Peace Project Water Use Plan

Peace River Hydraulic Habitat

Reference: GMSWORKS #4

Peace River Hydraulic Habitat Study

Study Period: September 13, 2009– August 25, 2011

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November 30, 2012

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PEACE RIVER HYDRAULIC HABITAT STUDY (CONTRACT Q9-9105)

Prepared for

BC Hydro, Water License Requirements
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EXECUTIVE SUMMARY

The regulation of the Peace River by the Bennett and Peace Canyon Dams has altered the downstream hydrologic regime and resulted in daily and seasonal variations in water levels that affect fish and fish habitat. The Peace River Hydraulic Habitat Study was commissioned by BC Hydro to investigate how changes in water levels affect fish habitat on the Peace River in the area between the Peace Canyon Dam and Taylor, BC. The purpose of the study was to quantify fish habitat of the Peace River at several steady state discharges.

The study used a series of five air photos flown during a representative range of flows that varied between 283 cms (10,000 cfs) and 1,982 cms (70,000 cfs) to map the surface area of near shore fish habitats. The study objectives were as follows:

1. Develop a habitat classification system that is sensitive to changes to Peace River discharge;
2. Delineate fish habitats of the Peace River at five discharges using air photographs provided by BC Hydro;
3. Prepare digital maps of fish habitats for each discharge;
4. Quantify fish habitat availability at each discharge; and,
5. Model habitat availability as a function of river discharge.

The habitat classification system used by the study was based on the physical characteristics of the active channel bed and adjacent river banks. Use of physical characteristics to classify fish habitat was chosen for three reasons. It allowed quantification of habitats using physical features assumed to be important to fish species and life stages found in the Peace River. Physical characteristics used by the classification system were identifiable on large scale colour air photos. Finally, physical characteristics used to define habitats were stable over different flow regimes, which allowed quantification of habitat availability within the same habitat unit at different water levels. The system does not incorporate attributes such as water velocity or water depth because changes to these features were not easily identifiable on air photos.

The results of the study indicated that large scale air photos could be used to map the water line boundary at each of the five flows at a high level of precision. And, the habitat classification system could reliably identify and delineate near shore habitats using the same large scale air photos. We were able to calculate habitat surface area by combining the digital habitat boundaries with the wetted area of the river at each flow.

The habitat surface area data allowed quantification of habitat availability at several spatial scales. Habitat availability was related to river reach, channel type, and habitat type.

Habitat availability was strongly related to discharge. Modeling established that there was a high correlation between habitat surface area and discharge, the relationship was curvilinear, and was most often expressed by a power function.

The Peace River Hydraulic Habitat Study has successfully achieved its goal to map the various types of near shore fish habitat and to make a determination of the numerical relationship between habitat area and discharge. However, the study identified a number of deficiencies:

1. The assumption that the habitat classification system reflects differences in habitat utilization by the various fish species and life stages that reside in the Peace River needs to be verified;
2. The habitat classification system did not incorporate attributes such as water velocity or water depth because changes to these features were not easily identifiable on air photos; however, these characteristics can influence fish habitat utilization;
3. A large area of the Peace River was underwater at the lowest study flow of 283 cms, and as such, the areal extent of submerged habitats could not be mapped. Consequently the study data only represents changes in habitat availability within the portion of the Peace River channel affected by flows between 283 cms and 1,982 cms. The data do not represent changes to habitat availability within the entire river channel; and,
4. The study results reflect present habitat conditions. The channel and habitat characteristics of the Peace River are still adjusting to the effects of river regulation and the study results will not necessarily reliably describe future conditions.

The following recommendations are made to address deficiencies in the data or to utilize the information collected by the study to further our knowledge of the effects of BC Hydro operations on Peace River fish habitats and fish populations:

1. Quantify the physical characteristics of the river bed below the water level elevation at 283 cms to ascertain habitat types and habitat availability within the wetted portion of the Peace River channel;
2. Better predict the speed, location and magnitude of future changes to fish habitat characteristics due to the effects of river regulation and determine the time period over which the present results can be reliably employed; and,
3. Undertake a pilot study to compile and synthesize the existing Peace River hydraulic habitat and fish population data. The study objective should be to determine if there is sufficient data to reliably undertake an analysis of habitat suitability as a function of factors such as water depth, water velocity, bed material texture or other factors.

ACKNOWLEDGEMENTS

Mainstream Aquatics Ltd. would like to thank Stewart McGregor and Alan Chan-McLeod from BC Hydro for initiating the study and for providing advice during the design phase. Thanks also go to Karen Skibo, Michael McArthur, and Aileen Grant of BC Hydro for administering the contract and providing technical advice. Personnel involved in the project are as follows:

Mainstream Aquatics Ltd.

Rick Pattenden	Senior Biologist and Report Author
Chantal Pattenden	Senior Technician
David Winarski	Technician

M. Miles and Associates Ltd.

Mike Miles	Senior Geomorphologist and Contributing Author
Elizabeth Goldsworthy	Staff Scientist
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Integrated Mapping Technologies Inc.

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1.0 INTRODUCTION

1.1 BACKGROUND

The G.M. Shrum and Peace Canyon generating stations on the Peace River are part of BC Hydro's integrated generation system and provides approximately 29% of BC's energy requirements (nhc 2010c). The Peace facilities are normally managed to meet provincial electricity demand and are generally operated over the day to meet peak loads, respond to market opportunities and/or manage unit outages (BC Hydro 2007).

The maximum instantaneous generation diversion quantity from Peace Canyon facilities (PCN Dam) into the Peace River is 1982.2 cms (70,000 cfs). The minimum flow release is 283.2 cms (10,000 cfs) as measured at the Water Survey of Canada's (WSC) stream gauging station Peace River 'at Hudson's Hope' which is located approximately 7 km downstream of the PCN Dam. There are no other water management constraints on the operation of the PCN Dam (BC Hydro 2007). This includes frequency of discharge fluctuation, rate of change of discharge or water level, and duration of discharge.

Peace River fish habitat is influenced by daily and annual operation of the Peace generating facilities, but the functional connection between habitat and discharge is not known (BC Hydro 2007). Issues of concern include loss or alteration of fish habitat, dewatering, elevated water temperatures, and fish stranding (Sigma Engineering Ltd. 1994). The portion of the Peace River most affected by dam operations is predicted to be the section between the PCN Dam and the Pine River confluence (BC Hydro 2007). Downstream of the Pine River, fluctuation effects are reduced by inputs from the Pine River and attenuation of flow variation.

The nature, spatial extent, and magnitude of discharge fluctuation effects on Peace River fish habitats have not been previously characterized. An initial method to assess the influence of discharge is to quantify the surface area of available habitat on the basis of a series of air photos flown during a representative range of flows. BC Hydro contracted Mainstream Aquatics Ltd. and its study team to complete this task.

1.2 PURPOSE AND OBJECTIVES

The purpose of the study is to quantify fish habitat of the Peace River at several steady state discharges.

Specific objectives of the study are as follows:

1. Develop a habitat classification system that is sensitive to changes to Peace River discharge, that represents key aspects of fish habitat requirements, and can be implemented from air photographs;
2. Test the efficacy of the habitat classification system via a preliminary digital mapping exercise and ground truthing;
3. Delineate fish habitats of the Peace River at five (5) river discharges evenly distributed between 283 cms and 2000 cms using air photographs provided by BC Hydro;
4. Prepare digital maps of Peace River fish habitats for each discharge.
5. Quantify fish habitat availability at each discharge;
6. Model habitat availability as a function of river discharge; and,
7. Prepare a concise report that summarizes the study results and discusses their implications for future work.

1.3 STUDY AREA AND PERIOD

The study area is a 105 km section of the Peace River between the Peace Canyon Dam and the confluence of the Pine River (Figure 1.1). The study area boundaries encompassed the main channel, side channel, and tributary confluence areas of the Peace River from the downstream margin of the structural base of the Peace Canyon Dam to the center line of the Highway 97 Bridge that crosses the Peace River 1.5 km downstream of the Pine River confluence. The upstream boundary of each tributary confluence was set at a fixed location which encompassed the range of Peace River flows to be investigated.

The initial completion date of the study was March 31, 2010. However, BC Hydro was unable to provide all the required discharge aerial photography until March 2012. The study period was therefore extended until July 31, 2012 to allow completion of all project objectives.

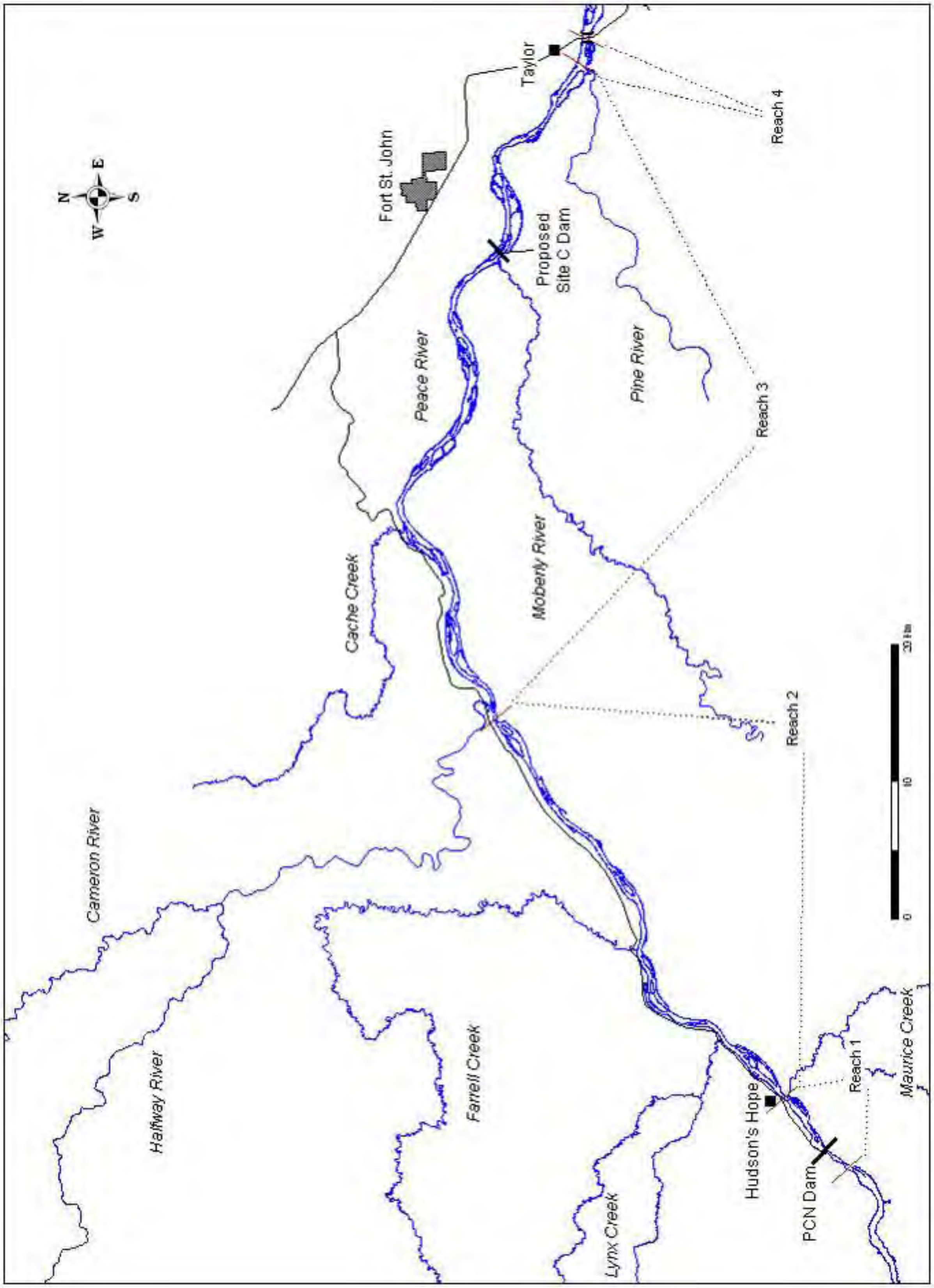

Figure 1.1 Peace River Hydraulic Habitat Study Area.

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2.0 METHODS

2.1 HABITAT CLASSIFICATION SYSTEM

The habitat classification system was developed by Rick Pattenden (M.Sc., P. Bio.), a professional fish biologist with Mainstream Aquatics Ltd. (Mainstream) who has extensive knowledge of Peace River fish communities and associated habitat requirements (RL&L 2001, P&E 2002, P&E and Gazey 2003, Mainstream and Gazey 2004 to 2012). Mike Miles (M.Sc., P. Geo.), assisted with all phases of the project. Mr. Miles is a professional geomorphologist with M. Miles and Associates Ltd. (MMA) who has extensive experience undertaking fish/hydrology studies on the Peace River and other large regulated streams (such as the Churchill, Nechako, Columbia, and Duncan Rivers).

An initial habitat classification system was developed during a two day field trip on the Peace River in May 2009. The work included identifying candidate factors thought to influence fish use and that would be amenable to interpretation on air photos. The scheme was subsequently tested and, where necessary, modified or expanded during an initial air photo interpretation and habitat mapping exercise undertaken at Integrated Mapping Technologies Inc. (IMT) offices on July 6, 2009. The system was then submitted to representatives of BC Hydro for review on July 7, 2009. BC Hydro accepted the habitat classification system and there have no substantive subsequent changes to the scheme.

2.2 AERIAL PHOTOGRAPHY

BC Hydro obtained the aerial photography used in this study (Table 2.1). Aerial photography flights were to be completed at five flows, each of which was to represent a specific steady state flow between 283 cms and 2,000 cms.

Table 2.1 Summary of information for aerial photography provided by BC Hydro.

Target Discharge		Flight Identification	Acquisition Date	No. Photos
Units in cms	**Units in cfs**			
283	10,000	SRS8046	13-Sep-09	505
566	20,000	SRS8047	20-Sep-09	505
991	35,000	SRS7942	26-Oct-08	506
1,557	55,000	AP11081	26-Aug-11	760[a]
1,982	70,000	AP11080	25-Aug-11	590[a]

[a] Includes photo coverage of Peace River downstream of study area, which is not part of this project.

IMT of Coquitlam, British Columbia was responsible for processing the aerial photography. IMT completed three study tasks related to the aerial photography. The first was converting the digital aerial photography supplied by the client into a form that could be used for study purposes. The second was delineating the location and elevation of the water line for each of the five discharges. The third was providing digital orthophotos of the mapping results to Mainstream in a form suitable for use with MapInfo Professional™ software.

Task 1 - Aerial Photograph Conversion

The digital aerial photographs were converted into Digital Image Analytical Plotter [DiAP] format. The DiAP plotter employs hand wheels, foot pedals, and 3-dimensional viewing to delineate object boundaries.

Aerial photographic imagery was provided in Tiff format and Aerial Triangulation data was provided in PAT-B format. Aerial Triangulation conversion was completed using the I.S.M. International Systemap Corp. DiAP_ATM module version 3.91.04. Images were converted to SJS format with an 85 compression rate. SJS is a tiled pyramid and JPEG compressed image format proprietary to ISM software but can also be read by DA/TEM and PurVIEW software. Aerial Triangulation data was imported into DiAP_ATM and fiducials were manually measured to allow the DiAP software to create stereo viewable image data.

Task 2 - Delineating Water Line

Water line mapping involved delineation of the water-bank interfaces within the active channel, including ponded water isolated from the main waterbody. For purposes of this study, the active channel is defined as the wetted area and exposed river bed between established edges of perennial, terrestrial vegetation.

Water line delineation mapping was completed using the I.S.M. International Systemap Corp. SysImage DiAP workstation version 3.91.04 that runs inside Intergraph MicroStation Version SE Computer Aided Design software. Mapping was done using the 3d imagery by digitizing the wet edge of the water line on the shore along the river. In areas where tree canopy covered the water's edge, the water line was estimated. This method provided a mapping resolution of < 2.0 m. To reduce time requirements, isolated ponded water having a surface area ≤ 5 m^2 was not mapped. The water line map was provided to Mainstream Aquatics Ltd. in DWG vector format.

Task 3 - Orthophoto Conversion to Mr. Sid

Orthophotos were provided by BC Hydro in Tiff/Tfw format. Images were processed to Mr Sid format using Lizardtech Geoexpress 7 with 20x compression. Mr Sid files were processed as Mr Sid Version 2 to allow compatibility with the MapInfo Professional™ Version 7.5 GIS software. The orthophoto from BC Hydro had pixels with rotation values which MapInfo Profession™ Version 7.5 cannot handle. The information was therefore re-processed with no rotation using Inpho Ortho Vista Version 4.4, and then saved to Mr Sid.

2.3 GROUND TRUTHING

Ground truthing was used to verify the reliability of digital habitat mapping. Habitat units were mapped on hardcopy Google Earth Maps at a scale of 1:5,000 from a boat by an experienced fish biologist. This information was transcribed into digital format for comparison to water line maps developed using the DiAP system and the Mr Sid orthophoto base maps. Checks included accuracy of habitat type classification and the position of the habitat unit boundaries.

2.4 EVALUATION OF WATER LEVEL AND DISCHARGE

As previously discussed, BC Hydro was responsible for obtaining five sets of aerial photos which could be used to quantify fish habitat characteristics within the section of the Peace River between Peace Canyon Dam and the Pine River confluence. The original intent was to fly air photos associated with flows of 10,000, 20,000, 35,000, 55,000, and 70,000 cfs in 2008 and 2009. These flows correspond to metric discharges of 283, 566, 991, 1,557 and 1,982 cms respectively. Ideally, the higher discharge values were to be associated with normal reservoir releases rather than a project specific, non-revenue spill. Conditions suitable for obtaining the higher flow air photos did not occur until 2010 and 2011 and this required a release of water to meet the stream flow objective. As a consequence, some of the released flows were of short duration and it was necessary to determine how the flows varied over the study area during the period when the air photos were collected.

Flight logs were obtained from Selkirk Remote Sensing and Kisik Aerial Survey to determine the dates and times at which the photos were acquired. The corresponding stream flow values have been determined at PCN Dam and at the downstream WSC gauging stations.

2.5 HABITAT MAPPING AND ANALYSES

Habitat mapping and habitat summary calculations (i.e., surface area and perimeter) were completed using MapInfo Professional™ Version 7.5. Habitat analyses were completed using IBM® SPSS® Statistics Version 20.

Habitat Mapping

The orthophoto set that represented the minimum predicted discharge (283 cms) was used as the base map onto which all habitat units were mapped. Use of the 283 cms orthophoto set:

a) facilitated habitat typing by exposing physical characteristics used to define habitat types, thus making them readily available for interpretation; and
b) exposed habitat units that were not directly associated with channel margins (e.g., shoals), which were inundated at higher discharges.

Initial habitat mapping was completed using the Digital Image Analytical Plotter at IMT's office, which allowed stereo viewing identification, and mapping of habitat units to as small as 2 m^2 (which was beyond the scope and budget of the study). Subsequent habitat typing was completed on a standard workstation equipped with a high resolution 58 cm (24 in) color monitor using MapInfo Professional™ Version 7.5. This system allowed identification and precise delineation of habitat units to as small as 10 m^2.

Habitat types were delineated for all bank margins within the study area that had the potential to be wetted at one or more of the five discharges examined by the study. Habitat typing was undertaken as follows:

1. The upstream and downstream boundary of each habitat unit was delineated on the minimum discharge (283 cms) orthophoto base map (Figure 2.1a);
2. The upstream and downstream boundary of each habitat unit was set perpendicular to the channel margin and then extended to the maximum extent of the wetted surface area, which was represented by the maximum discharge (1,982 cms) orthophoto base map (Figure 2.1.b). Setting the boundaries perpendicular to shore resulted in reduced accuracy of habitat unit surface area calculations because the water line geometry rarely remained static across all discharges. This procedure was adopted to avoid time requirements to map subtle changes to habitat unit boundaries for each of five discharges;
3. The maximum surface area of the habitat unit was delineated by forming a polygon around the perimeter of the unit. The unit boundary was juxtapositioned with the adjacent habitat unit boundaries to eliminate overlap (Figure 2.1c);
4. The total wetted surface at each of the five discharges was overlain with the habitat unit polygon to generate a wetted surface polygon specific to that habitat unit (Figure 2.1d); and,
5. The final step was to calculate the surface area and perimeter of the wetted habitat unit at each discharge. This step was not completed for 283 cms, because the underwater area potentially available to fish could not be delineated using air photo interpretation.

Mapping included delineation of channel types. Side channel boundaries were delineated by a straight line connection between adjacent habitat polygon units (e.g., island habitat polygon to valley wall habitat polygon). Tributary confluence boundaries were delineated by line placement at the boundary between the tributary confluence and the main or side channel. Main channel boundaries were juxtapositioned with previously delineated side channel and tributary confluence boundaries.

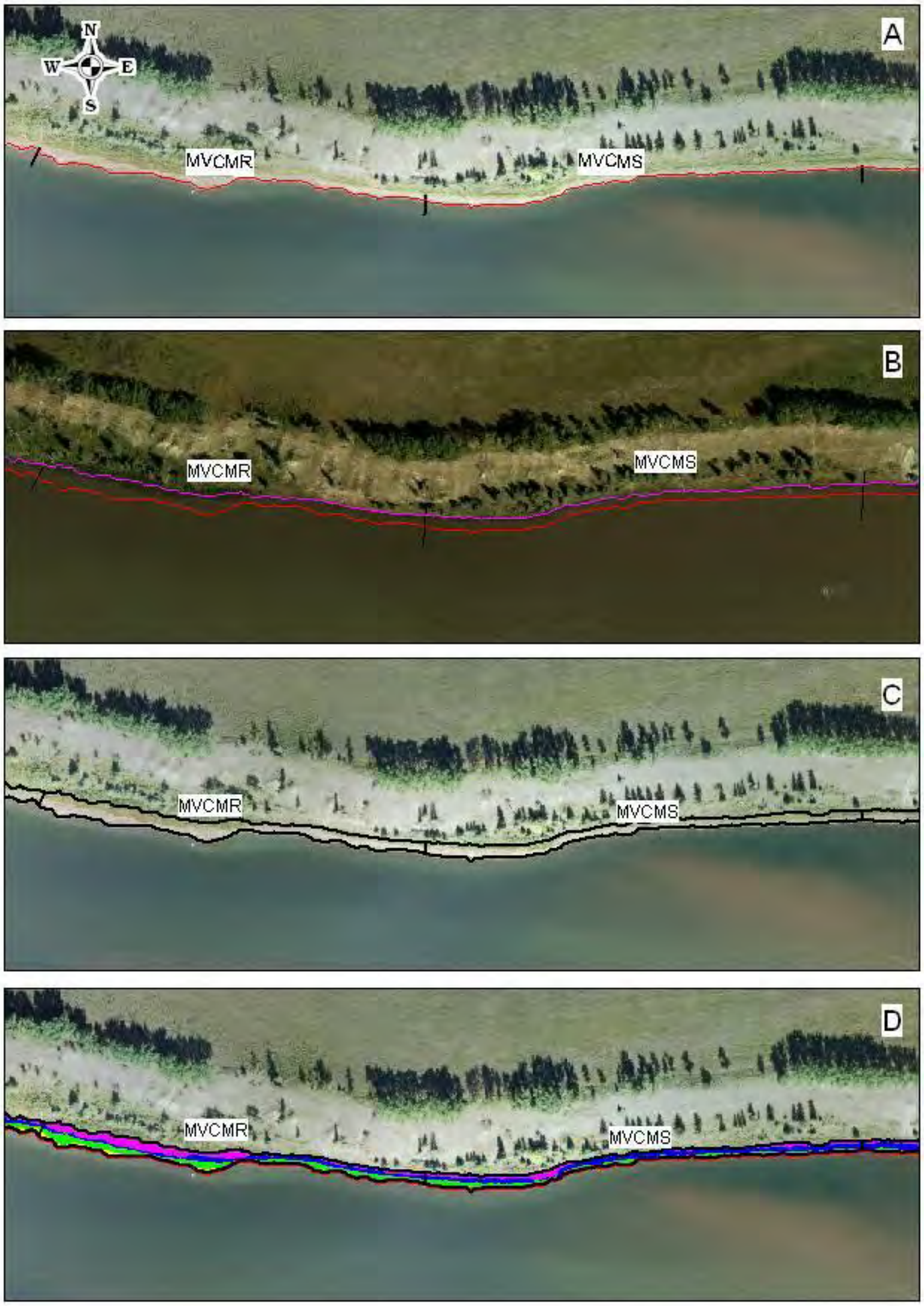

Figure 2.1 Illustration of habitat type mapping steps. A -- The upst. and dwst. boundary of each habitat unit was delineated on the minimum discharge (283 cms) orthophoto base map. B -- The upst. and dwst. boundary of each habitat unit was set perpendicular to the channel margin and then extended to the maximum extent of the wetted surface area, which was represented by the maximum discharge (1,982 cms) orthophoto base map. C -- The maximum surface area of the habitat unit was delineated by forming a polygon around the perimeter of the unit. The unit boundary was juxtapositioned with the adjacent habitat unit boundaries to eliminate overlap. D - The total wetted surface at each of the five discharges was overlain with the habitat unit polygon to generate a wetted surface polygon specific to that habitat unit.

Quality Assurance Procedures

Quality assurance (QA) procedures included field ground truthing, habitat typing by qualified staff, visual checks of habitat unit typing against orthophoto base maps, and analytical summaries to identify outliers. A description of each QA procedure is as follows:

1. Ground truthing of the initial habitat classification system was used to ensure that the information was able to meet the study objectives (see Section 2.3). A delay in the collection of all aerial photography sets until August 2011 provided a large window for ground truthing of habitat typing information. In August 2010, a qualified biologist completed ground truthing of 100% of main channel and 75% of side channel areas. During the ground truthing period (10 to 30 August) daily river discharge recorded at WSC Station Peace River above Pine River (07FA004) ranged between 369 cms and 840 cms (median = 459 cms). The ground truthing did not identify any major discrepancies between habitat typing and field observations. Discrepancies were recorded for some habitat unit upstream and/or downstream boundaries [approximately 2% of examined habitat units (16 of 850 units)];
2. All digital habitat typing was completed by trained biological staff that had two to four years of field experience within the study area. This allowed efficient and accurate interpretation of the orthophoto base map;
3. Overlap of wetted surface boundaries were visually identified and corrected. If corrections could not be completed (e.g., in heavily shaded zones), the water lines were assumed to converge and the overlap was deleted; and,
4. Redundant summary calculations of habitat surface area allowed identification of errors caused by incorrect delineation of habitat boundaries. The primary method included comparison of wetted area generated from water surface area maps to wetted surface area generated from habitat polygon maps. Following the final quality assurance assessment, the comparison indicated a difference of 4.7% or, 58.4 ha of the total potential habitat surface area was not accounted for by the habitat polygons.

Analyses

The target flow 1,982 cms (70,000 cfs) was assumed to represent the maximum available habitat within the study area and was used to delineate the maximum wetted surface area. This data set was used to calculate the available habitat in study area reaches, and channel zones within each reach. Analyses of habitat type included basic summaries of surface area at each target discharge.

Digital Map Format

Digital map and associated data were developed using MapInfo Professional™ Ver. 7.5. As part of the required deliverables, digital maps were translated into shapefile format (.shp) compatible with ArcGIS mapping software for submission to the client.

2.6 HABITAT MODELS

2.6.1 Approach

Hydraulic habitat models typically describe how hydraulic parameters of the river (i.e., depth, velocity, temperature, etc.) change with flow, and assess how aquatic species may respond to these changes. These types of models require a large amount of data and typically use 1D or 2D hydraulic modeling. These types of studies are also often limited to describing changes in a small section of the river due to costs and time constraints associated with data collection and modeling large reaches.

In the case of the Peace River hydraulic habitat study, the study area of interest was 104.9 km in length. The objective of this study was to determine how the habitat area changes with flow.

The habitat classification system that describes reach, channel type, and habitat type attributes was used as a basis for modeling. Models were generated using the surface area of the habitat polygon types at the five target discharges as measured at 283, 566, 991, 1,557 and 1,982 cms. Habitat area at each flow was directly measured from the orthophotos (see Section 2.5). This technique does not permit quantification of wetted surface of available habitat at the lowest flow of 283 cms. Habitats potentially available to fish at this flow are under water, and therefore, cannot de delineated. For habitat modeling purposes, one could assume that the area available to fish equaled zero at 283 cms. Alternatively, one could estimate the amount of available habitat at 283 cms. This latter approach was adopted because wetted habitat is available at this discharge. The use of zero or an estimate value also does not change the modeled relationship between habitat surface area and discharge.

The habitat surface area available to fish in each habitat polygon at 283 cms was estimated using an assumed width times the wetted length of the polygon along the 283 cms water line. Estimated widths of slope categories were as follows:

Low Slope = 45 m width
Moderate Slope = 15 m width
High Slope = 5 m width

2.6.2 Hydraulic Habitat Model Scale

Models were developed to describe changes in habitat area relative to changes in discharge at the following four scales:

1. The 104.9 km study area (i.e., from the PCN Dam to the Taylor Bridge);

2. Study reach (i.e., Peace Canyon, Hudson's Hope, Halfway River, and Pine River);
3. Channel type (i.e., main, open side channel, closed side channel, and tributary influence areas); and,
4. Habitat unit type.

Hydraulic habitat models were developed by isolating the relevant parameters from the data set for each model. Simple models describing the relationships between hydraulic habitat area and discharge were developed using non-linear regression.

3.0 PHYSICAL SETTING

3.1 RIVER DISCHARGE AND CHANNEL CHARACTERISTICS

3.1.1 Discharge and Water Level

Available Information

BC Hydro collects data at Peace Canyon Dam (basin area 68,900 km^2) and WSC operates three mainstem gauging stations between Peace Canyon Dam and the BC Border. These include Peace River 'at Hudson's Hope' (basin area 73,100 km^2), 'above Pine River' (basin area 87,200 km^2) and 'near Taylor' (basin area 101,000 km^2). Stream discharge is also monitored on two tributary streams 'Halfway River near Farrell Creek' (basin area 9,400 km^2) and 'Moberly River near Fort St. John' (basin area 1,520 km^2).

A number of studies undertaken for BC Hydro have collected water level or discharge data within the study area. Mainstream installed a series of up to five water level and temperature recorders which operated in late-summer between 2002 and 2006 in support of a fisheries study. These data, which are not referenced to a common datum, are presented in annual project reports (P&E 2002, P&E and Gazey 2003, Mainstream and Gazey 2004 to 2006). Northwest Hydraulic Consultants Ltd. [nhc] installed five water level recorders in September 2009 as part of BC Hydro's GMSWORKS-6 project. All stations, which are located between the WSC stream gauging stations 'at Hudson's Hope' and 'near Taylor', are still operating. A summary of the initially available information from these sites is presented in nhc (2010a) and a discussion of the associated hydraulic model is described in nhc (2010b).

Station locations are indicated in Figure 3.1 and the available data record is summarized in Table 3.1.

Effects of River Regulation

The stream flow record from the WSC's 'Hudson's Hope' and 'near Taylor' mainstem stations include data which were collected prior to the construction of Bennett Dam. The seasonal variation in stream flow observed at these two sites is illustrated in Figures 3.2 and 3.3. The data have been sub-divided into the pre-regulation (≤ 1967) and post-reservoir filling (≥ 1973) time periods. This analysis illustrates how storage in Williston Lake and power production has reduced the size of the snowmelt freshet and increased winter flows. As a consequence, the river now experiences a substantially reduced seasonal variability in discharge. The post-regulation graphs also illustrate the moderating effects of tributary inflows upstream of the 'near Taylor' gauging station.

Table 3.1 Hydrometric Data Availability.

Station Operated By	**Station Name & Number**	**Basin Area (km^2)**	**Type of Record**	**Type of Flow**
BC HYDRO	Peace River at Peace Canyon Dam	68,900	1984-2012 RC	REG
WSC	Peace River at Hudson's Hope [07FE001]	73,100	17-22 MS; 47-48 M#; 49-51 MS; 52 MC; 53-54 MS; 55 MC; 56-57 MS; 58-68 MC; 69-2012 RC	REG
	Peace River above Pine River [07FA004]	87,200	79-85 RC; 86 RS; 87-2012 RC	REG
	Peace River near Taylor [07FD002	101,000	44-48 MS; 49 MC; 50-51 MS; 52 MC; 53-54 MS; 55 MC; 56-67 MS; 58-59 MC; 60-2012 RC	REG
	Halfway River near Farrell Creek [07FA006]	9,340	81-82 Level RS; 83 Level RS; 84-93 RC; 95-2012 RC	NAT
	Moberly River near Fort St. John [07FB008]	1,520	80-2012 RC	NAT
Mainstream	Peace 1	na	2002-2009 Level RS	REG
	Peace 2	na	2002-2003 Level RS	REG
	Peace 3	na	2002-2006 Level RS	REG
	Peace 4	na	2002-2003 Level RS	REG
	Peace 5	na	2004-2009 Level RS	REG
NHC	1-3	na	2009-2012 RC	REG
	2-9	na	2009-2012 RC	REG
	3-25	na	2009-2012 RC	REG
	4-29	na	2009-2012 RC	REG
	5-35A	na	2009-2012 RC	REG

REG – Regulated NAT – Natural R – Recording C - Continuous S – Seasonal na – not available

The historical variation in annual maximum daily discharges observed at the four mainstem stream gauging sites is illustrated in Figure 3.4. A comparison of pre- and post-1967 data indicates that regulation has substantially decreased the peak flood magnitudes. Anomalies occurred in 1972 (spillway test, 5,132 to 5,690 cms), 1996 (emergency drawdown, 5,190 to 6,220 cms) and, to a smaller extent, in 1990 (1790 to 5,190 cms) when a spring 'cold low' storm resulted in substantial inflow from streams draining the east side of the Rockies. The magnitude of a sizeable rainfall causing a flood in May 2011 was unknown at the time this analysis was prepared.

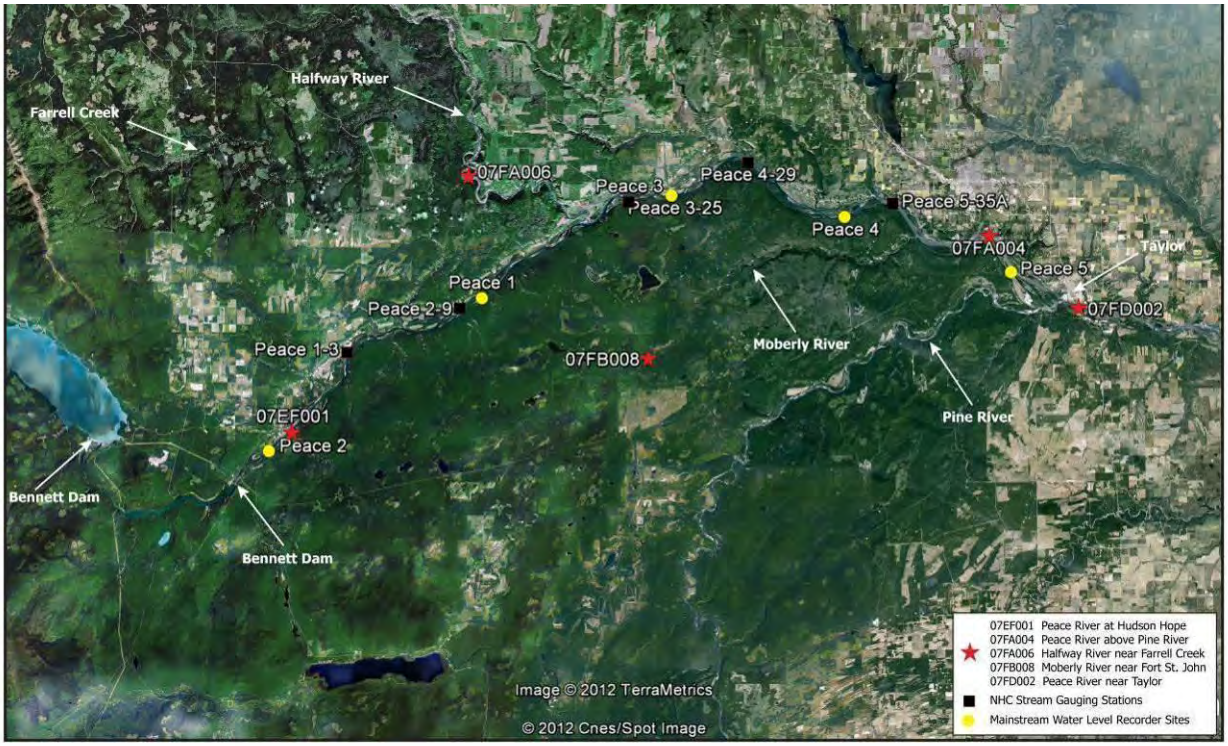

Figure 3.1 Station locations used for assessment of water discharge and water level.

The comparative size of pre- and post-regulation flood flows is as follows:

	Annual Maximum Daily Discharge (cms)					
Location	**Pre-Regulation Range**			**Post-Regulation Range**		
	Low	**Average**	**High**	**Low**	**Average**	**High**
Peace Canyon Dam	n/a	n/a	n/a	1.683	1,918	3,293
Peace R. at Hudson's Hope	4,760	6,165	8,810	1,640	1,927	3,170
Peace R. above Pine River	n/a	n/a	n/a	1,590	2,211	4,040
Peace R. near Taylor	5,380	7,525	11,500	1,820	2,837	5,190

This analysis includes data collected to 2010. Unusual floods in 1972 and 1996 have not been included in this compilation.

The average post-regulation annual maximum daily flow (under the 'normal' operating regime) is therefore approximately 36% of the average pre-regulation value 'at Hudson's Hope' and 45% 'near Taylor'. Stream channel geometry is commonly related to the average (or 2-year return period) flood flow. The documented reduction in flood magnitude provide a basis for estimating the regime dimensions which the Peace River will eventually adopt (see Church, 1995, Ashmore and Church, 2001, Church, in prep. c).

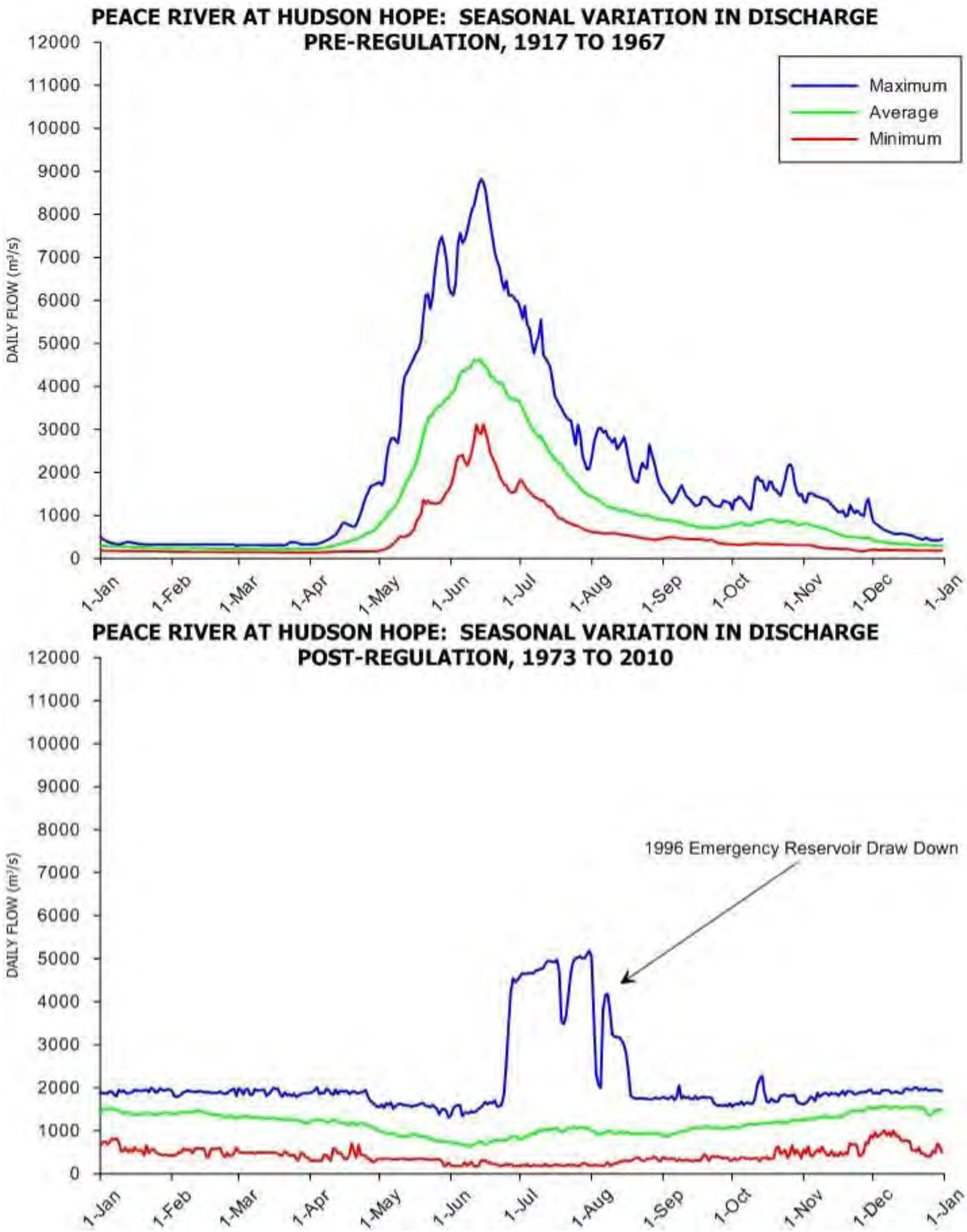

Figure 3.2 Seasonal variation in pre- and post-regulation stream flow data, Peace River at Hudson's Hope.

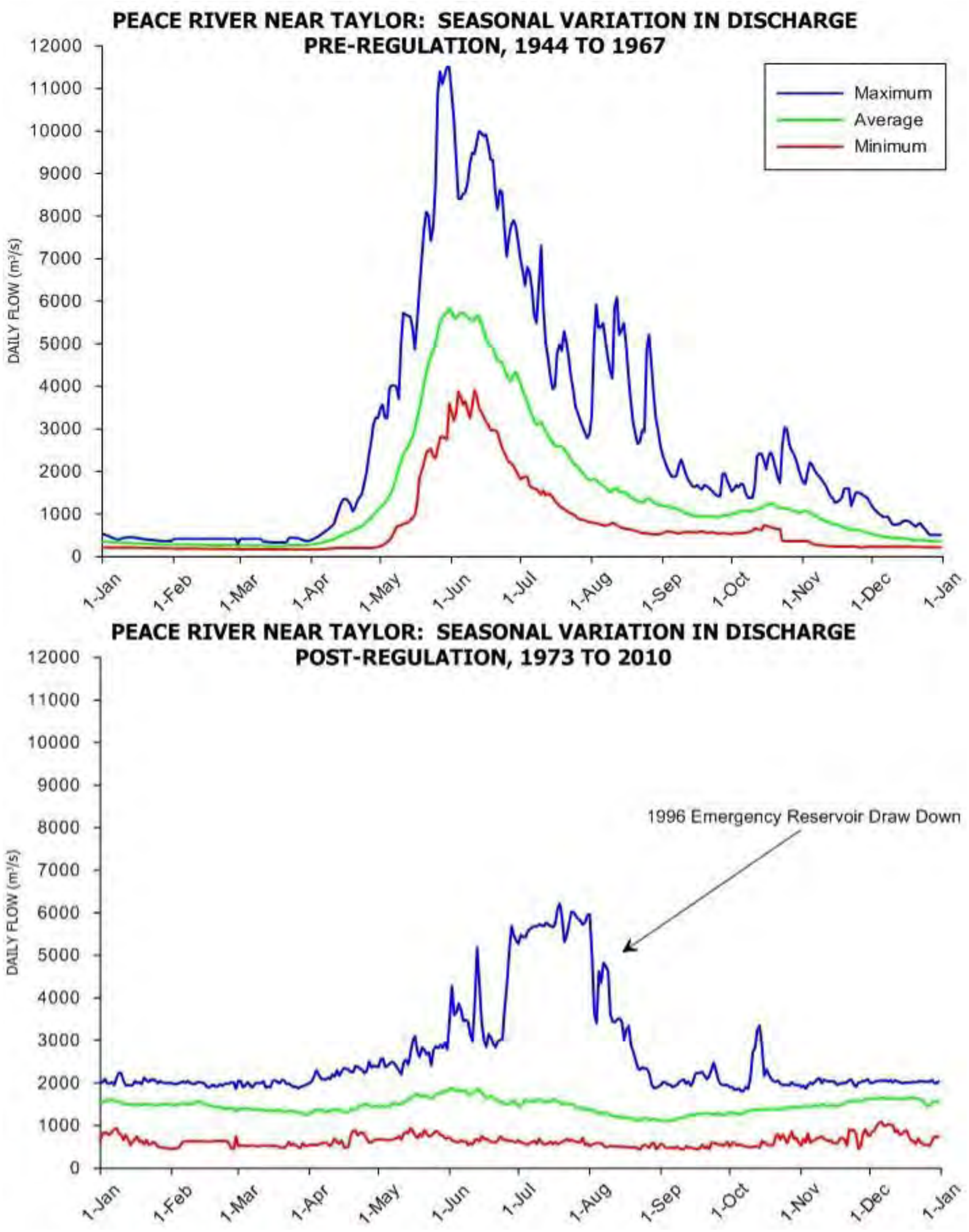

Figure 3.3 Seasonal variation in pre- and post-regulation stream flow data, Peace River near Taylor.

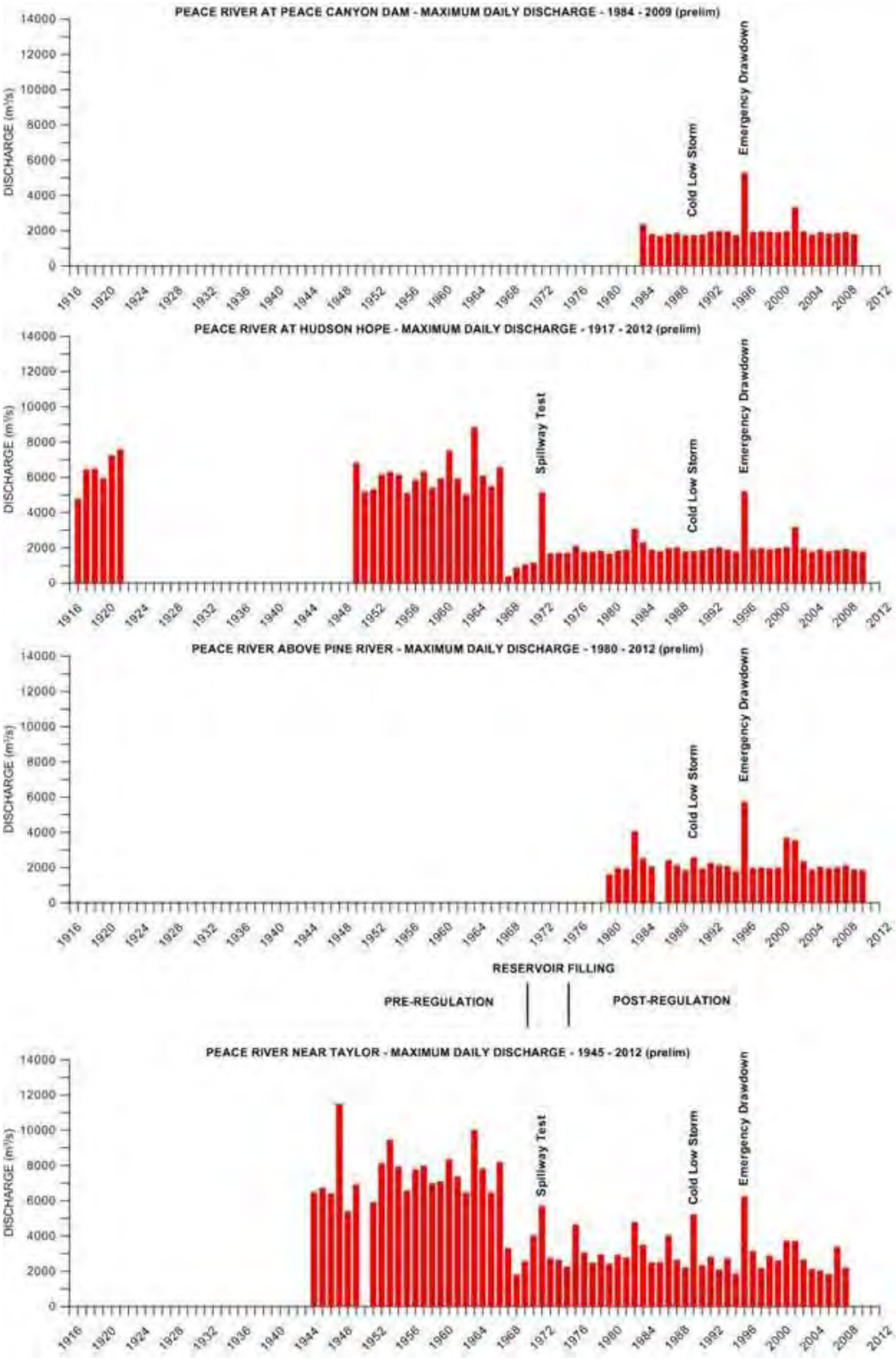

Figure 3.4 Historical variation in annual maximum discharge.

In addition to changing the timing and magnitude of the annual hydrograph, operation of Bennett and Peace Canyon Dams can significantly affect daily variations in water level and discharge. Specifically, on a daily basis, water level and discharge would have changed comparatively slowly prior to construction of Bennett Dam. However, within the regulated regime, mainstem flow releases can vary substantially in response to 'load following' requirements (northwest hydraulic consultants, 2010b). For example, Figure 3.5 illustrates the variations in water level observed between September 2 to 8, 2002, based on data from Mainstreams' four gauges and WSC's 'at Hudson's Hope' and 'near Taylor' stations.

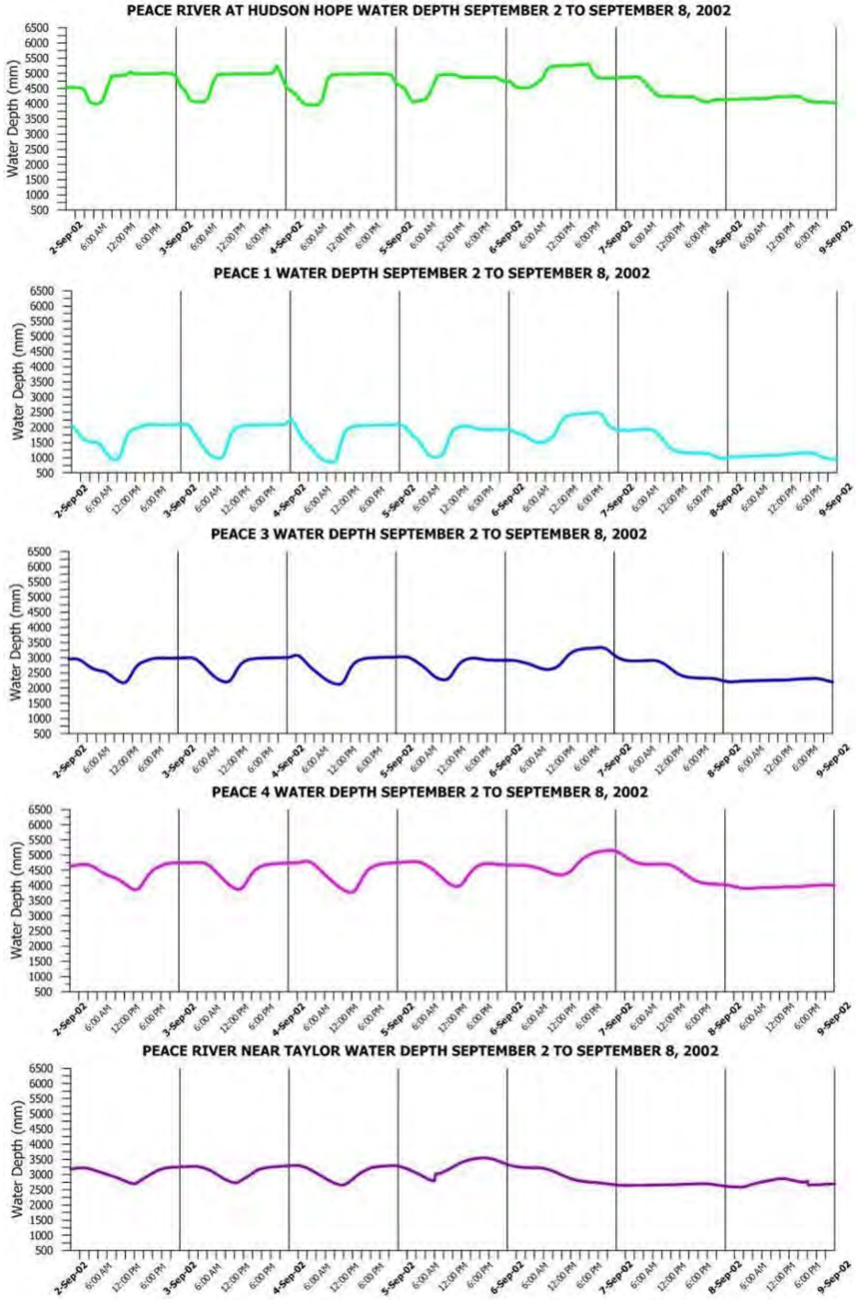

Figure 3.5 Downstream variation in short term changes in water levels as a result of 'load following' power generation on Peace River (data from P&E 2002).

This analysis indicates that daily water level variations can exceed 1.5 m and that rates of change in water level can exceed 0.16 m/hour. The data also illustrate how both the range and rate of change are attenuated as the flood wave passes downstream from Hudson's Hope to Taylor. Readers are referred to the comprehensive discussion of pre- and post-regulation changes in hydrology and water level presented in nhc (2010a, b), Church (in prep., a, b) and Xu and Church (in prep.).

3.1.2 Channel Characteristics

The Peace River has a length of approximately 107 km in the area between Peace Canyon Dam and Taylor. NHC (2010c) indicates that the average water surface slope within this area is 0.0022 m/m. Farrell Creek (basin area 610 km^2), Halfway River (basin area 9,400 km^2), Moberly River (basin area 1,520 km^2) and Pine River (basin area 13,800 km^2) are the four largest tributaries within this area.

The Peace River has generally formed a sinuous channel which is occasionally confined by the valley walls which are up to 250 m in height. The valley flat is discontinuous and ranges up to 1,300 m in width. Hydraulic geometry data collected at the three WSC gauging stations are summarized in Figures 3.6 to 3.8. The wetted river channel width can range between approximately 200 m at low flow and 500 m at high flow. Figures 3.6 to 3.8 also illustrate how average depth, wetted channel area and average velocity vary with discharge at the gauging sites. The WSC data is influenced by pre-regulation winter ice cover and by changes in both measurement location and the river cross-section. Interested readers are referred to Church (in prep., c) for a more complete discussion.

The Peace River frequently contained unvegetated gravel bars or islands prior to regulation (Church and Rood, 1982). Many of these bars are now in varying stages of re-vegetation. Decreased flood flows have also allowed sediment deposition and vegetation growth in former secondary channels. Depending on elevation, secondary channels can be free flowing, seasonally wetted or non-functional. Church and Rood (1982) investigated the post-regulation loss in side channel length between 1967 and 1977 in the area between Hudson's Hope and the Alberta border. The study documented the loss of 128 km of backchannel length (288 to 160 km, a 44% decrease). The braiding index (i.e., thalweg plus backchannel length ÷ thalweg length) also decreased from 3.26 to 2.25. The paper by Ayles and Church (in prep., a) indicates these values "subsequently changed very little" in comparison to the 1982 results. They indicate that the loss of side channels is "the immediate consequence of the elimination of the highest flows" and results from fine textured sediment deposition and vegetation growth (see Teversham and North, 1982; North and Church in prep.). The five flows investigated in this study are representative of the current operating regime.

River bed materials typically consist of gravels and cobbles which are infrequently mobilized in the post-regulation hydrologic regime (Church in prep. b). Bedrock is also locally exposed in the river bed below Peace Canyon Dam.

The major tributaries have formed fans at their confluences with the Peace River. Studies by Ayles (2001) and Ayles and Church (in prep., a) indicate that mainstem aggradation has occurred adjacent to the larger streams (such as the Halfway, Moberly and Pine) in the post-regulation period. However, in some cases, the tributary channels have locally down cut due to the reduced water levels on the Peace River during the freshet period (Ayles and Church, in prep., b). Only limited development activities have occurred along the Peace River. These include local clearing for farming or ranching and the limited construction of bank revetments to protect engineering works, such as boat launches, industrial facilities or transportation infrastructure.

The study area is stratified into four reaches based on differences in Peace River channel characteristics as per designations of RL&L (2001) – Peace Canyon, Hudson's Hope, Halfway River, Pine River (Table 3.2; Figure 1.1).

Table 3.2 Peace River reach characteristics.

Reach	**Km Location**[a]	**Channel Thalweg Length (km)**	**Channel Surface Area**[b] **(ha)**	**Channel Perimeter**[b] **(km)**	**Dominant Bed Material**	**Dominant Feature (s)**
Peace Canyon	0 to 7.3	7.3	251	35	Bedrock	Bedrock sills; Vertical bedrock valley walls
Hudson's Hope	7.3 to 46.6	39.3	1,526	190	Boulder and Cobble	Island complexes; shoals
Halfway River	46.6 to 103.0	56.4	2,235	337	Cobble and Gravel	Multiple island complexes; numerous shoals
Pine River	103.0 to 104.9	1.9	103	22	Gravel	Anthropogenic structures; side channel complexes
Total	-	**104.9**	**4,115**	**584**	-	-

[a] Measured from base of PCN Dam; [b] Generated from target discharge of 1,982 cms.

The Peace Canyon reach is characterized by bedrock dominated bed material and bedrock valley walls (Plate 1). The Hudson's Hope reach (Plate 2) and Halfway River reach (Plate 3) are generally similar, but one difference is the influence of the Halfway River on channel features recorded in the Halfway reach (i.e., numerous island complexes and shoals immediately downstream of the Halfway River confluence). The Pine River reach (Plate 4) is located within the mapped area, and represents a short, 1.9 kilometer section that is located immediately downstream of the formal defined study area (i.e., PCN Dam to Pine River confluence).

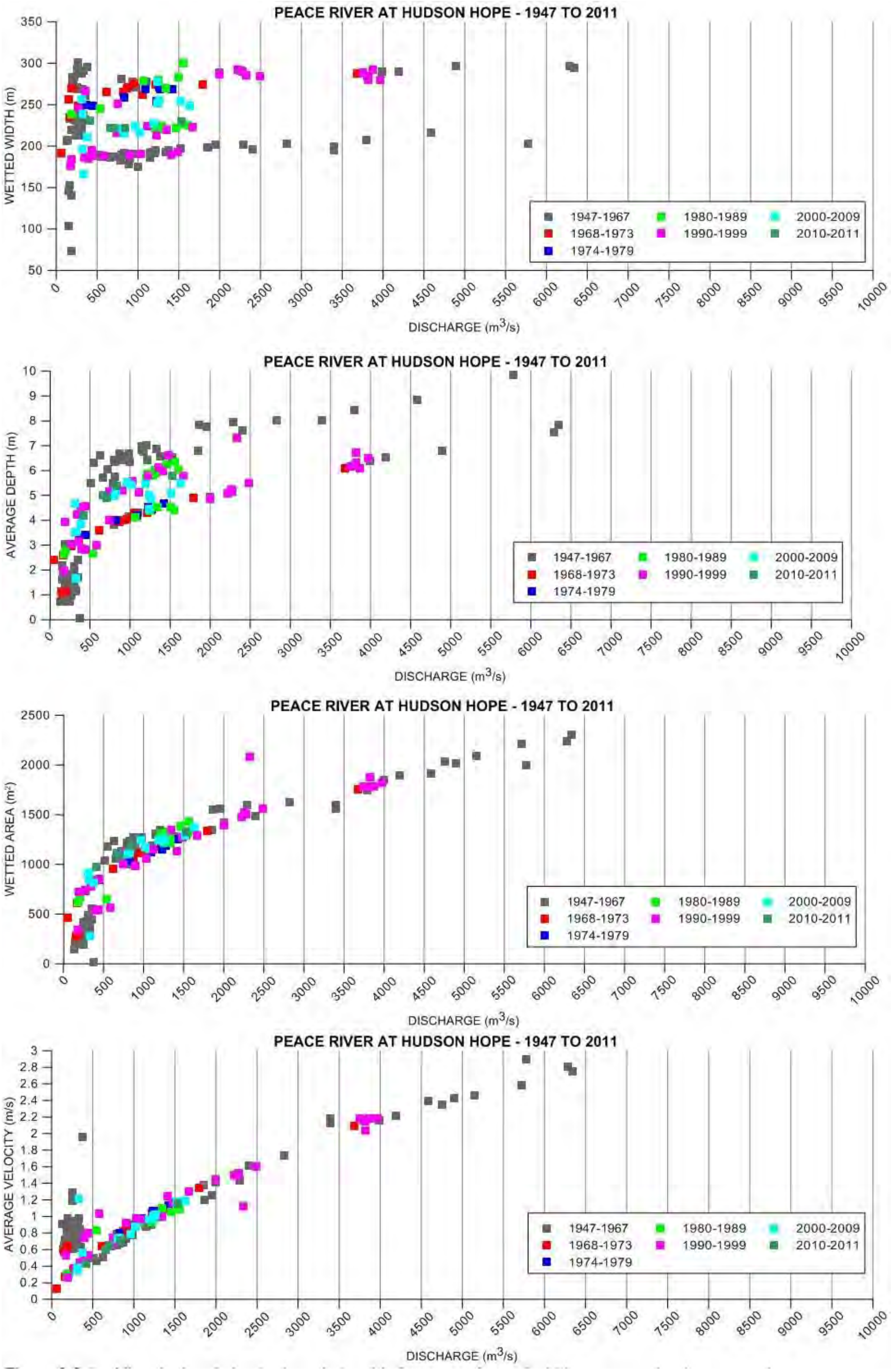

Figure 3.6 Historical variation in the relationship between channel width, average depth, area and average velocity as a function of discharge on the Peace River at Hudson's Hope.

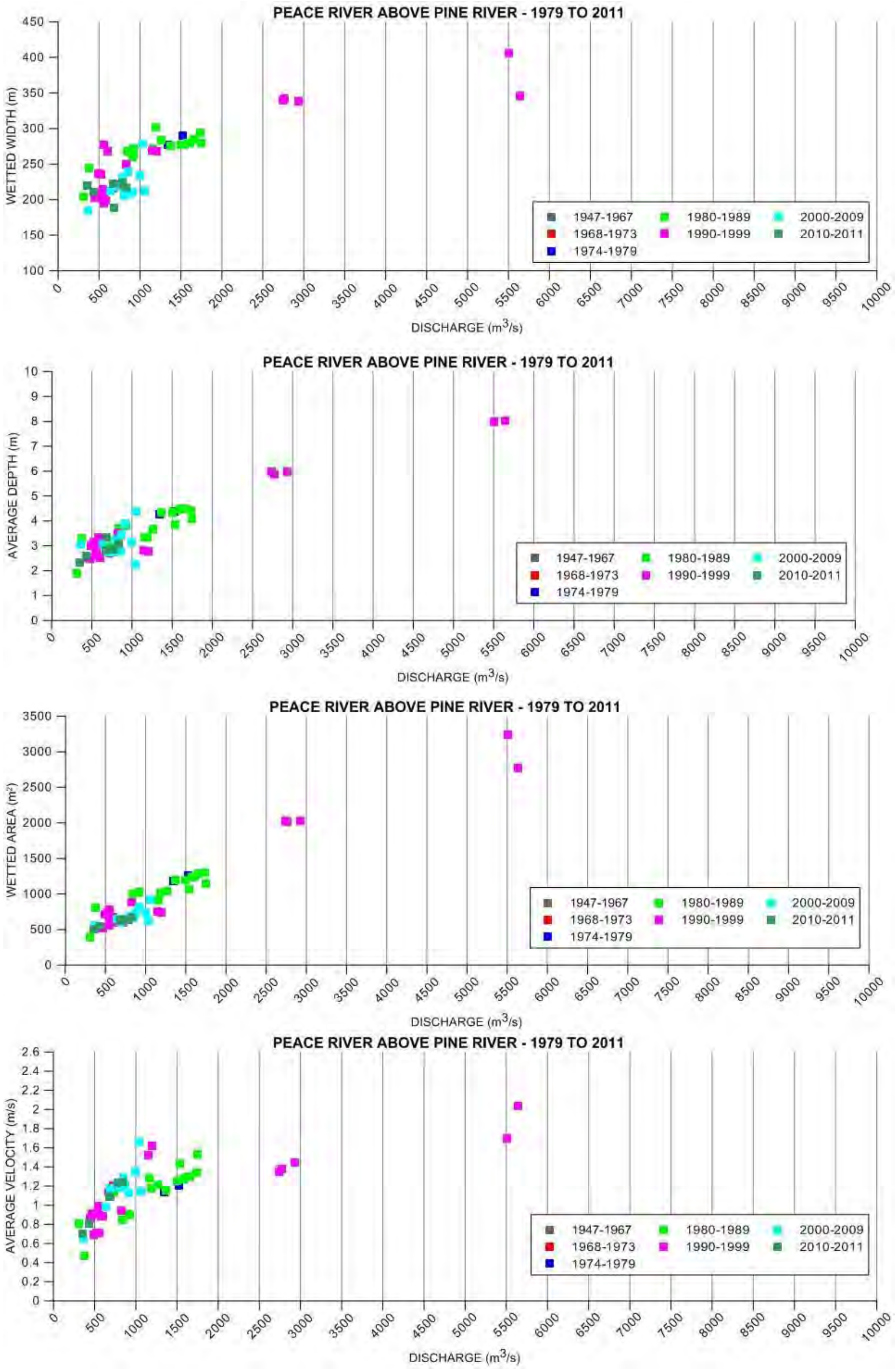

Figure 3.7 Historical variation in the relationship between channel width, average depth, area and average velocity as a function of discharge on the Peace River above the Pine River.

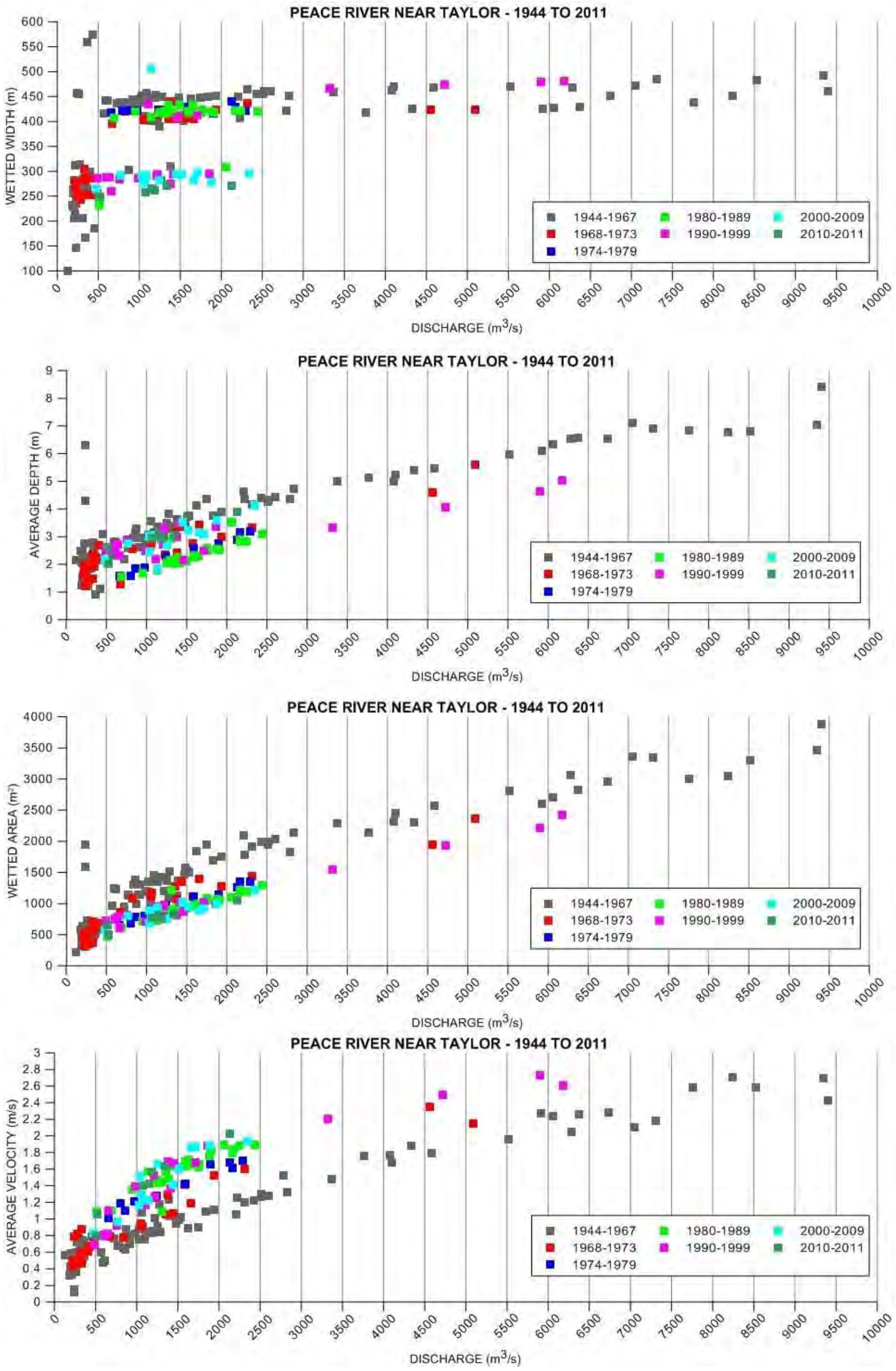

Figure 3.8 Historical variation in the relationship between channel width, average depth, area and average velocity as a function of discharge on the Peace River near Taylor.

The total wetted surface area within the boundaries of the study area is 4,115 ha and the total wetted perimeter is 584 km. The largest surface occurs in the Halfway River reach (2,235 ha, 54%), followed by the Hudson's Hope reach (1,526 ha, 37%), Peace Canyon reach (251 ha, 6%) and the Pine River reach (103 ha, 3%). The total wetted surface area within each reach, as well as channel perimeter, is roughly related to reach length. This pattern was not observed for the short Pine River reach (1.9 km). This is due to the presence of the large Pine River confluence area and several side channel complexes located immediately downstream of the confluence.

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4.0 RESULTS

4.1 HABITAT CLASSIFICATION SYSTEM

The habitat classification system is based on the physical characteristics of the active channel bed and adjacent river banks within the study area. Use of physical characteristics to classify fish habitat was chosen for three reasons. Firstly, fish community investigations on the Peace River indicate that there are differences in species composition, fish abundance, and life stage use based on the physical characteristics of the channel and the river banks (Hildebrand 1990, R&L 2001, P&E 2002, P&E and Gazey 2003, Mainstream and Gazey 2004 to 2012). Secondly, physical characteristics are identifiable on large scale colour air photos. Thirdly, the use of physical characteristics to describe fish habitat allows the quantification of habitat availability within the same habitat unit at different water levels. This system does not incorporate attributes such as water velocity or water depth because changes to these features are not easily identifiable on air photos. Similarly, features such as changes to water clarity caused by tributary inputs have not been considered as they are not in the scope of the study.

The habitat classification system utilizes three levels of habitat characterization (Table 4.1). The first level characterizes the channel type, or spatial location of the habitat unit. The second level characterizes the bank type, or the genesis of the habitat unit (e.g., bedrock, fluvial sediments etc.). The third level characterizes the physical features of the habitat unit that influence utilization by fish.

4.1.1 Channel Type

The channel type, or location parameter, differentiates between ‘Main Channel’, ‘Side Channel – Open or Closed’ and ‘Tributary Confluence’. Side Channels are defined as areas between islands or between an island and the shoreline that represent < 50% of the total river channel width. Side Channels are defined as ‘Open’ if there is an unvegetated connection to the main channel at the upstream and downstream ends indicating regular wetting under the post-regulation flow regime. The Open Side Channel typically exhibits characteristics similar to the Main Channel. A ‘Closed' side channel is only connected via an unvegetated channel to the main channel at the downstream end or exhibits no unvegetated channel connection. The Closed Side Channel typically exhibits characteristics that differ from the Main Channel and Open Side Channel due to the presence of large areas of fine sediment deposition and presence of aquatic vegetation. These areas can provide habitats for fish populations not typically found in main channel and open side channel areas and they are locations that can provide important amphibian habitats.

Table 4.1 Habitat classification system.

Level	**Physical Characteristic**	**Code**	**Type**
Channel		M S C T	Main channel Side channel - open Side channel - closed Tributary confluence
Bank		A F M R V	Anthropogenic Fluvial or terrace bank Mass wasting deposit Bedrock wall Valley wall bank
Habitat	Bed Material	R B C F	Bedrock Boulders Coarse (gravel and cobbles) Fine (>50% sand or finer)
	Near shore slope	L M H	Low Moderate Steep
	Bank Irregularities	I R S	Irregular bank Rough bank Smooth bank
	Cover	B R W V	Backwater Rock Woody debris Non wood vegetation
Isolated Habitat Type		POND	Isolated

‘Tributary Confluence’ areas delineate the fans of intermittent and permanently flowing tributaries that enter the Peace River. They include the immediate deposition zone where the tributary enters the Peace River and the zone immediately downstream that is directly affected by the tributary.

Main, side channel, and tributary confluence types are illustrated in Plates 5 to 8.

4.1.2 Bank Type

The bank type, or material forming the edge of the channel, is initially described based on its genesis. Identified materials include the following:

- Anthropogenic or man-made structures such as rip-rap or bridge abutments;
- Fluvial or Terrace Banks which include recent fluvial deposits, along with both fluvial terrace and glacio-fluvial terrace materials. This category includes periodically inundated bars or shoals;
- Mass Wasting Deposits, consist of material deposited into the river by slope failures from the valley wall;
- Bedrock Walls consist of bedrock exposures that form the edge of the channel or exposed bedrock sills in the river bed; and
- Valley Wall Banks are where the valley wall forms the channel edge.

Representative photographs are presented in Plates 9 to 13.

4.1.3 Habitat Descriptor

The habitat descriptor includes four features that influence fish utilization. These are bed material, near shore bed slope, bank irregularities, and physical cover.

Bed Material

The near shore river bed is described on the basis of the texture of the bed material that can be identified using air photo interpretation. The classification includes:

- fines (>50% sand or finer sediments);
- coarse (>50% gravels or cobbles up to 256 mm in diameter);
- boulder (> 50% boulders >256 mm in diameter); and
- bedrock (> 50% bedrock).

Representative river bed material textures are illustrated in Plates 14 to 17.

Near Shore Slope

The slope of the near shore area has been classified as 'low', 'moderate', or 'steep'. This ranking is subjective and based on visual observations rather than field measurements. Representative near shore slopes are illustrated in Plates 18 to 20.

Bank Irregularities

Irregularities in the river bank have been observed to provide habitat complexity and physical cover. The bank configuration has therefore been defined as 'smooth, 'irregular', or 'rough'. Representative bank irregularity photographs are presented in Plates 21 to 23.

Physical Cover

Physical cover for fish can be provided by local reductions in flow velocities and by roughness elements located within the channel or along the bank. Coded features include 'backwater area', 'rock', 'large woody debris' and 'non-wood vegetation' (aquatic emergent and submergent vegetation). It should be noted that inundated terrestrial vegetation was not delineated during the habitat mapping exercise. Representative photos are presented in Plates 24 to 27.

Isolated Habitat

Changes in water level can, in some circumstances, result in the formation of isolated wetted areas that are coded as 'Pond'. These areas are not fish habitat per se, but represent locations where fish stranding may occur. Representative examples are presented in Plates 28 to 30.

4.2 AERIAL PHOTOGRAPHY

Five sets of aerial photographs representing the five steady state flows were used in this analysis. Completed tasks included conversion of photos, delineation of water lines, and creation of orthophotos. Table 4.2 summarizes the work completed for this study component.

Table 4.2 Summary of tasks completed for aerial photography provided by BC Hydro.

Target Discharge		**No. Photos**	**Raw Photo Conversion**	**Water Line Delineated**	**Orthophoto Development**
Units in CMS	**Units in CFS**				
283	10,000	505	√	√	√
566	20,000	505	√	√	√
991	35,000	506	√	√	√
1,557	55,000	760[a]	√	√	√
1,982	70,000	590[a]	√	√	√

[a] Includes photo coverage of Peace River downstream of study area, which are not part of this project.

4.3 EVALUATION OF DISCHARGE

BC Hydro was responsible for obtaining five sets of aerial photos which could be used to quantify fish habitat characteristics within the area between Peace Canyon Dam and Taylor. The original intent was to fly air photos associated with flows of 10,000, 20,000, 35,000, 55,000, and 70,000 cfs in 2008 and 2009. Ideally, the higher discharge values were to be associated with normal reservoir releases rather than a project specific, non-revenue spill. Conditions suitable for obtaining the higher flow air photos did not occur until 2010 and 2011 and this required a release of water to meet the stream flow objective. As a consequence, some of the released flows were of short duration and it is necessary to determine how the flows varied over the study area during the period when the air photos were taken.

Flight logs were obtained from Selkirk Remote Sensing and Kisik Aerial Survey to determine the dates and times at which the photos were acquired. This information is summarized in Table 4.3 along with the range in flow observed during the photo period at Peace Canyon Dam.

Table 4.3 Air Photo Acquisition Dates and Concurrent Flows at Peace Canyon Dam.

Air Photo Dates	**Contractor**	**Requested Flows**		**Range in Flows at PCN Dam During Air Photo Acquisition (cms)**		
		cfs	**cms**	**Low**	**Average**	**High**
Sep.13, 2009	Selkirk Remote Sensing Ltd.	10,000	283	301	302	303
Sep. 20, 2009	Selkirk Remote Sensing Ltd.	20,000	566	600	601	602
Oct. 26, 2008	Selkirk Remote Sensing Ltd.	35,000	991	969	972	974
Aug. 26, 2011	Aéro-Photo (Kisik Aerial Survey)	55,000	1,557	1,498	1,505	1,513
Aug. 25, 2011	Aéro-Photo (Kisik Aerial Survey)	70,000	1,982	1,642	1,802	1,960

This analysis indicates that the average flows released from Peace Canyon Dam were within 2 to 9% of the desired value.

The air photo acquisition should ideally have occurred under a 'steady' flow condition. Discharge and water level elevation data were therefore obtained from the WSC stream gauging stations Peace River ‘at Hudson’s Hope’, Peace River ‘above Pine River’, and Peace River ‘near Taylor’ to determine how these parameters varied over the study area during the photo period. Stream flow data from the two gauged tributaries, ‘Halfway River near Farrell Creek’ and ‘Moberly River near Fort St. John’ were also analyzed to assess downstream tributary inflows. A large storm affected the Peace River watershed in May 2011 and the WSC technicians were still attempting to verify the August 2011 stream flow data for the WSC ‘at Hudson’s Hope’, ‘above Pine River’, ‘near Taylor’, Halfway, and Moberly stations when this report was prepared in July 2012. Downstream data characterizing stream flow values for the two air photo flights undertaken in 2011 (at nominal flows of 55,000 and 70,000 cfs) were therefore unavailable.

The available water level and stream flow information is compiled in Appendix A and summarized in Tables 4.4 and 4.5.

Table 4.4 Water levels during periods of air photo acquisition.

Photo Acquisition Date and Time	**Water Level Elevation (m geodetic) at**												**Water Level Elevation (m assumed datum) at**					
	Peace Canyon Dam			**Peace River at Hudson's Hope**			**Peace River above Pine River**			**Peace River Near Taylor**			**Halfway River Near Farrell Creek**			**Moberly River Near Fort St. John**		
	Start	**End**	**Avg**	**Start**	**End**	**Avg**	**Start**	**End**	**Avg**	**Start**	**End**	**Avg**	**Start**	**End**	**Avg**	**Start**	**End**	**Avg**
October 26, 2008:11:00 AM to 2:00 PM	461.38	461.39	461.38	451.94	451.95	451.95	407.09	407.10	407.09	402.87	402.87	402.87	0.52	0.52	0.52	1.78	1.78	1.78
Sept 13, 2009: 11:00 AM to 2:00 PM	460.46	460.58	460.52	450.63	450.87	450.75	405.77	405.77	405.77	402.17	402.16	402.16	0.79	0.74	0.77	1.86	1.86	1.86
Sept 20, 2009: 11:00 AM to 2:00 PM	460.93	460.95	460.94	451.35	451.43	451.39	407.05	406.68	406.86	402.42	402.42	402.42	0.67	0.67	0.67	1.84	1.85	1.85
August 25, 2011: 8:00 AM to 2 PM	462.36	461.99	462.17			0.00			0.00			0.00			0.00			0.00
August 26, 2011: 8:00 AM to 4 PM	461.99	461.96	461.98			0.00			0.00			0.00			0.00			0.00

Table 4.5 Discharge during periods of air photo acquisition.

Photo Acquisition Date and Time	**Water Discharge (m³/s)**																	
	Peace Canyon Dam			**Peace River at Hudson's Hope**			**Peace River above Pine River**			**Peace River Near Taylor**			**Halfway River Near Farrell Creek**			**Moberly River Near Fort St. John**		
	Start	**End**	**Avg**	**Start**	**End**	**Avg**	**Start**	**End**	**Avg**	**Start**	**End**	**Avg**	**Start**	**End**	**Avg**	**Start**	**End**	**Avg**
October 26, 2008: 11 AM to 2:00 PM	968.9	974.4	971.6	968.7	975.7	972.2	1005.3	1011.6	1008.4	1034.1	1036.0	1035.0	27.3	27.2	27.3	1.3	1.3	1.3
Sept 13, 2009: 11 AM to 2:00 PM	300.9	303.3	302.1	304.0	302.0	303.0	367.0	367.0	367.0	407.0	400.0	403.5	47.3	47.1	47.2	3.8	3.8	3.8
Sept 20, 2009: 11 AM to 2:00 PM	601.9	599.7	600.8	606.0	644.0	625.0	650.0	649.0	649.5	617.0	617.0	617.0	40.2	39.8	40.0	3.4	3.6	3.5
August 25, 2011: 8 AM to 2 PM	1941.5	1642.4	1791.9			0.0	2145.2	2047.4	2096.3			0.0			0.0			0.0
August 26, 2011: 8 AM to 4 PM	1512.5	1497.8	1505.1			0.0			0.0			0.0			0.0			0.0

The data indicates that, with the exception of the August 25, 2011 planned 1,982 cms (70,000 cfs) discharge, all stream flow values were held constant at Peace Canyon Dam over the photo period. Similarly, flows at downstream gauging sites were relatively constant over the photo period in 2008 and 2009 (2011 data is presently unavailable). The change in discharge at Peace Canyon Dam on August 11, 2011 occurred in the last hour of the 9 hour photo period and is therefore expected to have limited effect.

Inspection of the data in Appendix A (which are based on observations at 15 minute or 1 hour intervals during the period of air photo acquisition) indicates that flows increased downstream of Peace Canyon Dam due to tributary inflow. The magnitude of this effect is indicated in Table 4.6.

Table 4.6 Downstream changes in stream flow during the period of air photo acquisition.

Air Photo Date	**Requested Flow**		**Average Discharge (cms)**				**Maximum Increase in Discharge**	
	cfs	**cms**	**Peace Canyon Dam**	**At Hudson's Hope**	**Above Pine River**	**Near Taylor**	**cms**	**%**
Sep. 13, 2009	10,000	283	302	303	367	404	102	34
Sep. 20, 2009	20,000	566	601	625	650	617	49	8
Oct. 26, 2008	35,000	991	972	972	1,008	1,035	63	6
Aug. 26, 2011	55,000	1,557	1,505	na	na	na	na	na
Aug. 25, 2011	70,000	1,982	1,802	na	na	na	na	na

4.4 FISH HABITATS

The summaries presented in this section are calculated from digital maps that delineate wetted surface area and habitat types at each of the five target discharges of 283 cms, 566 cms, 991 cms, 1,557 cms, and 1,982 cms. Addendum A includes digital maps that delineate individual habitat unit polygons. Addendum B includes digital maps that delineate habitat unit polygon surface area at each target discharge. Descriptions of methods and assumptions used for calculations are presented in Section 2.5.

4.4.1 Channel Type

The number, surface area, and perimeter of channel types available to fish differed between reaches (Table 4.7). The number of side channel zones, which include one or more individual side channels, was highest in the Halfway River reach with 11 open side channel and 12 closed side channel zones. Within the Hudson's Hope reach, 7 and 4 open and closed side channel zones were recorded, respectively. The highest number of tributary confluences, which included permanent and intermittent streams, was recorded in the Hudson's Hope (n = 17) and the Halfway River reaches (n = 16). Closed side channels were absent in the Peace Canyon reach and open side channels were not recorded in the Pine River reach.

Table 4.7 Summary of channel zone characteristics.

Reach	Channel Type	Number[a]	Surface Area (ha)	Perimeter (km)
Peace Canyon	Main Channel	1	202.0	20.8
	Open Side Channel	2	48.4	14.1
	Closed Side Channel	0		
	Tributary Confluence	1	0.2	0.2
	Total	*4*	*250.6*	*35.1*
Hudson's Hope	Main Channel	1	1,127.7	92.6
	Open Side Channel	7	282.6	56.4
	Closed Side Channel	4	95.1	28.8
	Tributary Confluence	17	20.3	11.9
	Total	*29*	*1,525.7*	*189.7*
Halfway River	Main Channel	1	1,694.7	149.9
	Open Side Channel	11	306.3	82.7
	Closed Side Channel	12	154.8	75.4
	Tributary Confluence	16	79.3	28.8
	Total	*40*	*2,235.2*	*336.9*
Pine River	Main Channel	1	52.1	6.3
	Open Side Channel	0		
	Closed Side Channel	1	15.4	9.2
	Tributary Confluence	1	35.0	6.4
	Total	*3*	*102.5*	*21.9*

[a] For side channel type (open and closed) the number represents zones that contains one or more individual units.

Main channels accounted for the largest percentage of surface area within each reach (Figure 4.1; 51% to 81%). Open side channels are second in importance in three of the four reaches (19% to 14). Closed side channels and tributary confluences comprised < 15% of most reaches. In the Pine River reach, closed side channels and tributary confluences (i.e., Pine River confluence) accounted for 15% and 34% of the total surface area, respectively.

4.4.2 Bank Type

Bank type length differed by reach and channel type (Table 4.8, Figure 4.2). Anthropogenic bank types were not a significant component of any reach. In three of four reaches, fluvial and terrace bank was the dominant bank type - 118.2 km in Hudson's Hope, 259.1 km in Halfway River, and 15.2 km in Pine River reaches. Bedrock wall was the dominant bank type in the Peace Canyon reach followed closely by fluvial or terrace bank (16.6 km and 14.5 km, respectively). Bedrock walls were only observed in the Peace Canyon reach (16.6 km) and a small section of the Hudson's Hope reach (5.4 km). Valley wall was second in importance to the fluvial and terrace bank type in the Hudson's Hope reach and the Halfway River reach (36.7 km and 41.9 km, respectively).

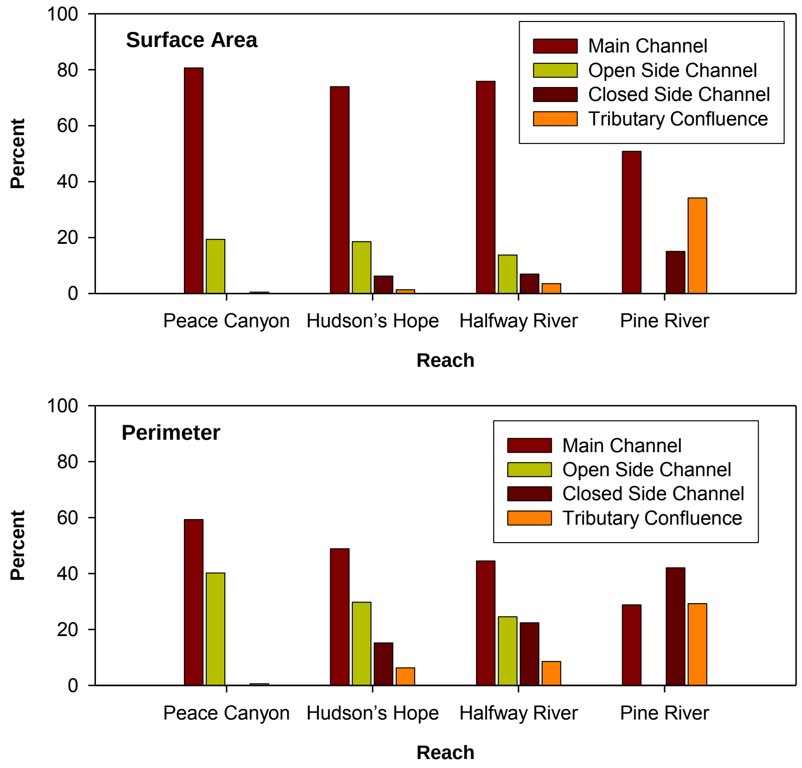


Figure 4.1 Percent surface area and perimeter of channel zones in study area reaches.

Table 4.8 Summary of bank type lengths.

Reach	**Zone**	**Length (km)**				
		Anthropo-genic	**Fluvial or Terrace Bank**	**Mass Wasting Deposit**	**Bedrock Wall**	**Valley Wall**
Peace Canyon	Main Channel	0.8	6.8		11.2	
	Open Side Channel		7.6		5.4	
	Closed Side Channel	0				
	Tributary Confluence		0.1			
	Total	*0.8*	*14.5*	*0.0*	*16.6*	*0.0*
Hudson's Hope	Main Channel	0.5	47.9	3.1	4.8	24.6
	Open Side Channel		37.4	0.1	0.6	11.9
	Closed Side Channel		26.8	0.1		0.2
	Tributary Confluence		6.1			
	Total	*0.5*	*118.2*	*3.3*	*5.4*	*36.7*
Halfway River	Main Channel	0.1	103.2	1.3		28.8
	Open Side Channel	0.1	67.1	0.1		9.3
	Closed Side Channel		66.5			3.6
	Tributary Confluence	0.0	22.3	0.0		0.2
	Total	*0.2*	*259.1*	*1.4*	*0.0*	*41.9*
Pine River	Main Channel	2.4	1.1			0.3
	Open Side Channel					
	Closed Side Channel		9.1			
	Tributary Confluence		5			
	Total	*2.4*	*15.2*	*0.0*	*0.0*	*0.3*

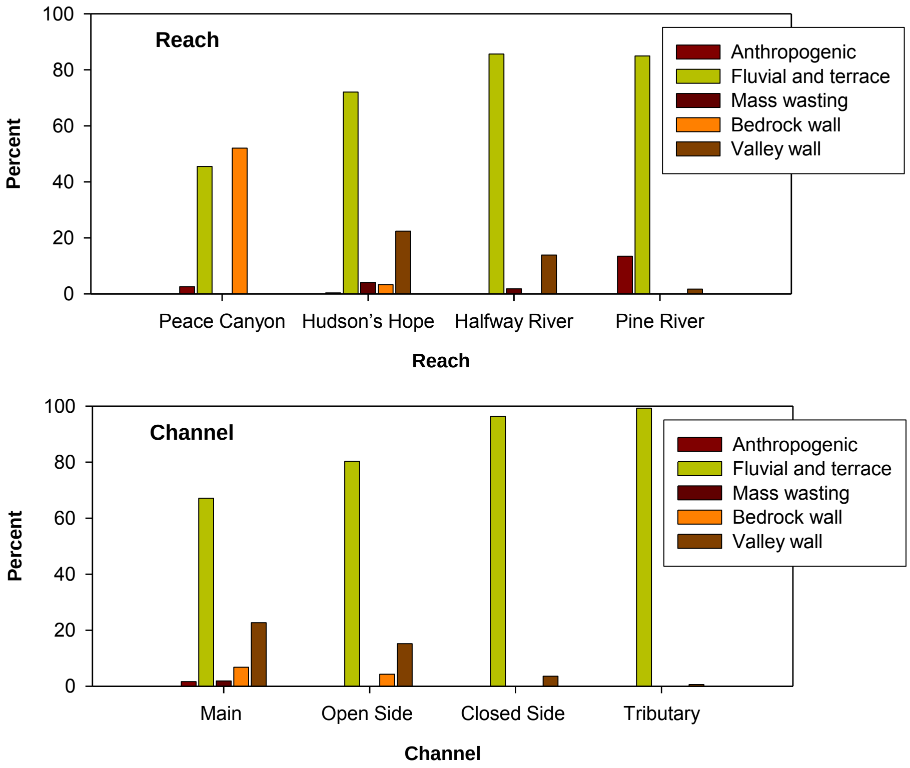


Figure 4.2 Percent length of bank type by reach and channel type.

4.4.3 Habitat Polygons

In total 1,185 habitat polygons representing 1,182.6 ha were recorded in the study area (Table 4.9, Appendix B, Addendum A). The number and surface area of habitat polygons varied by reach and channel type. The differences followed the amount of total wetted surface area available (see Table 4.7). The highest number and largest surface area of habitat polygons were recorded in the Hudson's Hope and Halfway River reaches.

Habitat polygons represent the portion of the Peace River river channel that is potentially influenced by BC Hydro operational discharge between the minimum 283 cms and maximum 1,982 cms target study flows. This information can therefore be used to identify reaches and channel types most affected by the operational flow regime.

The total area of habitat polygons (1,183 ha) represented 29% of the total available habitat (4,115 ha) within the study area. However, there are large spatial differences in habitat values. The data are summarized in Figure 4.3 and illustrations of surface area difference at each target flow for representative channel types are presented in Figures 4.4 to 4.7.

Table 4.9 Number and surface area of mapped habitat polygons.

Reach	**Channel Type**	**Number**	**Surface Area (ha)**
Peace Canyon	Main Channel	95	33.6
	Open Side Channel	37	20.1
	Closed Side Channel	0	0.0
	Tributary Confluence	1	0.2
	Total	*133*	*53.9*
Hudson's Hope	Main Channel	229	234.3
	Open Side Channel	146	127.5
	Closed Side Channel	11	72.5
	Tributary Confluence	34	13.7
	Total	*420*	*448.0*
Halfway River	Main Channel	346	355.1
	Open Side Channel	184	141.2
	Closed Side Channel	40	96.7
	Tributary Confluence	36	53.2
	Total	*606*	*646.3*
Pine River	Main Channel	19	3.1
	Open Side Channel	0	0.0
	Closed Side Channel	4	10.4
	Tributary Confluence	3	21.0
	Total	*26*	*34.4*
Overall Total		**1,185**	**1,182.6**

Changes in the main channel habitat were least affected by variations in discharge over the investigated range of flows. The data indicate that the area of available habitat varied by 6% in the Pine River reach to 21% in the Halfway River reach. The percentage of affected area was much higher for open side channels and ranged between 42% and 46%. The percentage of change in area of closed side channels was greater than for open side channels and varied between 63% and 76%. The affected area of tributary confluences also was high and ranged between 60% and 91%. These results demonstrate the large effect of post-regulation changes in discharge on the area of fish habitats.

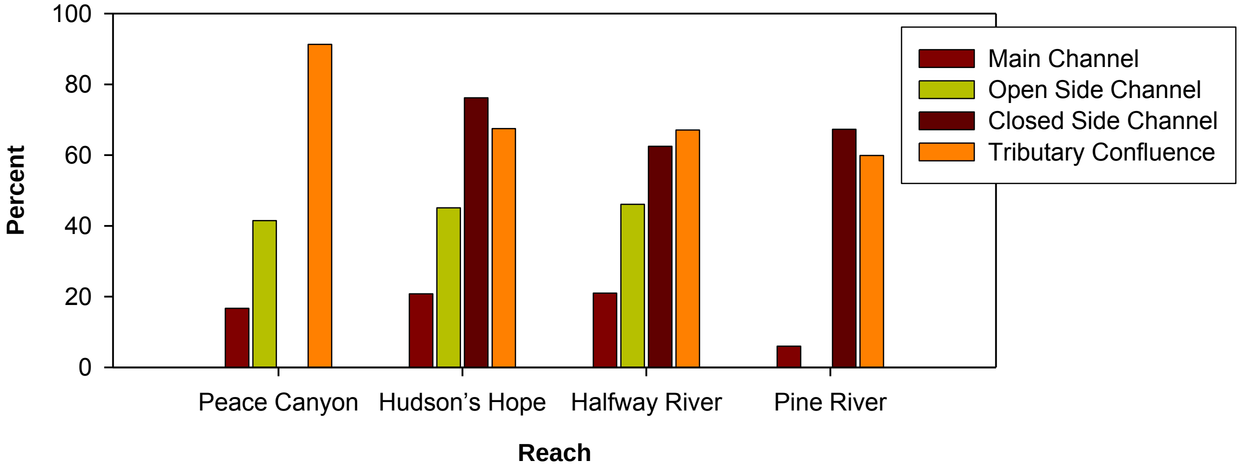


Figure 4.3 Percentage of available habitat area influenced by BC Hydro discharge operations.

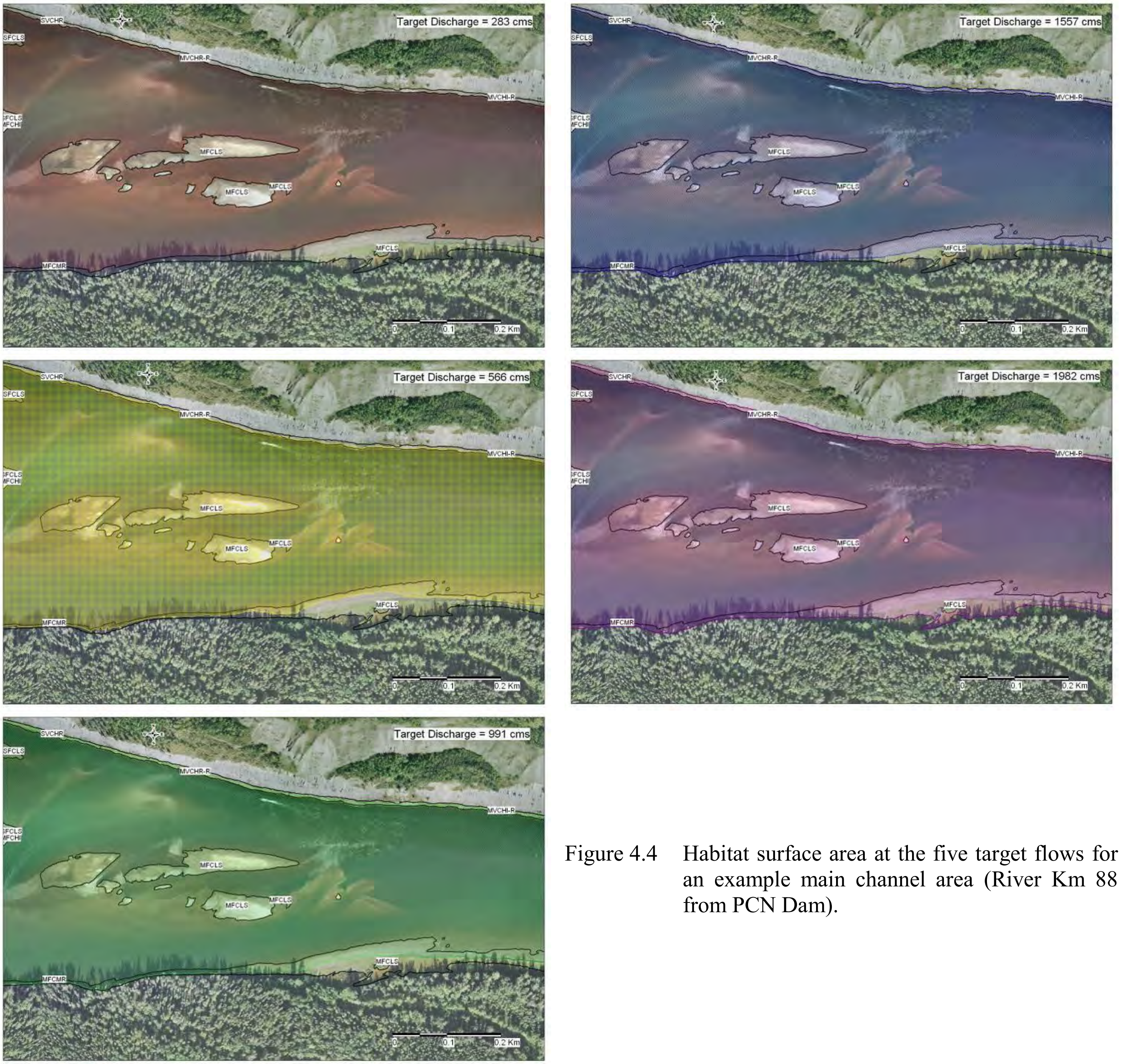


Figure 4.4 Habitat surface area at the five target flows for an example main channel area (River Km 88 from PCN Dam).

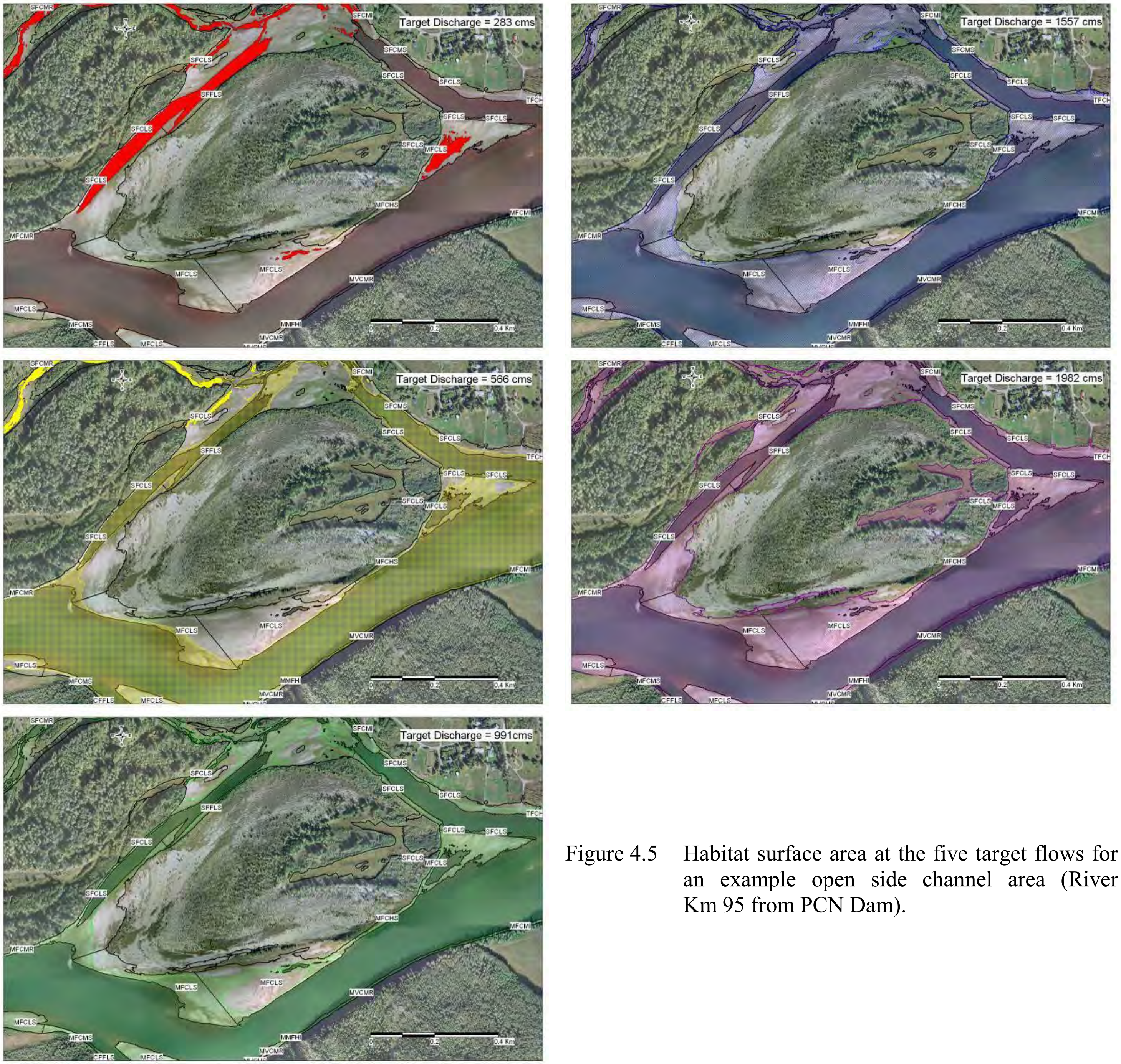


Figure 4.5 Habitat surface area at the five target flows for an example open side channel area (River Km 95 from PCN Dam).

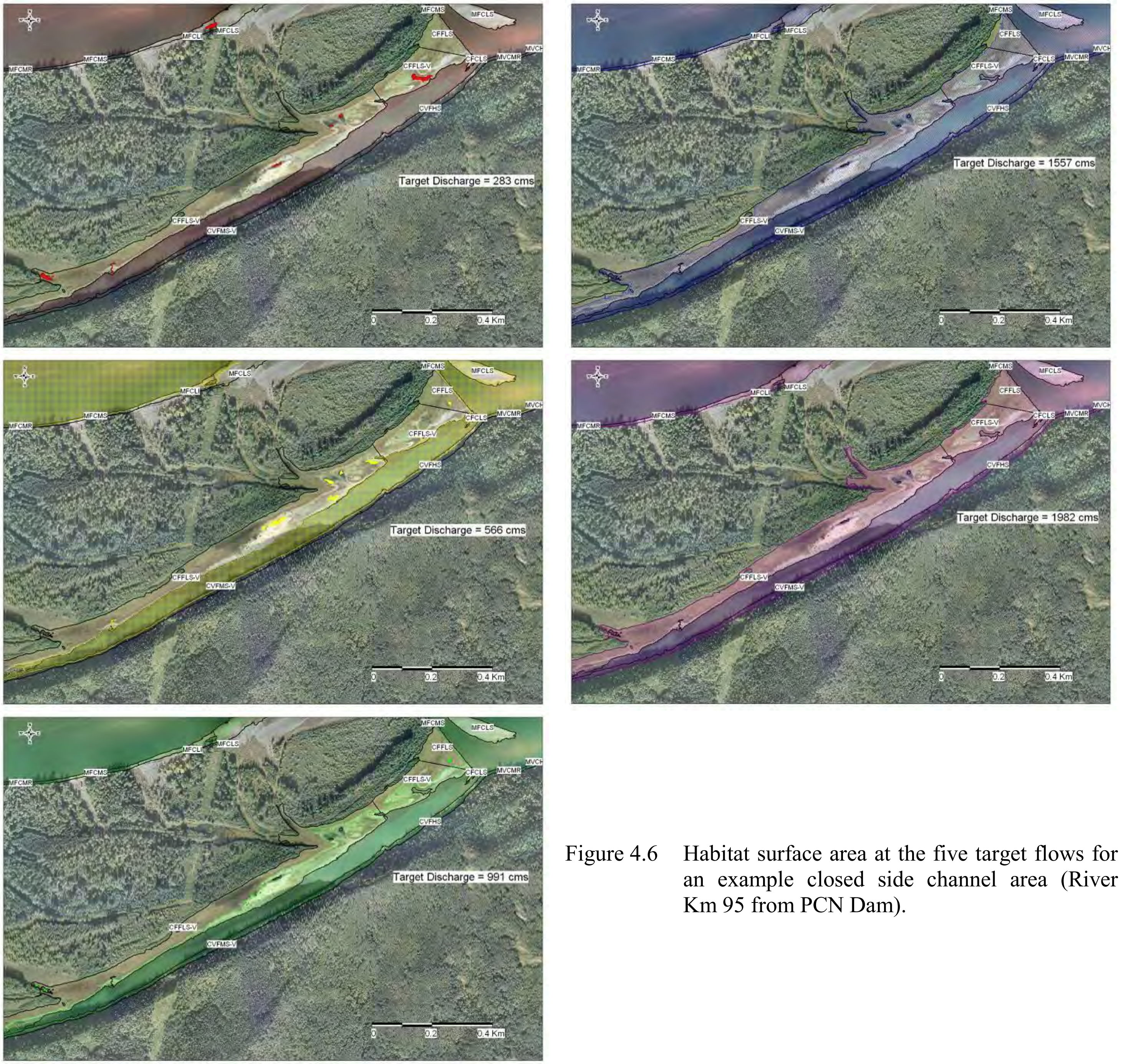


Figure 4.6 Habitat surface area at the five target flows for an example closed side channel area (River Km 95 from PCN Dam).

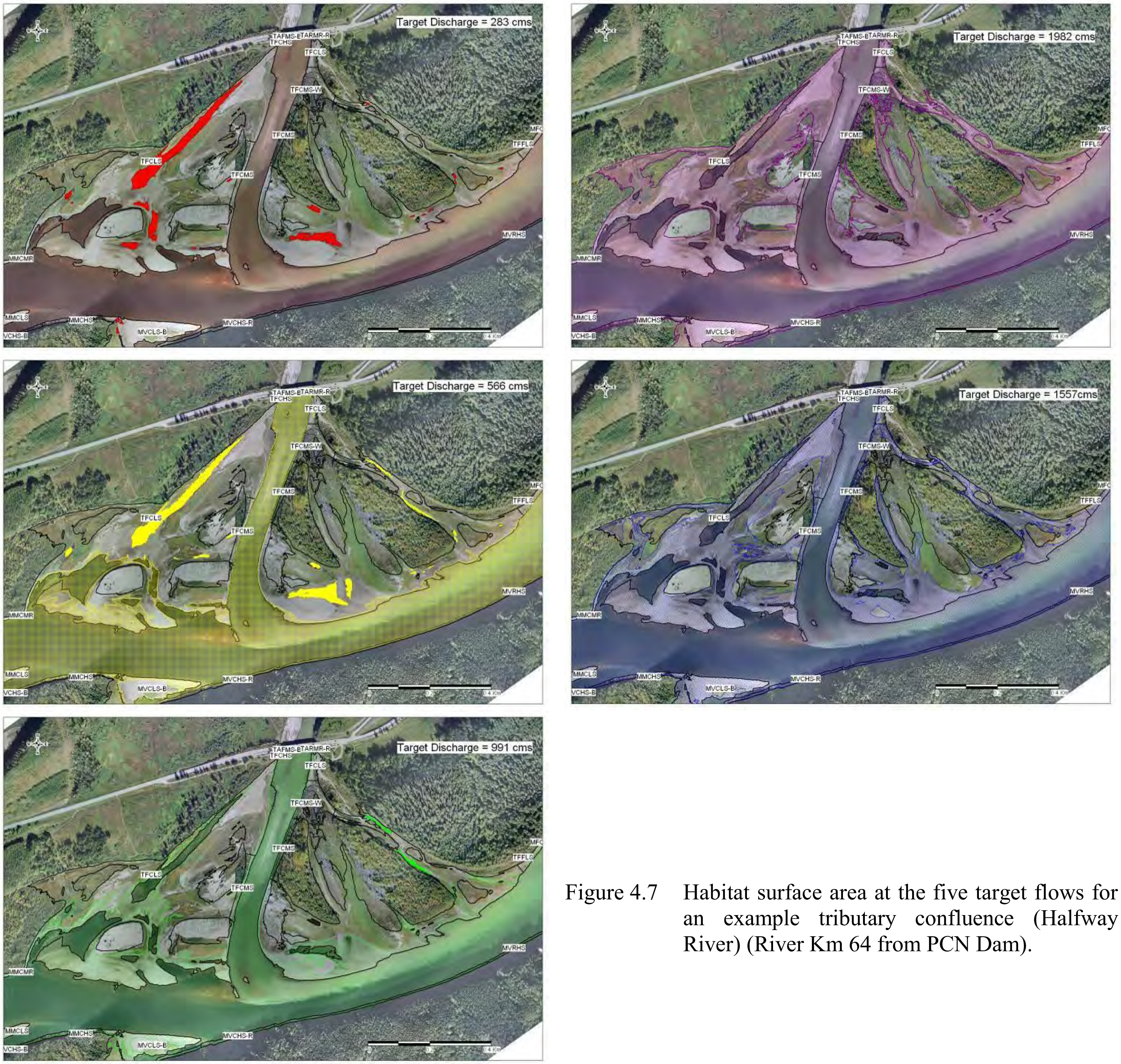


Figure 4.7 Habitat surface area at the five target flows for an example tributary confluence (Halfway River) (River Km 64 from PCN Dam).

4.4.4 Habitat Types

Habitat polygons were represented by 79 combinations of the four descriptors used in the habitat classification system - bed material type, bank slope, bank configuration, and physical cover. The numerical contribution of each descriptor is presented in Table 4.10. The surface area contribution for each descriptor, expressed in terms of percent of total habitat, is summarized in Figures 4.8 to 4.11.

The frequency of occurrence of a habitat polygon feature did not always reflect the surface area of that feature. For example, polygons having a high foreshore slope were numerically prominent in the Peace Canyon reach (n = 40), but accounted for only 11% of habitat polygon surface area. This is because the surface area available for dewatering would be much less in a high slope habitat compared to low slope habitat.

The summaries indicated some general patterns. Coarse bed material, low foreshore slope, smooth bank, and absence of physical cover were the dominant habitat polygon features in all reaches. These characteristics also dominated in main channel and open side channel areas.

There were exceptions to the general pattern. Bedrock and boulders were important bed material types in the Peace Canyon reach. The apparent importance of boulders in the Pine River reach was caused by a substantial amount of rip rap (anthropogenic bank type; see Section 4.1). Closed side channels, and to a lesser extent tributary confluences, contained substantive areas of fine bed materials. These are indicative of areas where active sediment deposition is occurring. Tributary confluences tended to have a larger amount of rough and irregular bank configurations combined with the rock cover type compared to other channel types. This reflects the deposition zones which are present at the mouths of most Peace River tributaries. Aquatic vegetation, which included submergent and emergent forms, was a prominent cover type only in closed side channels.

Table 4.10 Numerical contribution of habitat polygon descriptors.

		Bed Material				**Bed Slope**			**Bank Irregularities**			**Cover**				
Reach	**Channel**	**Fines**	**Coarse**	**Boulder**	**Bedrock**	**Low**	**Moderate**	**High**	**Smooth**	**Rough**	**Irregular**	**None**	**Backwater**	**Rock**	**LOD**	**Vegetation**
Peace Canyon	Main	1	28	12	54	42	13	40	74	5	16	48	6	40	1	
	Open Side	0	18	3	16	14	12	11	30	3	4	26	2	7	2	
	Closed Side															
	Tributary	0	1	0	0	1	0	0	1	0	0	0	1	0	0	
	Total	*1*	*47*	*15*	*70*	*57*	*25*	*51*	*105*	*8*	*20*	*74*	*9*	*47*	*3*	*0*
Hudson's Hope	Main	13	200	6	10	72	133	24	149	69	11	171	16	32	10	0
	Open Side	14	122	0	10	71	66	9	109	34	3	113	11	15	6	1
	Closed Side	4	6	1	0	7	3	1	10	1	0	5	2	1	0	3
	Tributary	16	18	0	0	22	11	1	22	10	2	22	5	5	2	0
	Total	*47*	*346*	*7*	*20*	*172*	*213*	*35*	*290*	*114*	*16*	*311*	*34*	*53*	*18*	*4*
Halfway River	Main	51	286	5	4	163	125	58	249	70	27	283	14	28	21	0
	Open Side	31	152	1	0	102	66	16	144	35	5	157	3	9	14	1
	Closed Side	26	14	0	0	31	6	3	40	0	0	24	1	0	1	14
	Tributary	12	22	0	2	11	16	9	22	11	3	29	3	2	2	0
	Total	*120*	*474*	*6*	*6*	*307*	*213*	*86*	*455*	*116*	*35*	*493*	*21*	*39*	*38*	*15*
Pine River	Main	2	11	6		4	10	5	16	2	1	12	3	3	1	0
	Open Side															
	Closed Side	2	2	0		4	0	0	4	0	0	2	0	0	0	2
	Tributary	2	1	0		2	0	1	3	0	0	2	0	0	1	0
	Total	*6*	*14*	*6*	*0*	*10*	*10*	*6*	*23*	*2*	*1*	*16*	*3*	*3*	*2*	*2*

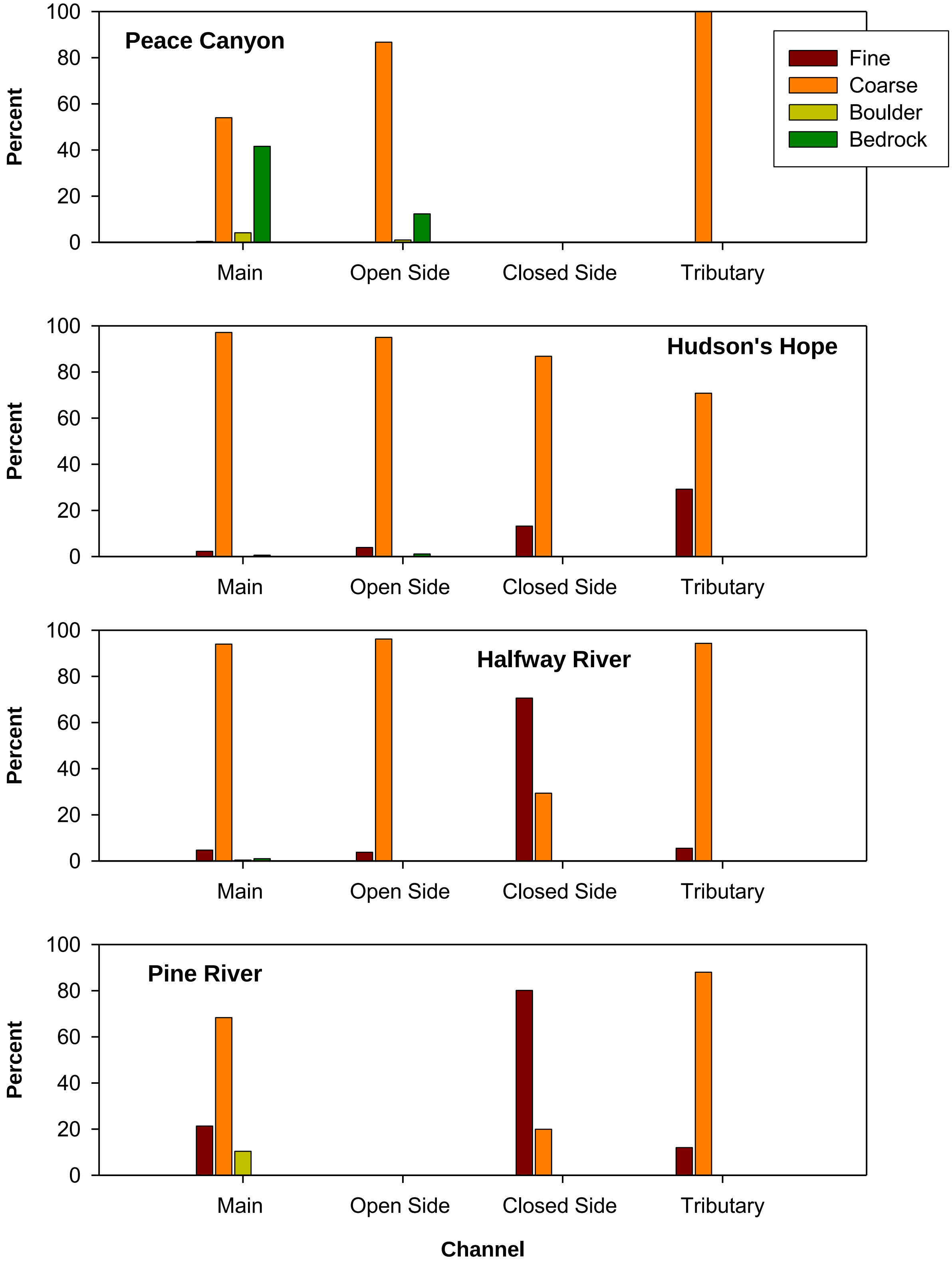


Figure 4.8 Percent contribution by surface area of habitat polygon bed material types by reach and channel type.

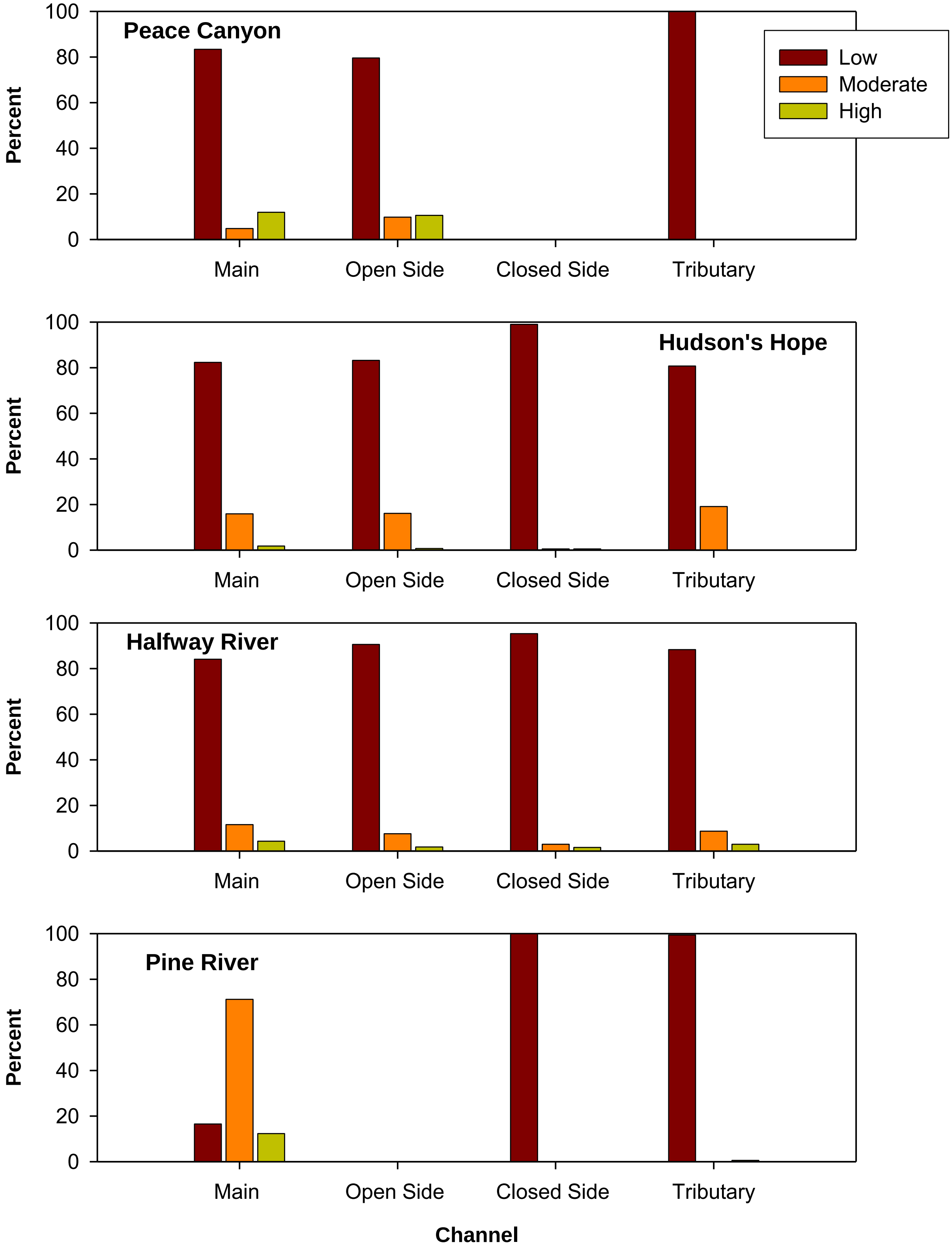


Figure 4.9 Percent contribution by surface area of habitat polygon slope type by reach and channel type.

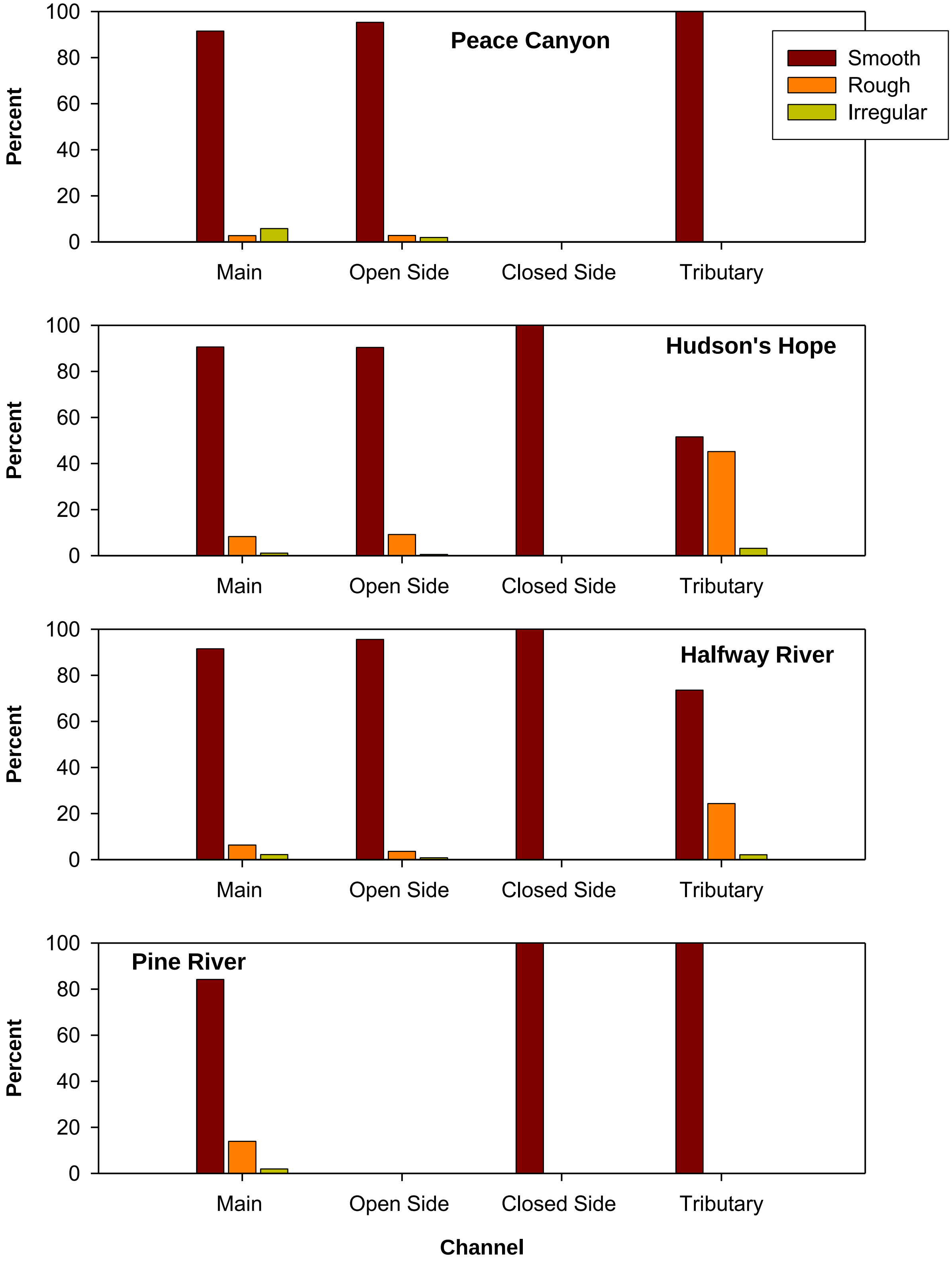


Figure 4.10 Percent contribution by surface area of habitat polygon bank irregularity type by reach and channel type.

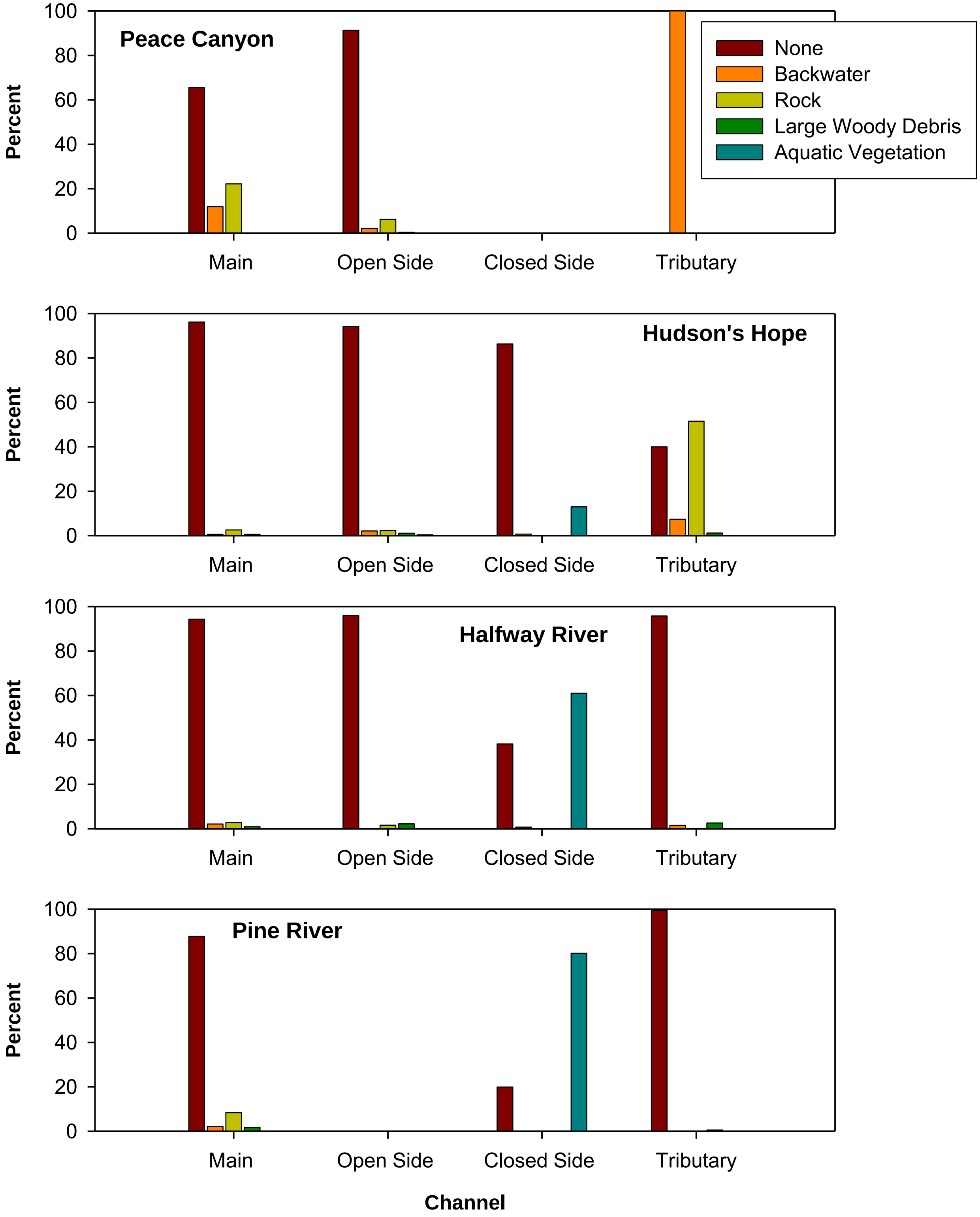


Figure 4.11 Percent contribution by surface area of habitat polygon cover type by reach and channel type.

4.5 HABITAT MODELS

In most cases, habitat models were found to follow a power function or a modification to the power function (i.e., shifted power, logistic power, and modified power). In a few cases, the power function was a poor fit to the data (i.e., $r^2 < 0.9$) and alternative fits are recommended such as the modified exponential, Weibull and rational models. The coefficient of determination (or r^2 value) multiplied by 100, indicates the percentage of the variability between the dependent and independent variables which is explained by the developed equation. Model functions are described below where habitat area is in square metres; a, b and c are model parameters; and x is the flow (cfs):

Power

$$Habitat\ Area = ax^{b}$$

Shifted Power

$$Habitat\ Area = a(x-b)^{c}$$

Logistic Power

$$Habitat\ Area = \frac{a}{\left(1+\left(\frac{x}{b}\right)^{c}\right)}$$

Modified Power

$$Habitat\ Area = ab^{x}$$

Modified Exponential

$$Habitat\ Area = ae^{b/x}$$

Weibull Model

$$Habitat\ Area = a - be^{-cx^{d}}$$

Rational Model

$$Habitat\ Area = \frac{a+bx}{1+cs+dx^{2}}$$

Exponential

$$Habitat\ Area = ax^{b}$$

4.5.1 Hydraulic Habitat Model for the Study Area

The available hydraulic habitat, considering all habitat units, in the study reach is estimated by the equation:

$$Habitat\ Area\ (sq.m) = 7.93x10^{5}x^{0.31}$$ ($r^2 = 0.998$)

Where: x is flow rate (cfs)

The model is shown in Figure 4.12.

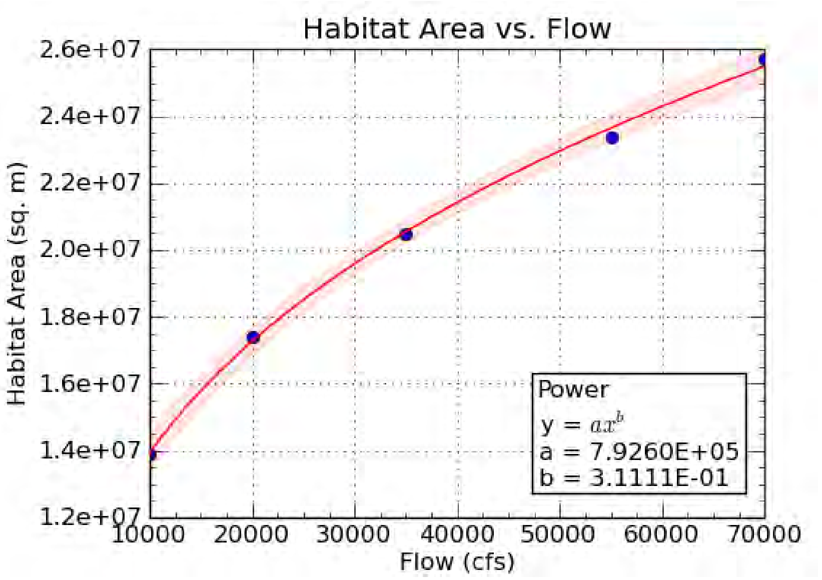


Figure 4.12 Hydraulic habitat model for the study reach. Data points are represented by dots, function by red line and pink bands are the 95% confidence area.

The results demonstrate a strong relationship between habitat surface area and discharge. This pattern was consistent at all scales investigated.

4.5.2 Hydraulic Habitat Model by Reach

Models describing the hydraulic habitat area in different river reaches are described in Table 4.11. The models are shown in Figure 4.13 (Peace Canyon), Figure 4.14 (Hudson's Hope), Figure 4.15 (Halfway River), and Figure 4.16 (Pine River).

Table 4.11 River Reach Hydraulic Habitat Models.

Reach	**Model Type**	**Model Parameters**				r^2
		a	**b**	**c**	**d**	
Peace Canyon	Power	97,677.77	0.24			1.000
Hudson’s Hope	Power	202,248.45	0.34			0.997
Halfway River	Power	517,097.08	0.30			0.998
Pine River	Modified Power	346,920.97	1.00			0.975

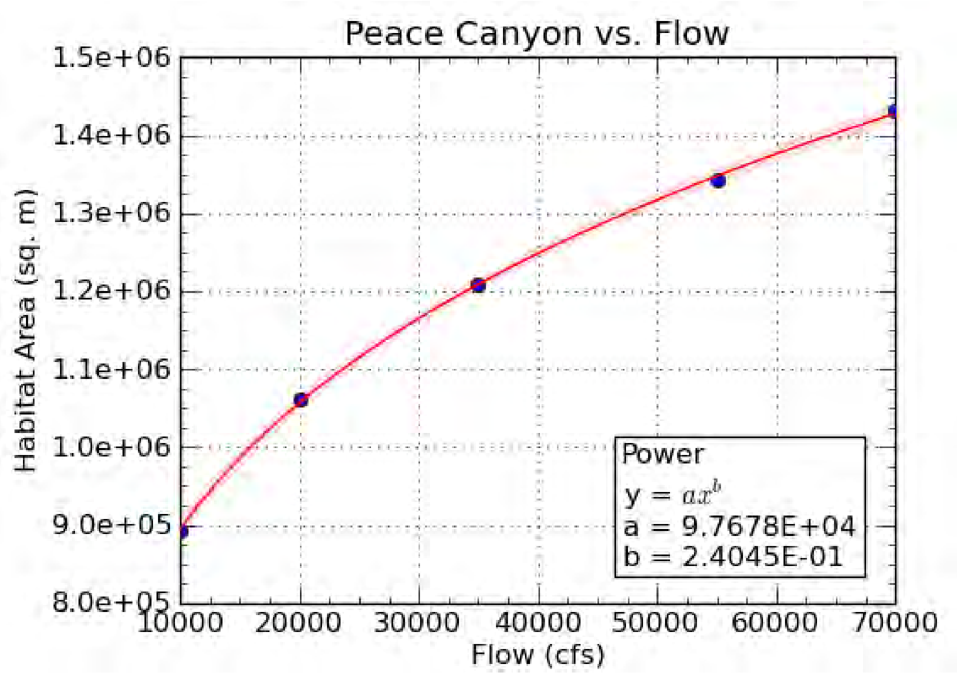


Figure 4.13 Hydraulic habitat model for the Peace Canyon reach. Data points are represented by dots, function by red line and pink bands are the 95% confidence area.

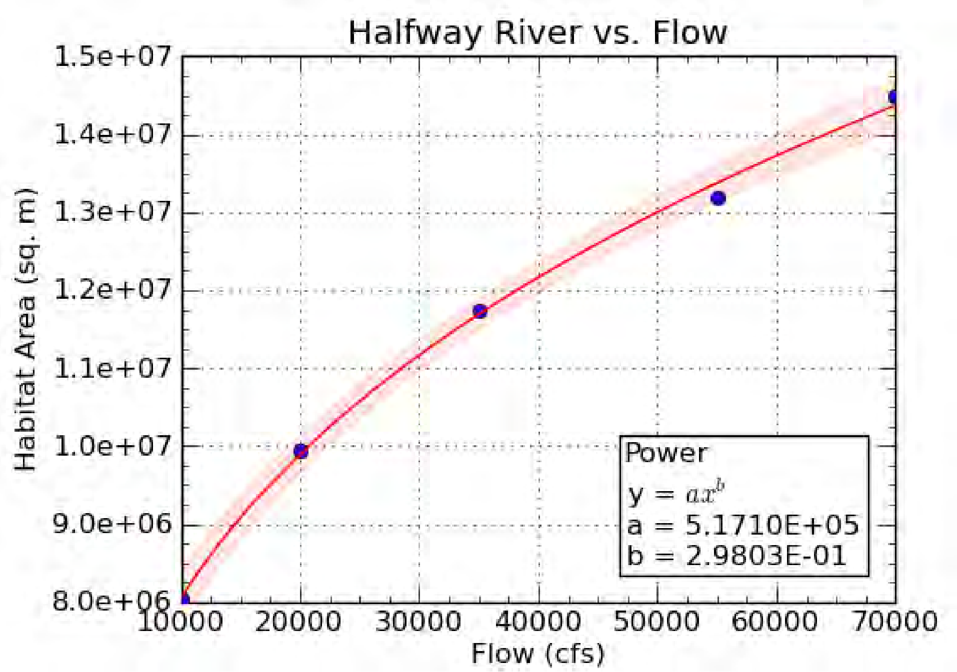


Figure 4.14 Hydraulic habitat model for the Halfway River reach. Data points are represented by dots, function by red line and pink bands are the 95% confidence area.

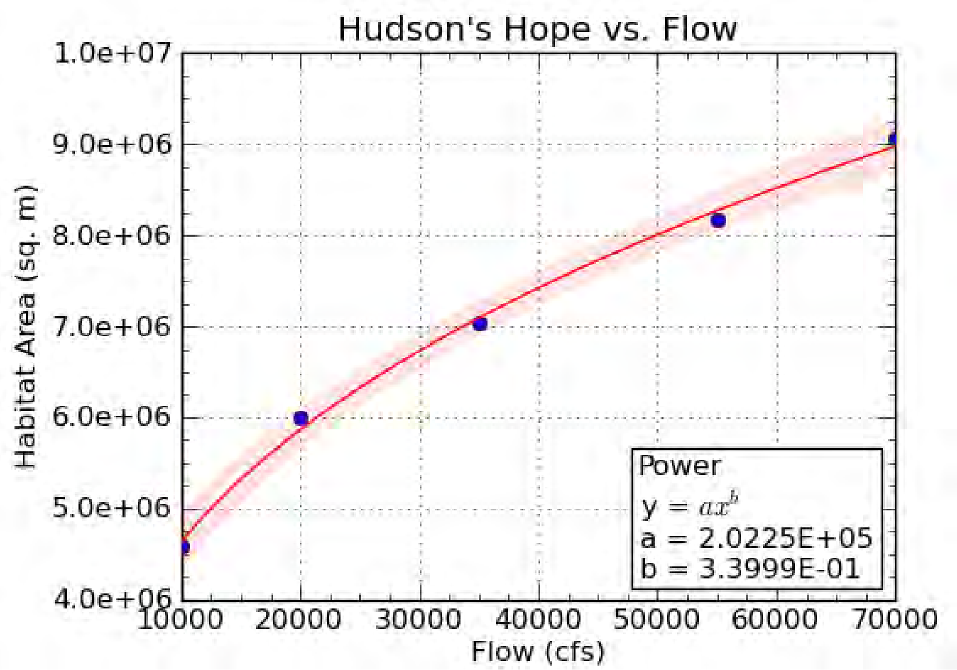


Figure 4.15 Hydraulic habitat model for the Hudson's Hope reach. Data points are represented by dots, function by red line and pink bands are the 95% confidence area.

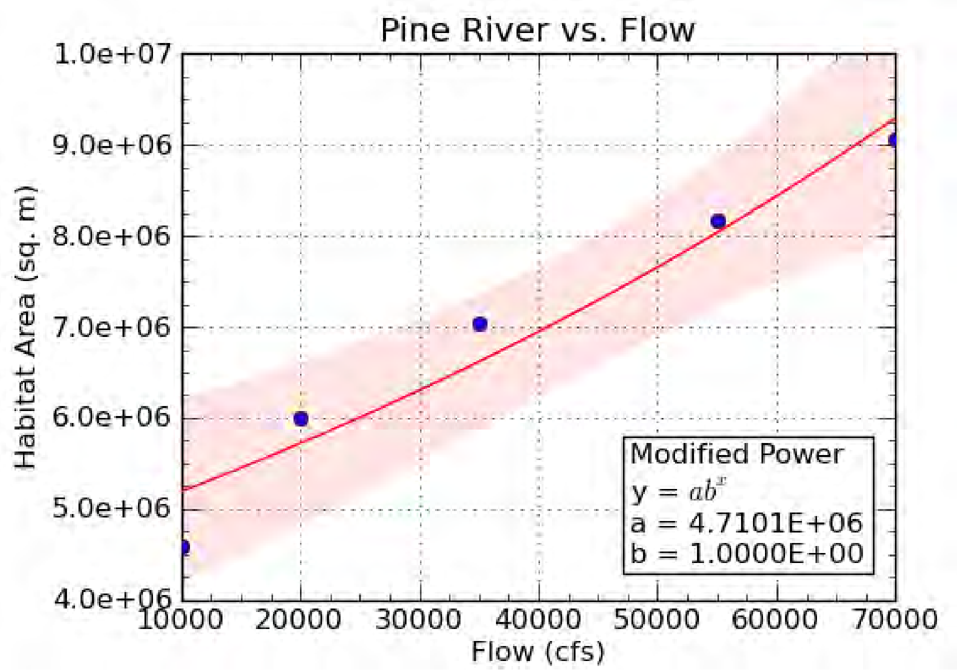


Figure 4.16 Hydraulic habitat model for the Pine River reach. Data points are represented by dots, function by red line and pink bands are the 95% confidence area.

4.5.3 Hydraulic Habitat Model by Channel Type

Models describing the change in habitat surface area by channel type with flow are provided in Table 4.12.

Table 4.12 River Channel Type Hydraulic Habitat Models.

Channel Type	Model Type	Model Parameters				r^2
		a	b	c	d	
Main Channel	Power	56.78	0.29			0.995
Open Side Channel	Power	22.55	0.30			0.999
Closed Side Channel	Exponential	145.88	1.00			0.998
Tributary Confluence	Power	2.35	0.39			0.983

4.5.4 Hydraulic Habitat Model by Habitat Type

Models describing the change in habitat types with flow are provided in Appendix C Tables C1 (main channel), C2 (open side channel), C3 (closed side channel), and C4 (tributary confluence).

To estimate the available habitat area of a specific habitat unit type, the individual estimations of the main channel, open side channels, closed side channel, and tributary confluence can be summed.

4.7 ISOLATED PONDS

Although not part of the study scope, the habitat mapping identified isolated waterbodies, or ponds. The ponds may have formed as water water levels dropped due to changes to river discharge associated with BC Hydro operations. However, factors outside of river discharge influence the formation and persistence of ponds. These include the duration of the dewatered period, rainfall events immediately preceding photo acquisition, subsurface flow, tributary inflow, and changes to channel topography over the duration of the study. As such, ponds identified during habitat mapping can potentially be attributed to changes in river discharge, but the data may not be a reliable measure of this effect.

In total, 1,136 ponds ≥ 5 m^2 were recorded within the active river channel that was exposed between target flows of 283 cms and 1,982 cms (Table 4.13, Appendix D, Addendum C). This value represents the combined number of ponds recorded from the orthophoto sets. It has been assumed that ponds located outside the wetted area at 1,982 cms were not influenced by BC Hydro operations investigated by the study. The surface area of included ponds varied substantially from 5 m^2 to 69,572 m^2. Median pond surface area ranged from 5 m^2 to 29,116 m^2.

Table 4.13 Number and surface area of isolated ponds.

Reach	Channel Type	Number	Surface Area (m^2)		
			Median	**Range**	**Total**
Peace Canyon	Main Channel	20	29	5 – 420	1,506
	Open Side Channel	1	162	162	162
	Closed Side Channel	0			
	Tributary Confluence	0			
	Total	*21*	*30*	*5 – 420*	*1,668*
Hudson's Hope	Main Channel	60	50	5 - 5,005	15,944
	Open Side Channel	35	32	7 - 10,585	17,306
	Closed Side Channel	51	176	5 - 46,857	219,341
	Tributary Confluence	4	7	5 – 15	34
	Total	*150*	*56*	*5 – 46,857*	*252,625*
Halfway River	Main Channel	244	33	5 - 24,615	110,229
	Open Side Channel	214	32	5 - 50,276	236,352
	Closed Side Channel	321	145	5 - 69,572	759,390
	Tributary Confluence	123	34	5 - 12,090	48,423
	Total	*902*	*50*	*5 – 69,572*	*1,154,394*
Pine River	Main Channel	2	227	23 – 430	453
	Open Side Channel	0			
	Closed Side Channel	31	225	16 - 29,116	128,739
	Tributary Confluence	30	42	5 - 13,099	17,371
	Total	*63*	*140*	*5 – 29,116*	*146,563*
Overall Total		**1,136**	**53**	**5 – 29,116**	**1,555,250**

The number, median area and total area of ponds differed between reaches (Table 4.13). In general, the greater the surface area available for dewatering (see Section 4.4.1), the higher the number and the greater the surface area of ponds. The Halfway River reach contained a much higher number of ponds (n = 902) and total surface area of ponds (1,154,394 m^2) when compared to the remaining reaches. Total area of ponds also differed between channel types. Within each reach, the closed side channel type consistently had the greatest surface area of ponds.

The number of ponds and total pond surface area was influenced by discharge (Figure 4.17). The number of ponds and surface area of ponds in the four channel types decreased with declining discharge; however, the relationship was not linear. The threshold of greatest change appeared to occur between 566 cms and 991 cms.

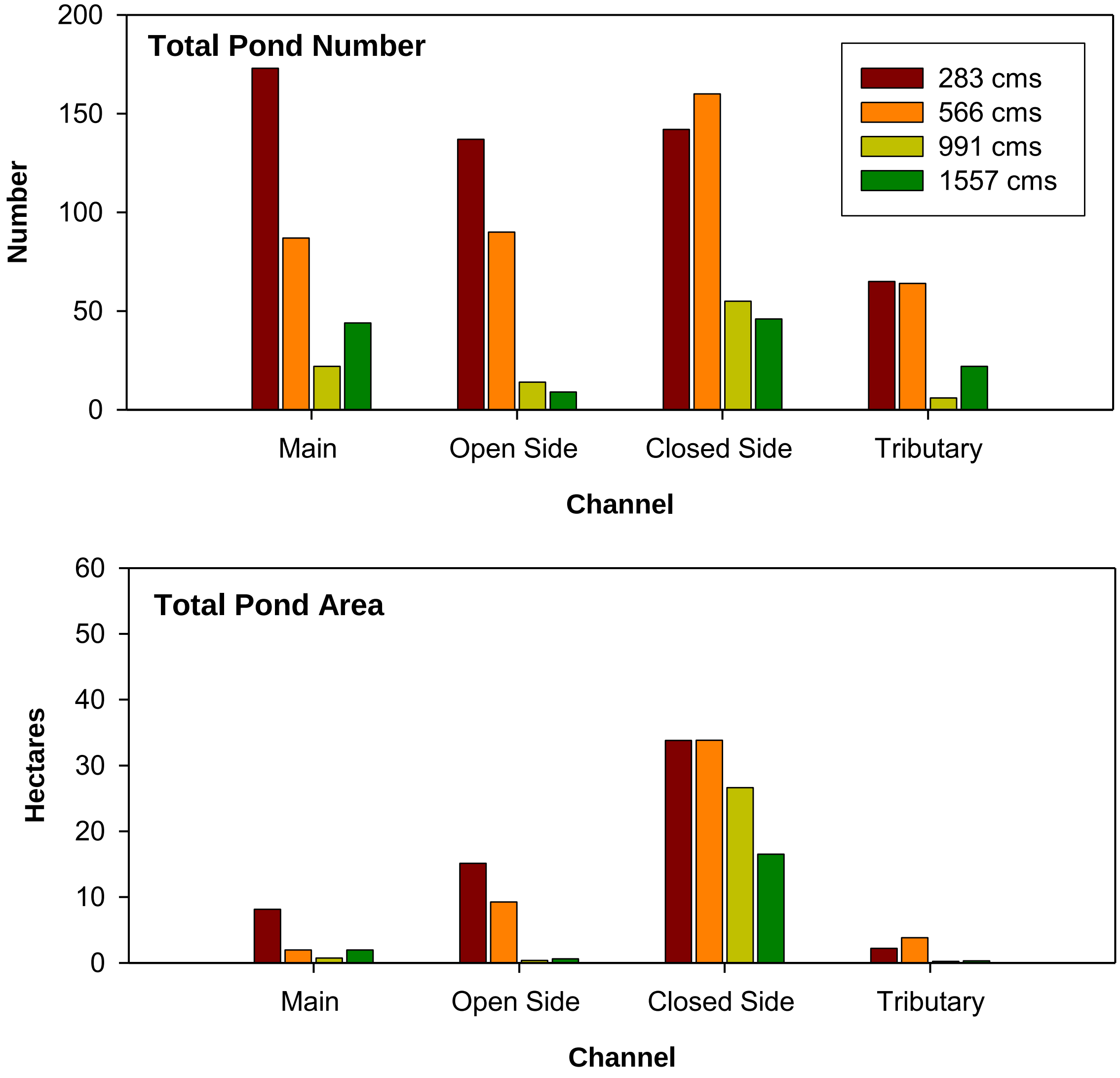


Figure 4.17 Pond number and pond surface area by channel type at each target discharge (target discharge of 1,982 cms assumed to have no isolated ponds).

5.0 DISCUSSION

5.1 UNCERTAINTIES AND SOURCES OF ERROR

5.1.1 Air Photo Interpretation

The habitat typing and subsequent calculations were based on mapping the water line boundary at each of the five target flows. The technique employed by this study facilitated water line mapping to within a few meters (see Section 2.2), which was deemed high precision. This level of detail exceeded the requirements of the study. However, some features of the air photos made it difficult to interpret the location of the water line. Specifically, deep shade caused by the angle of the sun at the time of air photo acquisition was problematic adjacent to steep, high, north facing valley walls. The prevalence of this issue depended on the time of year and the time of day the air photo was collected. The air photo set for 991 cms collected on October 26, 2008 was deemed the hardest to interpret. The approximate river bank length that was potentially subjected to shading was 45.6 km, or 7.8% of the total study area perimeter. The most affected area was the Peace Canyon reach (9.8 km or 28.1% of the reach perimeter). Future air photo acquisitions can mitigate this issue by appropriate scheduling of flights.

5.1.2 Changing River Flows during Air Photo Acquisition

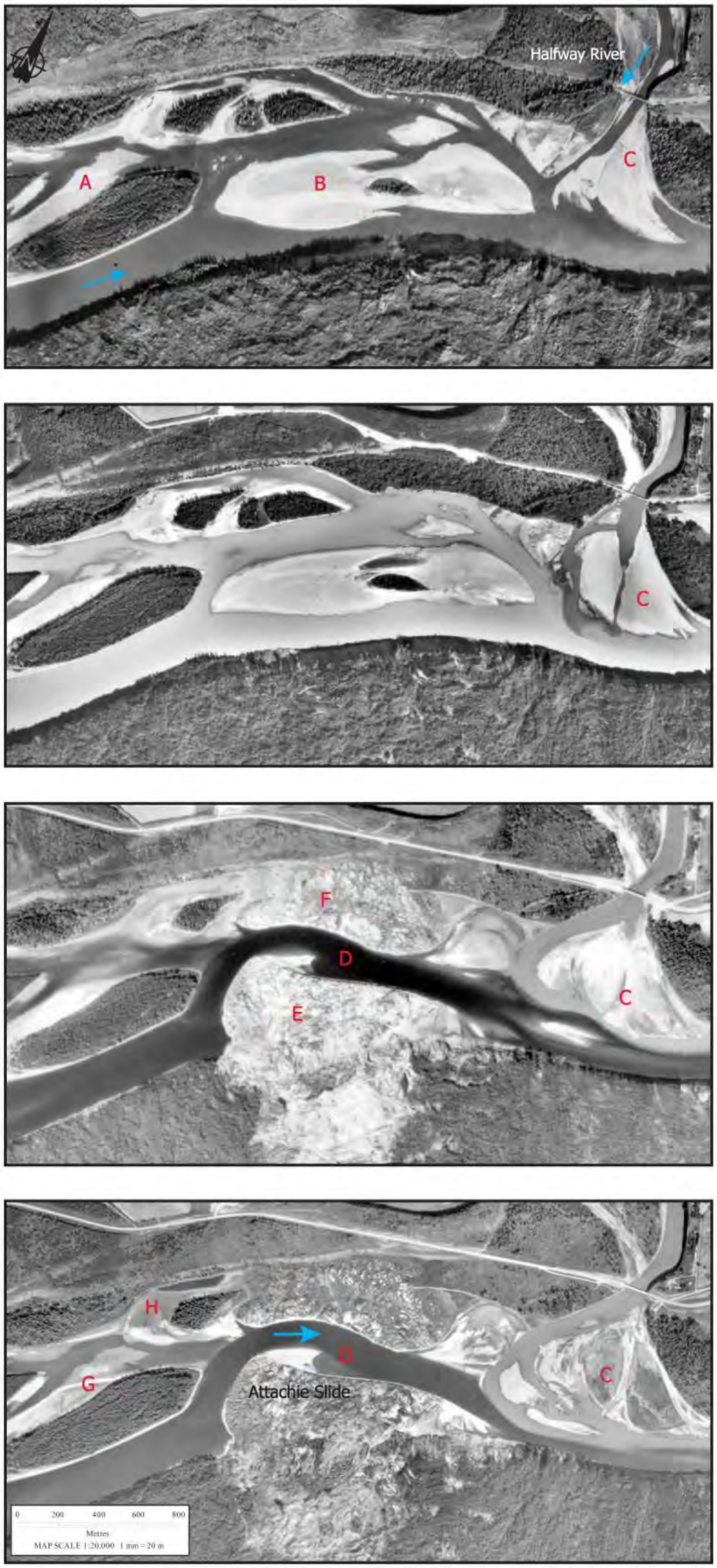
Flow releases from Bennett and Peace Canyon Dams were intended to provide constant discharges during the period when the air photos were obtained to document channel conditions. Air photos were collected at flows of 283 cms (10,000 cfs), 566 cms (20,000 cfs), 991 cms (35,000 cfs), and 1,557 cms (55,000 cfs). Although a constant discharge was not maintained during acquisition of the 1,982 cms, the most significant fluctuation in flows only occurred during the last hour of the 9 hour photo period (see Figure 16, Appendix A). This is expected to have only limited effect. The location of individual photos flown during this period would need to be determined in order to define the area that was influenced by flow fluctuation.

5.1.3 Changes to Channel Over Short and Long Term

The original goal of the program was to collect all the required air photos in 2008 and 2009. However, as discussed in Section 2.4 air photo acquisition occurred over a four year period (2008 to 2011). This period allowed changes in channel morphology to occur in some areas. This effect was most noticeable at and immediately downstream of tributary confluences. The changes included realignment and degradation of channels, bed material deposition (i.e., new and enlarged shoals), bed and bank material erosion, and deposition of large woody debris. Many of these changes resulted from the sizable flood that occurred on tributaries to the Peace River in June 2011. Tributary flows approached or exceeded the maximum flow on record at the WSC Stream Gauging sites on the Pine River (Pine River at East Pine (BC) [07FB001]), Moberly River (Moberly River near Fort St. John [07FB008]), and Halfway River (Halfway River near Farrell Creek [07FA006]) The effect of these changes on habitats that were delineated using air photos collected in 2009 is not known.

As discussed in Church (in prep., c), the observed post-regulation reduction in river width on the Peace River is less than expected in the area downstream to Taylor and the present channel width is approximately 50% wider than that which is predicted to eventually occur. The data in Xu and Church (in prep.) suggest that the average post 1967 rate of width reduction is about 5 m/yr in BC. They further indicate that the trends of width contraction are essentially linear and probably reflect the rate of progradation of perennial terrestrial vegetation in the former channel zones. These studies indicate that the Peace River is still responding to river regulation and that further changes in channel dimensions will occur. This implies that the availability of associated fish habitat will also continue to evolve over time.

The analyses described in Ayles and Church (in prep., a and b), Church (in prep., c) and Xu and Church (in prep.) are based on 34 river sections surveyed between the Peace Canyon Dam and the Alberta border plus channel mapping based on various aged air photos. Unfortunately, these data may not provide the necessary detail required to identify or quantify changes in fisheries habitat. For example, Figure 5.1 illustrates the changes in river conditions which have occurred in the Peace River adjacent to the Halfway River confluence and the Attachie Slide over the period between 1953 and 2007. This analysis documents the post-regulation changes in habitat conditions and, in conjunction with the previously discussed studies, provides a basis for estimating future site specific habitat evolution. Subsequent phases of this work might therefore need to consider how best to address the expected future evolution of fish habitat within the study area.



(i)

Date: September 13, 1953
BC1774 #76

NOTE:

- Pre-regulation channel conditions.
- Extent of unvegetated gravel bars in the mainstem of Peace River (A & B) and on the Halfway River fan (C).

Discharge:

Peace River near Taylor 685 m^3/s

(ii)

Date: August 15, 1967
BC5267 #64

NOTE:

- Enlarged fan on Halfway River (C).

Discharge:

Peace River near Taylor 1,170 m^3/s

(iii)

Date: August 15, 1977
A24780 #155

NOTE:

- Narrow channel (D) which cut through Attachie Slide deposits (E & F).
- Enlargement of Halfway River fan (C).

Discharge:

Peace River near Taylor 1,410 m^3/s

(iv)

Date: July 9, 1981
BR81041 L3 #89

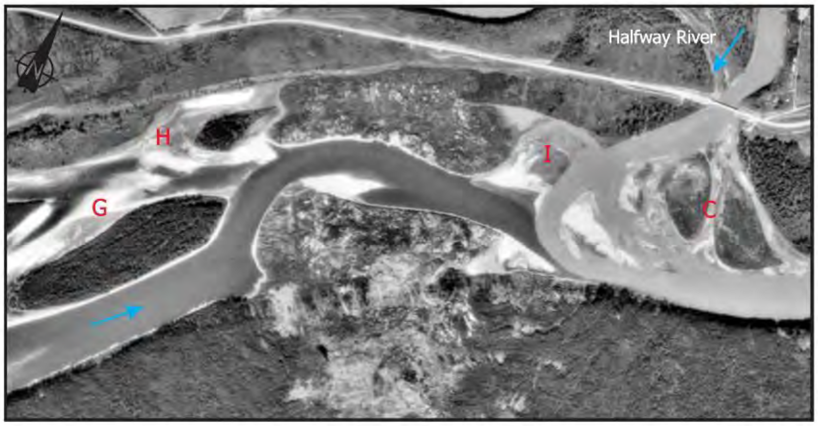
NOTE:

- Vegetation development of former secondary channels (G & H).
- Enlarged channel through slide (D).
- Further progradation of Halfway River fan (C) and vegetation development on former barren surfaces.

Discharge:

Peace River near Taylor 712 m^3/s

Figure 5.1a Historical changes in channel morphology, Peace River in the vicinity of the Halfway River confluence and the Attachie Slide.



(v)

Date: July 27, 1986
15BC86047 #124

NOTE:

- Further sediment deposition and vegetation development in former secondary channels (G & H) and in left bank lee area downstream of Attachie Slide (I).
- Island developing at the mouth of Halfway River (C).

Discharge:

Peace River near Taylor 745 m^3/s

(vi)

Date: July 26, 1996
15BCB96020 #21

NOTE:

- Extent of inundation during 1996 spillway release.
- Enlarged channel (D).

Discharge:

Peace River near Taylor 5,920 m^3/s

(vii)

Date: June and September 2007
Orthophoto

NOTE:

- Further sediment deposition and vegetation development in former secondary channels (G & H) and in left bank lee area downstream of Attachie Slide (I).
- Vegetation development at (I & C).

Discharge:

Peace River near Taylor m^3/s

Figure 5.1b Historical changes in channel morphology, Peace River in the vicinity of the Halfway River confluence and the Attachie Slide.

5.1.4 Habitat Classification System

The habitat classification system uses physical characteristics of the active channel and adjacent banks of the Peace River to map habitat types. This system does not incorporate features such as water velocity or water depth because changes to these features are not easily identifiable on air photos. However, these characteristics can influence fish habitat utilization.

The habitat classification system assumes that the same physical characteristics within a predetermined area are equally available to fish at all flows that inundate those features, which is not always the case. Subtle changes potentially occur between flows. For example, with increasing river flow, the physical attributes of the water bank interface within a specific habitat unit may change from an unvegetated, low gradient gravel bar to a vegetated, moderately steep fluvial terrace. The water bank interface has changed, but the dominant characteristics within the available surface area, remain as an unvegetated, low gradient gravel bar. This issue is an inherent limitation of the habitat classification system used for the study. More detailed studies incorporating instream flow methodologies (described in Section 4.3) will be needed to examine the dynamic characteristics that change with flow.

A second limitation of the habitat classification system is the requirement to "see" the river bed in order to assign the habitat type and delineate the boundaries. Consequently, the extensive submerged habitats at 283 cms could not be mapped by visual examination of air photos. The study addressed this issue by assigning an assumed width to each habitat unit to calculate the available surface area. The reliability of this approach was not evaluated.

There are three alternative strategies to address this issue. Firstly, the physical characteristics of wetted portions of habitat units could be directly measured in the field. Secondly, river discharge could be reduced below the target base flow of 283 cms (e.g., 142 cms [5,000 cfs]) in order to map habitat units using the existing classification system. Thirdly, air photo interpretation using habitat unit width and length dimensions in combination with water surface/river bed elevation data collected and archived by this study could be used to calculate foreshore slopes. The slopes could then be used to calculate the habitat width to a predetermined depth in the wetted portion of the channel.

The habitat classification system is not able to directly incorporate temporal effects which may affect habitat suitability. The short term variations in discharge and water level, discussed in Section 3.1.1, could have a more significant effect on fish in low gradient habitats where changing water levels result in a comparatively large change in wetted area (such as in side channels, shoals or low gradient gravel bars).

Temporal variations in suspended sediment concentrations have also not been considered. Plate 31 illustrates how sediment loadings from tributary streams such as Lynx Creek (Km 14), Farrell Creek (Km 23), or an unnamed right bank tributary (Km 33) result in extensive downstream sediment plumes. Studies such as those by Newcombe & McDonald (1991), Newcombe and Jensen (1996), Shaw and Richardson (2001), Singleton (2001) and, Newcombe (1996, 2003) indicate that chronic exposure to elevated suspended sediment concentrations or turbidity can result in detrimental effects. The deposition of these materials can also affect bed material size and the biological use of 'substrate' material.

5.2 APPLICABILITY TO PEACE RIVER

The habitat classification system used by the study was based on the physical characteristics of the active channel bed and adjacent river banks. Use of physical characteristics to classify fish habitat was chosen for three reasons. It allowed quantification of habitats using physical features assumed to be important to fish species and life stages found in the Peace River. Physical characteristics used by the classification system were identifiable on large scale colour air photos. Finally, physical characteristics used to define habitats were stable over different flow regimes, which allowed quantification of habitat availability within the same habitat unit at different water levels.

Our initial trials in July 2009 indicated that ground experience or familiarity with site conditions increased the reliability of the classification process and was important for interpretation of features when viewing large scale colour air photos. Subsequent ground truthing established the efficacy of the habitat classification system and the accuracy of habitat mapping using large scale colour air photos. A quality assurance assessment of the digital habitat maps also indicated a high level of precision of mapped habitats. The habitat polygons contained 93.3% of total available surface area. These results demonstrated that the classification system could be applied to a large study area (104.9 km river length; 4,115 ha of active channel; 584 km of bank margin).

Total available habitat area was calculated for that portion of the active channel bed located between the base flow (283 cms) and the maximum flow (1,982 cms) targeted by the study. After stratification, the available habitat surface area was summed by reach, channel type, and habitat type parameter (e.g., coarse bed material versus fine bed material; low bed slope versus high bed slope; valley wall versus fluvial or terrace bank). This approach provided information on spatial differences in habitat availability. For example, the Halfway River reach provides the largest surface area and the greatest number of habitats, while bedrock bed material is restricted almost entirely to the Peace Canyon reach. Because the habitat maps are georeferenced this information can be summarized down to the specific habitat type of interest. For example, what is the distribution and available surface area of SVCMI-R habitat (side channel; valley wall; coarse bed material; moderate slope; irregular bank configuration; containing abundant rock cover) within the study area? Note that this habitat type is important to bull trout and Arctic grayling (P&E and Gazey 2003, Mainstream and Gazey 2004 to 2012), and the results of this study suggest that it is susceptible to dewatering.

Comparisons of habitat surface area to discharge indicated that there was a strong, quantifiable relationship at each of three spatial scales -- reach, channel type, and habitat type. Changes to discharge typically explained > 95% of the variation in habitat surface area and power functions usually provided the best fit. The majority of the power function equations indicated that habitat surface area was not approaching or had reached maximum availability at the target discharge of 1,982 cms (i.e., power curve did not develop a horizontal asymptote over the range of investigated flows). These results suggest that additional fish habitat would become available at higher discharge.

The results for each of the study tasks (including air photo acquisition, air photo interpretation, habitat classification system, habitat mapping, and habitat modeling) indicate that the goal of the hydraulic habitat study was achieved. More specifically, fish habitat of the Peace River could be quantified at several steady state discharges.

5.3 FUTURE STEPS - INSTREAM FLOW NEEDS

The present study provides an initial basis for estimating how changes in discharge or water level will affect fish habitat in the area between the Peace Canyon Dam and and the Pine River confluence. The hydraulic model being developed by nhc (GMSWORKS-5) will assist in this process by defining the relationship between water level and discharge at various locations in the study area. The developed habitat mapping includes the geodetic elevation of water levels along the edge of all mapped habitat units. Combining the two analyses would provide the ability to predict how river discharge would affect habitat area.

While useful, the above results do not provide information on how varying flows will affect factors such as water depth or velocity which (along with bed material size) are commonly employed to determine the 'probability of use' for various fish species or life stages (see Bovee 1982, Stalnaker 1993, and Stalnaker *et al.* 1994). Computer programs such as PHABSIM (Milhous *et al.* 1989, Milhous *et al.* 1984, Hardy 2002), RHYHABSIM (Jowett 1989a, 1989b) or RHABSIM (Thomas R. Payne & Associates Ltd. 1998) have traditionally been used for this purpose.

The principal authors of these aforementioned programs are in the process of releasing an updated version called System for Environmental Flow Analysis or SEFA (Payne *et al.* 2011, Payne, pers. comm.). The program includes the ability to undertake one and two dimensional analysis of habitat hydraulics, develop site specific habitat suitability criteria, and undertake other related analyses such as sediment transport, water temperature and dissolved oxygen analyses. It may be possible to use fish abundance data collected by P&E and Gazey (2003) and Mainstream and Gazey (2004 to 2012), coupled with one or two dimensional modeling results (based on NHC's GSMWORKS-5 and BC Hydro HEC-RAS cross sections) within SEFA to develop a numerical model which further evaluates the effects of changing discharge on various fish species and life stages.

It is recommended that an initial feasibility study be undertaken to better assess data availability, data requirements, and potential benefits. The first step should be an evaluation of existing fish abundance data, which has been undertaken over several years in different channel areas and habitat types. The evaluation should establish the level of spatial precision (i.e., habitat type level, channel type level, or reach level), and establish distribution of sampling effort and available sample sizes. If sufficient data are available, an index of fish use could be developed for target species and life stages.

6.0 SUMMARY AND RECOMMENDATIONS

6.1 SUMMARY

The regulation of the Peace River by the Bennett and Peace Canyon Dams has altered the downstream hydrologic regime and resulted in daily and seasonal variations in water levels that affect fish and fish habitat. The Peace River Hydraulic Habitat Study was commissioned by BC Hydro to investigate how changes in water levels affect fish habitat on the Peace River in the area between the Peace Canyon Dam and Taylor, BC. These questions have not been previously addressed due to the spatial extent of the project (the study area is 105 km long) and the complex relationship between variations in river discharge and habitat availability.

The study used a series of five air photos flown during a representative range of flows which varied between 283 cms (10,000 cfs) and 1,982 cms (70,000 cfs) to map the surface area of near shore fish habitats that occur within the study area. The completed tasks included:

1. Development of a habitat classification system that was sensitive to changes to Peace River discharge;
2. Delineation of fish habitats of the Peace River at five discharges using air photographs provided by BC Hydro;
3. Preparation of digital maps of fish habitats for each discharge;
4. Quantification of fish habitat availability at each discharge; and,
5. Modeling habitat availability as a function of river discharge.

The results of the study indicated that large scale air photos could be used to map the water line boundary at each of the five flows at a high level of precision. And, the habitat classification system could reliably identify and delineate near shore habitats using the same large scale air photos. We were able to calculate habitat surface area by combining the digital habitat boundaries with the wetted area of the river at each flow.

The habitat surface area data allowed quantification of habitat availability at several spatial scales. Habitat availability was related to river reach, channel type, and habitat type.

Habitat availability was strongly related to discharge. Modeling established that there was a high correlation between habitat surface area and discharge, the relationship was curvilinear, and was most often expressed by a power function.

The Peace River Hydraulic Habitat Study has successfully achieved its goal to map the various types of near shore fish habitat and to make a determination of the numerical relationship between habitat area and discharge. However, the study identified a number of deficiencies:

1. The assumption that the habitat classification system reflects differences in habitat utilization by the various fish species and life stages that reside in the Peace River needs to be verified;
2. The habitat classification system did not incorporate attributes such as water velocity or water depth because changes to these features were not easily identifiable on air photos; however, these characteristics can influence fish habitat utilization.
3. A large area of the Peace River was underwater at the lowest study flow of 283 cms, and as such, the areal extent of submerged habitats could not be mapped. Consequently the study data only represents changes in habitat availability within the portion of the Peace River channel affected by flows between 283 cms and 1,982 cms. The data do not represent changes to habitat availability within the entire river channel; and,
4. The study results reflect present habitat conditions. The channel and habitat characteristics of Peace River are still adjusting to the effects of river regulation and the study results will not necessarily reliably describe future conditions.

6.2 RECOMMENDATIONS

The following recommendations are made to address deficiencies in the data or to utilize the information collected by the study to further our knowledge of the effects of BC Hydro operations on Peace River fish habitats and fish populations:

1. Quantify the physical characteristics of the river bed below the water level elevation at 283 cms to quantify habitat types and habitat availability within the wetted portion of the Peace River channel;
2. Better predict the speed, location, and magnitude of future changes to fish habitat characteristics due to the effects of river regulation and determine the time period over which the present results can be reliably employed; and,
3. Undertake a pilot study to compile and synthesize the existing Peace River hydraulic habitat and fish population data. The study objective should be to determine if there is sufficient data to reliably undertake an analysis of habitat suitability as a function of factors such as water depth, water velocity, bed material texture or other factors.

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