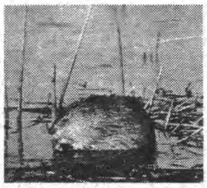
Canada Alberta Northwest Territories

Northern River Basins Study





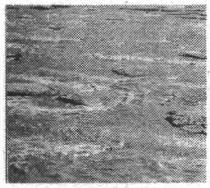




NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 81

A PILOT STUDY OF THE USE OF REMOTE SENSING TO ANALYSE FISH HABITAT

PEACE RIVER, JULY TO OCTOBER, 1994






Prepared for the
Northern River Basins Study
under Project 4131-D1

by

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

(Dr. Fred J. Wrona, Science Director)

10 Jan 96
(Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

(Dr. P. A. Larkin, Ph.D., Chair)

Jan 9/96
(Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington
(Lucille Partington, Co-chair)

Jan. 11/96
(Date)

(Robert McLeod, Co-chair)

11/01/96
(Date)

A PILOT STUDY OF THE USE OF REMOTE SENSING TO ANALYSE FISH HABITAT ON THE PEACE RIVER, JULY TO OCTOBER, 1994

STUDY PERSPECTIVE

Regulation of the Peace River has had a significant effect on its ecosystem. The relative amount of available aquatic and riparian habitat varies with the flow in the river and riverine species have adapted their life cycles to the natural flow cycle. Flow regulation disturbs the aquatic habitat by altering the historic natural flow cycle in the river. The Northern River Basins Study set out to assess the effects of flow regulation on the aquatic/riparian ecosystem of the Peace/Slave River system. A series of projects were proposed to examine the effects of flow regulation on the morphology and vegetation along the Peace River, the Peace River ice regime, the Slave delta and to evaluate tools that could be used to assess changes.

The two main purposes of this project were to:

1. develop and evaluate methods for mapping aquatic habitats using remote sensing; and
2. to describe the relationship between the river discharge and the amount of meso-habitat types (eg. side channels, sloughs, shoals, backwaters, riffles, pools) available.

Related Study Questions

6) *What is the distribution and movement of fish species in the watersheds of the Peace, Athabasca and Slave Rivers? Where and when are they most likely to be exposed to changes in water quality and where are they're most important habitats?*

10) *How does and how could river flow regulation impact the aquatic ecosystem?*

14) *What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems. These programs must ensure that all stakeholders have the opportunity for input.*

Four different imaging systems were evaluated to map the aquatic habitat in this project. They included: colour photography, colour infrared photography, multi spectral videography and compact airborne spectrographic imaging (*casi*). Colour infrared photography was judged to be the most cost-effective method for mapping aquatic habitat using remote sensing. The *casi* was judged the best instrument for difficult discrimination problems such as assessing substrates in the dry and near shore areas or correlating reflectance with field parameters such as total suspended solids. Aerial photography was much better than video or the *casi* for producing geo-referenced data. The video generally fell between the colour infrared photography and the *casi* in terms of expense and capabilities.

Attempts to describe the relationships between the amount of available habitat and discharge were less successful as the range of discharges during the study was fairly narrow. Additional imaging over a greater range of flows would be necessary to accurately characterize the relationships.

The results from this pilot study will be combined with information collected in four complementary projects ("Changes in Morphology and Riparian Vegetation Following Flow Regulation, Peace River 1968-1993," NRBS Report No. 102, No. 122 - "Effects of Flow Regulation on Freeze-up Regime, Peace River, Taylor to the Slave River", No. 74 - "An Assessment of Impacts on the Slave River Delta of the Peace River Impoundment at Hudson Hope", and No. 66 - "Proceedings of the Northern River Basins Study Instream Flow Needs Workshop") to comprehensively assess the effect of flow regulation on the aquatic ecosystem. This pilot study has shown that remote sensing is one tool that may be used to identify and monitor the aquatic habitat.

REPORT SUMMARY

The objectives of this project were to:

1. develop and evaluate several methods for mapping aquatic habitat using remote sensing; and,
2. describe the relationships between river discharge and the amount of meso-habitat types (eg. side channels, sloughs, shoals, backwaters, riffles, pools) at the two study segments chosen.

Four imaging systems were evaluated for mapping aquatic habitat, colour photography, colour infrared photography, multispectral videography and compact airborne spectrographic imaging (*casi*).

1. Colour aerial photography was judged to be inappropriate for habitat assessment, based on this trial. The colour photography did not allow for easy discerning of the water's edge because it does not include the infrared wavelengths of light and it was poor for discerning vegetation.

2. Infrared photography fared very well in this trial. Because water absorbs infrared light, imaging systems that include the infrared wavelength can identify the water's edge very accurately. The infrared colour photography was judged to be the most cost effective to meet the requirements of this study. Aerial photography also allowed inexpensive and accurate georeferencing. Infrared colour photography would not be a good choice for classifying turbidity, depth and substrate.

3. The *casi* system although the most expensive, but because of its 256 bands for spectral resolution, is the most accurate for determining features that have similar spectral signatures such as substrates in the dry and near shore areas or correlating reflectance with field parameters such as total suspended solids. In this study the *casi* resulted in some loss of accuracy in determining areas and was the least accurate in georeferencing.

4. Multispectral videography was midway between infrared aerial photography and the *casi* system in terms of cost and accuracy.

To meet the objectives of this study, infrared aerial photography was judged to be the most appropriate method in terms of meeting the objectives cost effectively.

Developing an available habitat versus flow relationship was not very successful as the range of flows that were available over the course of the study was limited. Additional imaging over a greater range of flows will be necessary to accurately characterize these relationships. Poor conditions for imaging also played a part in these difficulties.

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1.0 INTRODUCTION

An understanding of the effects of flow on fish habitat is important for managed rivers and streams where flows, and therefore available fish habitat, are controlled. The Peace River was impounded in 1967. Since that time concern has been raised that operation of the W.A.C. Bennet Dam has affected downstream aquatic habitat. The Peace River is a large river with mean summer flows of about 1000 cms at Alces River (Alberta Border) and 1400 cms at the town of Peace River. Arriving at a reasonable estimate of the flow-habitat relationship is a difficult task for a river the size of the Peace. Other methods of assessing physical fish habitat may be impractical because they become extremely expensive on such a large river. This study was a pilot project to determine if remote sensing was a less expensive, scientifically justifiable, method of assessing changes in fish habitat as a function of flow.

Relatively recently, remote sensing has been used to classify fish habitat on rivers. The use of video for collecting fish habitat information dates back at least to the early 1980's in Canada (Overton and Mussakowski 1983 in Jennings *et al.* 1992) and work is ongoing at Utah State (Anderson *et al.* 1993, Panja *et al.* 1993). Most of these studies deal with small study areas, on small bodies of water, and delineate few habitat classes (Jennings *et al.* 1992, Anderson *et al.* 1993, Panja *et al.* 1993). Classification of a river the size of the Peace with study reaches 100 km long is breaking new ground in remote sensing classification of fish habitat in rivers.

We used four different imaging systems to collect data. Although our primary objective was the classification of fish habitat, our secondary objective was to assess the cost-effectiveness and capabilities of the imaging platforms. We used colour photography, colour infrared photography, multispectral videography and the compact airborne spectrographic imager (*casi*) in this study. The *casi* was used to image three different discharges and the other platforms were used to collect imagery once each.

We know the Peace River has undergone changes in the flow regime due to the operation of the W.A.C. Bennett dam. The larger question is: What effects have the changes in flow regime had on aquatic habitat type distribution? To answer this question, one needs to empirically derive the flow versus habitat relationships for the various habitat types. Then the distribution of habitat under the recorded post-dam flow regime can be compared to the habitat expected if natural flow conditions prevailed. Determining the flow-versus-habitat relationships was the final objective of this study.

2.0 METHODS

2.1 The Study Area

The study was conducted on two reaches of the Peace River (Figure 1). The Peace River in Alberta can be characterized as a large, low gradient river. The upstream reach was located in a more deeply incised valley and had a slightly higher gradient than the downsteam reach. Although both reaches were primarily silt substrate, the upstream reach had more areas of coarse substrate (gravel to cobble-sized material). The downstream reach had higher flows and had more channel meanders and islands. Substrate was primarily silt. In the upstream reach, there were two areas where the river widened and formed a complex of islands with many small, shallow channels as well as deep, main channel habitat. One of these areas was Many Islands (Figure 1). The Many Islands area was used for more intensive study as the habitat was the most diverse habitat in either study reach. The downstream reach had no areas comparable to Many Islands.

2.2 Determination of Flow

The Peace River in the upstream study area was prone to considerable daily fluctuation in flow due to hydropeaking activities at the W.A.C. Bennet Dam (Figure 2). Thus, the flow that was imaged in one sample block could be very different from the flow in another block in the upstream study area, even on the same day. Our flow estimates for a given block in the upstream reach were approximations determined from hourly records, attenuation of hydropeaking and the time of travel between Alces River and Dunvegan gauging stations. We reviewed the hourly flow records for Peace River at Alces River (about 5 km upstream of the B.C.-Alberta border) and the Peace River at Dunvegan Bridge. We used the records for 6 days corresponding to the day of image sampling and the previous day for each of the three *casi* sampling occasions.

We estimated the time of travel to the start and end of all flight blocks. River distance was assumed to be directly proportional to time of travel for the water. Therefore if a flight block was 20% of the length of the Peace River from Alces River to Dunvegan, it would take 20% of the time for the water to travel through the block. Travel times were determined for the downstream and upstream boundary of each flight block and rounded to the nearest hour. Travel times were then used to determine mean flow in the flight block based on flow at the Alces River gauging station.

We determined the mean number of hours required for the daily maximum and daily minimum to travel from Alces River to Dunvegan Bridge. We also determined the attenuation of hydropeaking and any augmentation in flow from tributaries by comparing changes in daily minimum and maximum flows between Alces River and Dunvegan. We assumed a linear relationship between time of travel and hydropeaking flow attenuation, time of travel and tributary flow augmentation, and between time of travel and distance of travel. The formula we derived to determine the correct flow in a given sample block was:

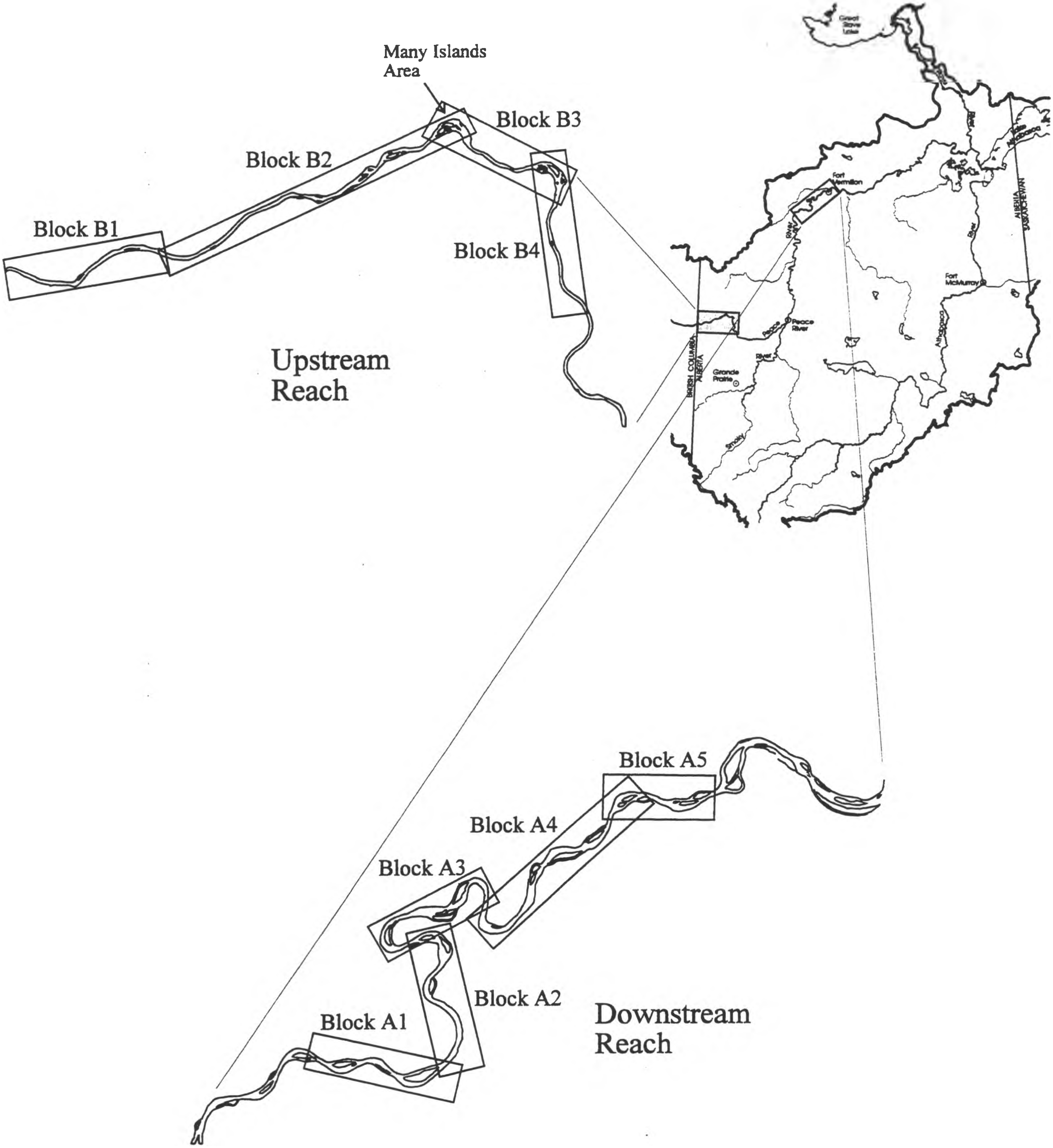


Figure 1. The study area.

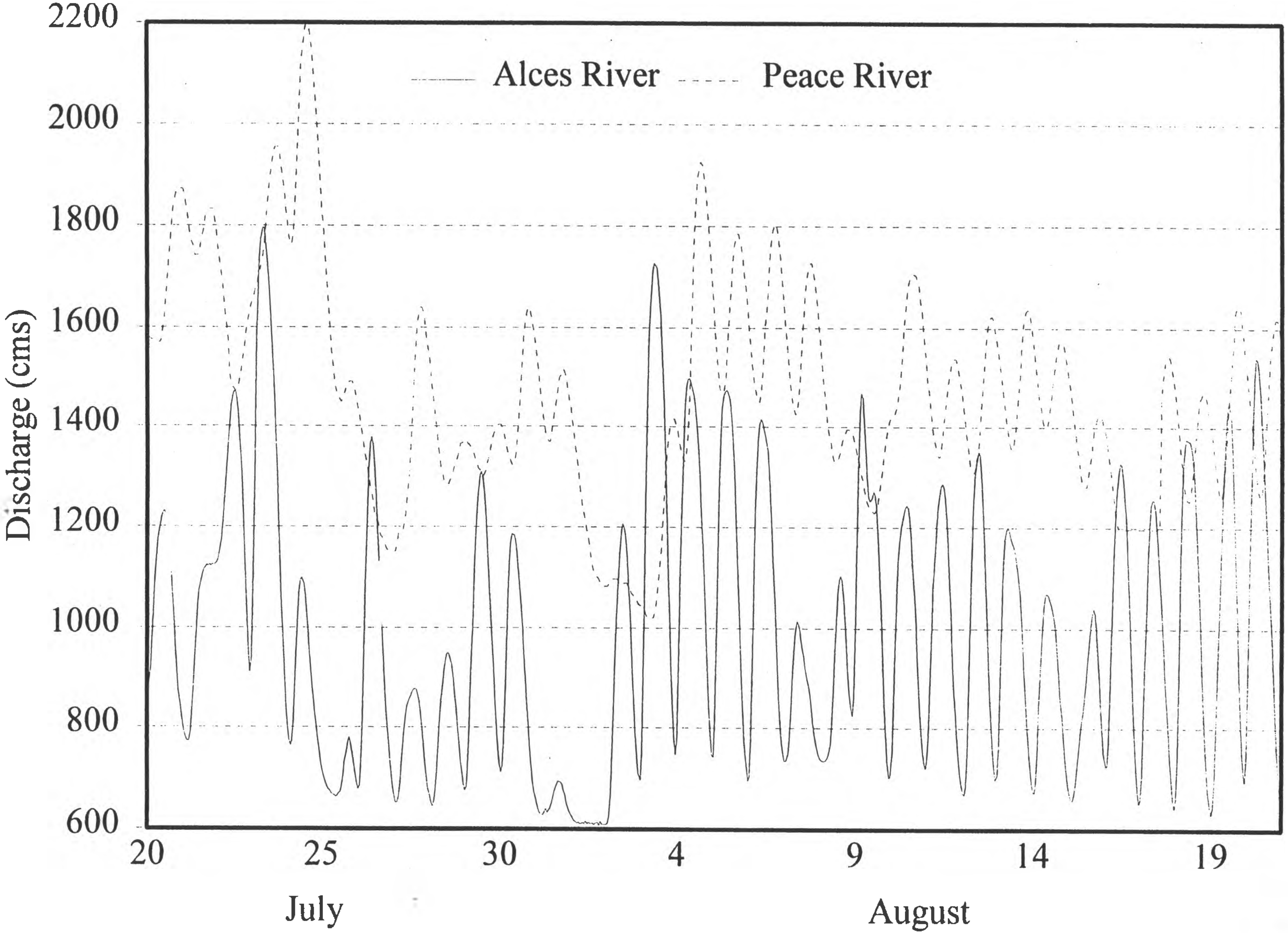


Figure 2. Sample hourly discharges measured on the Peace River at Alces River (near the British Columbia border) and at the town of Peace River, July 20-August 20, 1994.

$$Corrected\ Flow = \frac{\frac{Flow - MinAlcesQ}{MaxAlcesQ - MinAlcesQ} * (\%DiffMax - \%DiffMin) + \%DiffMin - 100}{100} * Flow * \frac{Hours}{18.3} + Flow$$

where: *Flow* = flow at Alces River gauging station that was expected to reach a location of interest based on time of travel.
MinAlcesQ = average of 6 daily minimum flows from the Alces River gauging station used to derive the attenuation relationship.
MaxAlcesQ = average of 6 daily maximum flows from the Alces River gauging station used to derive the attenuation relationship.
%DiffMax = % difference between Alces River gauging station mean daily maximum and corresponding Dunvegan gauging station mean daily maximum.
%DiffMin = % difference between Alces River gauging station mean daily minimum and corresponding Dunvegan gauging station mean daily minimum.
Hours = number of hours of travel for flow from Alces River to each block when imagery was collected.
18.3 = mean number of hours of travel for 6 daily maximum and minimum flows between Alces River and Dunvegan gauging stations used to derive the attenuation relationship.

Unfortunately, the downstream reach had no operating gauging stations in the area so flows were fairly rough estimates based on data from Peace River gauging station and intermittent information from Fort Vermilion. Hydropeaking was probably negligible for the downstream reach.

2.3 Data Collection

Starting in late July 1994, we collected remote sensing data using four different imaging systems; conventional colour aerial photography, colour infrared aerial photography, multispectral videography and the Compact Airborne Spectrographic Imager (*casi*). The objective was to collect as wide a range of flows as possible during the remainder of the 1994 open-water season (Table 1).

Each reach was approximately 100 km long. Because the *casi* was to be the primary sensor device, and because *casi* data collection and correction was best undertaken on straight flight lines, the reaches were divided into a total of 9 blocks, each containing 3 to 6 parallel flight lines (Figure 1). The multiple flight lines were necessary because the swath width of the *casi* imagery at 2.25 m resolution was only 1152 m. Also, the *casi* was a pushbroom scanner. Each scan line in the imagery was independently affected by aircraft roll and after corrections were made for roll, the useful width of the imagery was reduced. To account for the reduced image width, adjacent flight lines were overlapped. In this project, flight line sidelaps of 35% were used to accommodate both the high relief terrain in the upstream reach, extreme aircraft roll, and the possibility of cross winds skewing flight lines during data collection. The result was an effective swath width of 749 m.

Table 1. Dates of data collection for each study reach for each imaging system.

Date	Study Reach	Imaging System
26-27 July 1994	Downstream	*casi*
18 August 1994	Upstream	*casi*
19 August 1994	Downstream	*casi*
20 August 1994	Upstream	*casi*
25 September 1994	Upstream	Colour and Colour Infrared Photography
26 September 1994	1/4 of Downstream	*casi*
13-14 October 1994	Downstream	*casi*
13-14 October 1994	Downstream	Multispectral Videography
14 October 1994	Downstream	Colour and Colour Infrared Photography
17 October 1994	Upstream	*casi*
17 October 1994	3/4 of Upstream	Multispectral Videography

The flight block layout was designed to minimize flying time while maximizing the amount of river that would be represented in each flight line. Given the orientation of the river and the need to acquire imagery on different days to obtain different discharges, it was impossible to optimize flying direction for sun angle conditions. Flight lines remained fixed throughout the entire data collection period - ie., *casi* flights #2 and #3 repeated the flight lines of *casi* flight #1.

Both reaches were imaged three times with the *casi*, resulting in the collection of approximately 200 *casi* data files. During the October 13-14 downstream *casi* flight, the multispectral video system was mounted alongside the *casi* sensor head and video imagery was recorded coincident with the *casi* data. This method was repeated on October 17 when 3/4 of the upstream reach was imaged with the video system. In addition, both reaches were imaged once each by colour and colour infrared aerial photography.

Weather conditions during the study period were not ideal, with forest fire smoke and unsettled weather severely limited the number of suitable flying days. Added to this was the additional constraint of imaging specific target flows. As a result, a decision was made to record *casi* and video imagery with as high as 3/10 cloud cover and visibilities as low as 8 km (ideal conditions would be 0 cloud and 20-30 km visibility). Typically, cloud cover was only a minor problem, but poor visibility characterized some of the *casi* data collection days. The photography was collected on clear days.

The *casi* was configured to record 11 bands of imagery at a spatial resolution of approximately 2.5 m. The band selection was designed to maximize water penetration by using wavelengths in the blue region of the spectrum and to provide a sharp distinction in the land-water interface by using infrared wavelengths. Reference channels, (bands of predictable spectral response) and bands that were potentially useful in combination with other bands were also included.

Each of the bands in the NRBS band configuration was assigned a priority rating. When low light conditions were encountered during a flight because of smoke, haze or relatively low sun angle, the band configuration was progressively altered by widening or deleting low priority bands as required. As a result, a total of 4 band configurations were collected over the study area, but the most critical bands were the same in each configuration (Table 2).

The 3 channel multispectral video data were recorded coincident with the final flights of the *casi* at wavelengths comparable to the wavelengths recorded for the *casi*. It was impossible to exactly match the wavelengths because it was necessary to choose from a set of filters that did not completely correspond with the *casi* wavelengths (Table 2).

Table 2. The band configurations used for collecting *casi* and multispectral video on the Peace River study reaches, 1994.

USE/SPECTRAL FEATURE	NRBS	DARKNRBS	DRK2NRBS	DRK3NRBS
clear water penetration	510.0 - 530.4	-	-	-
water/vegetation discrimination	541.1 - 560.6	541.1 - 560.8	541.1 - 560.6	537.5 - 564.2
subsurface/water delineation	580.2 - 599.8	580.2 - 599.8	580.2 - 599.8	580.2 - 599.8
algae/bacteria detection	617.7 - 628.4	617.7 - 628.4	-	-
reference	640.9 - 660.6	640.9 - 660.6	-	-
chlorophyll absorption	669.6 - 680.4	669.6 - 680.4	669.6 - 680.4	669.6 - 680.4
start of vegetation "red edge"	700.2 - 709.2	700.2 - 709.2	700.2 - 709.2	696.6 - 714.6
"red edge" reference	736.2 - 745.2	-	-	-
reference	747.0 - 750.6	747.0 - 750.6	747.0 - 750.6	747.0 - 765.1
reference	770.5 - 784.9	-	-	-
reference	790.4 - 810.3	-	-	-
Multispectral Video				
water/vegetation discrimination	545-555			
chlorophyll absorption	665-675			
reference	780-820			

During the flights, Global Positioning Satellite (GPS) data were recorded directly to the *casi* to measure the aircraft position. A second GPS receiver on the ground recorded data to a laptop computer. Upon landing, these data were used to differentially correct aircraft location. In addition, ground-based differential GPS locations were recorded at selected sites within each block to provide a further level of positional correction during the geometric processing.

Also on board the aircraft and connected to the *casi*, was a vertical gyro which measured the aircraft pitch and roll coincident with each scan line of *casi* imagery. This was also used for geometric correction of the imagery.

2.4 Radiometric and Geometric Correction of the *casi* Imagery

Following collection, all remotely sensed imagery requires some level of basic processing (pre-processing) in order to prepare it for analysis. With imaging spectrometer data, this typically involves at least basic radiometric correction and some level of geometric correction. If the data are used for temporal analysis, as for this study, data must also undergo additional processing. This is necessary because the effects of atmosphere, sun angle and incident light vary between imaging dates. This is accomplished by converting the data from radiance to reflectance values through the use of additional measurements or by normalizing the imagery using the data values themselves.

In this project, the *casi* imagery was radiometrically and geometrically corrected. A normalization technique was applied and the imagery was mosaicked to join the flight lines within each block. Classification and analysis of the mosaicked images was performed after these corrections.

The video imagery and the photography also required some processing for comparison with the *casi* imagery

2.4.1 Radiometric and Geometric Correction of the *casi* Imagery

The *casi* is a passive remote sensing system. This means it emitted no signal, instead recording incoming electromagnetic radiation (light). Light entering the *casi* is split into discrete wavelengths at intervals of 1.8 nm and then measured. This information was recorded as 12 bits of information to an 8 mm cassette tape installed in the *casi* itself. In this raw format, the *casi* data values consisted, not only of the light-induced signal from the target itself, but also of components introduced as a result of the hardware characteristics of the instrument. These characteristics included:

- electronic offset; (a signal offset added by the A/D conversion electronics in the system)
- dark current; (signal generated in the sensor through random excitation of electrons over the silicon band gap)
- internal scattered light; (light scattered at each of the optical surfaces in the spectrograph)
- frame shift smear; (or FSS, the effect of image smearing during frame transfer in the image sensor)

Each of the above components was removed, leaving only the light-induced signal from the target. This signal was then multiplied on a pixel-by-pixel basis by a set of referenced coefficients particular to a given f-stop. These coefficients were synthesized from full-frame data obtained by viewing a calibrated uniform laboratory source during factory calibration of the instrument. A set of sensitivity files (.rad files) were created, one for each f-stop at which the instrument might be operated. During the radiometric correction procedure, these sensitivity files were applied to the raw data.

The result of the correction process was a set of intensity values that were corrected for response variations and were then converted into Spectral Radiance Units (1 SRU = 1 $W/cm^2/sr/nm$). The data, which was recorded as 12 bits and radiometrically corrected to radiance as 12 bits, was then scaled to 16 bits using a scaling factor called the Peak Spectral Radiance Unit (P. SRU). Scaling to 16 bits used a P. SRU of 65 535 which means that the data, which was recorded as values ranging from 0 to 4096 was scaled to range from 0 to 65 535.

Following radiometric correction, the spatial mode data underwent geometric correction. This involved the following steps:

- retrieved the gyro (roll and pitch data) from the *casi* data file
- filtered the gyro data to remove noise generated by the aircraft
- converted the data from dn to degrees
- retrieved the slave and master GPS data from their logging stations
- reformatted the GPS data
- calculated GPS differential data from the slave and master data
- merged the gyro and differential GPS data
- created a UTM grid from the GPS data
- geometrically corrected the imagery
- projected the image data onto the UTM grid

During the geometric correction process, we set the pixel size in both the X and Y directions. These values were derived from the speed and altitude of the aircraft as well as the integration time during the data recording process. During this project, the altitude of the aircraft remained fairly stable at approximately 1600 m above ground level, resulting in an across-track (X direction) spatial resolution of approximately 2.25 m. The speed however, varied from approximately 200 km/h to approximately 222 km/h owing to unpredictable winds aloft. Along-track (Y direction) spatial resolutions ranged from approximately 2.0 to 2.5 m. The goal was to produce square pixels, and to maintain as much geometric fidelity as possible with a push-broom scanner over multiple flight lines. Thus, the along-track and across-track pixel sizes were specified during the geometric correction process at 2.5 m. This resulted in a slight over-sampling in the across-track direction, but generated imagery that could be registered to existing data sets.

2.4.2 Normalization of *casi* Imagery

There are a number of common techniques used to normalize imagery, including histogram matching or contrast matching. In these processes, an image function is derived which can be modified into a desired reference function. The images are adjusted to produce new images that are represented by the reference function. However, care must be taken to determine the tolerance of radiometric fidelity to avoiding saturation or loss of signal. In addition, for extremely large data sets, the computation, processing, and handling time can make these techniques impractical.

Another approach is to use relatively homogeneous areas from similar spatial locations in overlapping flight lines as radiometric Image Target Control Points (ITCPs). These regions of interest are selected to normalize a given image to an adjacent reference image by first deriving a normalization coefficient. This coefficient is based on the relative spectral difference between the two lines and is derived using a ratio of the ITCPs from each image. This section describes the ITCP-approach and examines the inherent uncertainty and assumptions.

It was not reasonable to normalize between image blocks because of the between-block time intervals during collection. Each block was normalized independently and algorithm adjustment was necessary for each block. We extracted image spectra for each block and determined the changes that occurred due to atmospheric differences or sun angle changes. The results of these comparisons were used to adjust coefficients or boundary levels for both first- and second-order classifications.

ITCP regions were extracted from August 20, 1994 *casi* data acquired over the Many Islands region during low flow conditions. Analysis concentrated on two flight lines imaged within approximately 15 minutes of each other. Various ITCP regions were assessed to examine the uncertainty associated with different image surface features and how this may have influenced the imagery. The ITCP regions consisted of three gravel (gr), three within the main river channel (mc), one mixed region (mr), one vegetation (veg), and one submerged vegetation (wv) regions.

To determine the uncertainty associated with a data set we assumed that errors were random and could be assessed by statistical analysis. Although it was possible that systematic errors existed, it was outside the scope of this study to determine if this was the case. In a spatial sample of data from a remotely-sensed image, the uncertainty was considered to represent the spatial variation of a surface feature. In other words, the uncertainty was a key indicator of the degree or magnitude of feature homogeneity. However, within this variation, external influences were embedded. These include changes in atmospheric condition, bi-directional reflectance function (BDRF) effects, and aircraft attitude motion. Statistical analysis enabled the quantification of these random errors. If we assume the sample to be normally distributed, then the standard deviation of the mean (SDOM) represented an average uncertainty in the sample; as given in equation (1)

$$\sigma_{\bar{x}} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - \bar{X})^2} \qquad 1$$

where N is the number of samples, Xi is the individual sample, $\bar{X}$ is the sample mean value.

Assuming a normal distribution, the SDOM indicates a 68% probability that any given value in the sample lies within ±1 SDOM. Two SDOM deviations encompass a 95% probability, a larger representation of the population. In other words, SDOM provides an uncertainty range; a smaller SDOM value indicating increased homogeneity of the target. However, the SDOM does not consider the number of measurements or samples, but is based only on individual measures. Increasing the number of samples of a homogeneous target will result in a more reliable (accurate) mean value, and thus the uncertainty will decrease. Therefore, an improved method of defining the uncertainty is to use standard error, as defined by equation (2)

$$SE = \frac{\sigma_{\bar{x}}}{\sqrt{N}} \qquad 2$$

Now considering the image ITCP regions, the percentage uncertainty for a given image is determined by equation (3)

$$\%Uncertainty = \frac{2 * SE}{\bar{x}} * 100 \qquad 3$$

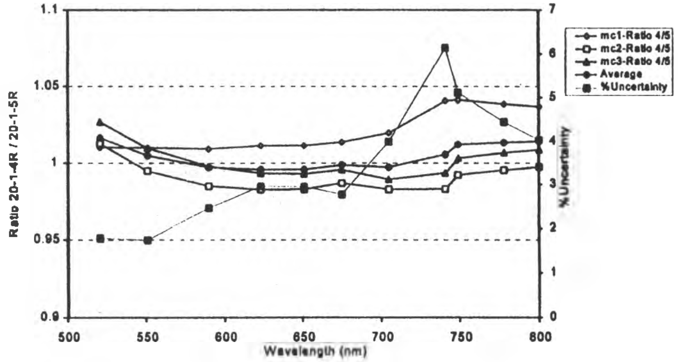
Using a ratio of the mean values, the propagation of the uncertainty with regards to standard error was evaluated using the quadratic sum given by equation (4)

$$\%Uncertainty\ (total) = \sqrt{(\%Uncertainty\ i)^2 + (\%Uncertainty\ j)^2} \qquad 4$$

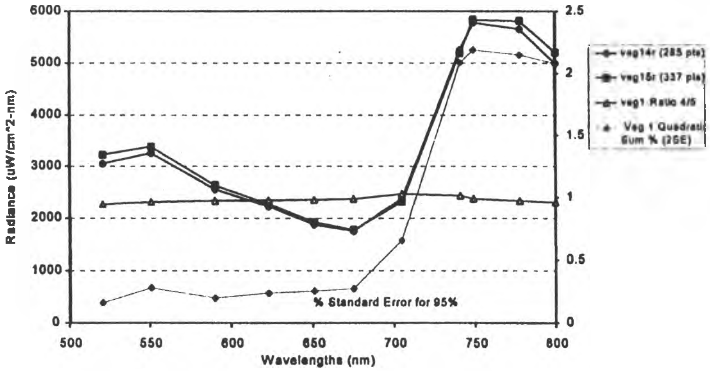
where i and j are the ITCP regions of the two corresponding images. This applies if the uncertainties are independent and random, which was assumed.

The four graphs below (Figure 3) represent a spectral plot of the ITCP surface regions used to evaluate the available features' coefficients (gravel, main channel, vegetation, and submerged vegetation) to derive normalization. Each plot shows image radiance for the given feature, a ratio of the two ITCP regions, and the total uncertainty. Figure 4 provides an overlay of all the surface ratios in the ITCP regions.

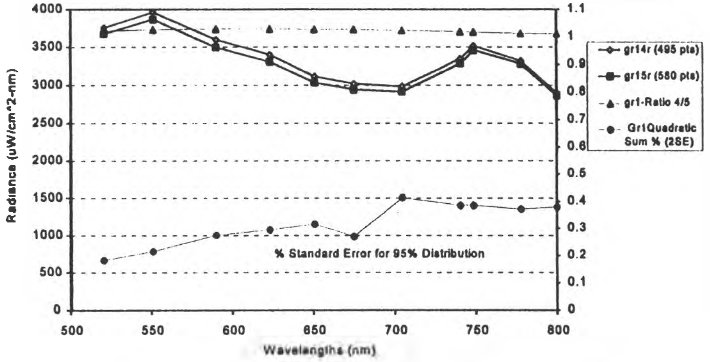
Of the four ITCP regions, the best results were obtained from the region collected along the main river channel. For the particular image set, 3 ITCP regions were used to normalize one image to the reference image. These ITCP regions, referred to as mc1, mc2, and mc3, can be seen in Figure 4. Figure 5 illustrates the uncertainty in the use of the average ratio value to normalize the image. The actual errors used to derive normalize coefficients may be 0.08% to 0.2% higher than the value illustrated in Figure 5.



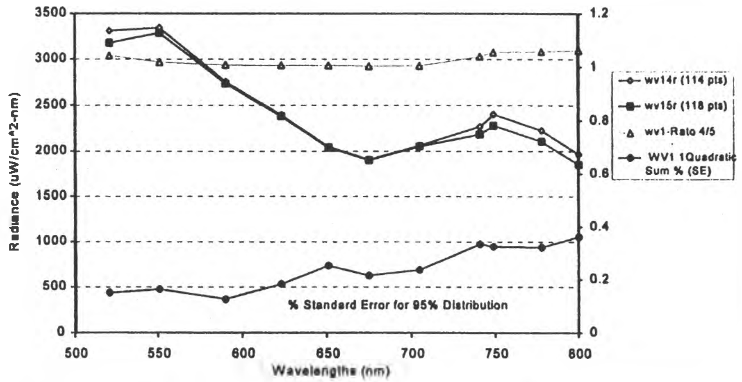
The three ITCP main channel regions selected and the uncertainty in using the average ITCP extracted from August 20, 1994 *casi* data over Many Islands at low flow.



A comparison of ITCP Vegetation 1 from images 20-1-4r and 20-1-5r to derive a normalize coefficient. Vegetation 1 ITCP extracted from August 20, 1994 *casi* data over Many Islands at low flow.



A comparison of ITCP Gravel 1 from images 20-1-4r and 20-1-5r to derive a normalized coefficient. Gravel 1 ITCP extracted from August 20, 1994 *casi* data over Many Islands at low flow.



A comparison of ITCP Subsurface Vegetation 1 from images 20-1-4r and 20-1-5r to derive a normalize coefficient. Subsurface Vegetation 1 ITCP extracted from August 20, 1994 *casi* data over Many Islands at low flow.

Figure 3. Spectral plots of the ITCP surface regions used to evaluate the available features coefficients, Peace River, 1994.

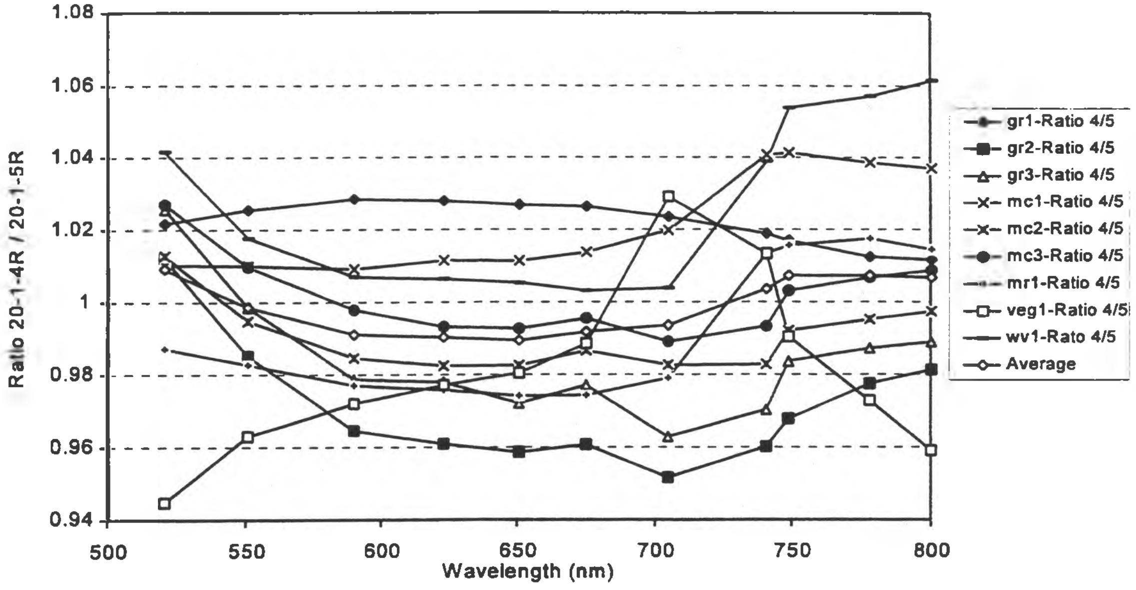


Figure 4. A comparison of all ITCP normalize coefficients from Images 20-1-4R and 20-1-5r. ITCP extracted from August 20, 1994 *casi* data over Many Islands at low flow.

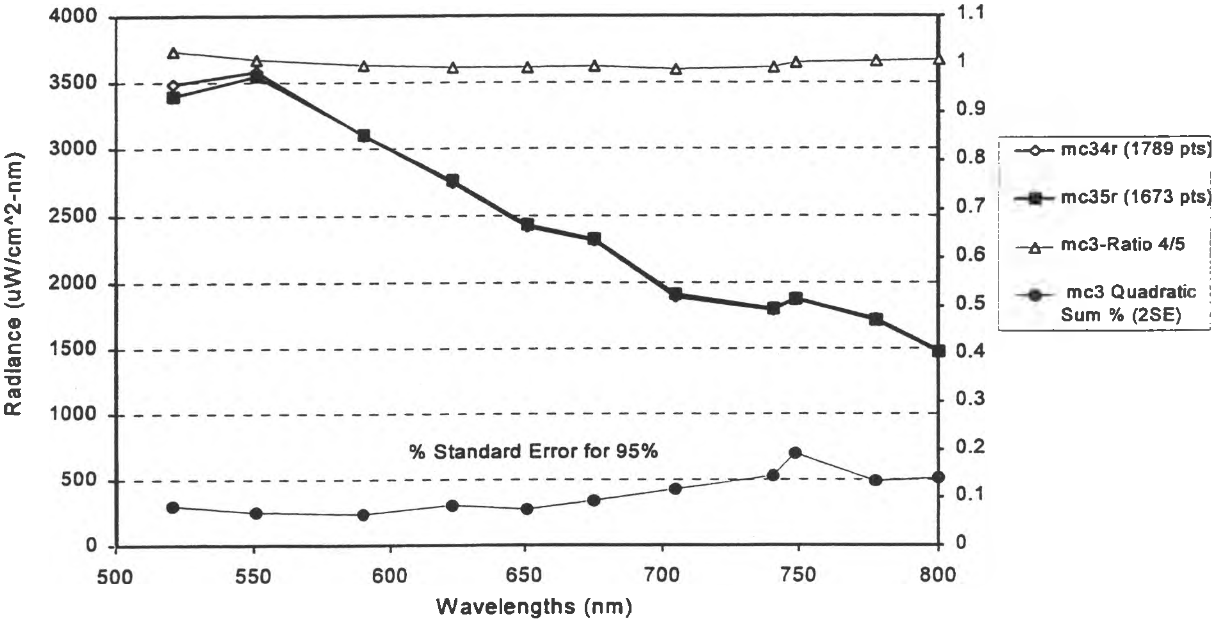


Figure 5. A comparison of ITCP Main Channel 3 from images 20-1-4r and 20-1-5r to derive a normalize coefficient. Main Channel 3 ITCP extracted from August 20, 1994 *casi* data over Many Islands at low flow.

The uncertainty of the average coefficient value ranged between +2% to approximately +6% for this particular image set. However, a number of assumptions were inherent in this estimate:

- the angle between the sensor (view angle) and the illumination (sun) did not change significantly.
- the atmosphere over each of the merging scenes was assumed to be relatively constant. Atmospheric conditions can vary due to smoke or clouds, and low sun angle may enhance edge effects.
- there was a high degree of confidence in locating the targets spatially ensuring the same feature was being compared in each flight line.

As all the flight lines in a given block were taken over a period of one hour or less, the first two assumptions were met fairly well. The final limitation resulted from the feature types available for ITCP regions which may cause the uncertainty to increase. For example, if vegetation or gravel, which were more heterogeneous than the main channel, had to be used to derive the normalization coefficients. The acceptable uncertainty level depends on the nature of the work.

The required normalization for the Peace River imagery was carried out using ITCP region ratios derived from the normalization coefficients. This method was successful for matching radiance intensities of contiguous flight lines without compromising the spectral content or integrity of the data. Radiometric inconsistencies were mitigated to an acceptable level for digital classification within a reasonable processing time.

2.4.3 Mosaicking and Image Registration

The final stage in data preprocessing involved joining (or mosaicking) the normalized image files to create a single image for each block. The procedure was relatively simple, but very time consuming. The first stage of the three step process was warping one image to another. Warping was necessary to optimize the geometric alignment between the flight lines. Using the middle flight line as a reference, adjacent lines were geometrically fitted to the middle flight line. The warping calculations were based on control points common to overlapping flight lines. The x and y co-ordinates of these points were used to mathematically warp each image to the reference image, usually based on a first order polynomial, nearest-neighbour algorithm. More complex algorithms were available but were considerably slower and in many cases overcompensated for geometric distortions.

Once warped, the adjacent image files were mosaicked together by fitting one image on top of the other in areas of overlap. No further warping took place at this stage, so trial and error was used to select an overlay alignment that minimized any geometric inconsistencies. Geometric imperfections still existed in the imagery where features did not align perfectly. These were primarily a result of instability of the airborne platform (i.e. aircraft pitch, yaw, and crab, fluctuations in ground speed, changes in altitude above ground), and small errors inherent to the GPS and geometric correction calculations. In most cases, these effects were minimal relative to the area covered (typically a 5 pixel misalignment in a 512 pixel swath for an error of <1%).

Once each block was mosaicked together, the entire block was warped again to fit the UTM grid. For the downstream reach, UTM coordinates were derived from NTS 1:50 000 maps in NAD27. For the upstream reach, GPS data (in NAD83) were acquired from ground-based measurements consisting of approximately three points for each flight block. Although no quantitative comparison was conducted, the ground-based measurements wee typically more accurate (±5 m) than those extrapolated from 1:50 000 scale maps (±10 m). The effectiveness of warping imagery to the UTM grid was limited by the number of known locations derived from maps or the GPS. Because only three GPS readings were available for each flight block in the Upstream Reach, there was difficulty locating suitable points (visible on both imagery and maps) from the 1:50 000 maps, and distortions remained in the mosaicked imagery. UTM co-ordinates imbedded in the imagery should not be relied upon for a high degree of locational precision.

2.4.4 Processing the Video Data

Because of the nature of the video system (see system description, Section 3.3) no radiometric calibration of the video was undertaken. Nevertheless, laboratory measurements of the video data at various aperture settings were taken using an integrating sphere in the event that such information would be required later.

All of the video imagery was characterized by brightness variations that resulted not only from variations in the scene, but also from sensor and atmospheric effects. A normalization technique that used the brightness values of deep water targets was applied throughout each video image to minimize the sensor and atmospheric brightness variations.

The video data was recorded at the rate of one frame every 1/10 second. This rate of recording resulted in considerable overlap between the video images that allowed us to use only the central (near nadir) portion of each image throughout most of the area of interest. However, a few gaps existed in the imagery due to severe roll and turns in the flight path of the aircraft.

Following normalization, successive images from each channel were mosaicked together and the mosaics created from each channel were co-registered using image-to-image feature matching. This resulted in a 3 channel colour composite of the video imagery. Systematic noise from either aircraft vibration or electronic interference was observed in the data but no attempt was made to account for this noise which is apparent only as a slight "jitter" in the imagery.

Only the video data for the Block B3 in the upstream reach were prepared for analysis.

2.4.5 Processing the Aerial Photography

The colour and infrared aerial photography were scanned at a ground resolution of 2.5 m and ported to the image analysis system.

2.5 Image Analysis

Two types of analysis were undertaken to derive classification results from the *casi* imagery; a spectral analysis (semi-automated) followed by a spatial analysis (interactive or manual). Both methods were used because it was clear that some of the features we wished to classify were quite distinct spatially, but were very similar spectrally. Image processing has not reached the level where targets with the same spectral characteristics can be distinguished by shape alone without human interaction. An example of this is the comparison of side channels that have many different shapes and also have spectral characteristics similar to a snye or slough. In these cases it was not feasible to develop an algorithm to automatically discriminate these features.

The spectral (semi-automated) analysis of the *casi* imagery was undertaken using the measured radiance values of the data which were a function of the spectral absorption and scattering properties of the target. Spectral shape signatures (Farrington et al. 1994) and band ratios were studied and we determined that spectral shape signatures were the most useful for discriminating targets. Band ratios caused the misclassification of many pixels due to the complexity of the high resolution imagery. In most cases band ratios were found to be unstable and many times encompassed not only the desired class but many others. As a result, the spectral analysis relied mainly upon spectral shape signatures. Once a spectral algorithm was developed to distinguish a specific class, it was applied across the entire image block.

The semi-automated nature of the spectral analysis was performed independently of the shape, size or location of a feature. Once a spectral algorithm was developed to distinguish a specific class, it was used freely on the entire image block. When a pixel was classified it could fall into one of three primary categories - vegetation, deep water or geological substrate. All primary classes were mutually exclusive. Second order categories were all geological substrate, all vegetation, relative depth, water level, relative turbidity, subsurface vegetation substrate, subsurface geological substrate and mixed vegetation and geological substrate.

The spatial analysis or interactive analysis did not work for fish habitats which had either specific shape, size or position within an image and crossed more than one spectral analysis boundary (e.g., two depth levels, or a turbidity and a depth level). Riffles were one of these complex classes, with a possible signature crossing two depth levels or having a specific signature of high turbidity. For these habitat classes, a human interactive approach was implemented.

Since it was not possible to normalize between image blocks, each block was normalized independently, and algorithms we developed had to be adjusted. This was performed by extracting image spectra for each block and determining the subtle changes that may have occurred due to atmospheric differences or sun angle changes. The results of these comparisons were used to adjust coefficients or boundary levels for both first and second order classifications.

2.5.1 Primary Classification

In order to derive relative turbidities, depth, presence of submerged vegetation and other second order effects, primary parameters such as vegetation, deep water regions, and pixels that contain geological substrate were determined.

Vegetation

Vegetated regions were the first areas to be determined within all imagery. We used the presence of the chlorophyll-a absorption well at 675 nm and the increasing red-edge effect, from 675 to 750 nm (Hare et al. 1984). This method did not discriminate between pure, mixed or subsurface vegetation spectra, classifying all pixels exhibiting a chlorophyll-a well and a consistently positive red-edge slope signature as vegetation. Due to the high resolution nature of the imagery, this method provided accurate classification of shadowed canopy and vegetation regions that generally have very low and complex signatures.

Deep Water

Once pixels with vegetation within the image were discriminated, pixels containing only deep water were determined. A deep water pixel was defined as a region covered by water where the bottom was not spectrally visible. Again, this was a relative method of discrimination, since turbidity of the water plays a very large role in depth determination. All optical platforms were affected by turbidity loading with respect to determining depth.

The method used to determine deep water pixels in the *casi* imagery was to recognize the decreasing slope from 675 nm to the minimum at 740 nm, and the assumption that a vegetation class did not exist in deep water. In general, the relative boundary of deep water was located where the infrared regions of the spectrum (band 9 or 10) increased beyond band 5 or 6. At the same time, a limiting magnitude of the spectra was imposed, derived from spectra that were extracted at the exploratory stage.

Geological Substrate

The final primary class to be discriminated was that of geological substrate, which existed where the previous two classes did not. Therefore any pixel that was not classed as vegetation or deep water was assumed to be a spectral function of above or below water surface geological material. The assumption used to develop this class was that if a pixel did not include vegetation or deep water, it must fall into the class of above water surface or shallow non-vegetated material.

2.5.2 Second Order Classification

The second order classification group encompassed the relative turbidity, depth and the bottom type (geological or vegetation) classes.

Turbidity

As mentioned in the previous section, deep water was the second primary class to be discriminated. Within this class relative turbidity could be determined. It should be noted that turbidity was not determined for shallow regions. This would require a large field project to obtain a solid understanding of the spectra of the substrate. This data would be needed to attempt an unmixing of water and substrate, and would require extensive effort. This relationship would be difficult to quantify due to the changes in particulate size from one section of the river or flow level to the next.

Turbidity was an important feature when determining fish habitat, as regions such as snyes and sloughs had lower turbidity levels than main channel regions. To calculate relative turbidity within deep water regions, shape signatures between 650 and 740 nm were used. It was found that increased turbidity overpowered any chlorophyll-a absorption at 675 nm (Dekker 1993), to the point of causing a slope inflection and maximum at 675 nm. The positively increasing slope between 650 and 675 nm normalized to 675 nm, and the negatively increasing slope between 675 and 705 nm was linked to increases in turbidity level.

Shallow Water

The most complex areas to analyse were shallow water regions, which existed from the deep water boundary to the above water surface, wet substrate boundary. The lower boundary of the shallow class was determined from the upper boundary of the deep water class. This left the most difficult boundary to locate, the dry/wet water boundary. A pixel could be mixed with a percentage of both above and below water surface spectra. It was assumed that the water level boundary was fuzzy with a ±2 pixel error, calculated by interactive analysis.

The water level boundary was calculated using a comparison of 551 and 800 nm along with the normalized slope changes of 705 and 741 nm to 705 nm. The first comparison attempted to account for the presence of subsurface vegetation. The second was associated with slope changes observed in subsurface geological substrate spectra. Depending on image quality or signal strength, a third infrared band was sometimes used to stabilize or add extra information to the algorithms.

Once the shallow class was determined, the presence of subsurface geological or vegetation substrate was calculated using Boolean mathematics. At this point a relative depth grading was determined between the water level boundary and the deep water boundary within the shallow class. Since only two relative depths were requested, from only the low flow imagery, the shallow class results were separated into two groups. Decreasing values of the shallow class were a function of increasing depth. This association was made assuming that at low level flows, when turbidity was at it's lowest, bottom effects from the substrate were much greater than optical effects caused by slight turbidity changes near shore.

2.5.3 Spatial Classification

Physical features or habitat regions in the imagery, such as shoals, riffles, upwelling areas, snyes, side channels, secondary and primary channels, were discriminated using interactive or manual interpretation and their relationship with second order classification results. No reliable automatic method or algorithm could be applied to successfully separate these features. This was due to the spectral similarity between different features and the variable physical shapes, even within a class.

All passive optical data were analysed using interactive methods. Regions were visually discerned and digitized. In the case of the *casi* imagery, the classification results were compiled within these regions to assist with the flow habitat analysis.

3.0 RESULTS AND DISCUSSION

3.1 Image Analysis

The image analysis of the *casi* data resulted in a series of different classes (Table 3). The image analysis was divided into two main categories; spectral classification and spatial classification. There were two sub-categories of spectral classification; primary and secondary classification.

Table 3. Classification outline for *casi* imagery, Peace River, 1994.

Class	High Flow	Med Flow	Low Flow	Comments
Primary Spectral Classification				
Water	Yes	Yes	Yes	All water in imagery, semi-automated
Vegetation	No	No	Yes	All vegetation in the imagery, semi-automated
Geological substrate	No	No	Yes	All non-vegetation / not deep water in the imagery, semi-automated
Secondary Spectral Classification				
Deep water	Yes	Yes	Yes	All water with no visible bottom effects, semi-automated
Shallow water	No	No	Yes	1st level below water surface substrate (very shallow), semi-automated
Medium water	No	No	Yes	2nd level below water surface substrate (deeper), semi-automated
Turbidity 1 (higher)	Yes	Yes	Yes	The highest turbidity (in deep water), semi-automated
Turbidity 2 (lower)	Yes	Yes	Yes	The lowest turbidity (in deep water), semi-automated
Subsurface vegetation	No	No	Yes	Subsurface vegetation (dependent on image quality), semi-automated
Mixed vegetation and geological substrate	No	No	Yes	Regions of mixed vegetation with substrate and/or water, semi-automated
Spatial Classification				
Riffle	Yes	Yes	Yes	Manually interpreted
Snye	Yes	Yes	Yes	Manually interpreted
Slough	Yes	Yes	Yes	Manually interpreted
Deep river	Yes	Yes	Yes	Manually interpreted
Primary channel	Yes	Yes	Yes	Manually interpreted
Secondary channel	Yes	Yes	Yes	Manually interpreted
Side channel	Yes	Yes	Yes	Manually Interpreted

3.1.1 Spectral Classification: Primary Classes

Vegetation

The presence of a chlorophyll-a well between the green and red section of the spectra, and the increasing infrared shoulder that is observed in all green vegetation, was a very accurate discriminating feature. It can be seen in Figure 6 that only pixels with these spectral characteristics contain some amount of vegetation in them. This accurate and automated discrimination process required more than three spectral channels positioned in specific wavelength regions to increase the confidence in the classification. This level of automation was only possible using *casi* imagery.

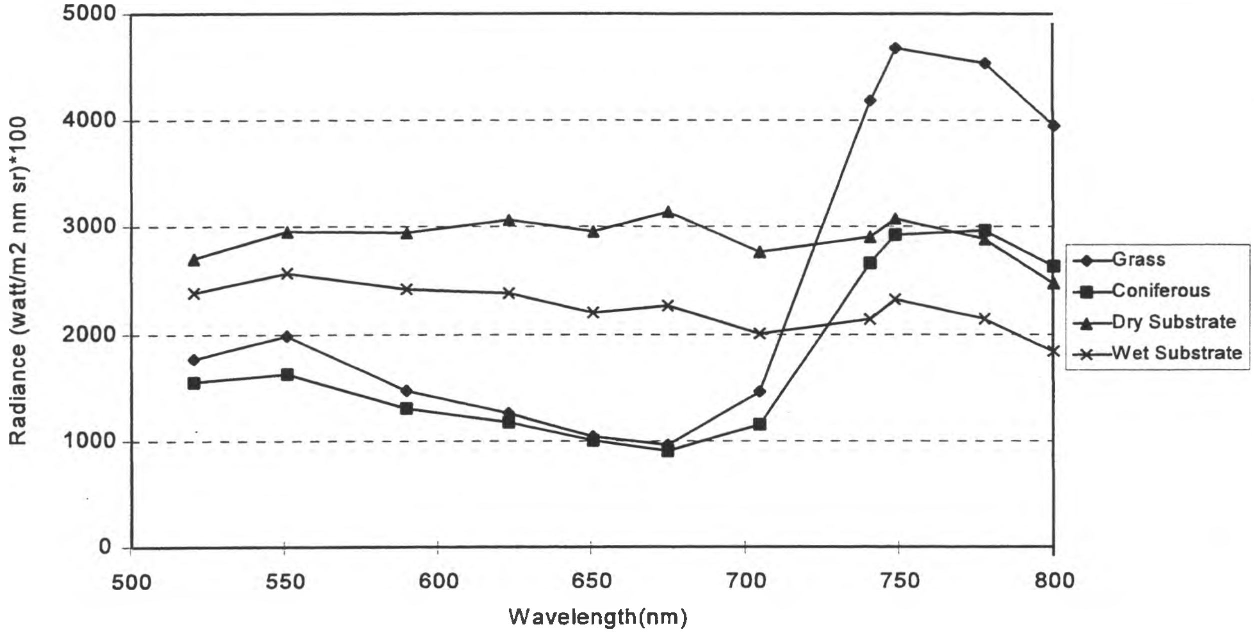


Figure 6. Spectral signatures of above water surface targets, Peace River, 1994.

Deep Water

Once pixels with vegetation within the image were discriminated, remaining pixels containing only deep water were determined. A deep water pixel was defined as a region covered by water where the bottom was not spectrally visible. This was a relative method of discrimination, since turbidity of the water medium plays a very large role in depth determination. All of the imaging systems used were affected by turbidity loading when determining depth. An example of *casi* deep water spectra can be seen in Figure 7.

The deep water analysis for the *casi* imagery was much more stable under varying conditions than the digital videography or aerial photography. The range of signals in the aerial photography was much lower and the analysis was reduced to determining the pixels with the lowest values caused by the strong absorption of infrared light by the water medium.

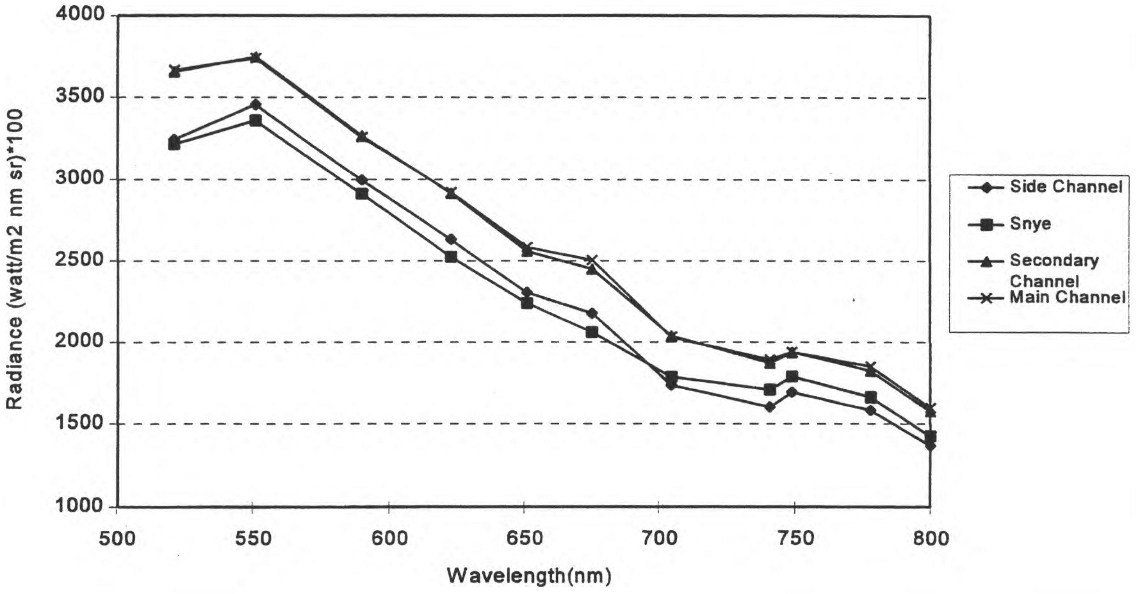


Figure 7. Deep water spectral signatures, Peace River study area, 1994.

Geological Substrate

The final primary class to be discriminated was geological substrate. Geological substrate existed where the previous two classes did not. An example of the spectral signature of a dry and wet geological surface from the Many Island region can be seen in Figure 6.

In order to separate pixels into finer classes such as different substrates (cobble, sand, gravel, or a mixture), dead vegetation or log jams and man-made targets, a detailed ground study would have to be performed. Spectral signatures, sizes, shapes and the type of local environment would have to be recorded. It is possible to develop algorithms that could discriminate these targets. It should be noted that a system such as the *casi* with programmable spectral band positions and high spectral/spatial resolution would be optimal for this application.

3.1.2 Spectral Classification: Secondary Classes

The secondary spectral classification was a refinement of the primary classification. This generated classes for shallow and medium depth water, two levels of relative turbidity and bottom type (geological or vegetation).

Turbidity

As mentioned in the previous section, deep water was the second primary class to be discriminated. For this class, relative turbidity was also derived. It should be noted that turbidity was not determined for shallow regions as this would have required intensive field work to develop the necessary understanding of the spectral substrate. The data would be needed to attempt an unmixing of water and substrate, and would require considerably longer analysis time than permitted by the project. It is also important to note that even with detailed ground data, turbidity analysis for shallow water areas would be difficult to quantify due to the varying turbidity level from one reach and flow level to the next.

Turbidity was an important feature for determining fish habitat, as key habitat features like snyes and sloughs generally had lower turbidity levels than the main channel. It was found that increased turbidity overpowered any chlorophyll-a absorption at 675 nm (Dekker 1993), to the point of causing a slope inflection and maximum at 675 nm. The positively increasing slope between 650 and 675 nm normalized to 675 nm, and the negatively increasing slope between 675 and 705 nm was linked to increases in turbidity level. This change is apparent in Figure 7, where spectra were obtained from different habitat regions and show an increasing order of relative turbidity: snye, slough, secondary channel, and main channel.

Shallow Water

The most complex areas to analyse were the shallow water regions, which existed from the boundary of the deep water to the land/water interface. The lower boundary of the shallow class was simply the upper boundary of the deep water class. The upper boundary was more difficult to determine. Because of the hydropeaking dam activity, the water level of the river was prone to rapid change. This meant that the shoreline fluctuated with dam activity, making a distinction between very shallow water and damp shoreline features difficult. In addition, each pixel represented 2.5 metres on the ground, meaning that any given pixel imaged at the shoreline could be a mixture of both above and below surface spectra. An example of just below water surface geological and vegetation substrate can be seen in Figure 8.

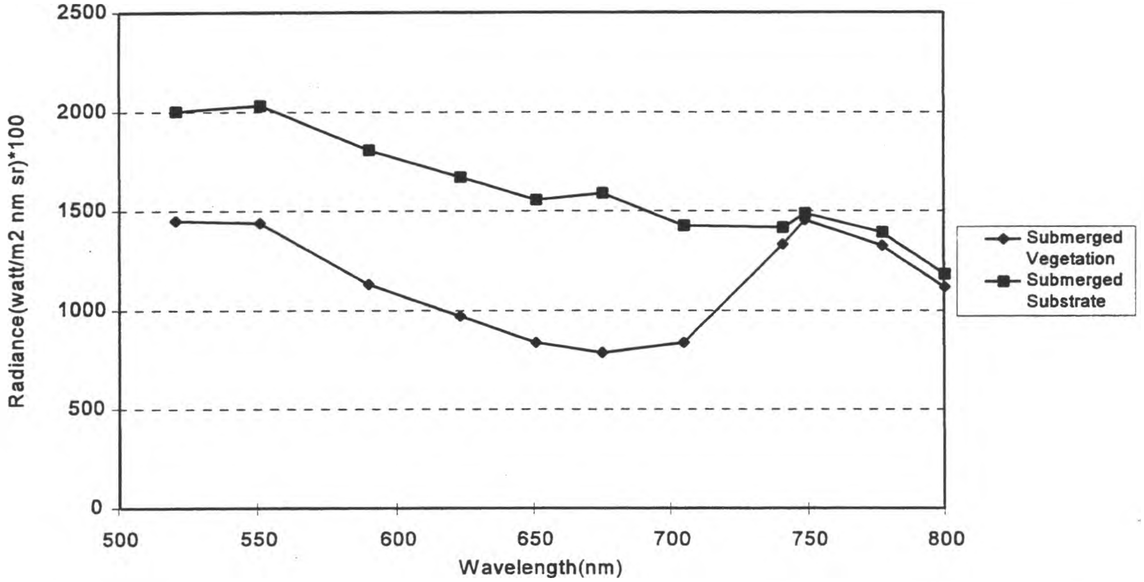


Figure 8. Below water surface spectral signatures, Peace River study area, 1994.

Bottom Type

Once the shallow water/shoreline boundary was determined, the presence of subsurface geological or vegetation substrate within the shallow water class was calculated using Boolean mathematics. This led to a relative depth grading within the shallow class. Two relative depths from within the low flow imagery were designated. Decreasing values of the shallow class corresponded with increasing depth. This association was made assuming that at low level flows, when turbidity and depth were generally at their lowest, bottom effects from the substrate were much greater than optical effects caused by slight turbidity changes near shore. An example of below-water-surface geological and vegetation substrate can be seen in Figure 8.

3.1.3 Spatial Classification: Physical Features/Habitats

Physical features or habitat regions in the imagery, such as riffles, upwelling areas, snyes, side channels, secondary and primary channels were discriminated using interactive or manual interpretation and their relationship to second order classification results. At present, no reliable automatic method or algorithm can be applied to successfully separate these features. This is due to the spectral similarity between different features and the physical shape differences that are seen within a class.

As noted earlier, all of the initial image analysis was applied on a spectral basis which, as expected, resulted in targets with different spatial shapes but similar spectral characteristics being classified as the same feature. As a result, a manual interpretation of the spectral classes was required to derive spatial classes.

Primary Channel

The primary channel habitat class was the most abundant habitat type in the Peace River study areas. The main channel was defined as the largest channel of the river. Typically, it is was moderate velocity and deep with high turbidity.

Secondary Channel

Secondary channels were large channels containing less than half the total width but greater than 10% of total width. These channels were smaller versions of the main channel and had similar characteristics.

Riffles

Riffles were high velocity areas in the main or secondary channels. They were also shallow with a visible bottom. We hoped to use surface glint to help delineate riffles, but the smoke in the atmosphere removed glint, precluding this approach.

Side Channels

Side channels were small channels less than 10% of the width of the primary channel. They were connected at the upstream and downstream end to primary or secondary channels. Consequently, there was flow through the side channels. Turbidity typically declined with distance from the upstream main channel. Side channels sometimes connected sloughs.

Snyes

Snyes were backwaters formed by shoreline irregularities. Generally they were associated with areas that were islands at higher flows. Snyes generally became part of side channels at higher flows or were flooded by the main channel when the associated island was flooded. Snyes were broadly connected to the main channel at one end only. Snyes had lower turbidities than the main channel to which they were connected.

Sloughs

Sloughs were areas of side channels that were ponded with no or very little inflow and outflow. Sloughs were typically very wide relative to any inflow or outflow and had very low turbidities.

Shoals

Shoals were extensive areas of shallow water that were islands at lower flows. We defined them as having areas exceeding 50x100 m.

Along-shore Backwaters

Along-shore backwaters were areas of low velocity in the primary and secondary channels as evidenced by low turbidity. These areas were quite variable, consisting of shallow inside bends of the river, small backwaters behind outwash fans from coulees and small tributaries, and any other low turbidity areas. These areas did not include snyes.

3.2 Habitat Analysis

The *casi* was used for the habitat analysis component of the study. The *casi* was flown at three different discharges to determine how habitat varied as a function of flow. The objective of this component of the study was to differentiate as many habitat classes as possible and determine how they related to flow.

3.2.1 Determining Discharge

Discharge or flow is fundamental to determining the habitat-flow relationship. However, determining flow, especially for the upstream reach, is not straight forward because of the influence of hydropeaking.

Upstream Reach

The upstream reach was subject to considerable daily flow fluctuations from hydropeaking at the W.A.C. Bennet dam. The result was that, at the B.C.-Alberta border, the minimum daily flow was only about 50% of the maximum daily flow on a typical day during the study period. Hydropeaking was generally reduced on weekends. It required about 2.5 to 3 days for the water to reach the Alces River monitoring station (approximately 5 km upstream of the B.C.-Alberta border) so low flows from weekends were observed the following week in Alberta (Figure 2).

Deriving the flows in each flight block during our sampling required that we determine the time of travel from the Alces River gauging station to the Dunvegan Bridge gauging station. We examined a two-day period for each of the three sample dates and determined the time of travel for both peak and low flows. The time of travel was variable, ranging from 17 to 21 hours with a mean of 17.8

hours for minimum daily flows and a mean of 18.7 hours for maximum daily flows. The overall mean was 18.3 hours. The variability may have been a function of the timing of dam releases and/or local weather events increasing or decreasing local runoff and thereby influencing timing of peak and minimum daily flows.

Another confounding factor was the fact that peak daily flows were reduced and minimum daily flows were augmented with distance downstream of the hydropeaking source. Thus the hydropeaking influence was gradually dampened with distance from the dam. Using the same data used to calculate time of travel, we found that minimum daily flows were increased 26% and maximum flows were decreased 4% from Alces River gauging station to the Dunvegan gauging station. The differences in the percentages were a result of some small rivers and creeks augmenting the flow of the Peace River. Therefore flows, especially low flows, had to be adjusted based on position in the maximum-minimum daily flow continuum and distance downstream of the Alces River gauging station. For example, a flow had to be adjusted for hydropeaking flow attenuation and tributary flow augmentation based on the discharge value and the estimated time of travel to each flight block from the Alces River gauging station. We assumed direct linear relationships for both of these adjustment criteria.

The flows derived from the Alces River gauging station and their adjusted equivalents are presented in Table 4.

Downstream Reach

Hydropeaking was assumed to be negligible for the downstream reach. Although we had no hourly gauging stations near the downstream study area, hydropeaking was greatly attenuated from Alces River gauging station to the Peace River townsite gauging station (Figure 2). The Peace River townsite was about half way between the Alces River and the beginning of our downstream study area so we expected that attenuation would continue and hydropeaking would be a minor factor in the downstream study area. Also, the lack of nearby hourly gauging station data, made it impossible to estimate what the flows were in the study reach with the detail required for tracking hydropeaking. The lack of gauging station data even made determining daily mean flows in the downstream reach problematic.

3.2.2 Habitat

This study was based on work being done in Utah (Anderson et al. 1993, Panja et al. 1993). This work used multispectral videography to determine meso-scale habitat features or meso-habitat. Examples of their habitat classification systems are:

- turbulent
- riffle
- shoal
- shallow
- intermediate
- deep

from Anderson et al. 1993

- turbulent
- run
- shoal
- sand

from Panja et al. 1993

Table 4. Travel time, Alces River flow and flows adjusted for time of travel and hydropeaking attenuation, upstream study area, Peace River, 1994.

Flight Block	Date Flown	Time Flown	River Travel Time	Corresponding Flow at Alces River	Adjusted Flows	Mean Flow
1	18/8/94	17:00-18:00	1-3 hours	1187 1117 1049	1200 1129 1056	1129
	20/8/94	14:40-15:50		1317 1268 1204	1320 1273 1208	1267
	17/10/94	12:47-13:50		1604 1616 1613	1575 1596 1603	1591
2	18/8/94	16:00-16:48	3-9 hours	1468 1409 1357 1305 1249 1187 1117	1430 1392 1355 1313 1263 1205 1135	1299
	20/8/94	18:10-19:10		1375 1373 1372 1364 1344 1317 1268	1367 1366 1366 1361 1344 1321 1275	1343
	17/10/94	13:55-14:50		1534 1554 1564 1570 1578 1591 1604	1473 1794 1508 1521 1535 1555 1575	1523
3	18/8/94	17:10-17:56	9-11 hours	739 870 1086	854 967 1145	989
	20/8/94	11:58-12:39		1360 1375 1373	1355 1366 1365	1362
	17/10/94	15:09-16:00		1534 1554 1564	1460 1479 1492	1477
4	18/8/94	18:00-18:30	11-13 hours	695 739 870	833 865 977	891
	20/8/94	12:50-13:30		1322 1360 1375	1332 1355 1365	1350
	17/10/94	16:00-16:30		1487 1534 1554	1423 1453 1471	1449

These classifications were mutually exclusive. For example, a shallow area could not be a riffle. These fairly simple classifications identified only major classes of habitat. The Peace River differed greatly from the study areas used by Anderson et al. (1993) and Panja et al. (1993). Their rivers were very small; <3 cms for Panja et al. (1993) and 23 cms for Anderson et al. (1993). This was compared to the Peace River which had flows in the 900-2200 cms range during our study. They worked with study reaches of only a few hundred metres while we used two study reaches of 100 km each. Consequently, the Peace River was expected to differ significantly in terms of meso-habitat types. The Peace River was also in a completely different geographic and climatic area, further increasing expected differences.

We derived a habitat classification based on habitat types that were discernable and habitat types that were found to be important in previous fisheries studies in the area. Briefly, our categories were:

- primary channel
- secondary channels
- riffles
- side channels
- snyes
- sloughs
- shoals
- along-shore backwaters

All of the above categories were mutually exclusive except for along-shore backwaters. An area of the river could only be categorized as one of the meso-habitat types. Along-shore backwaters were considered a component of primary and secondary channels. In addition to the meso-habitat types, we also classified the river into two depth categories - shallow and deep, and two turbidity categories - turbid and less turbid. These categories overlapped the classification presented above. For example, a primary channel would consist of shallow and deep areas. It would also have both turbid and less turbid areas. The less turbid areas of the primary and secondary channel were considered an important habitat type in their own right and were designated as along-shore backwaters.

Turbidity was an important indicator of habitat. Lower turbidity was associated with lower velocity areas. These included snyes, sloughs, along-shore backwaters, and side channels. Most of the area of the Peace River was primary channel habitat with little habitat diversity in terms of velocity. The primary and secondary channels were essentially run habitat at the flows we were sampling. Low turbidity indicated areas of habitat diversity and probably important low velocity rearing habitat. Originally, it was anticipated that we could use sun glint on the water to identify riffle areas. Unfortunately, the almost continuous smoke in the atmosphere during the data collection period severely limited any opportunities for using sun glint.

We used the classification proposed in the Terms of Reference for this project in only a general sense. We used the broad categories (e.g., run, riffle, shoal, backwater, snye, slough) but could not classify habitat to the level of subcategory (e.g., for runs). Also, because we were unable to accurately classify substrate, the bank categories could not be used. The categories we derived have quite different and distinct habitat characteristics in terms of depth, velocity and substrate. Although this is a coarse habitat classification dictated by the methodology, the categories will have very different use by the various species and lifestages of fish in the river. They also provide discrete types that can be feasibly sampled to determine preference and, in turn, predict habitat gains and losses. The habitat categories as presented in the Terms of Reference would be unworkable for determining habitat change with flow.

Depending on study objectives, classification of habitat can vary greatly in effort and cost. In this pilot study, we attempted to derive as much information as possible (within our financial constraints) from the image data. Consequently, we chose the *casi* because of its superior spectral capabilities. The *casi* could be used to derive substrate, depth and turbidity classes with a high degree of classification accuracy, but we would have to invest considerably more time in the field and all the imagery would have to be collected under suitable conditions. The costs for this type of study are considerable and greater than those allocated for this project. Also, the field study would have to be better planned. We had missed the two best months of the year for remote sensing by the time this project started.

An alternative approach is to work with a meso-habitat classification similar to the one derived for this project and not classify substrate, depth or turbidity using spectral analysis. This type of project would entail considerably less effort and cost. A combination of digital and manual classification methods would be used to analyse infrared aerial photography. The main digital use would be determining the extent of the water and perhaps delineating shallow areas at low flow. The digital images would be geocorrected and overlays could be used to determine depth categories at higher flows. Most of the meso-habitat categories would be derived from manual interpretation of the imagery (e.g., snyes, sloughs, secondary channels, side channels, riffles and shoals). Primary channels would be determined by subtracting the other meso-habitat categories from the total water area. Essentially, this is the approach eventually used to classify meso-habitat in this study. This approach would not be adequate for classifying substrate or turbidity. Clearly, an understanding of classification goals is essential for determining which approach is suitable.

3.2.3 Area

Fundamental to determining the habitat versus flow relationships was an accurate determination of both habitat area and flow. We were not always able to determine habitat areas to the level of accuracy required to detect trends. There were a number of reasons for this:

- The range of flows for which habitat was determined was very narrow, requiring high accuracy to detect habitat area differences. Even field-based methods like the IFIM recommend that the high flow be at least 10 times the low flow to provide a suitable data set for modelling. Our study time period from late July 1994 to early October 1994 limited the available flows for data collection. Consequently, the widest range of flows we sampled for any area was a high flow of about 1.5 times the low flow. All the flows we measured were moderate flows in the same range. Changes in area between the high and low flow were even smaller than the changes in flow, as the banks of the river were relatively steep at the flows we were sampling. Thus, an error in determining area of ±5% would be a large percentage of the change in area due to flow. The narrow range of flows would obscure relationships for all imaging systems.

- A significant portion of our imagery was collected under poor conditions. This was especially true of the October imagery. We were dually constrained by trying to achieve certain target flows and by the weather. This forced us to collect some imagery late in the day and late in the season with consequently long shadows and poor spectral data. The shadows of the valley often obscured the shoreline in these conditions, requiring manual digitizing of water's edge with resultant errors. Simply digitizing the edge with an error of one pixel would result in an error of almost 1% for most of the study area (2.5 m in a wetted width of 300-400 m) and errors in shadows could easily exceed 1 pixel. Generally poor image quality, in addition to the shadow effect, was also a problem for some of the imagery. Image quality would be a problem for all imaging systems.

- The *casi* was a push-broom imager which increases the complexity of geocorrection and georeferencing compared to frame imaging systems like video and photography.

Considerable effort was expended to remove positional errors, but error remained and exceeded the error in frame imagery, especially aerial photography.

- Stitching together multiple images introduced additional positional error. The extent of this error was unknown but was least for the aerial photography because it had the fewest images. It was moderate for the video and highest for the *casi* where multiple flight lines and many more images were required.

- Flows at which the imagery were taken were far from constant due to the effects of hydropeaking (Table 2). In flight Block B2 of the upstream reach, flows ranged from 1135 cms at the upstream end to 1430 cms at the downstream end of the block. Since the downstream end contained Many Islands while the upstream end was almost entirely primary channel, the total wetted area of the block was higher than expected based on a mean flow of 1299 cms. Clearly, these kinds of differences obscured relationships. This effect applied to all imaging systems and would be exaggerated with longer study reaches.

- There was error in determining flow at any given point in the study areas. This error increased with distance from gauging stations. Therefore the downstream study reach had the highest error in flow. We collected some flow data from a Water Survey gauging station that was not currently operating at Fort Vermillion. A measurement of the discharge was compared to the formerly used stage discharge curve on 24 August 1994. The discharge was 7% greater than the discharge derived from the curve. This was considered an acceptable error. Therefore, even at the gauging station, the error in determining flow was 7%. The error in determining flow for the imagery from the downstream reach was probably at least 10%.

  In the upstream reach, we had hourly discharge information from two gauging stations. However, hydropeaking in this section was severe, forcing us to make a number of assumptions and corrections to the gauging station data. The error in the upstream reach was probably at least 10%.

- Daily hydropeaking also affected primary and secondary channels differently from side channels. Side channels filled and drained slower than main channels. Because they were always lagging behind, they were relatively high at a low flow and low at a high flow at certain points on the hydropeaking cycle. We obtained some imagery exhibiting this characteristic.

The net result was that the habitat area versus flow relationship had a significant portion of unexplained variance contributed by the sources outlined above. Since the range of flows was so narrow, these sources of variance were important and obscured habitat-flow relationships. The relative importance of the various sources of error is unknown but errors in flow and errors in area determination would obscure the results to the extent we observed.

3.2.4 Habitat Area versus Flow

Clearly, meso-habitat area was a function of flow. At low flows, side channels disappeared. At high flows side channels increased in area and snyes disappeared. In a managed river like the Peace, changing the natural flow regime changes the distribution of meso-habitat types. Also, hydropeaking has a number of other effects on habitat (e.g., macrophyte growth, invertebrates) because conditions change on a daily basis.

As discussed in Section 3.1.3, there was error in our determination of the habitat area versus flow relationships. Consequently, our discussion focused on trends in habitat change with flow and ignored cases where results appeared to be obscured by error variance.

Primary Channel

Primary channel habitat was defined as the main channel of the river and was characterized as deep water with moderate velocities. Primary channels were essentially run habitat. The primary channel was determined by subtracting all the other meso-habitat types from the total water area. Primary channel habitat was the most common habitat type of all, making up an average of 87% of the upstream and 88% of the downstream study areas. From a fish habitat perspective, this habitat was unlikely to be limiting to any life stage.

Clearly, the area of primary channel should increase with increasing flow. However, examining the habitat versus flow graphs for primary channels revealed few trends (Figure 9). This was an example of two problems with the data. Firstly, the differences in area were small over the range of flows we sampled and secondly, errors were affecting our ability to measure the small differences. In Block B2 of the upstream reach, one of the most aberrant blocks, the low flow had the highest area of primary channel. Examining Table 2, we see that flows in this block ranged from 1135 to 1430 cms. The high flow occurred at the Many Islands end of the block where change in flow had the greatest impact on change in area. This variation in flow probably accounted for the higher area. Other errors discussed in Section 3.2.3 also affected the results in Figure 9.

Secondary Channel

Secondary channels were defined as large channels containing less than half but greater than 10% of the flow of the river. Secondary channels were also run habitats. Secondary channels were the second most abundant habitat type, averaging 8.5% of the upstream and 5% of the downstream study areas. Functionally, these areas were similar in habitat to the primary channels, with similar velocity and depth characteristics. Consequently, they were unlikely to be limiting habitat for any life stage.

As for primary channel, secondary channel should increase in area with increase in flow. Our curves were quite flat because of the narrow range of flows and an upward trend in area was difficult to discern (Figure 10). Once again, unexplained variance was obscuring any trends.

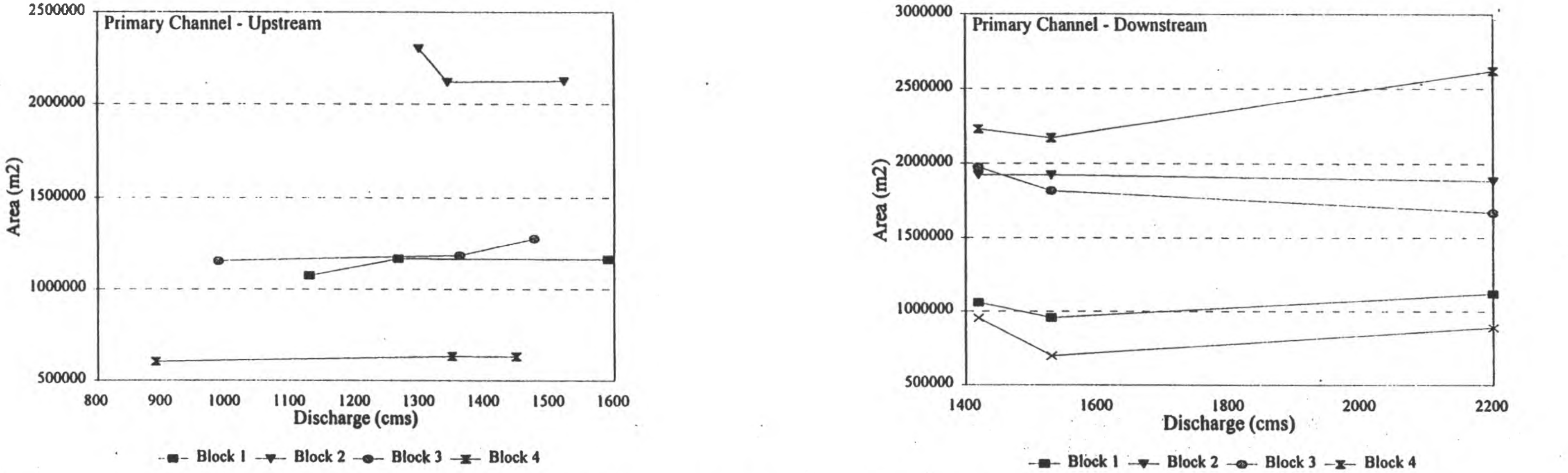


Figure 9. Relationship between discharge and habitat area for primary channel habitat in the upstream and downstream study reaches, Peace River, 1994.

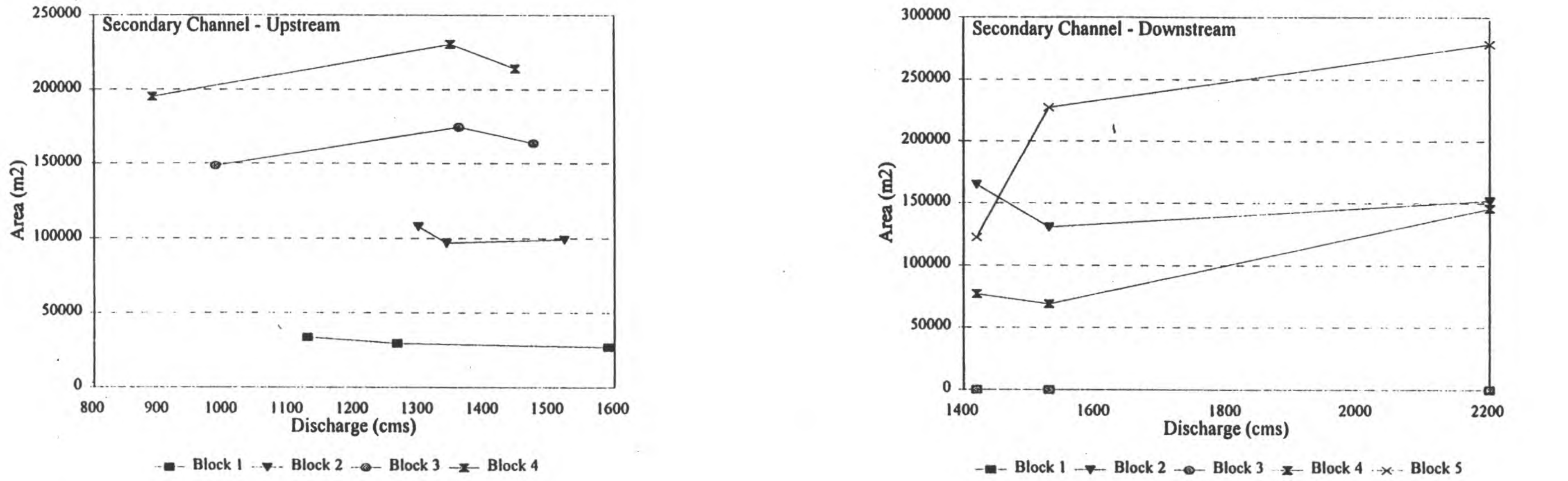


Figure 10. Relationship between discharge and habitat area for secondary channel habitat in the upstream and downstream study reaches, Peace River, 1994.

Riffle

Riffles were high velocity areas in primary or secondary channels that typically had coarser substrates. They were manually digitized from the imagery. Riffles were not expected to show any simple or consistent relationship with flow. As stage rises, some areas will be flooded and become riffles. In other areas, existing riffles may be flooded and become run habitat.

Riffles were a relatively rare habitat type in the Peace River study areas. They made up only 0.13% of the upstream and 0.02% of the average downstream habitat area. This rareness and the high suitability of riffles for spawning habitat for many fish may mean that riffles are limiting to some species.

From Figure 11, it can be seen that only two flight blocks, one in each study reach, had riffle habitat. Changes in habitat area as a function of flow were considerably greater than seen for primary and secondary channels. However, because of the sources of error, we can't be sure that these trends are real.

Side Channel

Side channels were less than 10% of the width of the primary channel. They were characterized as small streams in a larger channel that were mostly dry at the flow being sampled. Although sloughs also occurred in side channels, they were not included in the side channel area. Side channels were expected to increase with flow. Side channels were a moderately abundant habitat type, averaging 4.6% of upstream and 3.9% of downstream habitat.

Side channels are potentially a very important habitat type in the Peace River. They have lower depths and velocities, making them important for rearing habitat. They also exhibit a characteristic that may make them very important for mitigating the effects of hydropeaking. Side channels are narrowly connected to the main channel and typically lead to sloughs which have a considerable storage capacity relative to the size of the side channel at moderate flows. Consequently, the side channels are more stable habitat than the primary and secondary channels. We have found instances where the side channel was high when the primary channel was low and was low when the primary channel was high. This more stable habitat could be an important refugia for fish, especially for fry and juvenile life stages.

There was a general trend for side channels to increase in area with increasing discharge in the range of flows we sampled (Figure 12). This was best seen in the downstream study reach but the trend was not consistent. In the upstream study reach, the results were even less consistent, suggesting greater error. If we had a wider range of flows, it is expected that side channel habitat would be greatest at moderate flows as side channels would take on the characteristics of secondary channels at higher flows and would be dry at low flows.

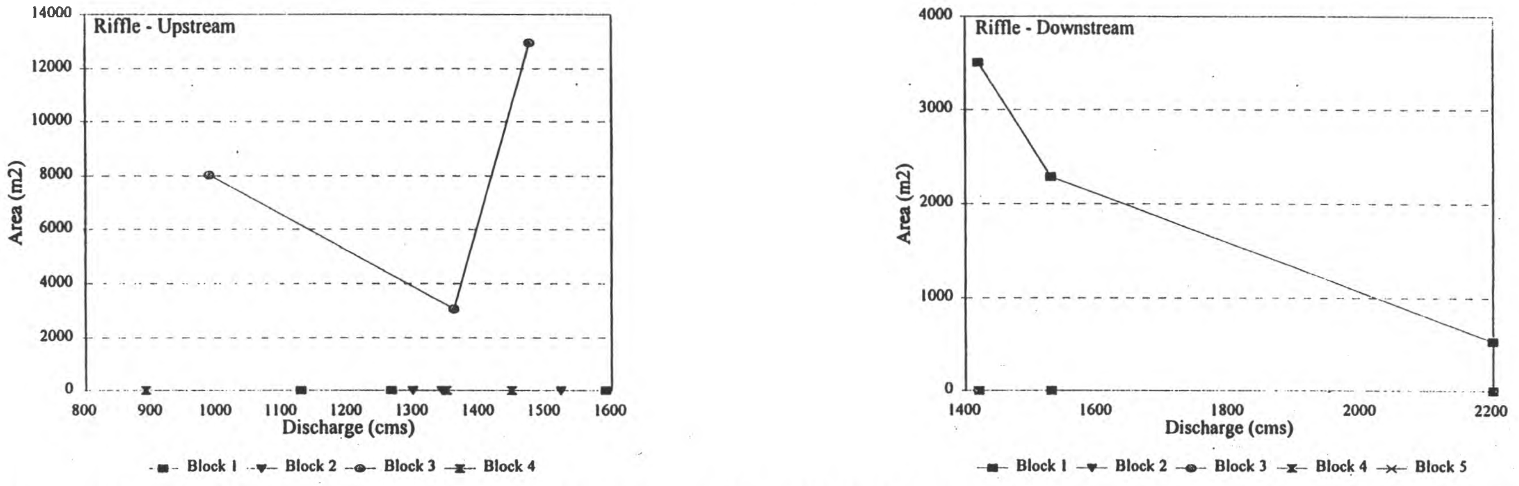


Figure 11. Relationship between discharge and habitat area for riffle habitat in the upstream and downstream study reaches, Peace River, 1994.

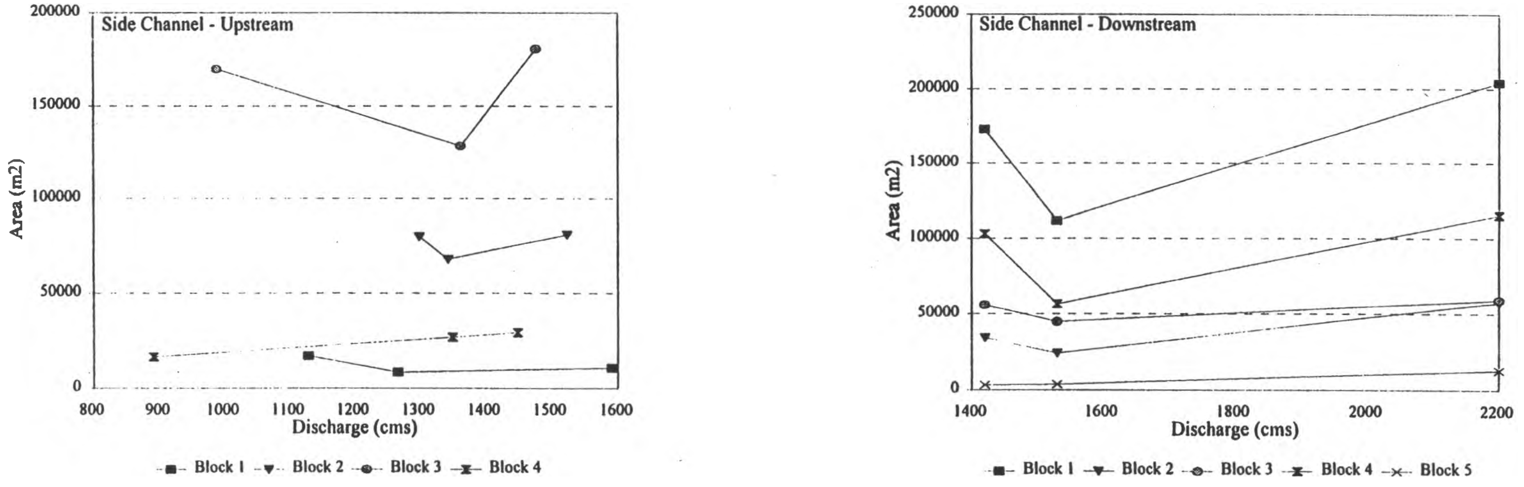


Figure 12. Relationship between discharge and habitat area for side channel habitat in the upstream and downstream study reaches, Peace River, 1994.

Snye
Snyes were large, deep backwaters formed by shoreline irregularities. The current in the primary or secondary channel bypassed the backwater resulting in a gentle back eddy that had low velocity and low turbidity compared to the higher velocity areas. Snyes were generally associated with side channels that were not flowing at the sampled flow. Any inflow or outflow was minor. Thus snyes were an intermediate stage in side channel hydraulic characteristics. They were formed at the stage between a dry and a flowing side channel. At low flows there will probably be more snyes. At moderate flows, as sampled for this study, snye response to flow is variable. At high flows, snyes will disappear.

Snyes made up a relatively small portion of the total habitat area, especially in the upstream reach. Snyes were an average of 0.13% of the upstream and 1.5% of the downstream habitat area. Snyes are probably important fish habitat as they provide deep, low velocity refugia for fish adjacent to primary and secondary channels. Since they are directly connected to the primary and secondary channels, they are equally prone to the influences of hydropeaking.

Overall, snyes appeared to follow a downward trend with flow although the results were variable (Figure 13). Once again, it was not known if the variations on the downward trend were real or if they were artifacts of the various error sources.

Sloughs
Sloughs were larger bodies of water in side channels. They were characterized as having very little inflow or outflow. They typically filled most of the width of a side channel that had little or no flow at the flow being sampled. They were generally shallow, pooled water with low turbidity and little or no velocity. As for snyes, sloughs were an intermediate stage in the inundation of side channels. They may be dry at very low flows, fill at moderate flows and become part of a secondary channel at high flows. Given a broad range of measured flows, they should show a unimodal relationship with flow, being highest at moderate flows. Once full, they may persist after water levels drop. They were the only aquatic habitat type in the Peace River commonly containing aquatic macrophytes.

Sloughs were much more common in the downstream reach (1.2%) compared to the upstream reach (0.005%) but they were relatively rare habitat overall. Sloughs may play a major role as rearing habitat, but they could also become a stranding trap for fish. The relative importance of the two potential results is unknown. Sloughs play a major role in stabilizing water levels in side channels which can benefit a variety of aquatic life.

Sloughs showed no consistent trend in area as a function of flow (Figure 14). Once again, it was impossible to determine if the relationships were real or if they were an artifact of the sources of error. Sloughs were very uncommon in the upstream reach compared to the downstream reach.

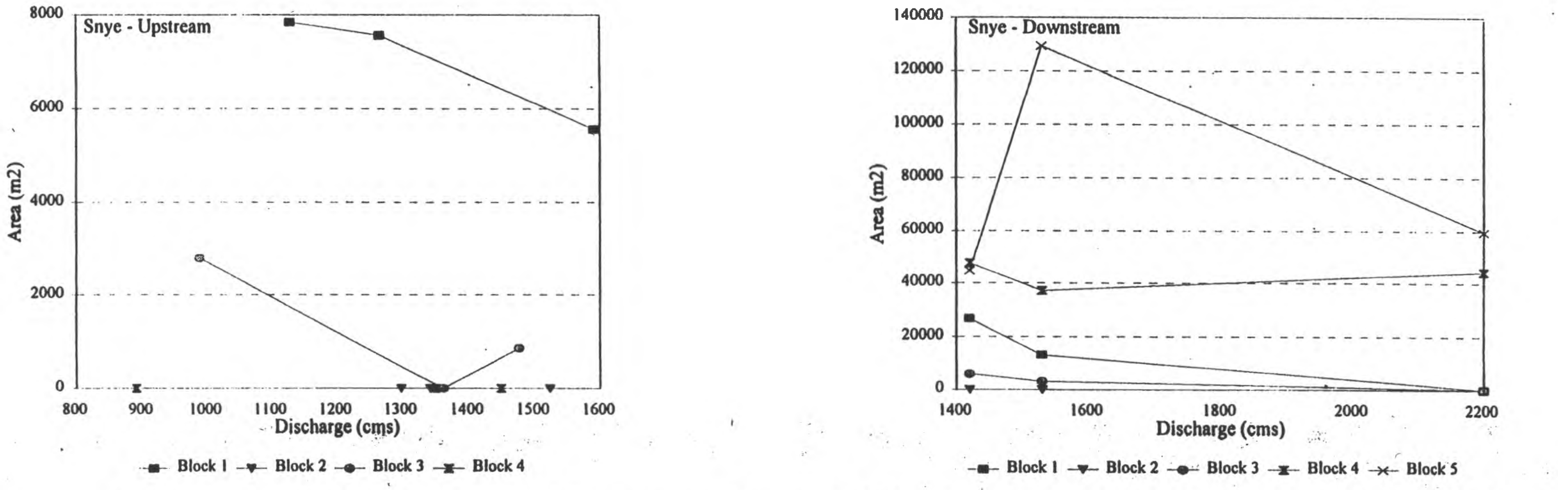


Figure 13. Relationship between discharge and habitat area for snye habitat in the upstream and downstream study reaches, Peace River, 1994.

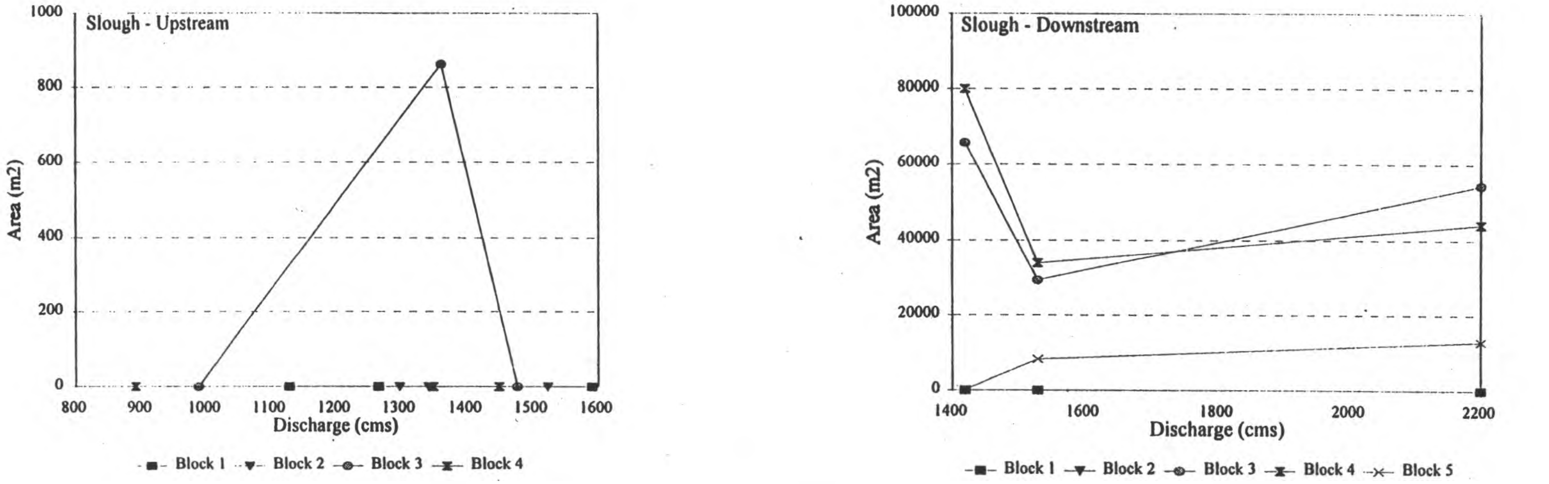


Figure 14. Relationship between discharge and habitat area for slough habitat in the upstream and downstream study reaches, Peace River, 1994.

Shoals

Shoals were extensive areas of shallow water. Typically, they were bars or parts of islands that were under water at the flow being sampled. Shoals may be important foraging and spawning areas under natural conditions, but hydropeaking probably strongly impacted their usefulness. Shoals were one of the rarest habitat types with 0.19% of upstream and 0.45% of downstream habitat being shoals.

Over a broad range of flows, it was expected that shoals would be most abundant at low to moderate flows and would decline with higher flows. In the upstream reach, shoals were variable in their response to flow (Figure 15). In the downstream reach, where more shoals were found, they showed a general decline in area with flow.

Along-Shore Backwaters

Along-shore backwaters were low turbidity areas in primary and secondary channels that did not include snyes. The low turbidity was an indicator of low velocity areas and these areas were commonly found in relation to minor shoreline irregularities such as small outwash fans from tributaries and inside bends of river meanders.

The low velocity nature of the backwaters in main channels where most of the area was higher velocity and deeper makes backwaters important fish habitat. However, backwaters were derived from areas classified as low turbidity. We discussed the problems with assessing turbidity in Section 3.2.2. To summarize, low turbidity classified at one flow was probably not the same thing as low turbidity at another flow because flow interacted with turbidity. Therefore, we were not sure if the graphs indicated real relationships or not (Figure 16). Considerably more ground truthing would have to be conducted before we could develop the relationships between flow, turbidity and along-shore backwater habitat.

Along-shore backwater habitat was a fairly large component of the total habitat area. It made up an average of 14% of the upstream and 12.6% of the downstream water area. This habitat type was actually a subset of the primary and secondary channels and the area was included in the areas for those habitat types. Backwaters may be an important habitat type for fish providing a low velocity refuge in main channels. There seemed to be a downward trend in backwater area with increasing flow, especially in the downstream reach. Intuitively, this appears to make sense as at higher flows, backwaters in primary and secondary channels would be reduced.

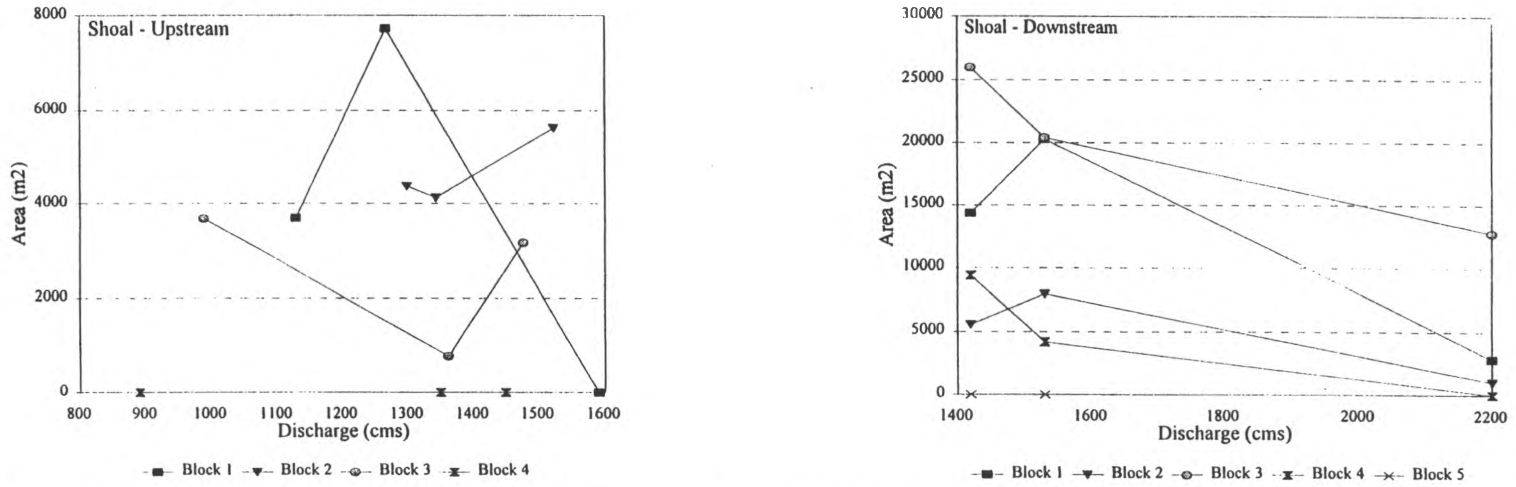


Figure 15. Relationship between discharge and habitat area for shoal habitat in the upstream and downstream study reaches, Peace River, 1994.

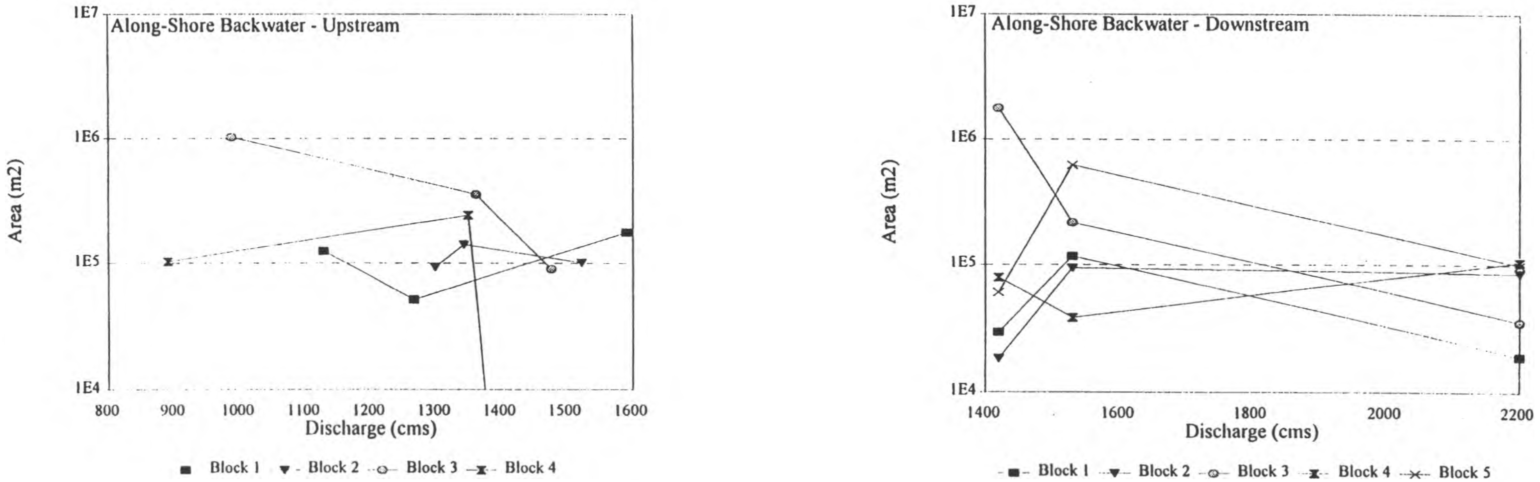


Figure 16. Relationship between discharge and habitat area for shoal habitat in the upstream and downstream study reaches, Peace River, 1994.

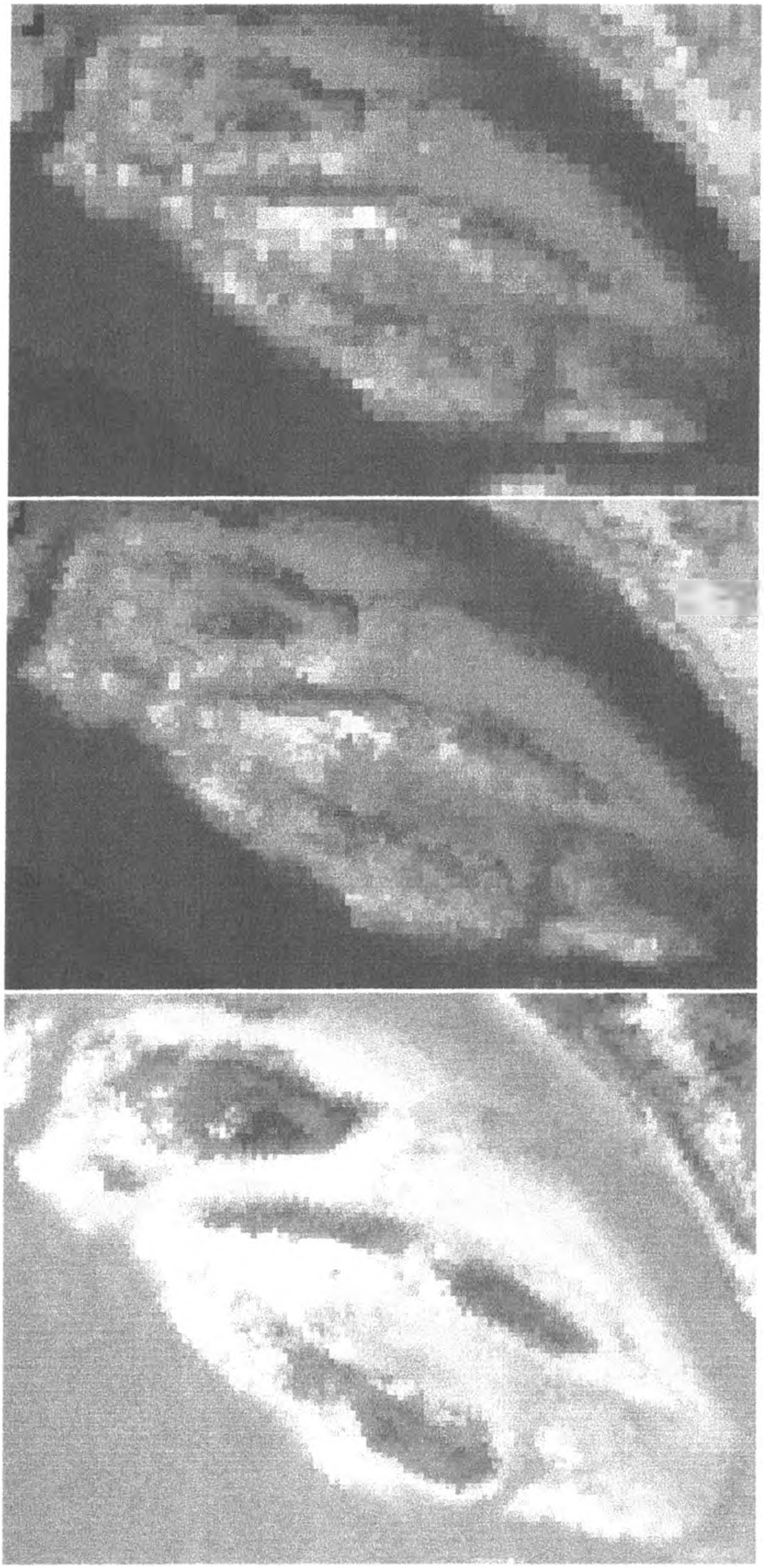
3.2.5 Effect of Pixel Size

The effect of pixel size was assessed to determine if smaller pixels provided better information or if larger pixels provided sufficient information compared to 2.5 m pixels used for the majority of this work. Pixel size was defined as the length (on the ground) of the area depicted by one cell of the imagery. The pixel size analysis was based on the *casi* data. Pixels of 1.0, 2.5 and 5.0 m were compared in the analysis (Figure 17). The 1.0 m pixel imagery examined was one flight line of the Many Islands area. Pixel sizes of 5.0 m were derived from the 2.5 m pixels by combining pixels using the pixel average values.

Pixel size had little effect on the meso-habitat classification in this study. The Peace River is a large river and meso-habitat features of interest are also quite large. A pixel size of 2.5 m was adequate for determining the habitat classification used in this study. A pixel size of 1 m provided no improvement in the ability to detect any of the habitat features. Most of the habitat features we classified measure greater than 1 ha in area and greater than 50 m in width. The exception would be shallow areas which were quite variable in size and tended to be narrower. The large size of the habitat features meant that 1 m pixels provided no advantage in discrimination. A pixel size of 1 m would result in the database increasing over 6 times in size. For the *casi* data this would mean the database for the study area would increase from about 30 gigabytes to 200 gigabytes. Similar increases would be seen for the other image platforms.

Larger pixels could have been used for this study. As discussed above, the large size of the meso-habitat features means that even 5 m pixels are generally adequate for the Peace River. The advantage of larger pixels is that doubling pixel diameter means the image files are ¼ as large requiring half as much processing. Also, half as many flight lines are required to collect the data. The disadvantage is that some resolution would be lost which might be useful, especially for side channels where features are smaller and much of the critical habitat is found. One advantage of aerial photography is that one can rescan the imagery at a higher resolution in the future if necessary (up to 0.5 m pixels because the 1:30 000 scale photography has an effective resolution of about 0.5 m). The maximum resolution of the video and *casi* systems is the maximum pixel resolution at which they are collected.

For the Peace River, a resolution of 2.5 m worked well and is recommended. However, on the considerably smaller rivers more typical of Alberta, the pixel size would have to be decreased accordingly. Deriving resolution from Panja et al. (1993), we find a resolution that gives about 150 pixels across a typical narrow run of the river was considered adequate. This corresponds well with a resolution of 2.5 m for the Peace River where runs are about 300-450 m wide in the upstream reach and 400-500 m wide in the downstream reach. A rule of thumb would be a resolution that requires about 150 pixels to span a typical narrow run on a river is suitable for that river.



5 m Resolution

2.5 m Resolution

1 m Resolution

Figure 17. A comparison of imagery with 1, 2.5, and 5 m pixel sizes, Peace River, 1994.

3.3 Imaging System Comparison

The second objective of this study was to compare several imaging systems and determine the pros and cons for each system for conducting a fisheries meso-habitat assessment. The imaging systems we used were:

- 1:30 000 scale colour aerial photography
- 1:30 000 scale color infrared aerial photography
- multispectral videography with 2.5 m pixels (approximately)
- compact airborne spectrographic imager (*casi*) with 2.5 m pixels (approximately)

3.3.1 Color Aerial Photography

Color aerial photography encompasses the wavelengths of light visible to the human eye (400-700 nm). The appearance of features in the photographs should be similar to the appearance of the features in the field. We expected this imaging system to work well for discriminating depths.

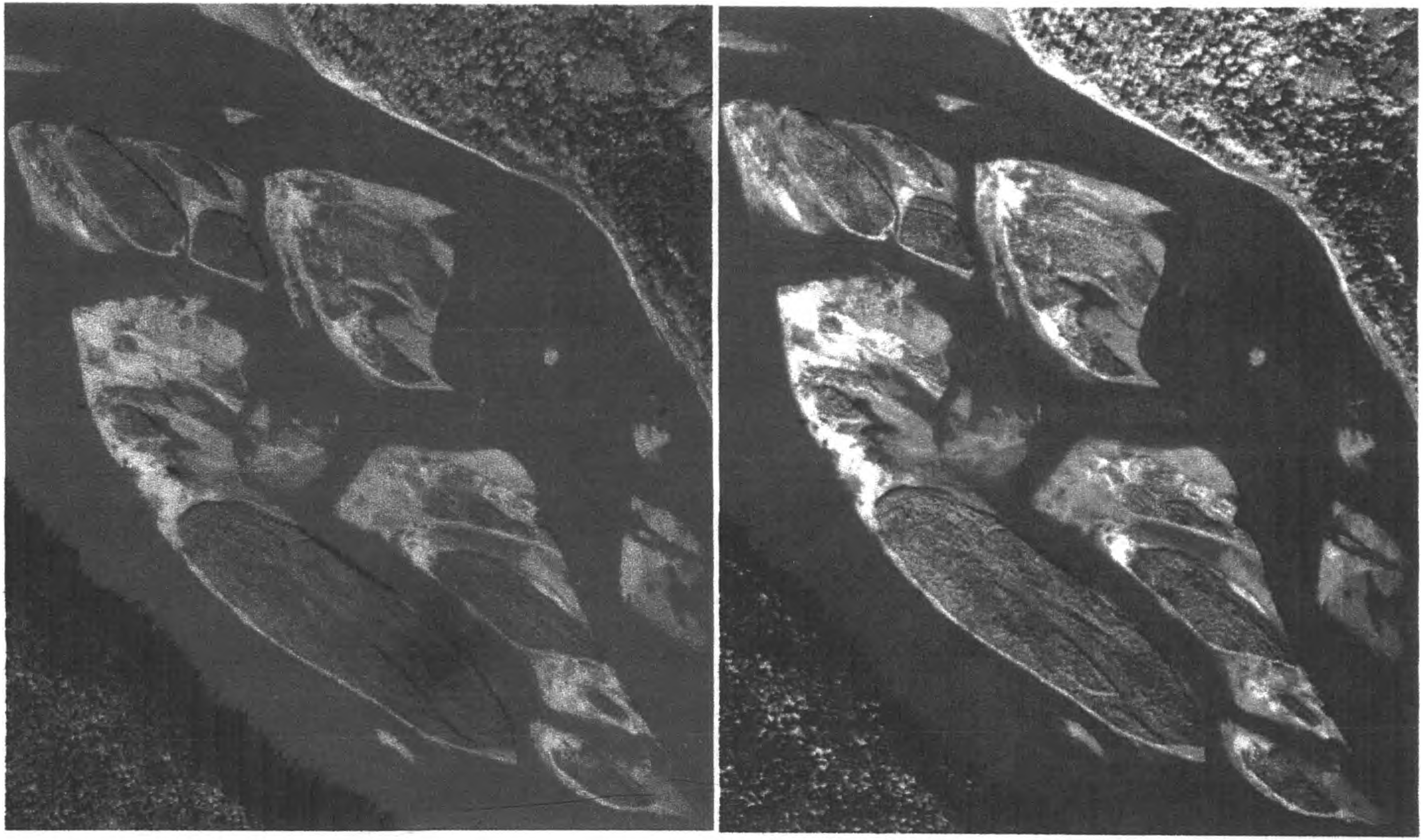
The performance of color photography was poor in our trial. There were two reasons for this result. Firstly, the color photographs were overexposed by the contractor (Geodesy Remote Sensing Inc. based in Calgary, AB). Therefore development of the imagery required that the negatives be underexposed. This resulted in a severe loss of contrast and reduced color saturation (Figure 18). There were also a number of artifacts of the photographic printing process such as halo effects and smearing. These problems made the color photography the poorest product in our study for assessing fish habitat.

Secondly, even if the color photography were properly exposed and developed, it would not be the best product for assessing fish habitat. It was very difficult to determine waters edge on the color photography. All of the other imaging systems extend into the infrared. The infrared is the best wavelength for determining waters edge as water strongly absorbs the infrared wavelengths of light.

Similarly, color photography was poor for discerning vegetation. For example, in some cases, vegetation features had reflectances similar to water (Figure 18). In terms of water penetration, our sample did not provide a good indication of the usefulness of color photography. However, colour infrared aerial photography provided good water penetration and was a better choice for other reasons outlined below. The inability to determine waters edge was a shortcoming of color photography that made it unsuitable for aquatic habitat studies.

3.3.2 Colour Infrared Aerial Photography

Colour infrared photography samples the wavelengths of light visible to the human eye as well as the near infrared spectrum (400-900 nm). A yellow filter is used to absorb blue wavelengths and colour infrared film is good at penetrating haze. The colour of features in the imagery are generally quite different from their appearance to the human eye. For example, healthy, green, deciduous or herbaceous vegetation appears red in colour infrared photographs.



Colour

Infrared

Figure 18. Colour and colour infrared aerial photography for part of the Many Islands area reproduced from a scanned image with a ground resolution of 2.5 m pixels, Peace River, 1994.

Infrared photography was collected under good conditions and the exposure and processing were much better than for colour photography. There were some problems with the imagery however. The colour balance was somewhat skewed to the blue and weak in the red end of the spectrum because the contractor did not use the correct filter to balance the colours in the imagery. The photographs were also dark around the edges because the contractor used a 6-inch camera lens. A 12-inch lens would have improved the imagery considerably. All of these problems are correctable and avoidable with a very specifically worded terms-of-reference for the contractors.

Colour infrared photography has many characteristics that make it excel for certain aquatic habitat applications. An advantage of the imagery is the ease of georeferencing due its frame imaging nature. The imagery can be easily georeferenced by scanning the images and using an image analysis package to resample the digital image. The digital image is mathematically warped to conform to control points determined using differential GPS (a survey accurate to <5 m using a global positioning system in the field). With the collection of 4-5 GPS control points per image, the digital images should be accurate to <10 m and areas would probably be accurate to <1%. This level of accuracy would be very good for assessing the change in habitat with flow.

Also, each image covers a relatively large area. At 1:30 000 scale, each image covers a ground area of about 6.8x6.8 km. This image size requires much less manipulation to mosaic and produces more accurate mosaics.

The colour infrared film also has very high resolution for a given scale of image. Each photograph was taken using 9 inch negatives to make contact prints at 1:30 000 scale. At 1:30 000 scale, the grain of the photographs limits resolution to about 0.5 m on the ground. Of course, 0.5 m pixels will result in an enormous database that would not be practical for our study area with current computer technology. It is estimated that this project would have produced several hundred gigabytes of information at that resolution. One of the advantages of aerial photography is that the imagery is collected at high resolution and available for later scanning at whatever resolution is appropriate.

In terms of cost, aerial photography was the least expensive method that was used. We were able to fly the imagery at 1:30 000 scale which allowed us to collect the imagery with a single flight line for each reach of river. Also the contractor could fly at a higher speed and collect the imagery with the least air time. The infrared aerial photography cost about $1,250 for film and processing and about $4,000 for flying time. Future studies should take more images to allow production of stereo pairs and avoid using imagery too close to the edge. Thus imagery costs would be about $2,500. Scanning and geocorrection would add about another $2,000 if the imagery were scanned at 2.5 m ground resolution. This results in a total cost of about $8,500 per flight for imagery. The other major cost of image acquisition is gathering differential GPS control points. This cost would be about $5,000 and would be lower than GPS costs for the other platforms. The GPS data would only be collected once for the project.

Water surface glint and sun angle affect all types of airborne imagery. For aquatic habitat differentiation, surface glint is both good and bad. Surface glint can highlight riffle areas, but it can also obscure subsurface features. Since aerial photography is flown at a relatively large scale, collecting overlapping images is inexpensive. Thus an image with glint and an image without glint could be obtained for the whole study area. Another advantage to photography related to obtaining overlapping images, is the ability to examine the study area in three dimensions using a stereoscope. This can greatly enhance the ability to interpret features in the imagery.

The infrared imagery can be scanned and converted from 24 bit colour to 3-band digital imagery using a variety of image analysis and image editing packages. The bands are 8-bit digital images of the red, green and blue colours in the image. The red roughly corresponds with the red and infrared portion of the spectrum, the green roughly corresponds with the green, and the blue roughly corresponds with the blue. The red portion of the image clearly delineates water as there is essentially no reflectance from the water in this band. The green and blue bands of the image penetrate the water surface well and it is possible to observe differences in turbidity and depth.

Splitting the imagery into three bands enhances interpretation of certain features. Converting the imagery to digital format permits the use of image analysis software like that used for videography and the *casi*. However, the lack of calibration of film and lens characteristics limits the applicability of image analysis techniques. Photography will not provide the discriminant power of *casi*. However, one important feature that can be captured using automated techniques is the extent of the water area.

In terms of conventional aerial photography interpretation, the interpretation of meso-habitat using colour infrared photography is a relatively simple exercise. Even differences in depth and turbidity are discernable (Figure 18) and can be used to help classify meso-habitat such as snyes using conventional interpretation techniques (tone, texture, shape, colour). For comparison, interpretation of forest stand type is a much more difficult, yet routinely practised, application of aerial photography.

There are also limitations of colour infrared photography. In terms of spectral resolution, colour infrared photography is the least capable of the three imaging systems. Therefore, the ability to discriminate features with very specific spectral signatures is quite limited. For example, it would not be possible to differentiate between substrate categories in any detail. In another example, colour infrared would not work well for correlating water quality parameters like turbidity with reflectance.

The high resolution and the relative low cost of collecting the photographic imagery makes colour infrared imagery a good choice for applications where the capabilities of the imagery are sufficient. For a study with the objective of differentiating meso-habitat to the level obtained in this study, colour infrared photography is the best choice. It is the least expensive method that can meet the requirements of this type of study and it has the best resolution capability for a given cost. For classifying turbidity, depth and substrate, photography is the poorest choice. There are many companies capable of collecting colour infrared imagery, but care must be taken when specifying contract requirements.

3.3.3 Multispectral Videography

The multispectral video system was configured with 3 monochrome CCD cameras, each fitted with a filter. The spectrum collected was controlled using the appropriate filters (Table 2). The cameras were mounted together in a frame that dropped into, and was fixed to, the aircraft camera port alongside the *casi* sensor head. The three images were composited to produce false colour images (Figure 19). The three images taken by separate cameras did not co-register exactly, but error would be minor with properly aligned cameras. New cameras have been developed that can record data for multiple spectral bands simultaneously (Snider et al. 1994) reducing this co-registration problem.

Operator access was provided during the flight in the event that the camera apertures required adjustment. Although the system was operated continuously, a user-programmable frame grabbing system was devised such that only necessary data were recorded. A monitor provided real-time assessment of the video data quality and allowed adjustments as required.

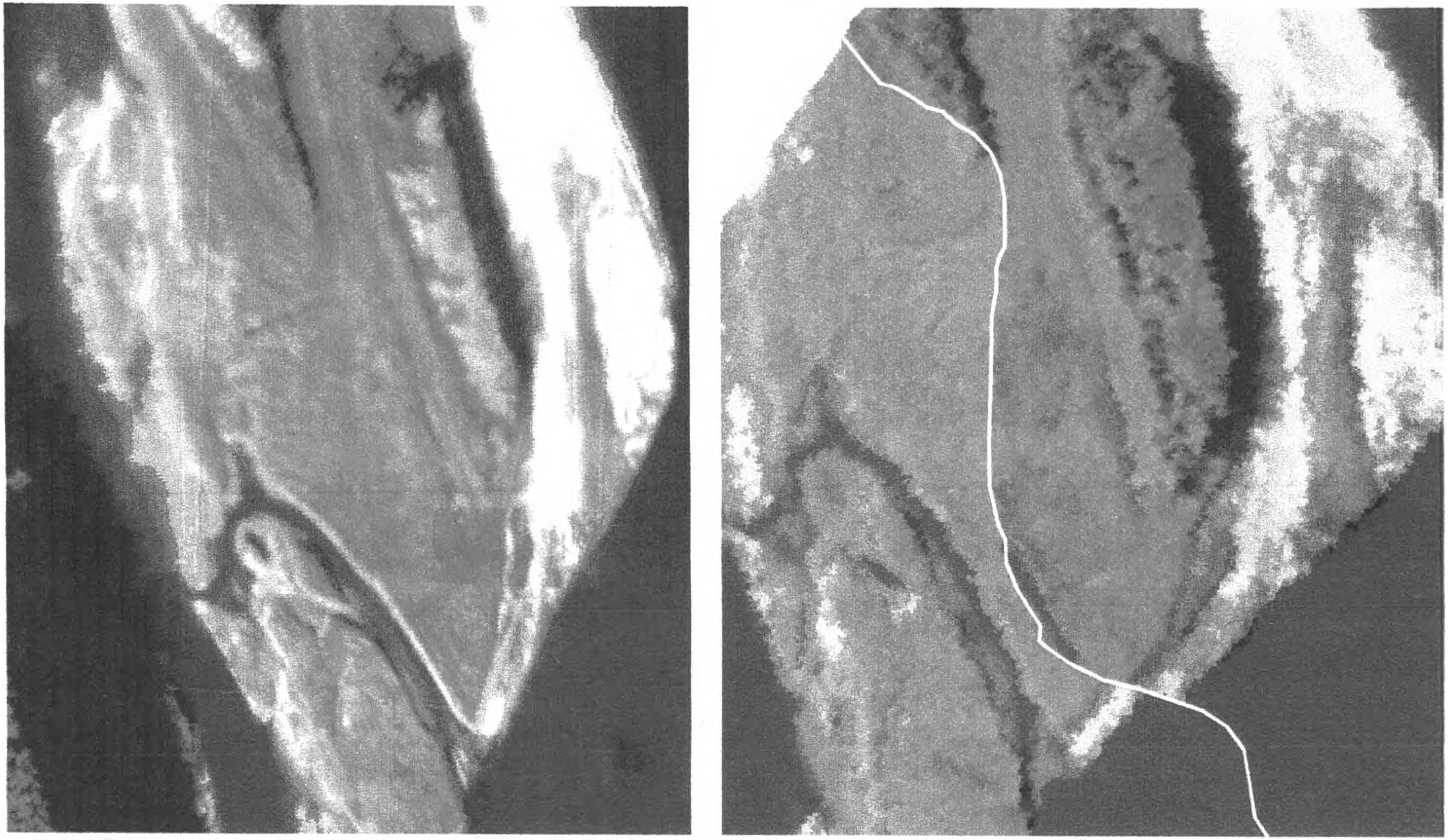
There was no automatic gain setting on this system which allowed for consistency in imaging, but resulted in some pixels being saturated while others suffered from a lack of signal. This was a direct result of the poor dynamic range inherent in the video system (effectively 6 bits). Radiometric correction of the video data was restricted to a normalization of the imagery using the imagery itself. Laboratory measurements of the system had been made in the event that they would be required for testing purposes later, but the nature of video systems made valid calibration is impossible

The spectral resolution of the video system was limited to 3 filters, one 50 nm wide, the others 10 nm wide. Unlike the casi, it was impossible to combine more than 3 channels in our system or to switch filters during flight.

Similar to colour aerial photography, georeferencing multispectral videography is a relatively simple exercise because of the two-dimensional nature of the imagery. However, a system of ground control points as described for aerial photography is required. Uncorrected distances can have an error as high as 15% (Panja et al. 1993) with corresponding errors in calculating areas.

One difficulty with videography is that, similar to the casi, images from 3-5 flight lines have to be stitched together to encompass the width of the river. Also, the numerous images that have to be stitched together each require 4 or 5 GPS locations to fully geocorrect the imagery. This would cost several times more than the cost for geocorrecting the aerial photography. The stitching together of so many images will lead to greater errors in determining area that would be intermediate between the *casi* and photography.

It is also possible to collect much smaller pixels compared to the *casi*. However, in a river the size of the Peace, we quickly run into data storage and data collection problems at small pixel sizes as explained for colour infrared photography. Also, like the *casi*, the video has to be flown at the maximum required resolution. This means that using pixels half as large requires twice as many flight lines and consequently, twice as many field days and twice the aircraft rental cost.



Multispectral Video

casi

Figure 19. False colour composite multispectral video and false colour composite of three bands of the *casi* imagery for part of the Many Islands area reproduced with a ground resolution of 2.5 m pixels, Peace River, 1994. Note the blurring of the video imagery caused primarily by misregistration of the 3 bands. The video mosaic has reasonable geometric fidelity. The difference in tones between different video images that were mosaicked together is evident. The split between two adjacent flight lines is highlighted on the *casi* imagery to illustrate the difficulty that the *casi* has with geocorrection. The tones in the two flight lines are very similar illustrating the *casi*'s strong radiometric correction capability.

Multispectral video is intermediate in cost between the colour infrared photography and the *casi*. Exact costs are hard to determine because suppliers vary greatly. The method requires specialized equipment that is available from relatively few sources in North America. Consequently, choice of supplier is limited and costs are fairly high. The total cost for flying is approximately equal to the *casi* ($10,000) because the video has a similar field of view in pixels requiring several lines to capture the width of flight blocks at 2.5 m resolution. Equipment rental costs are less than the *casi* ($2,000 per day), although quotes vary widely and some are more expensive than the *casi*. There are also additional costs for preprocessing that would exceed the scanning/georeferencing costs for the colour infrared photography but are not as high as the *casi*. At a pixel size of 2.5 m, video is estimated to cost about $20,000 per flight in our study area. Differential GPS data collection would be considerably higher than for the aerial photography. The video would only sample about 1/35th the area per image. Consequently, considerably more GPS control points are required. As for the *casi*, the video would have an on board GPS receiver stamping the imagery with location. Therefore, the field GPS data collection is reduced. GPS data collection would cost an additional $20 000.00 once during the project. As for photography, specifying contract requirements in the terms-of-reference is critical for ensuring that the imagery meets the goals of the project.

The digital nature of the multispectral videography makes it a suitable platform for assessing features like substrate and water quality parameters like total suspended solids. In this regard, it is better than colour infrared photography, but less capable than the *casi*. Deriving these types of relationships requires considerable field ground work as discussed for the *casi*. Replicate samples have to be taken of varying conditions to develop the relationships between reflectance and the parameters. This would add additional cost to the method.

Although the video data offers more spectral information than is available with the aerial photography, the usefulness of this feature is limited by the fact that, unlike the *casi*, the data cannot be radiometrically calibrated. This makes comparisons from one flight to another later in the year much less accurate. Therefore, the video would be useful for substrate categorization, a one-time data collection event. It would require a full ground-truthing effort on each flight for assessing changes in turbidity or other temporally variable targets, considerably increasing costs. In contrast, the *casi*, would only require a single major ground truthing effort for a multi-temporal study.

Multispectral videography would have been a suitable platform for determining a meso-habitat classification at the level developed for this project. Compared to colour infrared photography it would have been more expensive. It would have provided more spectral detail that could be used in discrimination of substrate, depth and turbidity. The low dynamic range and lower number of bits of data within a band are limitations that may affect the usefulness of video depending on the application. The lack of radiometric correction is also a problem for multi-temporal studies. For the classification developed for this study, low dynamic range was not a problem. It is likely that hardware developments will improve the dynamic range of video and thereby improve its usefulness for remote sensing.

3.3.4 Compact Airborne Spectrographic Imager (*casi*)

The compact airborne spectrographic imager (*casi*) is an airborne imaging spectrometer designed for deployment from light aircraft. Incorporating a 2 dimensional charge coupled device (CCD), the *casi* is capable of recording up to 512 spatial pixels per line, and up to 288 spectral channels within the spectral range of approximately 400 to 900 nm. Four modes of operation are possible, allowing the user to vary the number and width of the spectral channels as well as the number of spatial elements sampled.

The *casi* is a pushbroom scanner, meaning that the imagery is recorded line by line as the aircraft moves forward. For each image line that is recorded, the spatial information as well as the spectral information are recorded simultaneously. This results in data in with no opportunity for band-to-band misregistration. When imaging targets of a dynamic nature, such as rivers, this feature is especially significant, because it allows for true multispectral examination of the target area. When frame devices are used in the recording of multispectral imagery, simultaneous sampling is precluded and the possibility that the nature of the target will change between sampling intervals is likely. Another advantage in using pushbroom scanners is that the per-pixel integration time is typically much higher than that available with frame devices, meaning that it is possible to record data with a high dynamic range, and good quality imagery may be recorded under illumination conditions that may be inadequate for other imagers.

Because the *casi* is an airborne instrument and because it is a pushbroom scanner, the pixel sizes may be varied by changes in the ground speed and altitude of the aircraft as well as the amount of data recorded. While this is sometimes advantageous, it does limit the capability of the *casi* with respect to the generation of data with precise geometric fidelity (Figure 19). Changes in aircraft speed, position and altitude are reflected in the data itself and although geometric correction is possible through the use of simultaneously recorded gyroscope and GPS data, the accuracy of such corrections are typically ± 5 pixels.

In our study, the *casi* resulted in some loss of accuracy in determining areas. There are a number of potential reasons for the errors in area, many of which were independent of the imaging system, so the relative contribution of the *casi* geocorrection error is not known.

The *casi* was the most expensive imaging system we used. It cost $2,000.00 for each day of operation and with each data collection event requiring approximately 3 days of on-site time. This resulted in a cost of $6,000.00 for *casi* rental for each flow event. Because the sensor has a narrow spatial array (512 pixels across), it was necessary to fly multiple lines over each block of the river. This resulted in higher aircraft costs (about $10,000 per flight) than those required for the aerial photography. The most important *casi* cost resulting from the narrow spatial array, was the processing cost. As noted earlier, approximately 200 *casi* files were collected. Each of these files had to undergo all of the processing and analysis stages, costing approximately $14,000.00 for each flight. The total cost of the *casi* is about $30,000 per flight. As for the multispectral video, there would be a one time cost of $20,000 for the collection of differential GPS data for the project.

We derived turbidity and depth categories from the *casi* data. However, these data did not follow expected relationships. This was because turbidity directly influenced the ability to detect differences in depths. For example, if turbidity increased, then more of the river would appear to be deep. Although the *casi* is capable of considerable accuracy in discriminating between classes, the spectral signatures of the classes differ under different flow conditions. A spectral signature for low and high turbidity developed at one flow did not work at another flow. Similarly, a signature developed for shallow and deep water was not transferable between flows. Although signatures were developed independently for each flow, they were somewhat arbitrary and obvious trends were not apparent (e.g., higher area of turbid water at high flow compared to low flow). Considerable ground work is required to derive the relationships between flow, depth, turbidity and reflectance under different conditions. Spectral signatures must be derived in the field using a spectrometer or *casi* during image collection. This would add considerably to the cost of conducting a *casi* investigation. These comments are equally true if video were being used to classify depth and turbidity but video would have to conduct the field work for every flight.

For work where the ability to discriminate between features with very similar spectral signatures is necessary, the *casi* is the best imaging system. It is also the most expensive but this is directly related to the narrow spatial array. If future developments of the *casi* allow for a wider spatial array than currently available, this issue should be revisited. Also, if a study employs proper ground-truthing procedures for examining difficult spectral problems over multiple time periods, the *casi* may actually be less expensive than the video.

For work at the level of classification detail developed in this study, the *casi* is not the best choice due to the expense. Aerial photography is capable of this level of habitat discrimination and is much less expensive. The *casi* would have been capable of discriminating substrate type and the turbidity-depth relationship with better imagery and more ground truthing. In a study where substrate or other detailed data are required, the *casi* is the best choice.

Besides the multispectral capability of the *casi*, it is important to note that the *casi* can be accurately calibrated and the data corrected for both system and atmospheric influences. This makes the data especially useful for studies in which multi-temporal information is required.

3.3.5 Summary

To develop a meso-habitat classification like the one developed for this project, colour infrared aerial photography is the best choice. Multispectral videography and the *casi* would do equally well, but both methods are considerably more expensive. Even though the *casi* imagery was used, the meso-habitat types were essentially derived using conventional aerial photography interpretation techniques (shape, tone, texture, colour). Water's edge, depth and turbidity were derived using digital image analysis techniques. However, the calculated areas were unreliable because the flow, turbidity and ability to perceive depth all interacted as described above. The aerial photography is also the easiest image type to georeference, ensuring that areas are accurate. This capability also allows us to overlay images and determine areas. The *casi* was not georeferenced with the accuracy to allow meaningful overlay operations.

We originally wanted to classify substrate type in the dry and near-shore areas at low flow. Unfortunately, we had a limited timing window which prevented us from obtaining the imagery we wanted. Essentially, we had a low probability of suitable weather conditions (smoke was also a problem) on any given day compounded by a low probability of having a suitable flow. We also did not start the project until the end of July 1994 which meant we missed the best two months of the year for remote sensing. As a result of these constraints, we were forced to collect some of the imagery under relatively poor conditions. This meant that some of our data were not good enough to discriminate substrate types. However, the *casi* is a suitable instrument for assessing substrate types when the imagery is collected under good conditions. Neither multispectral videography nor colour infrared aerial photography were as capable as the *casi* for this purpose.

The overall capabilities of the three systems are summarized in Table 5. Colour infrared aerial photography is best where cost, high resolution and high positional accuracy are important and features are discernable using conventional aerial photographic analysis techniques. Simple features such as extent of water can be classified using image analysis of the digital images. The *casi* is best for difficult discrimination problems and for correlating reflectance with field parameters such as total suspended solids. However, it has the poorest georeferencing capabilities of the three systems. The multispectral videography is intermediate in capabilities between the *casi* and aerial photography. The *casi* will always be better at discriminating between objects that are difficult to separate based on their spectra, but where the video works and colour infrared aerial photography doesn't, video will be a cost-effective alternative to the *casi*. The video is a better platform than the *casi* and poorer than the photography for producing georeferenced data. Clearly, the best tool for future work is the least complex and least expensive imaging system that will achieve the study objectives.

An important consideration for this type of study is the requirements for data such as turbidity, depth and substrate type. Very detailed information can be derived using image analysis and extensive ground truthing, especially with the *casi*. However, accurately determining this information will greatly increase the costs presented in Table 4. Additional costs (which apply to both video and the *casi*) include detailed ground truthing and more sophisticated and time-consuming image analysis. Color infrared photography is not suitable for this type of work and the video is less capable than the *casi*. The requirements of the project have to be carefully considered to ensure that the correct imaging system is implemented.

Table 5. A comparison of the features of the three acceptable imaging systems for collecting image data for this study (costs include everything but ground truthing and image processing).

Imaging System	Cost per Flight for this Study	Georeferencing	Spectral Resolution	Spatial Resolution
Colour Infrared Aerial Photography	$6,750.00	Inexpensive and highest accuracy due to frame image sampling	maximum 3 bands no control of band width or location	0.5 m at 1:30,000 single pass to capture width of study area
Multispectral Video	$20,000.00	Inexpensive and medium accuracy due to frame image sampling but large number of images increases costs relative to photography	generally 3 bands some control of band width and location	2.5 m requires multiple passes to capture width of study area
casi	$30,000.00	Expensive and lowest accuracy due to pushbroom image sampling	up to 256 bands complete control of width and location	2.5 m requires multiple passes to capture width of study area

4.0 CONCLUSIONS

This was a pilot project, and as such we indulged in considerable experimentation to try and push the limits of what we were able to determine. Most of the effort in this study was spent trying to derive habitat classes from the *casi* imagery. In many cases we were unsuccessful, but we were generally able to determine what would be required for success and make suitable recommendations. Clearly, deriving a habitat classification similar to that which we developed could be done for considerably less money than was spent on this project. However, that was only one of our study objectives.

There were three main objectives of this study:

- assess the feasibility of classifying meso-habitat using remote sensing
- determine a habitat versus flow relationship for the Peace River study reaches, extracting as much information as possible from the imagery
- evaluate a variety of imaging systems to determine strengths and weaknesses for assessing change in meso-habitat with change in flow

The first objective, an assessment of using remote sensing to track changes in meso-habitat showed that remote sensing is capable of tracking meso-habitat change. The Peace River is such a large river and flows are changing so rapidly due to hydropeaking, that remote sensing is probably the only feasible method of tracking change in meso-habitat with flow. To derive a realistic understanding of change in meso-habitat with flow, large reaches of river containing numerous examples of each habitat type must be sampled. Sampling these large reaches in any other manner is not realistic.

The second objective of determining a habitat area versus flow relationship was not entirely successful in this study. Deriving this relationship requires sampling over a wider range of flows than were available during this study. However, the most important problem is accurately determining flow when the imagery is taken. Flow gauging stations are widely separated on the Peace River and do not provide sufficient data, even for the upstream study reach. At a minimum, stage-discharge relationships should be determined for the upstream, downstream and approximate centre of each study reach. Then, during each sampling period, stage should be monitored hourly for one day before image sampling, during image sampling, and for one day after sampling at each of the three sites. This would provide sufficient data for interpolating flow reasonably accurately for any given place and time for the study area during the imaging. In the absence of hydropeaking, flow gauging requirements could be reduced to fewer sampling sites and less frequent samples. How much sampling is required is a function of the diurnal variability of the expected flows.

Another factor preventing a good understanding of the habitat-flow relationship was the narrow range of flows we were able to sample. Deriving a relationship to model change in habitat with, and without, flow management on the Peace requires a much broader range of sampled flows. The flows from this study would only allow modelling over a very narrow range of flow values because the results should not be extrapolated much outside the measured flow range. The meso-habitat versus flow relationships are not based on any theoretical relationships and have to be derived empirically.

There are several requirements that must be met before the impacts of flow regulation on the Peace on fish can be determined:

- meso-habitat areas over a more complete range of flows.
- an assessment of the importance of each meso-habitat class to fish. This would be some kind of preference curve that could be developed using catch-per-unit-effort or radiotelemetry for target species and lifestages.
- naturalized and recorded hydrographs.

This information would allow a fisheries biologist to determine how flow regulation has affected fish in the Peace River using a modelling approach similar to that used for IFIM studies. Some standardized procedures have been developed for this type of analysis in Alberta and they could be applied to the meso-habitat data as well.

The final objective was an assessment of four imaging systems to determine which was best for meso-habitat analysis. This component of the study revealed that three of the four imaging systems were capable of meso-habitat discrimination. The choice of which system was best was a function of the objectives of the study. If the study objective was the determination of meso-habitat classes such as derived in this study (primary channel, secondary channel, riffle, side channel, snye, slough, shoal) then infrared aerial photography was the best choice as it was the least expensive system capable of discriminating these habitat features. Airphotos were also be capable of some depth discrimination. Airphotos were the easiest system to georeference and therefore are a good choice if the data are to be incorporated into a GIS. If a study is concerned with deriving detailed substrate, depth and turbidity classifications, then the *casi* is the best choice. It is also the most expensive system of all those used in this study and has the least accurate georeferencing capabilities. Multispectral video will also be capable of some level of substrate, depth and turbidity classification, but it will be almost as expensive as the *casi* and will have less spectral resolution. In multi-temporal studies it may be more expensive than the *casi* because it will require much more extensive ground-truthing. However, it does have better georeferencing capabilities. Georeferencing is only a critical consideration if a study objective is the production of a GIS database. Simply determining the habitat area versus flow relationships does not require a high level of georeferencing.

There are a number of other imaging systems that can be used for mapping meso-habitat. However, they correspond with the imaging systems used in this study. There are at least two other push-broom type scanners produced in North America by Daedalus Enterprises Inc. and Geophysical and Environmental Research Corp. (Meredith 1995). They share the strengths and weaknesses of the *casi* platform. There are a number of digital cameras which are frame imaging systems like the multispectral video. Also, the video is becoming more sophisticated as an airborne imaging system, incorporating better control of sampled wavelengths, better co-registration of cameras and more sophisticated radiometric correction. Companies involved in digital camera systems include Eastman Kodak Co., and Positive Systems Inc. Video systems are still generally custom setups independently developed by each researcher or company.

One of the important lessons from this pilot project was the requirement that these types of studies be properly implemented. We missed the best two months of the year for remote sensing by the time this study began. These were also months where a wider range of flows could be sampled. Also, August was a difficult month to sample because whenever the weather was good, we were plagued by smoke haze from forest fires. Consequently, we were forced to collect imagery under poor conditions and the range of flows was inadequate. Given the weather requirements for good imagery, studies like this should start in April to allow time for mobilization and to ensure that quality imagery is obtained. Achieving the dual coincidence of good weather and target flows on the same day requires a longer time line to achieve than many other applications of remote sensing. Consequently, a two-year sampling window may be required to obtain data without having to compromise on weather conditions (image quality) or target flows.

5.0 MESO-HABITAT STUDY RECOMMENDATIONS

From a meso-habitat mapping perspective similar to that produced for this study and that practised by Anderson et al. (1993) and Panja et al. (1993), we recommend using infrared aerial photography as the imaging system. The implementation of a project should be as follows:

1) The study should begin in April to allow time to mobilize and capture a low flow event prior to the spring freshet. Daily (and hourly if hydropeaking occurs) flow regimes for at least the past 5 years should be examined to identify windows of opportunity for capturing target flows. The objective is to image the widest range of flows possible during the open water season.

2) The aerial photography should use color infrared film. The choice of scale is a function of the size of the river being sampled. A scale of 1:30 000 is good for rivers down to about 100 to 150 m wide on a typical narrow run. Care must be taken with the procurement of a contractor to fly the imagery. The contractor must have the capability to determine and use the appropriate filters to color balance the imagery. They must also use a 12-inch camera lens. They should have a stable platform to avoid image degradation due to movement of the platform. Overlapping images should be taken to provide stereo pairs (60% endlap), allow use of near-nadir portions of the imagery and perhaps allow the use of sun glint to classify riffles.

3) Each image should have at least 4 differentially-corrected GPS locations developed by a ground crew. The GPS locations should correspond with features that can be accurately located on the imagery at any flow (e.g., crossroads, bridge abutments, section corners).

4) At least 3 flows should be imaged. This will include a very low flow, a medium flow and a very high flow. The high flow should be at least 3 to 4 times the discharge of the low flow. The study is constrained by the weather and flows in the year of the study. That is why the study must begin early enough to allow sampling at any time during the whole open-water season. Alternatively, the study could occur over multiple years.

5) If hydropeaking is a concern (e.g., the Peace River) then a stage-discharge relationship should be developed for the upstream boundary, downstream boundary and centre of each river reach being sampled. Hourly stage readings should be taken the day before, during, and the day after image sampling at each site. This will allow the researcher to determine the flow for any image. If hydropeaking is not a concern, then only the upstream and downstream sites are required. Stage readings need only be taken twice a day for the day before, during and after image sampling.

6) The imagery should be scanned at 24 bits at an appropriate resolution. We recommend a ground resolution that provides about 150 pixels for a typical narrow run for the main channel.

7) The low flow imagery will be interpreted using image classification software to determine the total water area. Image classification software will be used to identify any substrate visible through the water which will be designated as shallow water. The difference between the moderate flow and the low flow wetted area will be designated the next depth level. The difference between the high flow and the medium flow wetted area will be the shallowest depth level. This overlay operation requires a high degree of positional accuracy, necessitating the differential GPS field work.

   The remaining image analysis will be manual delineation of side channels, secondary channels, snyes, sloughs, riffles and shoals. Primary channels will be the remaining wetted area. This analysis must be done for each of the three flows.

8) Habitat use must be determined for each habitat type for each species-lifestage of interest. This requires an unbiased method of sampling fish habitat use which is a difficult problem on large rivers like the Peace River. The sampling method(s) must not be more efficient in one habitat type than in another. An alternative for large rivers is to ignore the main channel habitat, on the assumption that main channel habitat will never be limiting. The other habitat types are much easier to sample.

9) Determine habitat preference using the habitat use and habitat availability information and standard techniques developed for IFIM studies in Alberta.

10) Determine weighted usable area for several flows. This will be determined using habitat area availability interpolated from the habitat flow relationship multiplied by the habitat preference rating for each habitat type. The values are summed for all habitats to provide a weighted usable area for each of the several flows for each species-lifestage.

11) Determine a composite fish weighted usable area versus flow relationship.

12) Compare the naturalized and recorded, or naturalized and proposed, scenario curves for the period of record (for which flows are available) to determine how well the recorded or scenario flows compare to what would occur naturally. Again, this "fish rule curve" technique has been standardized for Alberta.

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NORTHERN RIVER BASINS STUDY

APPENDIX A - TERMS OF REFERENCE

Project 4131-D1: AQUATIC HABITAT MAPPING FOR INSTREAM FLOW NEEDS ANALYSIS - Peace River Pilot Project

I. BACKGROUND & OBJECTIVES

A description of instream flow needs (IFN) for fisheries, and for environmental protection in general, is needed primarily to address one of the 16 questions that have been formulated by the Northern River Basins Study (NRBS) Board to guide the study. This is Question #10; "how has and how could river flow regulation impact the aquatic ecosystem?". Instream flow needs studies will also address parts of three other Study Board questions. One of these (Question #3) asks, in part, about the non-consumptive uses of water. The development of models and/or analytical approaches for estimating instream flow needs and for evaluating effects of different flow regimes will also address parts of questions 13 and 14, which relate to predictive tools, cumulative effects assessments, and ecosystem condition assessment.

Analyses of instream flow needs for aquatic habitats have usually been based on micro-habitat requirements (i.e., depth, velocity, substrate) of selected fish species. However, accurate information on the relative suitability of various combinations of these micro-habitat characteristics for different fish species and life stages is often difficult and expensive to obtain. In addition, attempts to develop instream flow recommendations based on micro-habitat conditions are greatly complicated by the need to consider a potentially large number of species and life stages that have very different habitat requirements. There is also a need to better address instream flow needs for the whole aquatic ecosystem, and for this purpose it is desirable to undertake types of analyses that relate to a broader range of aquatic community constituents than has been common in the past.

One analytical approach that has potential for addressing these issues is based on examining aquatic habitats at a meso-scale level and describing the relationships between the amounts of different meso-habitat types (e.g., side channels, sloughs, shoals, backwaters, runs, riffles, pools) and stream discharge. These results can then be interpreted in the context of what is known generally about the role and significance of various habitat types in terms of ecosystem structure and function. Part of this interpretation would be based on known habitat needs of various fish species and information on their utilization of various meso-habitat types. Similar studies have been successfully undertaken previously using either aerial film photography or multi-spectral videography of streams at several different discharges.

An instream flow needs workshop was held during the 1993-94 fiscal year (Project 4103-C1) to develop a strategic plan for undertaking instream flow needs investigations as part of the NRBS.

The major conclusions of the workshop that relate to fisheries and aquatic habitats were as follows:

1. Emphasis and priority in IFN studies should be on the Peace River because of the existing flow regulation on this river.

2. There was a general consensus that we should probably not pursue, at this time, IFN studies based on the type of hydraulic modelling typically used to predict microhabitat characteristics (i.e., as in the PHABSIM model of the Instream Flow Incremental Methodology). Reasons for this recommendation are related to logistic problems on large rivers, expense of collecting the large amount of data required to implement the hydraulic model, and a lack of information on microhabitat preferences of fish species present in the Peace River.

3. The preferred approach to aquatic habitat IFN analysis was considered to be one based on mapping of various habitat types (e.g., main channel, side channels, shoals, sloughs, backwaters, etc.) at different discharges. This approach involves taking aerial photography, videography, or digital spectrographic imagery at several different discharges and developing habitat-discharge relationships.

This project is a pilot study to be conducted on the Peace River in Alberta with the following objectives:

1. Development and evaluation of methods for mapping aquatic habitat areas using aerial remote sensing techniques.

2. Description of relationships between river discharge and amounts of various meso-habitat types at selected locations on the Peace River.

II. REQUIREMENTS

1. Using a Compact Airborne Spectrographic Imager (CASI), obtain digital multispectral imagery at four different river discharges for each of two study segments on the Peace River. The two study segments are:

   a) the Peace River extending from the Alberta-B.C. border **downstream** for a distance of approximately 100 km, and

   b) the Peace River extending from the town of Fort Vermilion **upstream** for a distance of approximately 100 km.

2. The range of river discharges for which imagery is collected will be sufficient to describe relationships between river discharge and quantity of different meso-habitat types. This range should be as wide as is practical within the term of this contract. Specific target discharges will be identified in consultation with the Scientific Authority for the project.

3. The resolution of CASI image data collected for the two 100 km river segments will be approximately 2.2 m per pixel.

4. The number of spectral bands and wavelengths sampled will be suitable for discriminating the aquatic habitat features necessary to identify meso-habitat types.

5. Develop a classification system for categorizing aquatic habitat types. To the extent possible, this classification system will be compatible with the habitat categories used in previous studies on the Peace River and described by Hildebrand (1990), Boag (1993) and R.L. & L. Environmental Services Ltd. (1994). The classification system used in these studies is also described in Appendix A of these Terms of Reference. Habitat classifications may be more or less detailed than those described in Schedule A, depending on the ability to identify habitat features from digital image data. However, consistency with the previously used classification system is important because existing information on habitat utilization by fish in the Peace River is based on those habitat categories. The classification system used will be developed in consultation with the Scientific Authority for the project.

6. Develop algorithms for digital image analysis and classification of river areas into habitat type categories.

7. Conduct any ground-truthing studies that may be needed to verify habitat classifications. The amount and nature of ground-truthing studies will be determined in consultation with the Scientific Authority for the project.

8. Prepare digitized images (corrected geometrically and for incident illumination) from the two study segments, classify the aquatic habitats, and measure the areas of different habitat types at each discharge for which data are available.

9. Describe relationships between river discharge and quantity of each habitat type. Comment on the importance of the various habitat types and the significance of the habitat-discharge relationships in the context of assessing potential implications of river flow regulation. Prior to conducting the analysis and interpretation of habitat-discharge relationships, the approach to be used will be agreed upon by the Consultant and the Scientific Authority for the project.

10. Evaluate the suitability of the 2.2 m pixel size used for habitat classification and mapping in the two 100 km river segments and describe how image resolution affects habitat classification capability. This evaluation will be based on a comparison of imagery collected for a short (approximately 10 km) length of river in the Many Islands area at 1.0, 2.2, and 4.0 m pixel sizes.

11. Conduct a comparative evaluation of the relative suitability of different imaging systems for the purpose of discriminating aquatic habitat types. This comparison will include the CASI system, a multispectral videography system, and conventional aerial photography

film (colour and/or infrared) digitized using a scanner. The number, location, and length of sites to be used for this analysis as well as the number of flights and number and type of comparisons will be determined in consultation with the Scientific Authority for the project.

12. Prepare a report describing the results of this project and evaluating the potential for broader application of the methods for the purpose of instream flow needs analysis.

III. REPORTING REQUIREMENTS

1) The Contractor is to provide draft and final reports in the style and format outlined in the NRBS Style Manual. A copy of the Style Manual entitled "A Guide for the Preparation of Reports" will be supplied to the contractor by the NRBS.

2) Ten copies of the Draft Report along with an electronic disk copy are to be submitted to the Project Liaison Officer by March 31, 1995.

   Three weeks after the receipt of review comments on the draft report, the Contractor is to provide the Project Liaison Officer with two unbound, camera ready copies and ten cerlox bound copies of the final report along with an electronic version.

3) The final report is to include the following: an acknowledgement section that indicates any local involvement in the project, Project Summary, Table of Contents, List of Tables, List of Figures and an Appendix with the Terms of Reference for this project.

   Text for the report should be set up in the following format:

   a) Times Roman 12 point (Pro) or New Times Roman (WPWIN60) font.
   b) margins; are 1" at top and bottom, 7/8" on left and right.
   c) Headings; in the report body are labelled with hierarchical decimal Arabic numbers.
   d) Text; is presented with full justification; that is, the text aligns on both left and right margins.
   e) Page numbers; are Arabic numerals for the body of the report, centred at the bottom of each page and bold.

   - If photographs or digitized images are to be included in the report text they should be high contrast black and white unless colour is essential for communicating relevant information.
   - All tables and figures in the report should be clearly reproducible by a black and white photocopier.
   - Along with copies of the final report, the Contractor is to supply an electronic version of the report in Word Perfect 5.1 or Word Perfect for Windows Version 6.0 format.
   - Electronic copies of tables, figures and data appendices in the report are also to be submitted to the Project Liaison Officer along with the final report. These should be submitted in a spreadsheet (Quattro Pro preferred, but also Excel or Lotus) or database

(dBase IV) format. Where appropriate, data in tables, figures and appendices should be geo-referenced.

4. All figures and maps are to be delivered in both hard copy (paper) and digital formats. Acceptable formats include: DXF, uncompressed E00, VEC/VEH, Atlas and ISIF. All digital maps must be properly geo-referenced.

5. All sampling locations presented in report and electronic format should be geo-referenced. This is to include decimal latitudes and longitudes (to six decimal places) and UTM coordinates. The first field for decimal latitudes / longitudes should be latitudes (10 spaces wide). The second field should be longitude (11 spaces wide).

IV. OTHER DELIVERABLES

1. All videotapes, digital image data tapes, and film photography originals from all aerial survey flights together with any other information needed to make corrections to the image data.

2. Digitized and corrected image data used for habitat classifications and habitat area measurements, image resolution comparisons, and evaluation of different imaging systems. These data must be properly geo-referenced and in a format suitable for use in GIS systems.

3. Any algorithms developed for digital image analysis and habitat classification.

4. Six to ten 35 mm slides that can be used at public meetings to summarize the project, methods, and key findings.

V. CONTRACT ADMINISTRATION

The Scientific Authority for this project is:

Dr. Gordon Walder
Planning Division
Alberta Environmetal Protection
9th Floor, Oxbridge Place
9820 - 106 Street Phone: (403) 427-2375
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Questions of a scientific nature, including project planning, design, and scheduling should be directed to him.

The Component Coordinator for this project is:

James Choles, P.Eng.
Component Coordinator
Northern River Basins Study
690 Standard Life Centre
10405 Jasper Avenue Phone: (403) 427-1742
Edmonton, Alberta T5J 3N4 Fax: (403) 422-3055

Questions of an administrative nature should be directed to him.

VI. LITERATURE CITED/REFERENCES

Boag, T.D. 1993. A general fish and riverine habitat inventory, Peace and Slave rivers. April to June, 1992. Northern River Basins Study Project Report No. 9. Prepared for the Northern River Basins Study by D.A. Westworth and Associates Ltd. Edmonton, Alberta. June, 1993.

Hildebrand, L. 1990. Investigations of fish and habitat resources of the Peace River in Alberta. Report prepared for Alberta Environment, Planning Division by R.L. & L. Environmental Service Ltd. Edmonton, Alberta. March, 1990.

R.L. & L. Environmental Services Ltd. 1994. A general fish and riverine habitat inventory, Athabasca River. April to May, 1992. Northern River Basins Study Project Report No. 32. Edmonton, Alberta. April, 1994.

SCHEDULE A

HABITAT CLASSIFICATION AND DOCUMENTATION SYSTEM FOR USE IN FISHERIES SURVEYS CONDUCTED UNDER THE NORTHERN RIVER BASINS STUDY

1. CHANNEL TYPES

TYPE U - UNOBSTRUCTED CHANNEL

Only one main channel; permanent islands absent; side bars occasionally present with only limited development of exposed med-channel bars during low flows.

TYPE S - SINGULAR ISLAND

Presence of two channels around single, permanent island; side bars and mid-channel bars often present at low flows

TYPE M - MULTIPLE ISLANDS

More than two channels and permanent islands present; generally exhibit extensive side bar and mid-channel bar development during low flows.

TYPE R - RAPIDS

A special channel type used to identify the unique habitat at the Grand Rapids on the Athabasca River.

TYPE F - FALLS

A special channel type used to identify the unique habitat type at Vermilion Falls on the Peace River.

The classification of major habitat units Type U, Type S and Type M is to be based on field observations and air photo interpretation. For example, in instances where a single permanent island is present, but one of the channels around the island is dry, the habitat classification could be either Type U (unobstructed channel) or Type S (Singular Island) depending on conditions within the dry channel. If the dry channel exhibits a low relief at the inlet and is devoid of permanent vegetation, suggesting that it contained flow during some portion of the open water season (e.g., during spring runoff or freshet flows), the area is to be classed as Type S habitat. If, however, the entrance to the dry channel is at a level near the high water mark, well vegetated with either grasses or willows and appears to contain flows only during extreme flood events, the channel is to be classed Type U. These criteria are also to be used to differentiate between Type S and Type M channel habitats.

2. SPECIAL HABITAT FEATURES

Tributary Confluences (TC)

Confluence area of tributary entering mainstem; classified according to flow at time of survey and wetted width at mouth

TC1 - intermittent flow (dry/trickle); ephermal stream
TC2 - flowing; width at mouth <5.0 m
TC3 - flowing; width at mouth 5-15 m
TC4 - flowing; width at mouth 15-30 m
TC5 - flowing; width at mouth 30-60 m
TC6 - flowing; width at mouth > 60 m

Riffle (RF)

Portion of channel with increased velocity relative to Run and Pool habitat types; broken water surface due to effects of submerged or exposed bed materials; relatively shallow (less than 25 cm) during moderate to low flow periods.

> Riffle (RF) - Typical riffle habitat type; limited submerged or overhead cover for juveniles and adult life stages; coarse substrate.
>
> Riffle-Boulder Garden (RF/BG) - Riffle habitat type with significant occurrence of large boulders; availability of significant instream cover for juveniles (to lesser extent adults) at moderate to high flow events.

Rapids (RA)

Portion of channel with highest velocity relative to other habitat types. Deeper than Riffle (ranging from 25-50 cm); often formed by channel constriction. Substrate extremely coarse; dominated by large cobble and boulder material. Instream cover provided in pocket eddies (P3) and associated with cobble/boulder substrate.

Runs (RU)

Portion of channel characterized by moderate to high current velocity relative to Pool and Flat habitat; water surface largely unbroken. Deeper than Riffle habitat type. Can be differentiated into four types: deep-slow, deep-fast, shallow-slow, and shallow-fast.

> Run (Class 1) (RU1) - Highest quality Run habitat type. Maximum depth exceeding 1.5 m; average depth 1.0 m. High instream cover at all flow conditions (submerged boulders/bedrock fractures, depth). Generally of deep-slow type (to a lesser extent deep-fast) and situated proximal to upstream food production area (i.e., RF, RU3).

Run (Class 2) (RU2) - Moderate quality Run habitat type. Maximum depth reaching or exceeding 1.0 m, generally exceeding 0.75 m. High instream cover during all but low flow events (baseflow). Generally of either deep-fast type or moderately deep-slow type.

Run (Class 2)/Boulder Garden (RU2/BG) - Moderate quality Run habitat type; presence of large boulders in channel; high instream cover (boulder, bedrock fractures, turbulence) at all but low-flow events (baseflow). Depth characteristics similar to RU2; however, required maximum depth lower due to cover afforded by boulders.

Run (Class 3) (RU3) - Lowest quality Run habitat type. Maximum depth of 0.75 m, but averaging <0.50 m. Low instream cover at all but high flow events. Generally of shallow-fast or shallow-slow types.

Run (Class 3)/Boulder Garden (RU3/BG) - Similar to R# in depth and velocity characteristics; presence of large boulders in channel offers improved instream cover during moderate and high flow events.

Flat (FL)

Area of channel characterized by low current velocities (relative to RF and Ru cover types); near-laminar (i.e., non-turbulent) flow character. Depositional area featuring predominantly sand/silt substrate. Differentiated from Pool habitat type on the basis of high channel uniformity and lack of direct riffle/run association. More depositional in nature than RU3 habitat (sand/silt substrate, lower food production, low cover, etc.).

Flat (Class 1) (F1) - High quality Flat habitat type. Maximum depth exceeding 1.5 m; average depth 1.0 m or greater.

Flat (Class 2) (F2) - Moderate quality Flat habitat type. Maximum depth exceeding 1.0 m; generally average depth exceeding 0.75 m.

Flat (Class 3) (F3) - Low quality Flat habitat type. Maximum depth of 0.75 m, averaging less than 0.50 m.

Pool (P)

Discrete portion of channel featuring increased depth and reduced velocity (downstream oriented) relative to Riffle and Run habitat types.

Pool (Class 1) (P1) - Highest quality Pool habitat type. Maximum depth exceeding 1.5 m; average depth 1.0 m or greater; high instream cover at all flow-conditions (submerged boulder, bedrock fractures, depth, bank irregularities). Generally featuring high Riffle and/or Run association (i.e., food input). Often intergrades with deep-slow type of RU1.

Pool (Class 2) (P2) - Moderately quality Pool habitat type. Maximum depth reaching or exceeding 1.0 m, generally exceeding 0.75 m. High instream cover at all but low flow events (baseflow).

Pool (Class 3) (P3) - Low quality pool habitat type. Maximum depth of 0.75 m, averaging <0.50 m. Low instream cover at all but high flow events. Includes small pocket eddy type habitat.

Other Features

Includes the following instream features:

Chutes (CH) - Area of channel constriction, generally resulting in channel deepening and increased velocity. Associated habitat types are R1 and R2.

Ledges (LG) - Areas of bedrock intrusion into the channel; often create Chutes and Pools.

Other - Miscellaneous features (fallen tree, log jams, large boulder, etc.).

Shoal (SH)

Shallow (<1.0 m depth), submerged areas of coarse (SHC) or fine (SHF) substrates generally found in mid-channel areas or associated with depositional areas around islands and side bars.

Backwater (BW)

Discrete, localized area of variable size, exhibiting a reversed flow direction relative to the main current; generally produced by bank irregularities; velocities variable but generally lower than in adjacent main flow; substrate similar to that in adjacent channel although usually with a higher percentage of fines.

Snye (SN)

Area characterized by a non-flowing body of water (generally within a side channel_ which retained a connection to a flowing channel at its downstream end; most commonly associated with braided channel areas but also occurred in singular channels in association with point or side-bar development; substrate mainly silt/sand; depths within the snye proper were only recorded at snyes in intensive sites.

Slough (SL)

A non-flowing body of water located in the flood plain but completely isolated from flowing waters except during annual or irregular flood events. Often exhibited more extensive littoral development in comparison to snye areas (dependent upon frequency of inundation); substrate of silt and organic material; water levels maintained by seepage, springs, precipitation, etc.

N.B. - In all cases note whether the feature is associated with the main channel or a side channel.

3. BANK HABITAT TYPES

Armoured/Stable

A1 Banks generally stable and at repose with cobble/small boulder/gravel substrates predominating; uniform shoreline configuration with few/minor bank irregularities; velocities adjacent to bank generally low-moderate, instream cover limited to substrate roughness (i.e., cobble/small boulder interstices); overhead cover provided by turbidity.

A2 Banks generally stable and at repose with cobble/small boulder and large boulder substrates predominating; irregular shoreline configuration generally consisting of a series of armoured cobble/boulder outcrops that produce Backwater habitats; velocities adjacent to bank generally moderate with low velocities provided in Backwater habitats; instream cover provided by Backwater areas and substrate roughness; overhead cover provided by depth and turbidity; occasionally associated with C1, E4 and E5 banks.

A3 Similar to A2 in terms of bank configuration and composition, although generally with higher composition of large boulders/bedrock fractures; very irregular shoreline produced by large boulders and bed rock outcrops; velocities adjacent to bank generally moderate to high; instream cover provided by numerous small Backwater areas, eddy pools behind submerged boulders and substrate interstices; overhead cover provided by depth and turbidity; exhibits greater depths offshore than found in A1 or A2 banks; often associated with C1 banks.

A4 Rip-rap substrates consisting of angular boulder-sized materials; may be native rock or concrete debris; often associated with high velocity areas; generally with deep water situated immediately offshore; instream cover provided by substrate roughness; overhead cover provided by depth and turbulence; similar in many ways to A3 habitat but generally with smooth bank profile.

Canyon

C1 Valley walls forming banks; bank substrate consists primarily of large cobble/boulder/bedrock fractures; generally stable at bank-water interface although on upper bank slumps/rock falls common; typically deep with high current velocities offshore; abundant velocity cover provided by substrate roughness and frequent bank irregularities.

C2 Steep, stable bedrock banks associated with canyon cliffs or bedrock outcrops; deep to moderate depths offshore with generally moderate to fast current velocities; regular bank form; velocity cover occasionally provided by bedrock fractures in channel.

C2B Similar to C2 but bank is regular with no instream cover.

C3 Valley wall forming banks, bank substrate consists primarily of fines with some gravel/cobble at base; moderately eroding at bank-water interface, slumping on upper bank common. Moderate-high velocities - no instream cover.

Depositional

D1 Low relief, gently sloping bank type with shallow water depths offshore; substrate consists predominantly of fines (i.e., sand/silt); low current velocities offshore; instream cover generally absent or, if present, consisting of shallow depressions produced by dune formation (i.e., in sand substrates) or embedded cobble or boulders and vegetative debris; this bank type is generally associated with bar formations.

D2 Low relief, gently sloping bank type with shallow water depths offshore; substrate consists of coarse materials (i.e., gravels/cobbles); low-moderate current velocities offshore; areas with higher velocities usually producing riffle areas; overhead cover provided by surface turbidity or surface turbulence in riffle area; instream cover provided by substrate roughness; often associated with bar formations; and shoal habitat.

D3 Similar to D2 but with coarser substrates (i.e., large cobble/small boulder) more dominant; boulders often embedded in cobble/gravel matrix; generally found in areas with higher average flow velocities than D1 or D2 banks; instream cover abundantly available in form of substrate roughness; overhead cover provided by surface turbulence; often associated with fast riffle or rapid areas offshore; generally moderate to high velocities offshore; transitional bank type that exhibits characteristics of both Armoured and Depositional bank types.

Erosional

E1 High, steep, eroding banks often with terraced profile; bank unstable, frequently slumping and eroding; substrate consists of sand/silt materials; moderate to high offshore current velocities; steep bank profile extends under water surfaces resulting in deep water immediately offshore; instream cover provided by abundant submerged bankside vegetation (i.e., trees, shrubs, root wads, etc.) that has fallen into the channel from the eroding bank crest; overhead cover provided by partially submerged vegetation, depth and turbidity.

E2 Similar to A1 except without the high amount of instream vegetative debris (i.e., banks generally clean); depths offshore generally shallower than along E1 banks.

E3 High, steep and eroding banks, substrate consists of loose till deposits (i.e., gravel/cobble/sand mixture); moderate to high current velocities offshore; moderate depths offshore; instream cover availability limited to substrate roughness; overhead cover provided by turbidity.

E4 Steep, eroding or slumping highwall bank; substrates variable but primarily consisting of fines (i.e., clays/silts); moderate to high current velocities offshore; depths offshore generally moderate to deep; instream cover limited to occasional Backwater formed by bank irregularities; overhead cover provided by depth and turbidity.

E4B Same as E4, but instream cover also provided by log-jams and woody debris.

E5 Low, steep banks, often with terraced profile; predominantly composed of silt/sad substrates; generally low current velocities offshore; depths offshore variable but generally shallow to moderate; instream cover usually absent; this bank type is often associated with Backwater habitats in A1 and A2 bank types; overhead cover provided by turbidity.

E6 Low slumping/eroding bank; substrates may either be cobble/gravel or silt with occasional cobble/gravel patches; depths offshore moderate; velocities moderate-high instream cover provided by abundant woody debris of occasional boulders; overhead cover provided by overhanging trees and depth and turbidity; numerous small Backwaters often with A1 or A2 habitats right at bank interface.

Composite

These classifications are used in situations where the bank-water interface (i.e., nearshore bank) is predominantly one bank type but is still strongly influenced by the adjacent farshore bank (e.g., A2/C2 used where the nearshore bank is type A2 but was produced by active bedrock fracturing from the farshore bank type C2). In these composite bank types, the first bank type given is the dominant type at the bank-water interface.