDS or Autocad dxf which can be imported in conventional GIS or plotting programs. Most survey companies will complete the digitizing or measuring themselves which requires training or supervision. Alternatively, the digitizing may be completed by the habitat specialist themselves.

5.0 SIZE SCALES AND APPROPRIATE TECHNIQUES

5.1 Negative Scale

The amount of detail, or resolution of an image depends in large part on its scale. Scale is frequently discussed in terms such as "large" or "small"; the difference between them is frequently confused. Put simply, scale in these terms refers to the amount of ground detail shown; for example, a small scale photo (e.g., 1:50,000) shows much less detail but covers a much larger ground area than a large scale (e.g., 1:5000) photograph taken in the same area. A specific feature then, such as a log jam, would appear larger on the large scale photo. If scale is represented as a fraction, then the difference is further clarified. For example, 1:500 can be written as 1/500 or 0.002 while 1:50,000 is written as 0.00002, clearly a smaller number.

There are two fundamental methods of determining image scale. The first compares the distance shown between any two points on the image with the corresponding points on the ground; ground distance is commonly determined from a base map of the same region. An example of this calculation is given in equation [1].

$$S = \text{scale} = \frac{\text{photo distance}}{\text{ground distance}} = \frac{45\text{mm}}{2100\text{m}} = \frac{0.045\text{m}}{2100\text{m}}$$

$$S = 0.0000214 = 1{:}46729$$

Another method of determining scale is by the ratio of the camera focal length to the flying height above ground. For standard aerial photos, this information can be obtained from flight log records at Geographic Data BC (formerly Maps-BC) and may even be directly visible on the photo. Equation [2] provides an example of this calculation.

$$S = \frac{\text{camera focal length}}{\text{flying height above terrain}} = \frac{\text{cfl}}{\text{H}}$$

$$[\text{eg.}]\ S = \frac{305\text{mm}}{5000\text{m}} = 1{:}16393$$

Note: must be in same units (feet or metres)

Flying height (H) refers to the distance between the camera and the object being photographed, so a correction for ground elevation must often be made if the altitude of the plane is used. If, for example, an aircraft was flying at an elevation of 5000 metres above sea level and the average elevation of the land directly below the plane was 500m, then flying height (H) must be adjusted to 4500m.

For an object of a given size or area, it is generally useful to know at what elevation the camera must be; this is especially relevant for close range photography. An approximate relation between height, camera focal length and object dimensions is shown in equation [3] (adapted from Dorrell, 1989).

$$\text{camera height} = \frac{\text{length of feature}}{\text{film width}} \times \text{cfl}$$

$$= \frac{10\text{m}}{36\text{mm}} \times 28\text{mm}$$

$$= 7.8\text{m above ground}$$

By re-arranging the terms in this formulae, it is possible to determine the ground coverage that an image frame covers at a given camera height. This is simply the image scale multiplied by the film width.

5.2 Print Scale

Negative scale is not to be confused with print scale. Print scale is also called the display scale and more accurately gives the resolution of the viewed image. For standard aerial photography, the film negative size is the same as the print size (9"x9") so the scale is not changed by producing positive prints. However, this is not true of other formats. For example, 35-mm photographs are often printed at 4"× 6" although scale is calculated based upon the much smaller negative size. Note that this does not change the physical area of the ground that is shown! As an example, suppose a photo was taken at an elevation of 100 metres with a 28 mm lens. Using formulae [2] the scale of the negative is 1:3600. If the scale is multiplied by the negative width, then the corresponding ground coverage is 130 metres. When the negative is printed, it is enlarged, but still shows the same 130 metres of the ground. The new image scale can be calculated as the ratio of the print width to ground coverage; in this case 6" / 130 m, or 1:850. This is roughly equal to enlarging the negative by a factor of 4. Conventional films can be enlarged up to 10 times without any significant loss of resolution, hence information.

The same principle applies to aerial video, except that the final viewing scale is dependent on the TV or monitor size. Aerial video taken at 100 metres with a 12.5 mm lens has a negative scale of 1:8000 and a corresponding ground coverage of only 64 metres. Obviously, the larger the screen, the larger the scale of the image when viewed. On a 15" monitor, the 1:8000 film has a scale of 1:250. The printed video frame shown in Figure 3 is roughly 1:350 for comparison. It is perhaps more useful to consider video scale as a function of monitor size, as this is normally the format it will be examined in. Video resolution is ultimately dependent on the resolution of the camera, videotape and monitor, rather than on any magnification factor. The 'display' scale should be considered the maximum usable scale because the images can not be further enlarged without reducing the quality of the image. Also note that while resolution and swath width (ground coverage) change with different lenses and flying heights, a combination of both wide swath and high resolution is not possible (Leckie and Gillis, 1993). A good rule of thumb is that video should not be used at elevations greater than 300 metres, which gives a lateral ground coverage of 200 metres. At greater flying heights, ground coverage will increase, but smaller objects and channel features will be difficult to clearly discern.

5.3 Choice of Scale

The success of any data collection program depends upon choosing the most appropriate remote sensing technique to capture the intended feature at an appropriate scale. There are two main elements that should be considered (after Ritchie *et al.*, 1988):

1. the boundaries of the area of survey, and
2. the dimensions of the smallest object that must be clearly shown (image resolution).

The first element relates to general watershed parameters, and includes such characteristics as land cover type, stream numbers and locations, stream orders and drainage density. This information is most easily and effectively retrieved from TRIM based 1:20000 topographic maps. These data also can be collected from high level (small-scale) airphotos. By comparison, video surveys are mainly suitable for linear features only and are not a practical source of watershed scale information.

The second category relates to the morphologic and habitat characteristics within channels and includes such factors as pool: riffle spacing, logjam size and distribution and location of off-channel habitats. This information can not be determined from maps; it requires fieldwork, aerial imagery or a combination of both. The most appropriate platform will depend directly on the width of the channel and adjacent floodplain in addition to features of interest within the channel. Ground coverage visible on the image should be greater than the average bankfull width to account for channel widening and meandering; generally 2 to 3× average width is suggested. A useful general rule of thumb is to use the smallest practical scale as this reduces the number of images (photographs or video) required, hence mapping and interpretation costs. Figure 4 shows the relation between size scales of the feature of interest and the appropriate platforms for documentation.

Note that the range of channel widths that a platform is suitable for is only partly related to the corresponding ground coverage of the images. Recall that ground coverage is a function of image scale x film width, so wide format films (e.g., aerial film width = 230mm) can display a larger area than narrow format films (e.g., 8mm videotape) at the same image scale. As well, photograpic films provide superior ground resolution at all scales compared to other imaging systems and can be enlarged. Aerial photos, for example, cover at least 700 metres on the ground (1:3000) but can be magnified up to 8× using a stereoscope, and 20 × if taken with a forward motion compensating camera (Torlegård, 1992). Most standard photography can be similarly enlarged up to 8 × using conventional printing procedures or through the use of a stereoscope. Non- photographic platforms generally have much poorer resolution; depending on the exact system specifications, print medium (if used) and the computer monitor resolution, enlargement from 0 to 2× maximum is possible. Table 4 illustrates gives minimum ground resolution values for different platforms.

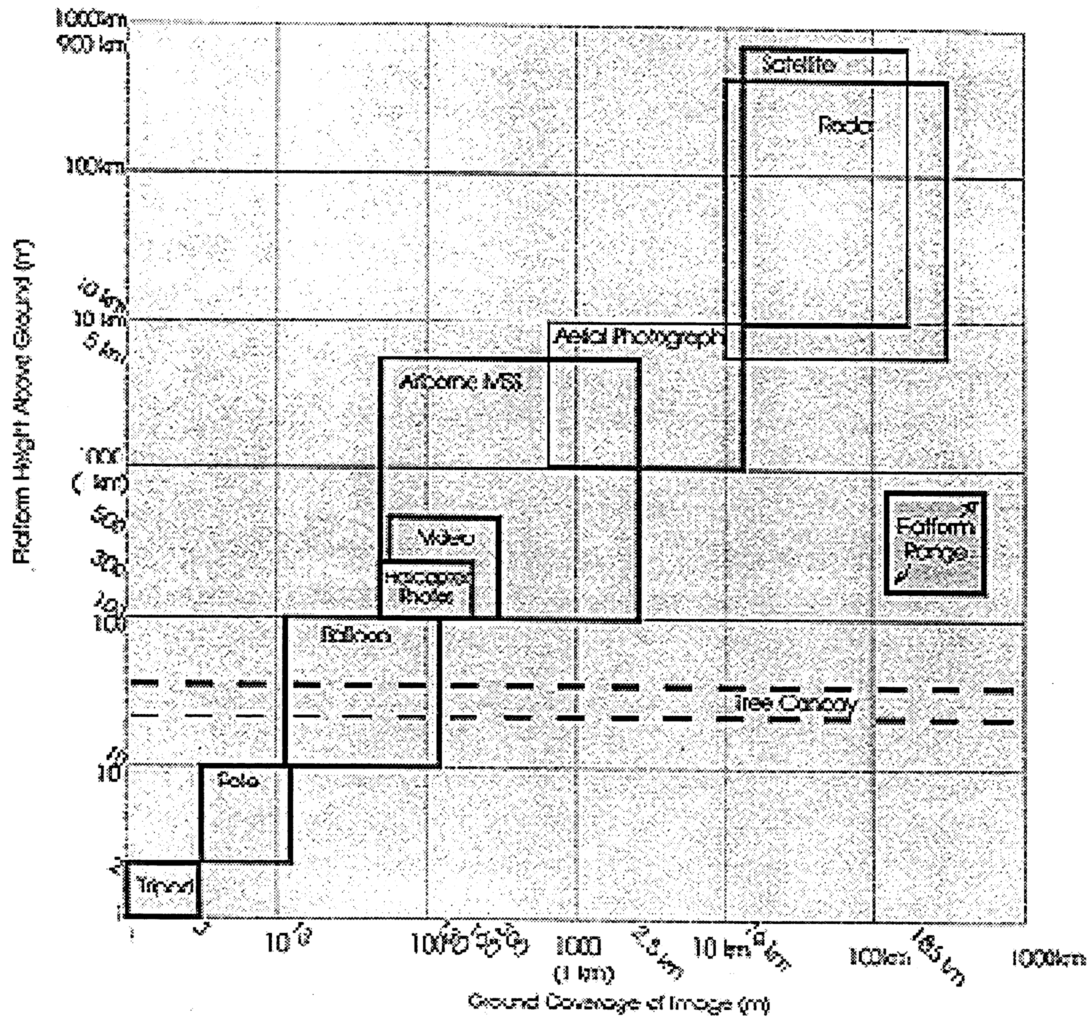

Figure 4 Size scales and appropriate remote sensing platforms

Table 4 Ground resolution for aerial platforms

a: assumes 305 mm lens, film resolution of 100 lines/mm

b: typical values given in literature at this flying height. Systems frequently flown at 500m maximum which gives ground resolution of 0.5 to 1m

PLATFORM	CAMERA HEIGHT	RESOLUTION	VISIBLE FEATURE
aerial photograph	1000 metres	0.08 metres[a]	gravel texture, fish in shallows
airborne video	1000 metres	1 to 2 metres[b]	gravel bar, logs, riffles

It is also critical to consider is the type of data capture needed from the imagery. Overview surveys using photographic or video techniques can never be used to collect reliable quantitative data such as bankfull width because the imagery can not be scaled or georeferenced. However, overview or reconnaissance surveys are suitable for orientation and delimiting study reach boundaries. By contrast, detailed inventory surveys are required to determine stream gradient, but are more detailed (and costly) than is necessary for locating habitat barriers or estimating canopy closure. As well, certain parameters such as channel depth and turbidity levels require field surveys; remote sensing platforms are not generally suitable. It is important to realize that no single technique is adequate for collecting all data on channel and habitat conditions required under terms of RIC or FRBC stream inventory programs.

The choice of the most appropriate technique for a given application is very important, and is a central theme to this document. Any project that begins with the wrong technique is bound to fail, or at least prove frustrating and expensive. Table 5 provides typical channel condition parameters that are collected and appropriate data collection platforms. This table roughly summarizes the three elements discussed in this section. Additional details on the different platforms are given in following sections of the report.

6.0 SURVEY INTENSITY AND DATA COLLECTION STANDARDS

6.1 Overview Photo Survey

Photographs taken from the ground or in the air using a hand-held 35-mm camera can be used for overview surveys. Photographs should always be taken in an upstream direction, to conform with other techniques. Each individual frame number should be recorded with notes about the location and key features of each photo as a minimum for aerial surveys. Upon completion of each complete photo survey, a project catalogue should be filled out (a photo/slide catologue procedure is currently in development by Ministry of Environment). This allows any acquired imagery to be accessed by other potenial users.

Overview imagery can never be used for more detailed study because the elevation above ground is not known so the photos can not be scaled (nor accurately located). This is the simplest and cheapest method of obtaining information on channel habitat features, but is not appropriate when continuous coverage is required over large areas or distances as the total number of images required would be very large. Overview photo surveys should be used to provide a permanent, high resolution 'record' of important sites and may be used to supplement smaller scale conventional airphotos or aerial video. For example Bobbe *et. al.* (1993) used a high quality 70-mm camera to serve as a companion visual reference and verification tool for image processing of aerial video. An important point to remember is that imagery taken at a higher survey intensity can always be used for lower level assessments. Therefore, recent conventional aerial photography can and should be used if a suitable scale is available.

6.2 Reconnaissance Photo Surveys

Photographs which are taken vertically can be used to record or measure channel features that require a reconnaissance level of survey intensity. Unlike oblique (overview) techniques, photos can be scaled provided the following parameters are known: camera or lens focal length, elevation of camera above ground, or length of known object in photograph (like stadia rod). The most important factor is that the camera is held in a truly vertical position, so that the scale remains roughly constant between any two points on the image. A photo record catalogue should similarly be completed for each planimetric photo survey for reference. All photos should be taken in an upstream direction, starting at the downstream end of the study area. The approximate UTM coordinates of the upper and lower ends of the study area/reach should also be recorded from a map or GPS. There are two basic techniques of interest for habitat studies which are described below (additional details and examples are given in Ham, 1995).

Pole Photography

Pole photography is introduced as a general method of obtaining detailed close-range vertical images. The basic setup involves a 5 to 10 metre long rigid pole which supports a 35-mm camera held aloft. A telescoping antennae or janitors "tuck" pole (available at janitorial supply stores) are both appropriate. The camera can be attached to the pole using a self-levelling gimbal that allows adjustments to accommodate different cameras and winders. An automatic winder enables frames to be advanced without lowering the pole after each shutter release. Two people are required to operate the system, which simply works by raising the pole, taking the necessary frames, and advancing the pole to a new position. Using a standard 35-mm camera with 28-mm lens, this technique provides a scale of 1:357 and ground coverage of around 10 metres (see Figure 5a).

This device can be used to document changes in sediment texture, channel bed disturbance and bank erosion, but has very limited general application in habitat assessment studies. Use of the pole to document channels is hindered by overhanging vegetation, but this acts to obscure the channel from aerial techniques in general. The principal advantage of the pole over hand-held 35-mm photos is that the images can be scaled if the height of the pole is known. This allows the technique to be used for both reconnaissance and planimetric surveys and it is possible to construct sketch maps of very small (< 10-m wide) channels. The accuracy of measurements made using this system will be dependent on both the pole being vertical, but ~20 cm horizontal error is probably reasonable.

Balloon Photography

Balloon photography is a fairly obscure remote sensing technique, but it permits good documentation of small (<20 metre wide) streams. This technique has been used by archaeologists for several decades (see Whittlesey, 1969) to provide detailed maps of historic ruins and could be used for planimetric surveys and mapping of short sections of small channels (see Figure 5b). A 35mm (or other) camera is attached to a tethered helium-filled balloon. The type of balloon used is flexible; party balloons, radisonde balloons and small blimps are all suitable. The main considerations are balloon shape (certain designs will be affected more by winds than others) and lift (must be able to support the weight of the camera and gimbal). A $4m^3$ balloon should support about 2.5kg, but greater lift than actually required is advised because lift will slowly degrade over time. Strong kevlar or monofilament fishing line can be used to tether the balloon to the ground. A remote camera controller is also required to signal the shutter and film winder. To operate the system, the camera is placed on a gimbal and tethered to the balloon, then raised to a desired height (using a surveyor's hip chain for example). The height will be determined by the size of the feature to be photographed and the lens used. Once the photos have been taken, the operators simply walk to a new ground position, where the distance moved is a function of both camera height and the desired overlap between frames. Hogan (1986, unpublished) has a short manual that can provide further instructions on balloon photography.

The technique can be operated at elevations between about 10 to 100 metres, but its actual use may be limited by the tree canopy and wind conditions (which should not exceed 5 km/h). In small streams with a closed canopy, the balloon may have to be flown quite low (i.e. <30m) and will require fast (≥400ASA) film because of poor light conditions. Where there is good natural light, slower film can be used. Photos are generally of high resolution and are provided at low cost, making them ideal for long-term projects requiring repeat surveys. However, these (pole and balloon) techniques are unsuitable for photogrammetric mapping (centimetre accuracy) because of camera tilt and drift, but are appropriate for projects where qualitative assessments or pictorial maps are required. As with other small format photography, the technique should also be limited to small lengths of channel (<1km) to limit the number of photos required.

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very small or large features are poorly represented by the typical range of available scales. For larger rivers (ie. 3rd- to 6th-order, or >30m width), conventional aerial photography can be effectively used to provide such information as logjam distribution, pool-riffle spacing, channel width and general habitat conditions. For wider rivers and where there is an unobstructed view of the channel (no tall canopy, shadows, etc.) the amount of detail and reliability of the information collected increases. At different scales, the types of data that can be extracted will differ and the photos may be unsuitable for certain applications; 1:5000 photos may show significant channel detail for example, but would be inefficient for channel mapping as 9X as many photos would be required as at 1:15000. Nonetheless, conventional aerial photography is especially useful for terrain analysis, habitat assessment and general mapping purposes because it is the most common, versatile and easy to use of all photographic platforms. Perhaps the greatest advantage of aerial photography is that they provide a historical record of events for comparison with present day (and future) conditions.

Where airphotos of a particular date, location, or scale are unavailable, a solution may be to contract a new flight project. There are several aerial photography companies located in Vancouver and Victoria, as well as Edmonton and Calgary, who regularly perform contract flights in British Columbia (listings can be found in the Yellow pages under Photography-Aerial). Though these companies can be contacted directly, it is strongly recommended that provincial ministries (and employees) contact the Surveys and Resource Mapping Branch in Victoria (address given in Appendix B). This branch contracts and monitors all photography flown as part of regular survey programs by the Province. There are several advantages to arranging a project through this office:

- simply by contacting them and giving some guideline specifics, they will tender bids for a project and perform all necessary arrangements to see it completed
- the branch has rigid specification guidelines for aerial photography requirements, ensuring that any photos received will be of best possible quality or the contract is invalidated
- a project can be combined with other projects (especially in leaf-free programs) to be completed on similar dates/times which results in cost savings for all parties
- completed projects are stored in the provincial database and can be accessed by other interested users

Once an appropriate scale and type of photography have been selected, the final step is to choose a time frame for the project to be flown. Complications to flying include low cloud and fog, inclement weather such as rain or high winds, low light levels, and snowcover. Therefore, there must often be some flexibility given as to actual completion dates. A map of the study area must then be obtained outlining the specific area of interest, and this material is sent to the Surveys and Resource Mapping Branch. Under extreme circumstances, a project will be refused because requirements for obtaining quality photos may be impossible to meet. For example, photos can not be taken in the far north regions of the province after early October due to the very low sun angle and probable snow cover. By comparison, photos can be obtained year-round in the southernmost regions, though shadows may be a problem. If the project is possible, then SRMB puts together a tender package which is sent to the various aerial surveying companies to bid if interested. When bids are received, the lowest is accepted and a proposed set of flight lines and cost is sent back for final approval and funding confirmation. This process generally takes less than one week. A copy of some final project specifications and costs for recent (1994) low level flights over Clemens and Carnation Creeks is given in Table 6.

Table 6 Special project flight summary for Carnation and Clemens Creek

PROJECT-ID	SITE NAME	SCALE	LENGTH (km)	No. PHOTOS	COST
B-156-FR-94	Clemens Cr.	1:3000	12.0	50 (5 lines)	$ 4780.00
B-157-FR-94	Carnation Cr.	1:3000	5.0	20 (1 line)	$ 3680.00

Note that combining the two projects together resulted in a cost savings compared to having the two creeks flown on separate days, though the exact savings is not known.

Though some may regard traditional aerial photography as an outmoded means of collecting data, this can not be considered true at present. There is simply no other technique that provides an equivalent areal coverage with the resolution of printed film and its potential measurement and mapping accuracy. An additional consideration is that a photograph is a true record of an event at a particular time and place and can always be referred to at a future date. This means that data can be both examined from historical records, or postponed for analysis at a future date. In this respect, this type of recording medium further has a distinct advantage over other data storage techniques. An analogy would be with the storage of data on paper or in books as opposed to early electronic mediums like punch cards. While books are easily referenced, regardless of age, it is nearly impossible to access data from punch cards. It is possible that a similar situation could arise from data stored on disks and hard drives in potentially obscure data formats.

6.4 Aerial Video Surveys

A discussion of requirements for different aerial video survey intensities was given in section 4.3 and 4.4 of this report, so will not be repeated in detail here. This section of the report summarizes these requirements in point form for convenience and presents standards and recommendations for future aerial video surveys.

6.4.1 Review of Techniques

Overview videography

- no special equipment needed - just point and shoot from helicopter
- imagery may be oblique so can not be scaled
- no formal positioning of video - users should be familiar with study area or present when imagery obtained
- commentary can be provided on audio channel to make notes and assist other users
- provides general information of study area
- can roughly transfer data to map of study area with accuracy of ±100 metres
- no specific data or measurements can be made
- low cost to obtain; does not require special equipment or expertise

Reconnaissance videography

- imagery must be taken vertically with special camera mount (looks like aerial photograph)
- scale can be approximately calculated if flying height is known; can not be calculated as precisely as with aerial photography because of helicopter motion
- can record and store GPS on tape for approximate positioning of imagery (±100 metres) but is not usually linked in separate file

- rough measurements can be made if prints can be produced
- fairly low cost to obtain and easy to use
- provides good coverage of most habitat characteristics

Detailed inventory videography

- requires precise scaling andgeoreferencing; need differentially corrected GPS and laser altimeter
- all data stored on computer; must be processed after flight to be used
- images can be digitized on screen using 'in-house' software or from optionally printed copies of individual video frames
- accuracy of 3-10 metres using differential GPS
- higher accuracy mapping (1-5 metres) requires aircraft motion be measured and compensated for; gyroscope for pitch and roll, compass for azimuth, high quality GPS
- terrain height data can be optionally collected for a digital terrain model; can be used to calculate gradient
- data can be exported to a GIS for mapping or further analysis
- commercial companies can supply imagery and completedigitizing if trained (at higher cost)

6.4.2 Standards and Recommendations

Aerial video will not meet the needs of everyone interested in habitat assessments. In general, it is recommended that persons interested in this technology obtain a copy of a completed aerial survey to better judge the quality and utility of this data compared to more conventional techniques. At present, there is only one manual that provides recommendations for aerial video surveys in British Columbia (see Harper and Reimer, 1995). That manual proposes standards for video resolution, positioning, documentation and supplemental recorded data. Further, the authors present a coded classification system for these standards. There are three main considerations that the report does not examine, however, which are presented here. These include standards and procedures for the planning, acquisition and cataloguing of videography survey data by the Ministry of Environment.

Planning

- What are the main features of interest that you wish to examine?
- Which level of survey intensity is most appropriate? Consider both the types of channel parameters that you wish to examine or measure, as well as the accuracy required.
- What is the physical size of the study area? The maximum width of the channel and adjacent riparian zone will determine the proper flying height, hence image scale. Maximum flying height is normally 500 metres with a corresponding ground coverage of 250 - 300 metres.
- What additional information is needed (e.g., differential GPS on file, audio narration on tape).
- Determine if an existing recent aerial video survey has been completed in area (this will mainly apply in future once video cataloguing is used).
- Contact commercial aerial video contractors to obtain competitive bids (unless completing overview survey on own).

Acquisition

Experienced commercial survey companies should have a rigorous set of self-imposed standards for obtaining aerial video and ancillary data such as laser altimeter profiles, differential GPS and aircraft motion. For example, if detailed (D2) video is required, then aircraft pitch, roll and crab should not exceed manufacturer's equipment specifications for recording and correcting these displacements. Once the aerial survey is complete, the quality of the imagery should be also examined. Imagery that is blurred, exhibits poor contrast or exposure or is otherwise difficult to view clearly is not acceptable. Similarly, video that wanders excessively providing incomplete coverage of the study area is not acceptable. Depending on contract specifics, the survey may have to be retaken or penalties imposed (i.e., cost discount per kilometre of flight). Similar final-product standards exist for aerial photography and could be adapted for aerial video. Finally, survey companies should provide details of their equipment specifications, flight procedures and product deliverables on request.

Flights should not be completed when atmospheric conditions are not satisfactory. Conditions that should be avoided where possible include periods of high wind that can cause excessive wandering of the plane or helicopter, heavy rain or dark cloudcover, winter (low sun angle causing shadows, snow cover on ground) and early and late times of day (noon to late afternoon is best – limits shadows). This will ensure that resultant imagery is as clear as possible given other factors so that it can be interpreted correctly.

All flights should proceed in an upstream direction starting at the furthest point downstream of the study area. The height above ground should be monitored to ensure sufficient lateral coverage as well as periodic adjustments for changing ground elevation. Where multiple flightlines are required to ensure complete ground coverage or to collect additional data, these lines should be parallel and spaced to ensure sufficient endlap coverage (i.e., small areas will be visible in both lines; at least 10-20% of image width). Adjacent lines should be flown in opposite directions as is the case with aerial photos. Upon completion of the first line, the aircraft should be turned around and continue surveying downstream. The same will apply when video is taken at multiple heights above ground (e.g., 100 and 300 metres) to provide different image scales. Always returning to the furthest point downstream will increase helicopter time, hence rental costs.

Cataloguing

All video surveys should be catalogued and copies stored at the Surveys and Resource Mapping Branch, Ministry of Environment. This type of cataloguing is used for aerial photographs and allows easy access to historic records. The adoption of this type of standard will allow potential users of video surveys to obtain existing survey data from Geographic Data-BC rather than completing a new survey. The data log sheet should be provided to, and completed by, the video equipment operator. A proposed data log sheet for cataloguing is given in Figure 7. The sheet is filled out with appropriate examples.

Most of the data in the log sheet should be self-explanatory. In the first box, the project is suggested as the main referencing code for future surveys, and could easily be adopted for past projects as well. The proposed naming convention is similar to that used for aerial photography. Each starts with **V** for standard colour video, or **VR** for infrared video. Following this is the year of photography, or **1996** in the example. The last section of the name is reserved for the BC Environment management region, followed by the project number within that region. The code **8006** would identify the project as the 6th completed in region 8

(Okanagan). The complete project name would be **V19968006**. Each videotape should also have this name affixed on a label.

The entries given in box 2 and 3 provide information about the survey intensity level, accuracy, scale and length of coverage. By examining the records given, another [potential] user of the video can determine if the imagery can be used for additional assessment projects. Flightline maps can also be produced for each video survey, and complete flightline maps for the province can be completed on an annual basis showing the approximate location of all surveys. These cataloguing standards should be further explored by Geographic Data-BC.

Project V19968003	Stream Name Shuswap River
Start Date MAY 5/96	Watershed Code
End Date MAY 5/96	TRIM Mapsheets
Weather and visibility	

Aircraft Bell 206	Video Contractor
Owner/operator	Navigator
Pilot	Equipment Operator
Camera Model JVC GR-SZ7	GPS Model Trimble Pathfinder+
Lens type 1/4" CCD	Differential Correction No
Recorder format S-VHS	Laser altimeter No
Image type Vertical, Oblique	Motion control No
Recorder features Audio, burned-in GPS	

Tape #	Date	Start time	End time	Flying height	Flying speed	Location notes
1	May 5	12:00	12:20	300m	40 kmh	Sugar Lake South
	"	12:25	12:48	100 m	30	
2	"	1:00	1:30	100 m	30	End survey

Figure 7 Proposed data log sheet for future aerial video surveys

7.0 GLOBAL POSITIONING SYSTEMS

7.1 What is GPS?

GPS is essentially a system of navigation by [up to 24] orbiting satellites, which can be used to easily and accurately locate a position anywhere on the Earth's surface. The satellites transmit a signal with an associated time tag based on a single master clock. Positions are calculated and recorded using a receiver, often a small hand-held device which can be carried or mounted in aircraft, automobiles or boats. A receiver calculates its position through triangulation - signals from 3 or more satellites are used to locate its position (minimum of 4 is required to give 3-D position). The receivers work by calculating the length of time it takes to receive a signal from a satellite and then converting that to a distance. Once several of these 'distances' are known, position can be calculated for each time tag (roughly every second). GPS is most accurate under open canopy and drier conditions, but signals can be received except where the canopy is closed deciduous trees, very wet or covered in snow (Walters, 1992). Another major obstacle to signals is high stem count or stand volume per hectare which can block satellite paths and degrade the incoming signal (vanDiggelen, 1994).

7.2 Why Use GPS?

Remote sensing data are of little value if the images can not be referenced to some known ground location. GPS technology can be used to determine an approximate ground position of aerial survey data and of photos taken on the ground. Photos of a section of stream channel for example, are of little value if the location on the channel is unknown and can not be located on a map. Although it is comparatively simple to orient a small-scale photograph, larger-scale photographs and video images can be difficult if not impossible to orient with respect to known ground locations. Global positioning systems can be used by surveyors using ground based or aerial techniques to identify their location on a map. It is very easy to lose one's way or be unable to pinpoint a ground location on a reference map or aerial photograph. Crews taking field measurements or photographing stream channel features could use a hand-held GPS receiver to either locate current ground positions or record groundcoordinates for each photograph to later reference them to a map. This information is useful for overview and reconaissance, but is not required.

The main use of GPS is for reconnaissance and detailed aerial surveys. Hadikan (1992) points out several advantages to adding a GPS receiver to the helicopter boom camera system. For example, the unit could record flight path and photo location data for plotting to a map, it could be used to monitor ground speed of the aircraft (needed to provide correct strip coverage and is more accurate than airspeed), and would aid in locating the relative aircraft position (as an alternative to ground targets). Standard aerial photographs are not currently available with associated GPS positioning data, but this option will be available in the near future. Note, however, that surveyed and georeferenced aerial photos are available from Surveys and Resource Mapping Branch (1:70,000 TRIM photos). GPS is commonly used by many contractors for aerial videography (reconnaissance surveys) to position individual video frames. For assessment projects requiring more detailed surveys, differentially corrected GPS positioning data is a mandatory requirement. GPS is optional (though still useful) for the lower level surveys, but is highly recommended. However, for any type of aerial surveying, the GPS only provides relative positioning of the sensor only. Also be aware that GPS receivers calculate the height above the ellipsoid, not the geoid (approximately represented as mean sea level). The ellipsoid is sherical representation of the earth's surface which is easily manipulated mathematically. It varies from the geoid by as much as 50 metres across Canada (Geomatics Canada, 1994). To calculate elevation above sea level, a correction must be made, although many receivers calculate this automatically, invisible to the user. Check the GPS user guide with the unit you are using, or contact the Geo-spatial reference unit (Appendix B) for further details. To determine absolute ground position, the flying height above ground must also be determined using devices such as arangefinder laser. This provide scaled, georeferenced imagery and is the only acceptable standard for mapping.

7.3 GPS Positioning and Accuracy

In general, the cost and complexity of GPS increases with the level of accuracy required. It is possible to obtain coordinates with millimetre accuracy using specified survey equipment, but at a cost and effort not required for general mapping applications of channel features. The type of accuracy that can be achieved is dependent upon the method of positioning that is used. The different types of positioning, and the accuracies that can be expected, are discussed below.

Single Point Positioning

This is the simplest, but least accurate method of obtaining position data. In single point positioning, a user collects data using a single receiver which calculates position at an unknown location based on the signal it receives from 4 or more satellites whose location is known. The satellites simultaneously broadcast signals at 2 different radio wavelengths. A long wavelength code known as C/A for coarseaquisition code is available to civilian users. Using a single receiver on the ground, one can expect position errors as large as 100 metres horizontal and 156 metres vertical (Gomatics Canada, 1994). Military users have access to precise or P-code signals which allow them to record position to within 10 metres using a single ground receiver (Geomatics Canada, 1994).

The United States military purposely degrades the signal (by altering orbits and clock times) using a process known as selective availability (S/A). This is done so that foreign powers will not be able to use GPS for precise military strikes on U.S. targets. The effect of S/A can be seen by standing in a single spot with a GPS receiver and watching your position constantly changing, giving you absolute positional errors between 30 and 100 metres in a random pattern around a stationary point (Novak, 1993). An additional safety feature is known as anti-spoofing (A-S) in which the P-code signal is randomly altered to prevent imitation of the signal (Emode and Eng, 1995). This prevents civilian users from accessing the more accurate codes, but the C/A codes are not similarly altered. To overcome these limitations, civilian manufacturers and users have developed techniques that allow them to improve accuracy to the 1 to 10 metre range, which is sufficient for most general mapping applications. Errors may be significantly reduced using a process known as relative positioning. The signal the user recieves is compared to a signal received at a second, stationary base site. This procedure is commonly known as differential positioning (Geomatics Canada, 1984).

Differential GPS

Differential GPS positioning is computed by comparing the position points at unknown sites (eg. recorded by the user) relative to positions recorded at a stationary point (e.g. at a fixed base station). Corrections may be performed in real-time or post-mission using special GPS software. Real time corrections are obtained by radio links with a base station that is usually set up at a known survey marker whose location is known. A disadvantage of real-time corrections is that there is a time delay in sending the correction signal to the mobile user and in processing and correcting this signal that slightly affects accuracy (Gomatics Canada, 1994). However, the main limitation is that this set-up is quite expensive and difficult to implement. Some contractors may be willing to provide real-time GPS positioning with their image acquisition, but this is not really necessary and would add to total project costs. The Canadian Coast Guard is currently testing real-time radio link corrections along the coast of British Columbia which may be available for general use in the near future (Surveys and Resource Mapping Branch may be able to provide details).

Post-mission corrections are the recommended technique for mapping habitats. This involves comparing the data collected in the field to the data collected at the base station. To apply the differential corrections, both sets of data are combined in a computer and matched according to the precise time-tag associated with each data point. All of the satellites transmit their signals with an associated time-tag based on a single clock. There are two approaches that can be used. Using the *position method* the coordinates of the base station as determined from the C/A code are compared to the known surveyed position Geomatics Canada, 1994). These position differences (up to 100-m horizontal, 156-m vertical) recorded at each time tag are then applied to the data collected by the mobile (user) GPS receiver. Correction data can be obtained from the British Columbia Active Control System, a province-wide network of base station data that can be accessed through a BBS (bulletin board service). The network consists of federally operated Turbo Rogue receivers which collect data at 30-second intervals and are accurate to 0.1 mm RMS and provincially operated Trimble base stations collecting data at 1-second intervals with errors of 1-5 metres. For more information on this program, contact the following:

Head, Geodetic Reference System Unit
Surveys and Resource Mapping Branch, 4th Floor
1802 Douglas St., Victoria B.C. V8V 1X4
Ph 387-8438; Fax 356-7831
or, alternatively, log on to BBS through modem at 480-1382

Note that the position method requires both the base station and mobile user receiver to 'see' the exact same satellites. As obstructions may block the signal to one of the units, this method is no longer recommended. Kassam (1995) points out that some manufacturers still use this system in their software even though a better method of correction has been developed.

The preferred technique for correcting position errors today is the *measurement method* (Geomatics Canada, 1994). The difference between satellite positions measured at the base station and the real position of the satellites is calculated to produce a correction which is then applied to the data collected by the user. The incorrect orbits and times that are broadcast by the satellites are replaced by precise orbits and clock times in the post-processing software. This data is available as a product of the Canadian Active Control System on a 30-second update (refer to the Appendix for obtaining this data). The accuracy of this technique is affected by small clock errors and signal delays through the atmosphere, but 1 to 10 metres accuracies are expected. Although the position method and the measurement method produce the same degree of accuracy, the measurement method is preferred because it is not subject to the same operating limitations. However, if there is a base station within 200km of the roving receiver, the position method is acceptable, (Yuan, 1995). A basic summary of positioning methods is given in Table 7.

Table 7 Summary of GPS Positioning Methods

Method	Use	Receivers	Accuracy	Cost	Notes
single point	recreation and basic navigation	1	100m (horiz) 156m (vert)	$500 - $2000	• simple, cheap • need 4 satellites
differential correction	general mapping	2	3 to 10 m	$2000 -$7000	• simple, cheap • requires base station data or ACS data
stop-and-go kinematic	geodetic mapping	2	1cm to 1m	$5000 -$40,000	• difficult and costly to implement • uses P-code with special techniques

Sources: Geomatics Canada, 1994; Kassan, 1995

Note: Staff and contractors interested in using GPS technology for mapping and provincial inventory purposes (D1, D2 surveys) should be aware of current GPS standards. The Surveys and Resource Mapping Branch (MoELP) can provide specifications and guidelines for resource surveys in British Columbia and the Ministry of Forests Inventory Branch can provide standards for georeferencing field sample plots. These standards will not apply to lower level surveys.

8.0 SUMMARY

The choice of conventional photographic techniques or aerial videography will depend on several factors. The main things to consider are the size of the study area, the resolution or amount of detail needed, data collection requirements and total cost. The advantages and disadvantages in choosing photographs versus video for stream habitat assessments can be summarized as follows:

PHOTOGRAPHS – ADVANTAGES

- high resolution (can be magnified)
- cover larger area on ground at same image scale
- stereoscopic viewing aids in interpretation of features
- easy to make copies and store for future use
- measurements simple if scale known
- conventional aerial photographs are easy to obtain
- well-known, established and accepted technique

PHOTOGRAPHS – DISADVANTAGES

- not generally georeferenced (at present)
- digitizing is difficult, especially for large scales
- picture cost can be high for small projects
- relatively long time required to obtain final prints

AERIAL VIDEO – ADVANTAGES

- images can be viewed in real-time (as obtained)
- some systems allow audio narration and GPS position data to be recorded on tape
- image acquisition is cheap
- can be viewed on computer monitor or ordinary television
- easy to convert to digital form
- easy to digitize (if D1, D2 video obtained)

AERIAL VIDEO – DISADVANTAGES

- fairly low resolution (can not be magnified)
- cover small (narrow) area on ground limiting use on larger rivers
- accurate measurement or digitizing requires special equipment / expertise
- overview and reconnaissance video can not be measured or digitized at all
- shelf life of video is only 5-10 years; archiving for future use may prove difficult

A summary table of the different image acquisition techniques described in this report is given in Table 8.

APPENDIX A: PLANNING AN AERIAL PHOTOGRAPH SURVEY

As every project will be unique in some respects, each requires some forethought into the conception, planning and execution stages. Conception of a plan comes in the form of determining the type of data analysis that is needed and choosing an appropriate platform from which to collect those data. Planning refers to the actual logistics of obtaining new aerial photos. This is necessary when data requirements can not be met from existing maps and/or photographs; typically, this occurs when an area of interest is not covered at an appropriate scale (usually large) or recent time period. In these circumstances, new photographic data records must be acquired. For traditional aerial photography surveys, the Surveys and Resource Mapping Branch of the Ministry of Environment, Lands and Parks should be contacted for all arrangements (see Appendix B). Forvideography projects, the commercial survey company should be able to plan the flights themselves. Generally, the only information that must be supplied includes a preferred imagery scale or minimum ground resolution and a map of the field site.

This section will specifically examine situations in which the researcher is collecting one's own aerial data. Though Surveys and Resource Mapping Branch and their flight contractors will do these calculations themselves, it may be useful to determine these parameters (e.g., scale required, number of photos needed) for pre-planning a project or even out of interest for budgeting or comparative purposes. Although these calculations will work for any type of remotely sensed data collection platform assuming some of the technical specifications of the equipment are known, they are mainly intended to calculate ground spacing for conventional film-based photographic platforms.

As an initial stage in the flight planning process, it is important to examine existing maps and photos (if available) for the area of interest to aid in choosing a desired scale, film type and stereo coverage desired. It is also important to gain a sense of the terrain conditions involved; one should note:

1. the base elevation of the study area
2. the slope and/or elevation change of the area or feature of interest and
3. the general flying conditions (i.e., safe area to fly at low elevations)

A sample project is given below to illustrate some of the key requirements (modified from example in Lillesand & Kiefer, 1994).

We are planning a flight for Carnation Creek to complete an overview habitat condition assessment procedure in the lower sections of the channel. The active channel zone is on average about 15 to 20 metres wide, though some sections of the floodplain are much wider (up to 100 metres). The helicopter boom-camera system is an appropriate platform to photograph this size of channel. The helicopter-boom uses a 70mm [Hasselblad] camera with 100.64 mm long lens as standard equipment. Assuming it is summer,100ASA colour or black & white film is appropriate.

a) <u>Examine a map</u> of the study area. Carnation Creek (92C/15) flows roughly west from the Pelham Range to Barkley Sound; the lower 4-km defines the area of interest for the project. The elevation change over this part of the creek is from 140-m to sea level. The small size of the channel (and instream features) indicates that the helicopter-boom would be appropriate for photographing the channel.

b) Determine an appropriate scale to cover the region of interest. Choose anareal coverage that is much larger or wider than the object to be photographed. This is due to the 'wandering' of ground in relation to the camera due to cross winds and difficulties in maintaining clear sight lines. As well, each frame should ideally contain off-channel features to aid in identifying photo location and lining up consecutive images. As a general rule, choose a coverage width at least 3X the object size to account for wandering or drifting of the aerial platform. In this example, we will use 60 metres as a 'safe' minimum channel width for Carnation Creek.

$$\text{Scale} = \frac{\text{film size}}{\text{ground coverage}} = \frac{52\text{mm}}{60\text{m}}$$

$$\text{Scale} = 1{:}1154$$

Note that the smallestusable scale for the fixed-wing camera system is 1:1800; this limit is not exceeded in this example as 1:1154 is a larger scale than 1:1200. If a specific photo scale is desired, as is normally done with aerial photography, then the equation can be used to determine the ground coverage per image. If, for instance, 1:1500 scale photos were required, the ground coverage would be 52mm / 1:1500, or 0.052 m x 1500, which is equal to 78 metres.

c) Calculate the aircraft flying height above the terrain and add this to the mean site elevation to compute total flying height above sea level:

$$H = \frac{\text{cfl}}{\text{scale}} + h_{avg} = \frac{100.64\text{mm}}{(1/1154)} + 70\text{m}$$

$$H = 116\text{m} + 70\text{m} = 186\text{m}$$

This new flying height can be reworked into equation [4] to recalculate scale and equation [6] to recalculate ground coverage. At sea level (or the origin of the flight path) the new scale will be 1:1850 with 96 metres ground coverage. Average scale and coverage over the entire study area will be 1:1500. The change in scale (and corresponding coverage) is generally acceptable as downstream reaches of a channel are usually wider than upstream reaches.

d) Determine the ground separation between successive photos. Note that standard aerial coverage (fixed wing) assumes 60%endlap, though the helicopter takes dual simultaneous pictures (roughly 90% overlap) with 20%endlap (40% and 80% frame advance respectively).

$$\text{for 60\% endlap: } (96\text{m}) \times (0.4) = 38.4\text{m}$$

$$\text{for 20\% endlap: } (96\text{m}) \times (0.8) = 76.8\text{m}$$

For ground-based photography (e.g., camera on a telescopic pole), these distances would be used as ground spacing to determine where the operators should stand when each frame is taken. This distance can also be computed (for all platforms) using a single equation based on the above:

$$\text{Dist} = (0.4) \times w \times \left(\frac{H}{cfl}\right)$$

Where: w = film length or width (24 or 36-mm) depending on the orientation of the camera. In a standard viewing position, the horizontal plane of the film is the longer edge. For a 28-mm lens at 10-m height this spacing would be 13-m along the longer film edge.

e) Calculate the time between exposures for automatic shutter releases (also referred to as intervalometer setting). Note that this does not have to be calculated ground-based photography; *if these types of platforms are being used, skip to part 'g'.*

A flying speed of 50 km/hr is used in this example and is reasonable for a lower limit considering helicopter stability. This figure is based on ground speed, so flying speed may have to be compensated for in head or tail winds. However, it is not advised to attempt to obtain photos if winds exceed 5 km/hr.

$$\text{time} = \frac{76.8 \text{ m / photo}}{50 \text{ km / hr}} \times \frac{3600 \text{ s / hr}}{1000 \text{ m / km}}$$

$$= 5.5 \text{ seconds}$$

f) Recalculate the distance between photo centres given the intervalometer settings (generally rounded down to nearest second forairplanes). This step can be ignored for helicopter-boom photography as the intervalometer can be set to the nearest 1/10th second.

$$\text{distance} = \text{exposure timing} \times \text{flying speed} \times \frac{1000 \text{ m / km}}{3600 \text{ s / hr}}$$

$$= 5\text{s} \times 50 \text{ km / hr} \times (1 / 3.6)$$

$$= 69.4\text{m}$$

In this example, the new distance between photo centres would be 69.4 metres, compared to 76.8 metres given earlier.

g) Determine the total number of photos that will be needed to cover the region of interest. The total number of photos is often surprisingly high, especially when areas are flown at large (1:3000-1:5000 scales). It is sometimes a useful practice to determine this figure as a guide to time and cost budgeting for projects.
In our example, the lower 4-km of Carnation Creek is of interest only.

$$\frac{4000\ \text{m / flightline}}{76.8\ \text{m / photo}} + 2$$

$$= 54.1\ \text{photos per flightline}$$

The '2' represents additional photos which are added to each end of theflightline to ensure complete stereo coverage. Notice that this is a substantial number of photographs to analyse given the scale used and small study area.

h) The next steps are useful only there is a requirements for multiple flightlines; they should only be needed where there is an extensive network of side- and backchannels, where the riparian zone is to be mapped or studied, or in channel reaches which are considerably wider than average. Under these circumstances, the following can also be calculated:

i) distance between flightlines (assuming 30% sidelap)

$$0.7 \times \text{coverage per photo}$$

$$= 0.7 \times 96\text{m}$$
$$= 67.2\text{m}$$

ii) number of flightlines required, based on total study area width

$$\frac{\text{study area width}}{\text{distance between flightlines}} + 1$$

$$= \frac{200\text{m (for example)}}{67\text{m}} + 1$$

$$= 4\ \text{flightlines}$$

Readers should make special note of the purpose for and method of analysis of the collected photographs. For example, if qualitative assessments (e.g., habitat quality) or simple mensuration (e.g., channel width, riffle/pool spacing) is to be completed, then fairly simple analytic techniques can be applied, and the number of photos is not very important because this type of data acquisition is rapid. However, if the negatives will be enlarged, then it makes sense to take fewer pictures at a smaller scale as this process will produce a larger final working scale (and will also lower print costs). Similarly, if the aim of the data collection project is to produce scaled maps, then the number of photos used is an important consideration as a stereoplotter or similar device would be required and total costs can become unmanageable where large numbers of photographs are involved. In the flight planning example used above, it was found that 54 photos would be needed to cover only 4-km of channel.

APPENDIX B: CONTACTS

Aerial Photo Sales

MAILING ADDRESS
Geographic Data B.C. (formerly Maps-BC)
Ministry of Environment, Lands and Parks
4th Floor, 1802 Douglas St.
Victoria, BC V8V 1X4

OFFICE ADDRESS
3rd Floor, 1802 Douglas
Ph: (604) 387-1441
Fax: (604) 387-3022
E-mail: mapsbc@crlv01.srm.crl.gov.bc.ca
Web site: http://www.env.gov.bc.ca/gdbc/

Aerial Photograph Flight Planning and Contracting

Airborne Remote Sensing Unit
Surveys and Resource Mapping Branch
Ministry of Environment, Lands and Parks
4th Floor, 1802 Douglas St.
Victoria, BC V8V 1X4
Fax: 356-7831

BC Active Control System

INFORMATION AND ACCOUNTS
Geo-Spatial Reference Unit
Ph: (604) 387-8438
Fax: (604) 356-7831

BC ACS Information Centre BBS
(604) 480-1382
E-mail bcacs@crlv01.srm.crl.gov.bc.ca

MAILING ADDRESS
Surveys and Resource Mapping Branch
4th Floor, 1802 Douglas St.
Victoria, BC V8V 1X4

APPENDIX C: COMMERCIAL VIDEO SERVICES

(Modified from Harper & Reimer, 1995; list may not be complete)

Coastal & Ocean Resources Inc.
107-9865 West Saanich Rd.
Sidney, BC V8L 3S1
Ph: (604) 655-1290
Fax: (604) 655-1290

EML Environmental Mapping Ltd.
273 Portsmouth Drive
Victoria, BC V9C 1S1
Ph: (604) 478-9727
Fax: (604) 478-5307

Nortech Surveys
#1, 820-28th Street N.E.
Calgary, Alberta T2A 6K1
Ph: (403) 248-5000
Fax: (403)

Range and Bearing Environmental Resource Mapping
200-1678 128th St.
Surrey, BC V4A 3V3
Ph: (604) 541-2634
Fax: (604) 541-2828

Terra Surveys Ltd.
1962 Mills Road
Sidney, BC V8L 3R9
Ph: (604) 656-0931
Fax: (604) 656-4604

Waberski-Darrow Survey Group
10720 100th Ave
Fort St. John, BC V1J 1Z3
Ph: (604) 787-0300
Fax: (604) 787-1611

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