Columbia River Project Water Use Plan

Columbia White Sturgeon Management Plan

CLBMON-30 – Lower Columbia River Opportunistic Assessment of High Flow Events

Study Period: January 01, 2011 to December 31, 2013
Implementation Years: 3-5

BC Hydro and Power Authority

Prepared by:

BC Hydro
Water License Requirements
Castlegar, B.C.

July 2015

Recommended Citation: BC Hydro. 2015. Lower Columbia River Opportunistic Assessment of High Flow Events (CLBMON-30). Years 3-5 Data Report. Report by BC Hydro, Castlegar, 49 pp + 1 Appendix.

Executive Summary

The population of White Sturgeon *Acipenser transmontanus* in the lower Columbia River is undergoing recruitment failure and as a result was one of four populations listed as endangered in Canada in 2006. Water management on the Canadian portion of the Columbia River for flood control and power generation has significantly altered the hydrograph in relation to historical patterns, and it has been suggested that these changes may affect environmental conditions (e.g. physical habitat, turbidity) necessary for White Sturgeon recruitment. In 2006, the Columbia River Water Use Plan Consultative Committee recommended that the return of a more historical freshet hydrograph involving a target flow of 200 thousand cubic feet per second (kcfs) at the international border during typical spawning periods (June to July) be considered as a possible recovery effort option. Based on this recommendation, this monitoring program was developed with the objective of determining if high flow events in the Columbia River positively affect levels of natural recruitment. In order to determine the mechanisms influencing recruitment, long term data are required to allow comparative analyses across years and associated flow regimes. This program was designed to identify recruitment success through monitoring adult movements, identifying adult spawning site selection, and describing early life stage (egg larvae and juveniles) success across a suite of flow regimes over a 10-year period.

Historical freshet levels, as defined in this study as 200 kcfs at the international border on the lower Columbia River were exceeded in 2011 and 2012. Freshet flows have only reached levels greater than 200 kcfs three times since 2001 and the duration these flows have been maintained above 200 kcfs has been relatively short. However, in both 2011 and 2012, flows exceeded 200 kcfs for 50 and 56 days, respectively. Further, peak flows reached highs of 267,000 (2011) and 280,000 (2012) which is comparable to the 1997 flow year when White Sturgeon recruitment was suspected. These two high flow years will serve as important test years in the long-term dataset.

This monitoring program was developed to ensure adequate data would be collected to evaluate White Sturgeon movements in relation to operations of the. This has been accomplished to date through the deployment of acoustic transmitters in adult male (n=67) and female (n=65) White Sturgeon that were predicted to spawn within 1-3 years of tagging. These long term tags will serve as an important tool to monitor movements and spawning site selection over the years of this study (2008-2018). For example, examination of individual fish movements have resulted in spawning being confirmed at the HLK/ALH location in both 2010 and 2011, a site that was previously unknown. Additionally, residency to specific habitats is high at the individual level and movements for feeding or spawning do not differ between flow years.

While early life stage monitoring will be important when evaluating spawning site selection, juvenile monitoring is one of the key aspects of this program to determine if wild recruitment has occurred, or specifically, if higher flows years have a positive effect on larval to juvenile survival in the lower Columbia River. While this report summarizes information collected in the first 5 years of this program, more complex analyses will be undertaken when sufficient data is available to evaluate adult movements over several operational scenarios. Importantly, determining if the 2011 or 2012 high flow years resulted in a change in movements will be important, as limited years for comparison currently exist.

The current state of knowledge for White Sturgeon with respect to the management questions for CLBMON-30 is provided in the following table:

Management Question	Status
Are there unidentified spawning sites in the lower Columbia River that are used during higher flows?	Relating spawning site selection and flows is challenging due to challenges associated with sampling at higher flows (e.g. 2012 flow year) and a relatively small dataset on spawning locations outside of the primary site at Waneta. Spawning (documented through egg and larval captures) had only been identified to occur at the Waneta area prior to the monitoring studies under the Columbia River Water Use Plan being implemented. Results from recent work reveal that spawning occurs downstream of HLK and ALH in some years, though it is not known if this site is used annually for spawning and continues to be the focus of additional monitoring. Spawning also occurs on an annual basis in the Kinnaird area, as egg and larval captures have been collected from 2007-2013. However, the main geographical boundaries of the spawning location where eggs are deposited remain uncertain. Finally, there are multiple sites used for spawning south of the international border on an annual basis. Additional years of data are required to address this management question in further detail.
How does the interaction among presumed subpopulations of sturgeon in the lower Columbia River change during high flow events?	White Sturgeon have high fidelity to specific habitat or location for a large portion of the year. Movements for feeding or spawning are primarily made during the summer and fall months. Further, movements that are suspected to be spawning related are made primarily within 20 km of where the individual is residing year-round. There is a large sample size of male and female White Sturgeon (n>100) with 10 year acoustic transmitters that are being monitored under this program. It is expected that at the end of this program, there will be sufficient data to describe White Sturgeon movements in the lower Columbia River.
Are probabilities of survival higher at the egg stage in years of higher flows?	Insufficient data exist to address this management question and complexities with sampling methods in large rivers may not allow this management question to be addressed directly over the course of this program. This stems from insufficient knowledge pertaining to numbers of adults spawning, egg distributional data, and knowledge around capture efficiency of the sampling gear is required to address this question. Given the non-random sampling technique employed when setting egg mats and drift nets, it will be difficult to provide an

Management Question	Status
	annual estimate of egg survival. Genetic work under CLBMON28 found that 121.5 ± 34.7 adults (mean ± SD) were spawning within the Canadian section of the lower Columbia River within each of two years (2011 and 2012). Ultimately, assessment of egg survival across flow years will be limited to detection of wild juveniles surviving and recruiting to the juvenile sampling program (CLBMON29). Importantly, 2011 and 2012 were considered to be above normal flow years (sustained flows >200kcfs) and will serve as test years for this program.
What effects do higher flows have on recruitment to the larval stage?	Further data are required to address this question. There is no relationship between flows and numbers of larvae captured for the years monitoring has been completed (~8 years).
What is the effect (and associated mechanisms) of higher flows on juvenile survival in the lower Columbia River?	Survival of juveniles released from the conservation aquaculture program is high and has been estimated at approximately 25% in the first year and more than 80% thereafter. Capture data from the lower Columbia from 2009-2013 suggests that annual survival estimates may be underestimated but further data are required to examine age specific survival. Finally, several wild juveniles that have been captured in the lower Columbia and in Lake Roosevelt are of an age that is consistent with the 1997 year class. 1997 was an above normal water year and though the sample size is small, it is possible that more juveniles of this age class will be picked up in future sampling. The 1997 flow year discharge data are presented in this report as a comparison to high flow years that occurred in the lower Columbia River in 2011 and 2012.

Acknowledgements

The 2011, 2012 and 2013 study years of the lower Columbia River Opportunistic Assessment of High Flow Events (CLBMON-30) represents years three to five of a ten year program, and is solely funded by BC Hydro Water License Requirements White Sturgeon Management Program in Castlegar, B.C. BC Hydro would like to thank the following individuals for their contributions to the program:

BC Hydro & Power Authority

James Baxter	Castlegar, B.C.
Gary Birch	Burnaby, B.C.
James Crossman	Castlegar, B.C.
Dean Den Biesen	Castlegar, B.C.

Terraquatic Resource Management Ltd.

Marco Marrello	Nelson, B.C.

Jay Environmental

Katy Jay	Nelson, B.C.

Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

In the Columbia River downstream of Hugh Keenleyside Dam (HLK) it has been suggested that reductions in the natural and historical freshet pattern has the potential to affect adult White Sturgeon (*Asipenser transmontanus*) spawning migrations, spawning site selection, timing, or fertilization success. Changes in adult demographics are further compounded by observations of poor early life stage survival and subsequent recruitment failure for several populations of White Sturgeon where hydroelectric development has occurred (McAdam et al. 2005; Paragamian et al. 2005; Irvine et al. 2007). As water management of the Columbia River for flood control and hydroelectric power has resulted in substantial habitat changes (e.g., turbidity, substrate distribution, flow regimes) since the building of the Canadian Columbia River Treaty dams, there have been substantially reduced total average flows during White Sturgeon spawning and incubation periods, with increased variability in daily flow rates due to flood control, storage, and power generation.

Historical freshet flows were characterized by high peak events followed by gradually descending flows. Water management on the Columbia River has altered this flow pattern and natural increases in water temperatures have been diminished except during high runoff events. Furthermore, much of the historical riverine habitat downstream of the primary spawning sites (Waneta Site; Hildebrand et al. 1999; Irvine et al. 2007) has been seasonally inundated by Lake Roosevelt since 1941. Natural suspended sediment transport capability has also been interrupted by reservoirs, and limited evidence suggests that total suspended solids (TSS), or turbidity, has decreased during the sturgeon spawning and incubation periods. This is of critical concern as decreases in turbidity have been shown to increase rates of predation on White Sturgeon larvae (Gadomski and Parsley 2005). The effects of modifying flow regimes away from historical patterns on mechanisms associated with recruitment in White Sturgeon populations warrants further investigation as recovery planning and implementation moves forward.

The Columbia River Water Use Plan Consultative Committee (CRWUP CC) recommended that evaluating a more natural freshet hydrograph involving a target peak flow of 200 thousand cubic feet per second (kcfs); equivalent to approximately 5,663 cubic meters per second (cms) of flow at the Canada/ United States border for a minimum of one month during typical spawning periods (June to July) be considered as a possible option to determine if a positive effect could be detected on White Sturgeon recruitment, either at the egg, larval, or juvenile stages. This natural freshet pattern is hypothesized to promote adult spawning migration, facilitate natural reproduction, reduce rates of predation on larvae and juveniles, and improve natural egg/larvae/juvenile rearing habitats. Further, extended periods of high discharge are also expected to help scour substrates used by early life stages for incubation and rearing. However, delivery of this natural freshet would require substantial changes from the current Columbia River Treaty and deviations to the operational regime at hydroelectric plants would be associated with high financial costs. In recognition of its high value power generation, the Columbia River was designated during the Water Use Planning (WUP) process as a working river and as such, major changes to the hydrograph were restricted (O'Riordan 2001). The CC shifted their focus to possible physical works and more limited flow management responses. To address concerns regarding reduced flows, the CC recommended assessment of important White Sturgeon demographic and biological parameters during high flow events on an opportunistic basis (CRWUP CC 2005). These data, compared to reference years, would allow for the development of a more adaptive management strategy that could be implemented in years of higher predicted flows if results proved effective in addressing recruitment failure.

Within the Canadian section of the lower Columbia River, spawning has primarily been documented at the Waneta site (Hildebrand et al. 1999; UCWSRI 2002) and more recently at several sites upstream towards Castlegar B.C. (Kinnaird and tailrace of Arrow Lakes Generating Station; BC Hydro 2015a). It is hypothesized that higher flow events in the lower Columbia River may, i) improve conditions necessary for successful spawning, ii) increase the number of spawning events that occur, iii) increase the number of spawning sites used, and iv) possibly increase survival at the egg, larval, and juvenile stages. Unfortunately, the effects of higher flows have yet to be evaluated through consistent long term monitoring. Several alternate recruitment failure hypotheses have been associated to the post-hydroelectric dam hydrograph including predation of eggs and larvae, changes to suitable habitat for larvae and juveniles, and juvenile food availability. If these hypotheses are accurate, opportunistic alterations to the hydrograph to provide higher and more prolonged flows during the spawning period could result in successful pulses in recruitment.

Various approaches to assessing recruitment success associated with high flow events have been discussed, including monitoring of changes in water quality, erosion effects, egg deposition, and larval and juvenile survival both in Canada and the US. The overall objective of this study is to determine the effect of high flow events on levels of natural recruitment through long term monitoring of adult and larval and juvenile White Sturgeon demographic variables in the lower Columbia River. Specific objectives during the early stages of the program were to: 1) tag sufficient numbers (>25) mature adult White Sturgeon with acoustic transmitters (10 year life span) to describe annual movement patterns, habitat use, and possible spawning site selection in relation to flows, 2) improve our understanding of how inflow forecast can be used to accurately predict high water years that could trigger a decision around opportunistic flow changes, as recommended by the CC, and 3) initiate consistent long term monitoring focused on early life stages (eggs, larvae, juveniles). This report summarizes the results of years 3-5 for this monitoring program.

1.1 Management Questions

Key management uncertainties encountered during development of the Columbia River Water Use Plan included how the operations of HLK Dam may adversely affect spawning habitat suitability for adult sturgeon, spawning incidence and success, juvenile survival, and ultimately, recruitment failure of White Sturgeon in the lower Columbia River.

Fundamental management questions to be addressed through this assessment of high flow events (exceeding 200 kcfs for prolonged periods of time) are as follows:

1. Are there unidentified spawning sites in the lower Columbia River that are used during higher flows?
2. How does the interaction among presumed subpopulations of sturgeon in the lower Columbia River change during high flow events?
3. Are probabilities of survival higher at the egg stage in years of higher flows?
4. What effects do higher flows have on recruitment to the larval stage?
5. What is the effect (and associated mechanisms) of higher flows on juvenile survival in the lower Columbia River?

1.2 Management Hypotheses

The following hypotheses are recommended to guide this monitoring study at both the adult and juvenile stages:

Adult Sturgeon Spawning Hypotheses

H_{o1}: Opportunistic high flows will improve sturgeon spawning success (as demonstrated by increased egg and larval captures) in the lower Columbia River reach.

H_{o2}: Opportunistic high flows result in sturgeon spawning at alternative site(s) between Hugh Keenleyside Dam and Waneta Eddy.

H_{o3}: Spawning at locations in the upper sections of the river will provide a greater reach of free flowing river for dispersal of early life stages, which will increase early life stage survival rates and promote natural recruitment.

H_{o4}: Adult White Sturgeon in the lower Columbia River upstream of Grand Coulee Dam will interact as a single interbreeding population in years including peak flows in the range of 200 kcfs with migration occurring over longer distances and a higher proportion of spawning occurring in more upstream sections of the lower Columbia River.

Early Life Stage Hypotheses

H_{o1}: Opportunistic high flows will have a positive effect on embryo survival in the lower Columbia River reach.

H_{o2}: High flows will result in increased embryo survival and subsequently increased free-embryo and larval captures.

H_{o3}: High flows result in free-embryos and larvae being dispersed over a wider geographical area compared to reference years, exposing them to increased and varying threats to survival.

H_{o4}: Higher flows increase probabilities of survival for juvenile (3 months+) White Sturgeon.

1.3 Objective and Scope

The CRWUP Fish Technical Subcommittee (FTC) defined the scope of an opportunistic assessment of high flow events program to include the following elements:

1. detection of spawning events,
2. juvenile detection,
3. water quality sampling, and
4. monitoring of erosion and flood impacts associated with the high flow events.

Based on the Comptroller of Water Rights (CWR) Order and recommendations of the UCWSRI, additional effort was needed in this program to ensure collection of adequate baseline data, and consistency in effort and sampling design across all years (reference years and high flow years). Specifically, objectives of this program are to:

- Identify alternative lower Columbia River spawning site(s) identified through the telemetric monitoring of adult movements in both high flow years and low flow years (CLBMON 28).
  - Through addition of sufficient resources to the existing adult monitor program (CLBMON#28) to provide for monitoring of changes in adult movement during high flow events.
- Compare habitat conditions of spawning and egg distribution locations during high flow years compared to reference years.
  - Through addition of sufficient resources to the existing adult monitor program (CLBMON#28) to provide for monitoring of changes in spawning events and egg distribution during high flow events.
- Detection of wild origin juveniles and determining the year of birth for these individuals to examine environmental conditions in those years. The collection of wild juveniles represents the highest probability of detecting a positive effect on recruitment from physical conditions in the lower Columbia River. Additionally, comparisons of juvenile growth and survival among years evaluated in the program are warranted. .
  - Through addition of sufficient resources to the existing juvenile survival program (CLBMON#29) to provide for monitoring of wild recruitment, juvenile abundance, growth and survival.

Information gained through this program, when compared to the baseline information acquired through other lower Columbia River sturgeon monitoring programs, may be used to 1) test existing and develop additional credible recruitment failure hypotheses, 2) develop new or modify proposed physical works options addressed at recruitment failure, or 3) develop possible options for modest, periodic, and clearly focused operational remedies necessary to improve conditions needed for natural recruitment.

1.4 Study Area

The study area consisted of the Columbia River between HLK Dam and the Canada/U.S. Border (just downstream of the Pend d'Oreille River confluence), a section of the Columbia River approximately 57 km long (Figure 1). The study area also included the section of Kootenay River from below Brilliant Dam to the confluence with the Columbia River.

2.0 METHODOLOGY

2.1 Opportunistic High Flow Events

Originally the CC defined a decision rule for triggering opportunistic assessments of high flow events for White Sturgeon in the lower Columbia River based on volume runoff forecasts (CRWUP CC 2005). However, the criteria for this decision had not been fully evaluated. The decision criteria were as follows:

1. When the March final volume runoff estimate is 10% or more above the average April - July average of 55 million acre feet at the Canada/US border, BC Hydro goes “on alert” that the program may be initiated in that year.

2. When the April 1 final volume runoff forecast is estimated at 15% or more than the April - July average of 55 million acre feet at the border, the monitoring program is to be initiated and efforts made to maintain the high flow for a period of one month.

3. When above normal snow loads, a cool spring and summer, and a suitable precipitation pattern provide the opportunity; an opportunistic high flow (maintenance of high flows for as long as possible) will be pursued.

Volume runoff forecasts for the Mica, Revelstoke, Arrow, Duncan and Kootenay basins are combined with the U.S. forecasts for Libby Reservoir and the Pend d’Oreille River, and are available through the U.S. River Forecast Center. The published runoff volume forecasts for the Columbia River at the International boundary are for January-September, April-September, and April-July. The CC recommended that the April-July forecasts be used as the best indicator for decision-making around initiation of the opportunistic assessments. It was noted that the first reliable runoff forecast would not be available by 1 April. This would provide a one-month lead-time required for planning and mobilization of field crews. The problem with this simplistic approach is that, if this rule was applied to the decade 1990-1999, the studies would have been initiated in 4 out of 10 years and conversely, if it was applied to the decade 1934-1943, no studies would have been initiated. The CC, therefore, recommended that BC Hydro go “on alert” whenever the runoff forecast is 10% above normal and a decision to initiate the studies (at that time) be based on consultation with other stakeholders. In the event that there has not been a high runoff year for 4-5 years, consideration should be given to reducing the threshold value.

In the early years of this program (2009 and 2010), projected inflow forecasts from April and June were used to determine if runoff estimates were below, at, or above normal for each of the respective water years. This was an attempt to evaluate the decision criteria outlined by the CC. In general it was determined that run-off forecasts were not good indicators of the probability of reaching a target of 200 kcfs at the international border. Based on inflow forecasts, it was not certain that a high water year might be achieved whenever the inflow forecast is 10% above normal. As such, inflow forecasting was not a priority for this program going forward as it was apparent that a long-term data set on spawning and movements would allow for a more quantitative comparison across a suite of flow years, rather than putting additional effort into a few single years. The previous work evaluating inflow forecasting also indicated the ability to predict freshet flows will be impacted by several factors including, Columbia River Treaty Flows, Non-Treaty storage, reservoir inflow rates during freshet, and Arrow Lakes Reservoir discharge rates.

2.2 Physical Parameters

2.2.1 Discharge

Daily discharge records for the entire Columbia River from Arrow Lakes Reservoir (combined HLK and Arrow Lakes Generating Station discharges) Kootenay River (downstream of Brilliant Dam), the Columbia River at Birchbank, and the Columbia River at the Canada United States border were obtained from BC Hydro power records for the period January 1, 2011 to December 31, 2013. This period was incorporated to include interpretation of high water events in the past, and more specifically for the only known wild recruitment event that happened in 1997.

Freshet flows, or discharge, are typically presented as metric measurements (cms) in technical reports and scientific publications; however the non-metric discharge measurements of kcfs (typically used to describe flow rates of large magnitude) and cfs are more readily used by water planners and biologists to discuss flows from hydroelectric facilities. As such, kcfs was used as the primary measure of flow when various representatives from the CRWUP CC proposed and developed this study. Both of these non-metric discharge measurement are commonly referenced and presented in this report in addition to the metric discharge measurement.

2.2.1.1 Inflow Forecasting

As discussed in Section 2,1, in 2009 and 2010 forecasts for Columbia and Kootenay projects were obtained and were an effective tool to gauge relative runoff within a given water year, however they present uncertainty when attempting to predict actual hydrograph flows due to a number of factors including i) Columbia River treaty flows, ii) non-treaty storage agreements; and, iii) system and operational constraints. As such inflow forecasting as a tool to predict flow years that could be opportunistically held above the 200 kcfs level was not evaluated in 2011, 2012, and 2013.

2.2.2 Water Temperature

Water temperature data for the 2011, 2012, and 2013 study period was collected at six locations on the Columbia River including immediately downstream of HLK (rkm 0.1), the Kootenay River confluence (rkm 10.5), in Kinnaird Eddy (rkm 13.4), at Genelle (rkm 26.0), at Rivervale (rkm 35.8) and in Waneta Eddy (rkm 56.0). Water temperatures were recorded hourly at each location using thermographs (Vemco Minilogs, accurate to ± 0.1°C).

2.2.3 Erosion

Erosion surveys will be done in high flow years with the primary objective to identify sites where high water discharges may be causing abnormal bank erosion. A secondary objective will be to identify sites where potential flooding issues might arise with higher flows. At each site that is surveyed, digital photos were taken, a location (river kilometer and UTM), and comments were made about the erosion issues.

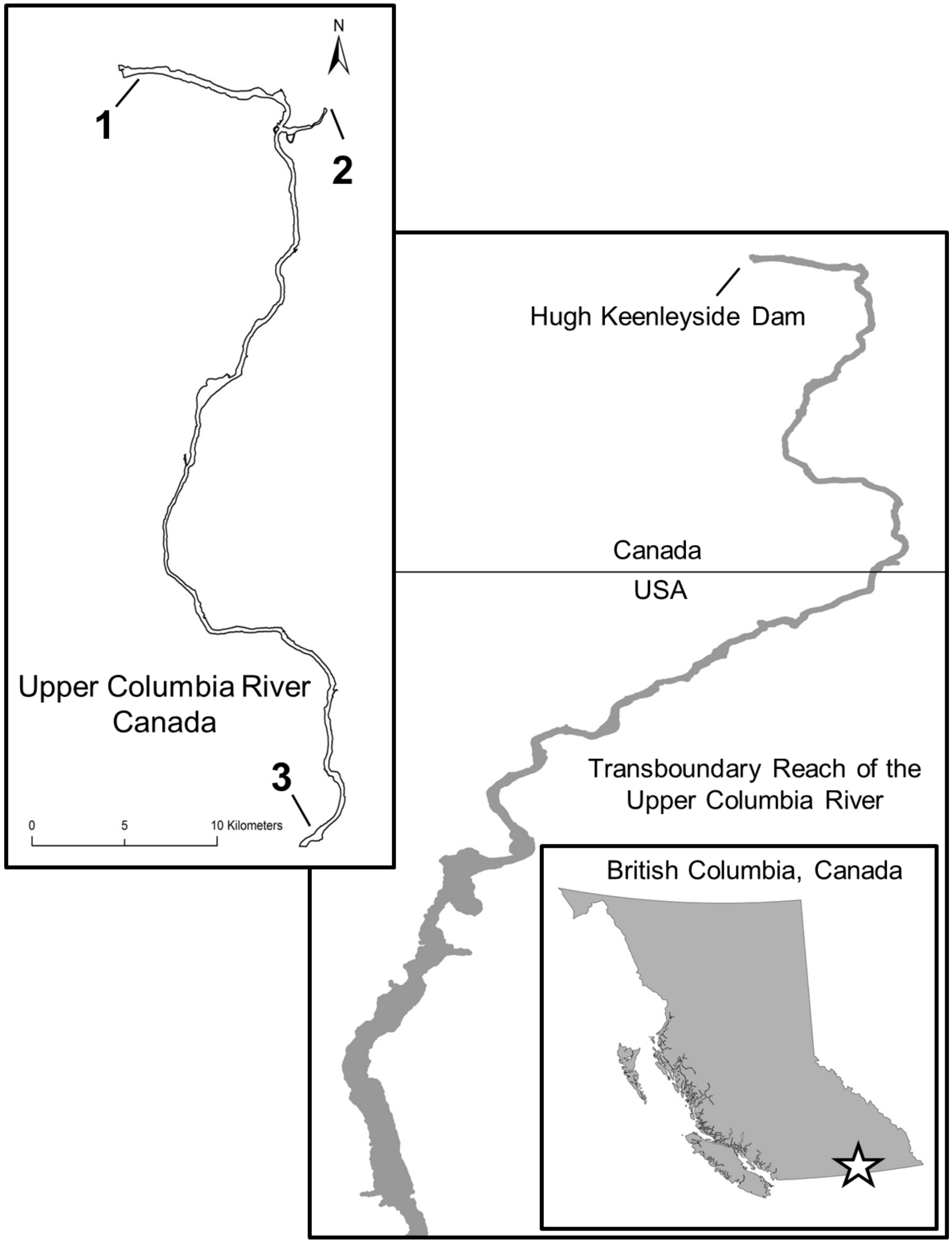

Figure 1. Overview of the study area between HLK and the Canada/US border. Hydro Dams are indicated on the map as 1: Hugh Keeleyside Dam and Arrow Lakes Hydro, 2: Brilliant Dam on the Kootenay River, and 3: Waneta Dam on the Pend d'Orielle River.

2.3 Early Life Stage Monitoring

2.3.1 Experimental Design

Sampling followed monitoring outlined in CLBMON 28 and 29, which is consistent with previous work completed in the lower Columbia River. Past studies of White Sturgeon in the transboundary area of the Columbia River have documented annual spawning occurring at two locations, the Waneta area (below the Pend d'Oreille-Columbia confluence), and the Northport area (near the town of Northport, WA). Although spawning has been detected at each of these areas in all years examined, wild origin juvenile age-classes from wild recruitment remain under-represented (less than 0.5% of captures) within the lower Columbia River (BC Hydro 2015a). The Waneta spawning area represents the only lower Columbia River site where long-term monitoring of White Sturgeon spawning activity has occurred. Information has been collected annually since 1993 (excluding 1997, 1999, and 2006) and establishes a long term baseline data set (reference years) that can be used to compare habitat conditions of spawning and egg distribution locations during high flow years. In more recent years (2007-2010), spawning activity has also been identified immediately downstream of HLK and ALH, near the Kootenay-Columbia rivers confluence (e.g. Kinnaird) (BC Hydro 2015b), and another spawning area is proposed downstream of the Northport site (Howell and McLellan 2006).

Annual monitoring of White Sturgeon spawning activity is expected to occur from 2008 through 2018 under two ongoing Water Use Plan programs, CLBMON 28 and CLBMON 29. Monitoring currently includes the strategic placement of substrate mats for egg collection and D-ring drift nets to identify if spawning occurred and for early life stage collection of eggs and larvae. Both methods are described extensively in other WUP reports (BC Hydro 2011a; BC Hydro 2011b). This monitoring will be used to document the total number of spawning events annually (as indicated by egg captures and subsequent staging), annual trends in reproductive success, and early life stages captured downstream of the spawning locations. This program is adaptive and monitoring using substrate mats and D-ring nets will be expanded annually if required to include sites that are defined as potential spawning sites based upon adult movement data and early life stage (egg and larval) collection.

2.3.2 Juvenile Stage Monitoring

The juvenile monitoring under CLBMON 29 will be a critical component when describing trends in recruitment over the life of this program as determining survival, and attributing it to specific flow years; will likely not be possible at the egg and larval stages. A specific objective of the juvenile program is to determine the distribution, growth and survival of both wild and hatchery origin juvenile sturgeon. Trends in distribution, growth, and survival will be captured under the CLBMON 29 monitoring program over a 10-year period and will provide the best opportunity to assess if higher flows years positively influence natural recruitment. This is due to logistical difficulties in sampling for early life stages (e.g. eggs and larvae) during years of high flows. The monitoring program for juveniles uses multiple capture techniques (e.g. gill nets, angling, and setlines) that follow a spatially balanced design similar to work described in this program (see section 2.4.1 details below). Juveniles of wild origin are aged based on pectoral fin ray samples. Describing the variation in pectoral fin ray ages is an objective of the juvenile program to ensure that when individuals of wild origin are captured, their year of birth can be determined with confidence. For further details regarding sampling methodology and ageing work refer to CLBMON 29 (BC Hydro 2015b).

2.4 Adult Life Stage Monitoring and Movements

2.4.1 Experimental Design

Key management questions for CLBMON-30 pertaining to the adult stage are focused on: 1) determining if there are alternative spawning sites in the lower Columbia River that are used during years of higher sustained flows, and 2) determining if the interaction among presumed subpopulations of sturgeon in the lower Columbia River changes during years of high flow events. While capture records help address habitat use and general movement between different areas of the lower Columbia River, describing movements at a monthly (or daily) scale would better address the management questions. In order to describe movements, adult White Sturgeon were surgically implanted with acoustic transmitters that will operate for the life of the monitoring program so that individual movements can be collected to examine spatial and temporal trends related to river discharges.

Previous sampling efforts for adult White Sturgeon in the lower Columbia River (e.g. broodstock collection, BC Hydro 2015a), population estimation (Hildebrand et al. 1999; Irvine et al. 2007), acoustic tagging (Golder 2002b)) has focused on areas of known concentrations in order to maximize catch per unit effort given the short-term nature of the projects and budgetary limitations. Since CLBMON-30 is a long term project (10 years), sampling was designed to address both spatial and temporal factors (e.g. habitat use, staging, spawning) both within and across years. Furthermore, it has been suggested that White Sturgeon in the lower Columbia River exhibit high site fidelity (Hildebrand et al. 1999; van Poorten and McAdam 2010). Documented site fidelity indicates the importance of ensuring that sampling strategies encompass the entire spatial distribution of habitats occurring in the lower Columbia River.

In order to ensure a spatially balanced sampling design, the lower Columbia River study area was stratified into 5 equal zones (11.2 km in length; Figure 2). Sampling effort was randomly distributed with equal probability within and across each of the zones. We used a generalized random-tessellation stratified (GRTS) design developed by Stevens and Olsen (2004) to assign sampling locations within each river zone. This was conducted with the statistical package R (Program R, version 2.9.0) using the library packages spsurvey and sp, provided by the United States Environmental Protection Agency. The library package spsurvey allows a user to input data/criteria needed for a GRTS sampling design. We developed shapefiles (i.e. geo-referenced maps) for each river zone using ArcMap (Environmental Systems Research Institute, Inc. (ESRI)). Each river zone shapefile was imported in to spsurvey and 50 sampling sites were randomly generated with equal probability and distribution. The locations of each sampling site (1 through 50) were output as coordinates in Universal Transverse Mercator (UTM) format for visual display on maps and for importing into handheld global positioning system (GPS) devices used for field application. Sites were sampled in ascending order until the required effort had been expended (further detail provided below). Within each river zone, a proportion of the randomly generated sites could not be sampled. This occurred if the sampling site was generated in an area where our sampling gear could not be deployed (e.g. water depth <1m) or where safety concerns were evident with the sampling gear (e.g. high sustained river flows). If a site was omitted due to an inability to sample, the next site occurring on the list was sampled

The stratified random sampling design described above is also used by the Washington Department of Fish and Wildlife (WDFW) from the Canadian-United States (US) border on the Columbia River to Grand Coulee Dam. This design is used on the US side of the Columbia River for both juvenile and adult sampling efforts. Consistency between sampling designs is important given the transboundary nature of the population (Hildebrand et al. 1999; Irvine et al. 2007) and allows for direct comparison of results in future years.

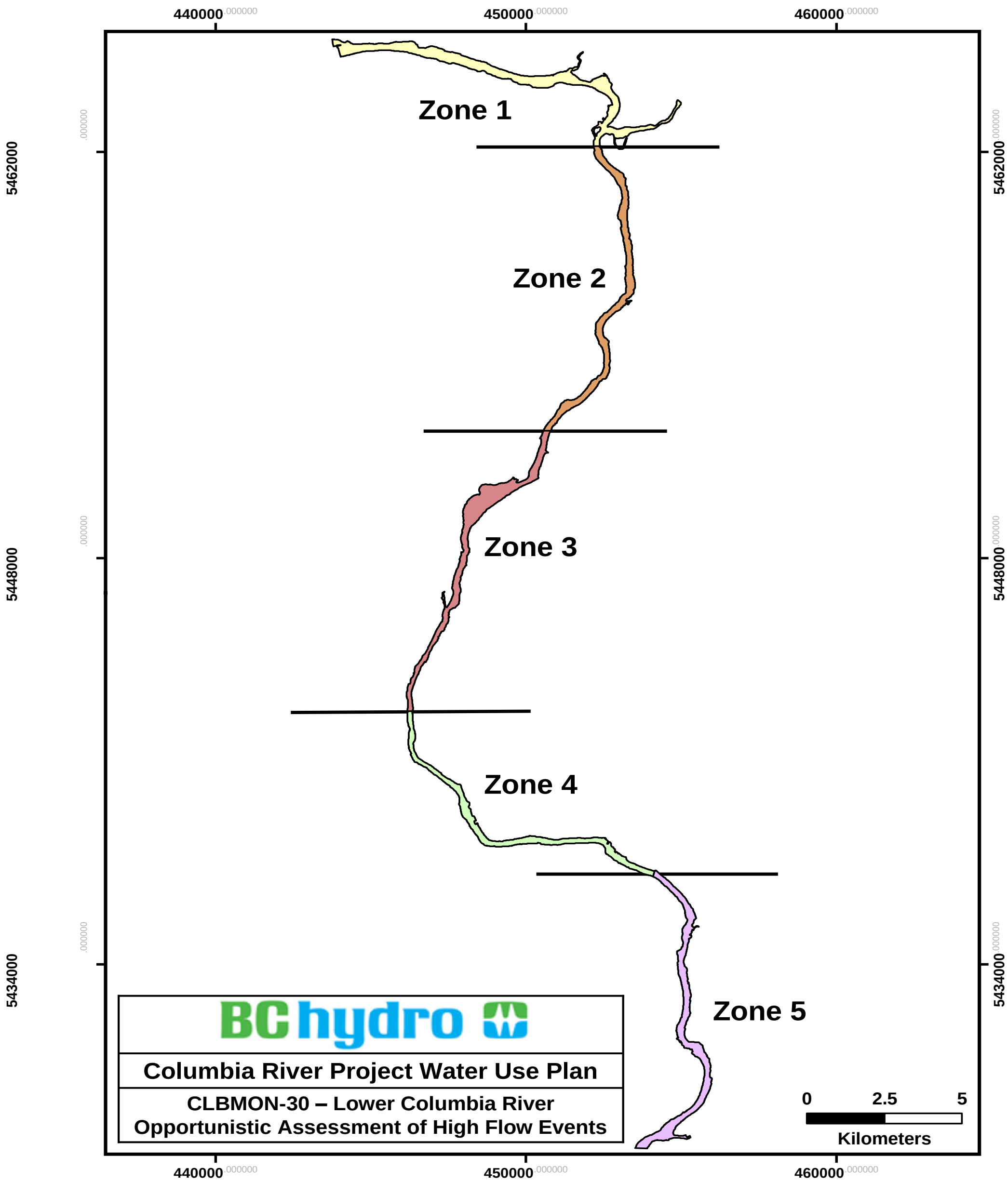

Figure 2. Stratified sampling zones for adult White Sturgeon research studies on the lower Columbia River.

2.4.2 Adult Capture Techniques

All adults that were captured and assessed for suitability for acoustic tags were handled according to the UCWSRI handling manual (UCWSRI 2006). Set lines were used to capture White Sturgeon as this method has been shown to provide higher White Sturgeon catch-rates, is less size selective compared to other sampling gear, and rarely captures non-target species (Elliot and Beamesderfer 1990). Set lines have been successfully used in the lower Columbia River to capture adult White Sturgeon for the past few decades (Irvine et al. 2007). A medium line configuration was used for set lines, similar to that used by the Oregon Department of Fish and Wildlife (ODFW) and the WDFW to capture White Sturgeon in the lower Columbia River (Nigro et al. 1988). Medium lines measured 54.0 m in length and consisted of a 0.64 cm diameter nylon mainline with 8 circle halibut hooks attached at 6.0 m intervals. Hooks were attached to the mainline using a 0.64 cm swivel snap and a 0.7 m long ganglion line tied between the swivel and the hook. Halibut hook sizes used were either 16/0 or 20/0. 4 hooks of each size were attached in random order on each long line. The barbs on all hooks were removed to reduce the severity of hook-related injuries and to facilitate fish recovery and release. All set line hooks were baited with Kokanee (*Oncorhynchus nerka*) obtained from the Meadow Creek Hatchery (Meadow Creek, BC). Set lines were deployed from a boat at the predetermined sampling location and set configuration was based on the physical parameters (depths and water flow) of the site. Set line configuration consisted of either deploying the line parallel to the shore in faster flowing water or perpendicular to the shore in slower moving water. This was conducted to ensure that fish were able to orientate themselves into the current and rest on the bottom of the river, minimizing stress. Prior to each set, water depth (m) was measured by an echo sounder, and this information was used to select a float line of appropriate length. Anchors were attached to each end of the mainline and a float line was attached to the back anchor of the mainline. The set line was secured to shore with a shore line of suitable length to ensure that the set line was deployed in water depths greater than 2m. Set lines were deployed and remained in overnight at each selected site.

The set line retrieval procedure involved lifting the back anchor using the float line, until the mainline was retrieved. The boat was then propelled along the mainline and each hook line was removed. If a fish was captured on a hook, the boat was stopped while the fish was removed. White sturgeon that were removed from the set line were tethered to the side of the boat. The 0.64 diameter tether line from the hook was attached between two anchor points along either the port or starboard side of the boat and allowed the entire body of the fish to remain submerged. Once all fish were removed from the set line, the boat was idled into shore or anchored within a nearby back eddy and White Sturgeon were individually brought aboard for biological assessment (described in section 2.4.3) and processing. All sturgeon were guided into a 2.5 m long by 1.0 m wide stretcher that was raised into the boat using a winch and davit assembly. The stretcher was secured on the boat and fresh river water was continuously pumped over the gills during the processing period. A hood on one end of the stretcher protected the head of the sturgeon from exposure to direct sunlight and also retained a sufficient amount of water allowing the fish to respire during processing. Wet towels were placed over the body of the fish to keep the skin cool and moist. White Sturgeon were returned to the water following processing and remained in the stretcher until they swam away under their own volition.

2.4.3 Adult Tagging Techniques

Once on the boat, White Sturgeon were immediately checked for tags indicating if they had been previously captured and tagged. Recaptured White Sturgeon were identified by either: 1) the presence of a Passive Integrated Transponder (PIT; Biosonics Inc.,400 kHz or 134.2 kHz ISO PIT tag), 2) a missing section from the first ray on the left or right pectoral fin (a noticeable mark on White Sturgeon results from the removal of a section of the first pectoral fin ray for ageing purposes; the removal of the fin ray section results in an identifiable mark that persists for several years and can easily be identified by experienced samplers); or 3) the absence of lateral scutes. Unmarked fish (considered to be wild fish not previously handled) had PIT tags injected subdermally behind the posterior edge of the bony plate on the head, slightly to the left of the mid-dorsal line. Prior to insertion, both the tag and the tagging syringe were immersed in an antiseptic solution (Germaphene). Care was taken to angle the syringe needle so the tag was deposited in the subcutaneous layer and not the muscle tissue. Pectoral fin ray section removal has been used on the Columbia River system since 1990 for ageing purposes. Unmarked fish received Oxytetracyline (OTC) injections which are used as a marker on bony structures (i.e., fin rays) for future age-validation studies. OTC was administered at a dosage of 0.2 mL Liquamycin-LP per kilogram of body weight and was injected either through a surgical incision (Apperson and Anders 1991; R.L. & L. 1996); or administered intramuscularly anterior to the dorsal fin if surgery was not performed on the fish

White Sturgeon were measured for fork length to the nearest 0.5 cm. Weight was determined by suspending the fish in the stretcher from the winch and davit assembly using a 250 kg capacity spring scale accurate to ± 2.2 kg. External examinations were conducted on each White Sturgeon to identify features such as colouration, deformities (either genetic or mechanical injury related), lesions, cysts, external parasites, and body form anomalies. All life history data were recorded in the field on standardized data forms and later entered into an electronic database.

White Sturgeon were also surgically examined to assess sexual maturity. A 1.5 to 2.0 cm long incision was made through the body wall just off the mid-line using a sterile scalpel. Maturity stages for both males and females were assessed according using a otoscope and classified based on qualitative histology presented by Bruch et al. (2001). Female developmental stages are usually more easily determined since ovary size, colour, average egg diameter, and egg colour can be used as indicators of maturity stage. Immature gonads or those in early stages of maturation are smaller and more difficult to find (especially in males). If the gonad was not visible through the incision, an otoscope equipped with a veterinary head and speculum was inserted into the incision to examine the gonads and to assist with determining sex and maturity stage. Following examination, the incision was closed using a half circle CP-2 reverse cutting-edge needle connected to a 2-0 polydioxanone violet monofilament suture

(PDS). Sutures were spaced approximately 1 cm apart and sufficient slack (approximately 2.0 to 4.0 mm) was provided in the sutures to prevent tissue damage caused by swelling during the healing process. Finally, lateral scutes were removed using a sterilized scalpel in a manner consistent with the marking strategy employed by WDFW and ODFW. The 2nd right lateral scute was removed from new or recaptured sturgeon that received OTC injections. The 2nd left lateral scute was removed from new or recaptured sturgeon that did not receive OTC injections.

2.4.4 Adult Movement Studies

The design of this aspect of the program is to collect data over a period of 10 years so movements in relation to flows can be evaluated. Examination of movements of adult White Sturgeon in the first several years of this program are limited to evaluating spawning related movements (defined in BC Hydro 2015a, 2015c) that can inform early life stage sampling, habitat use based on the proportion of detections of tagged White Sturgeon at each receiver location, and general movement patterns across years (2009-2013). Movement data were collected using an array of fixed acoustic receivers (Vemco model VR2), spaced at 3 km intervals in the lower Columbia River. Additionally, detailed methods for movement analyses by sex, seasonal habitat use within years, and total distance traveled by month are presented in the CLBMON-28 reports for the period of 2011-2014 (BC Hydro 2015a, 2015c)

3.0 RESULTS

Results of this long term monitoring program will be used to characterize sturgeon movements, spawning site selection, spawning frequency, characterization of habitats used, and early life stage distribution and survival under different flow patterns; with specific comparisons to years where peak flows in the Columbia River exceeded 200 kcfs at the US border. Data collected in 2011, 2012, and 2013 represent the third to fifth years of a 10 year study and are insufficient to provide a quantitative assessment of the management questions or test specific hypotheses relating to Columbia River flows and associated operations. Qualitative comparisons and inferences based on data collected in years 1 through 5 are highlighted below and discussed.

3.1 Physical Parameters

3.1.1 Discharge

Mean daily lower Columbia River discharge at the Canada/US International Border for the 2011, 2012, 2013 study period are presented in Figures 3, 4 and 5, respectively. The White Sturgeon spawning period (May 01 - July 31 annually) is based on a number of factors including egg and larval collections, historical river temperatures, and peak freshet flows. In 2011, mean daily discharges during the spawning period ranged from 2,647 cms (93,480 cfs) to 7,561 cms (267,000 cfs) with peak freshet flows reached on June 14, 2011. For the 2012 study period, mean daily discharges during the spawning period ranged from 4,299 cms (151,800 cfs) to 7,940 cms (280,400 cfs) with peak freshet flows achieved on June 28, 2012. For the 2013 study period, mean daily discharges during the spawning period ranged from 2,515 cms (88,820 cfs) to 5,720 cms (202,000 cfs) with peak freshet flows achieved on July 1, 2013. In contrast to the first two years of the study, the target flow of 200 kcfs was reached in each of the third to fifth years, but sustained periods above 200 kcfs were observed only in 2011 and 2012 (Table 2). These two years represent the first consecutive two year period of flow over the 200,000 cfs in the past 13 years and are similar in discharge pattern to 1997 (Figure 6), a year where suspected wild recruitment has been detected.

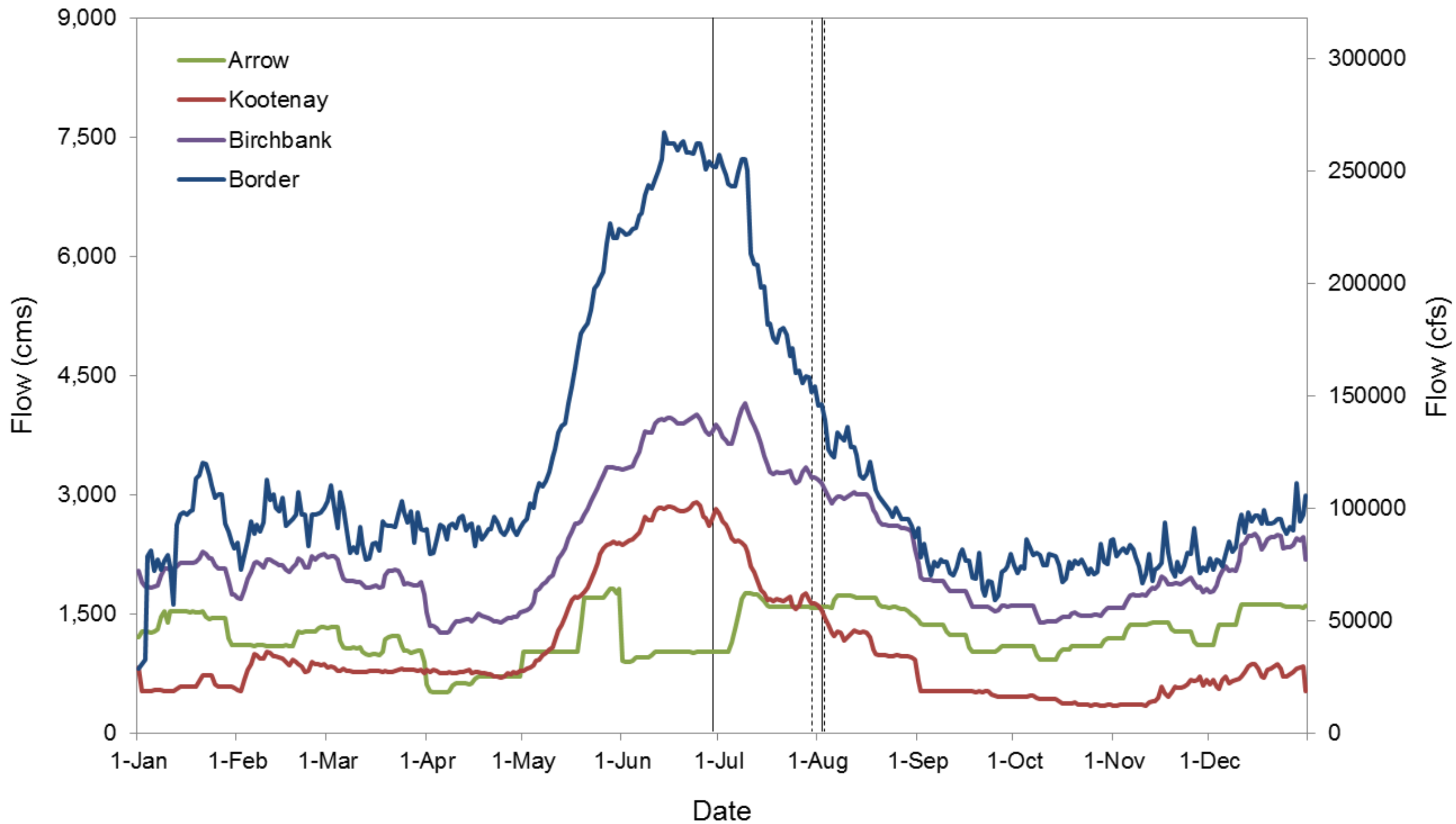

Figure 3. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the LCR from January 01, 2011 – December 31, 2011. The solid vertical bars represent the first and last estimated spawning dates at Waneta in 2011, either based on the collection of fertilized eggs or larvae. Vertical dashed bars represent the first and last estimated spawning dates in the upper portion of the LCR at the HLK/ALH spawning area.

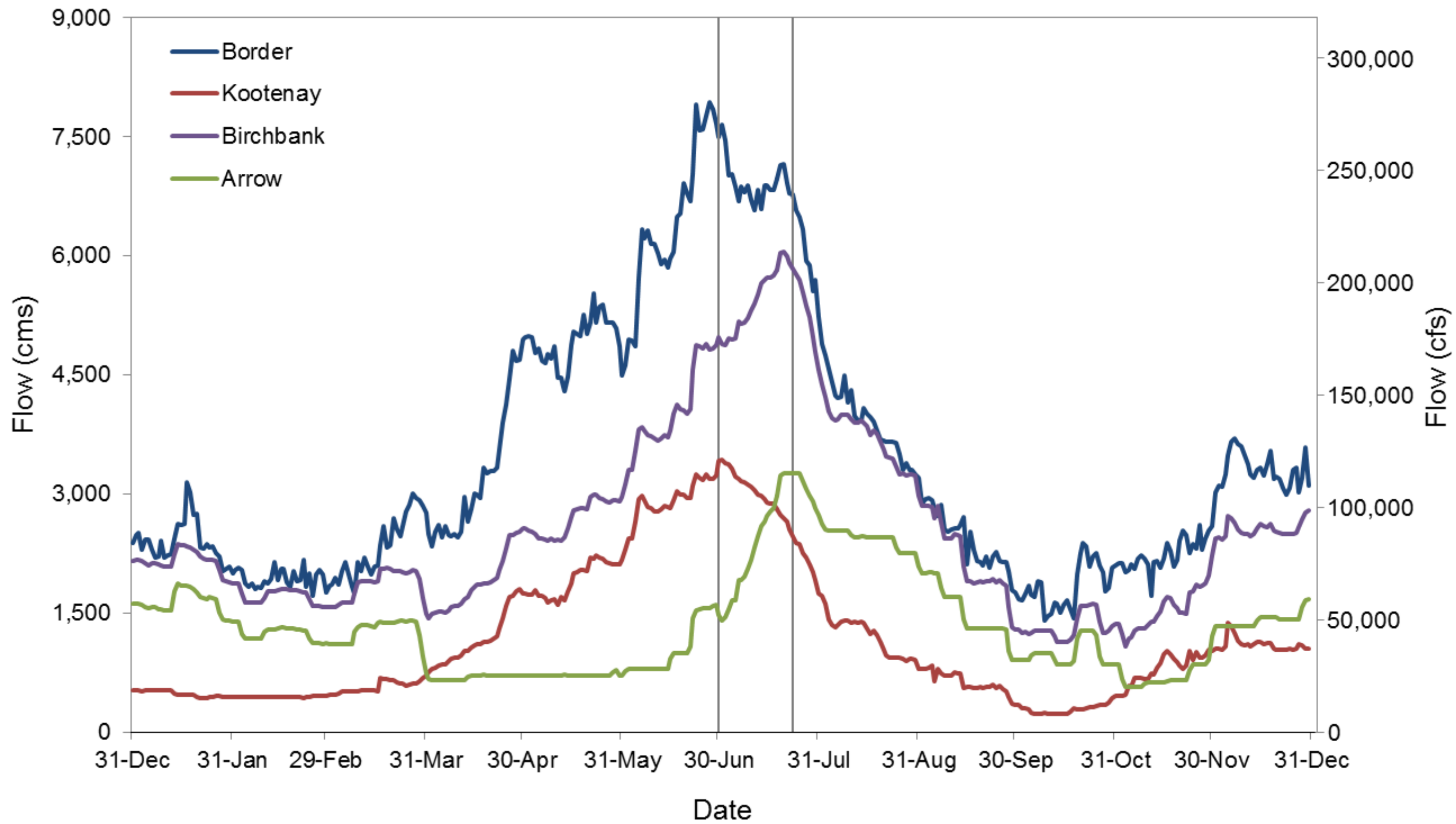

Figure 4. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the LCR from January 01, 2012 – December 31, 2012. The solid vertical bars represent the first and last estimated spawning dates at Waneta in 2012, either based on the collection of fertilized eggs or larvae. Despite sampling effort, estimated spawning dates were not calculated for the upstream locations.

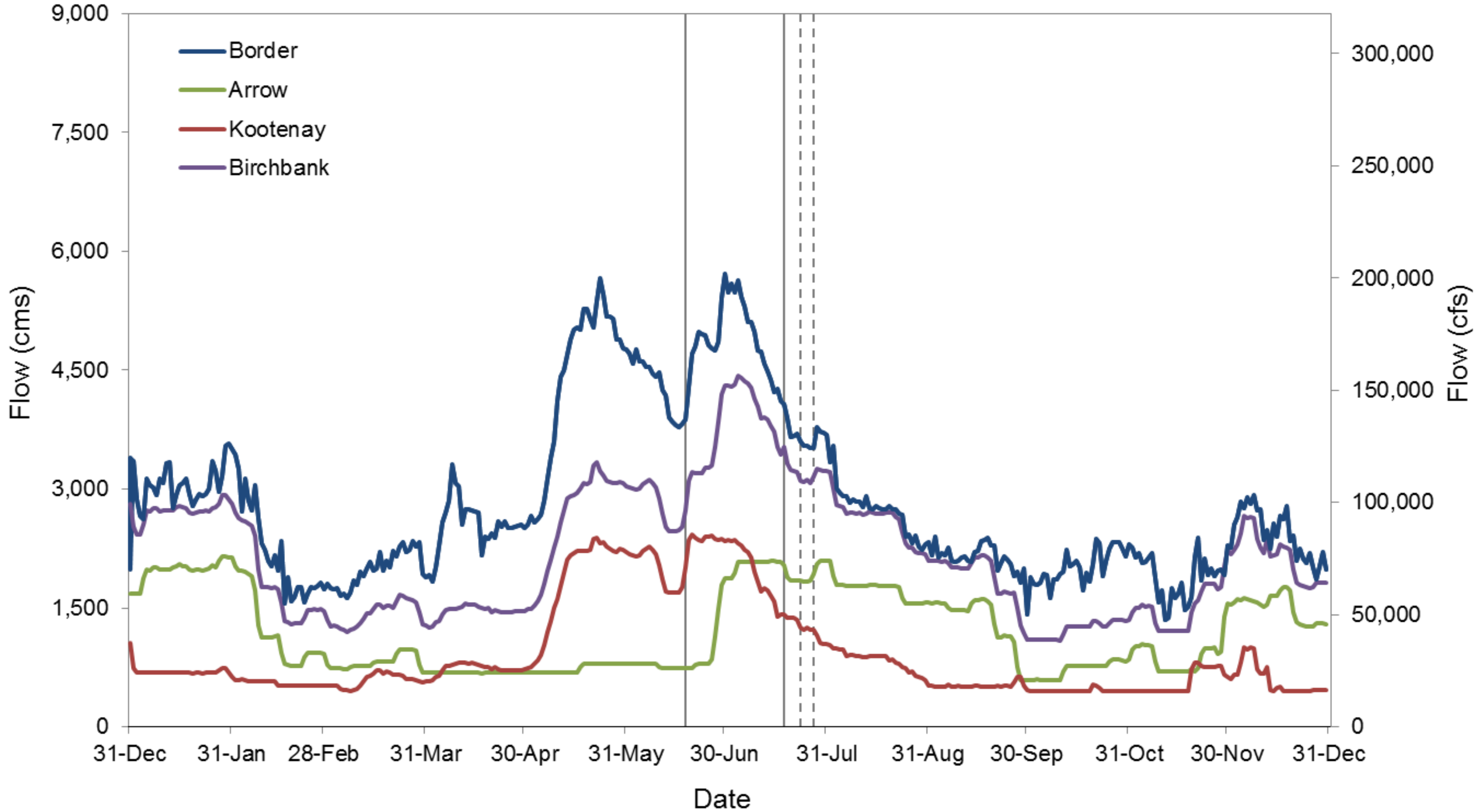

Figure 5. Mean daily discharge measured from Arrow Reservoir, Kootenay River, Birchbank, and the Canada/U.S. International Border on the LCR from January 01, 2013 – December 31, 2013. The solid vertical bars represent the first and last estimated spawning dates at Waneta in 2013, either based on the collection of fertilized eggs or larvae. Vertical dashed bars represent the first and last estimated spawning dates in the upper portion of the LCR (at or above rkm 18.2).

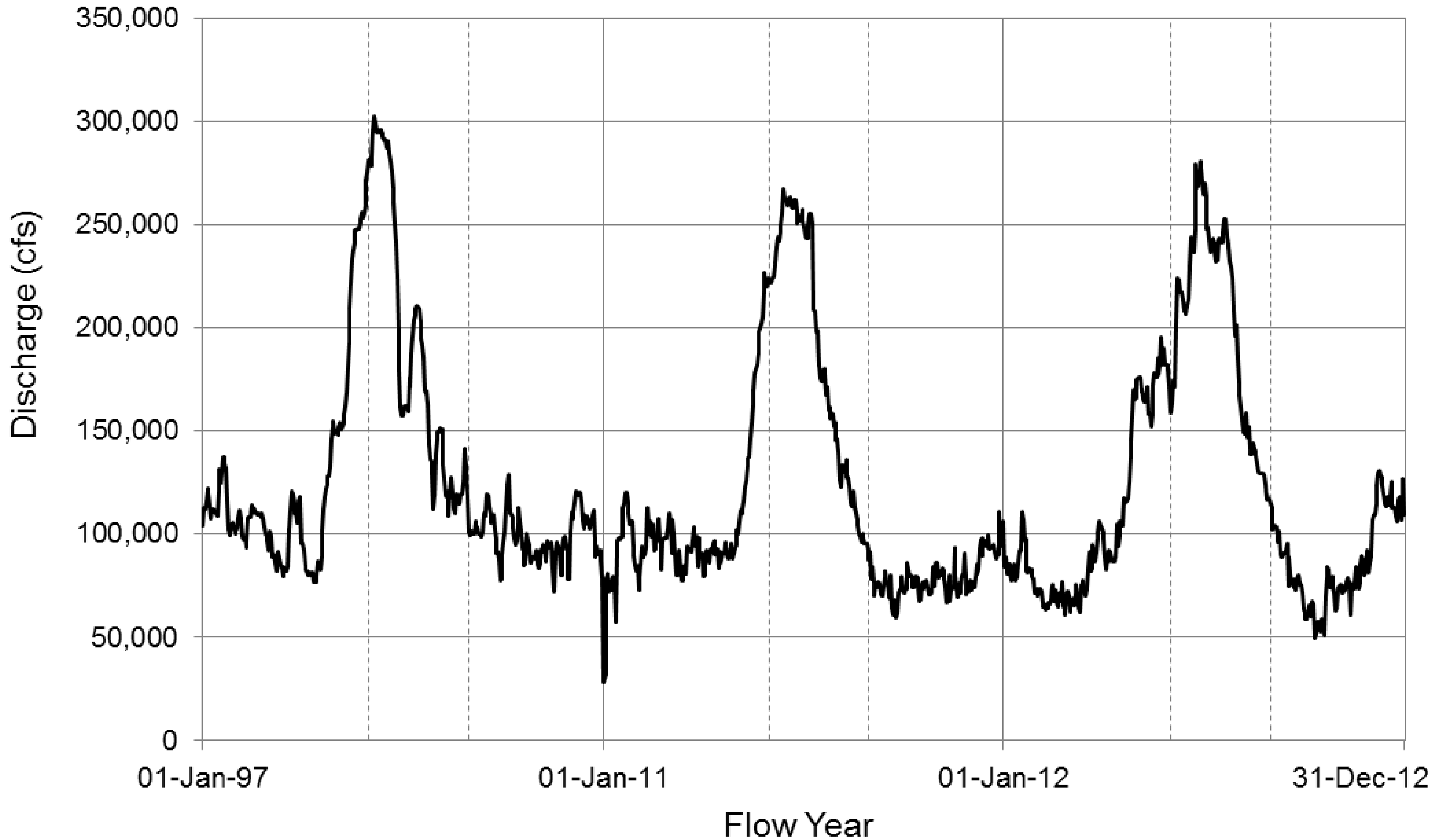

Figure 6. Columbia River discharge measured at the international border in 1997, 2011, and 2012 which were the highest flow years recorded from 1997-2013. The vertical dashed lines represent the period of June 1st through August 31st in each year when White Sturgeon are known to be spawning in the LCR. (Note: Flows at the Canada/U.S. border were not recorded until 2002. 1997 border flows were estimated using Columbia and Pend D'Orielle River flows and are within 5% of the true value)

3.1.2 Water Temperature

During the White Sturgeon spawning period in 2011, 2012, and 2013 average daily water temperatures are presented in Figure 7, 8, and 9 respectively. Temperatures during the documented spawning periods (indicated on the figures) in these years ranged from 14–16 °C, with subtle differences between years. In 2012, the highest flow year, spawning appeared to occur at lower temperatures than observed in the past (below 14°C). In all years spawning occurred as water temperatures were increasing.

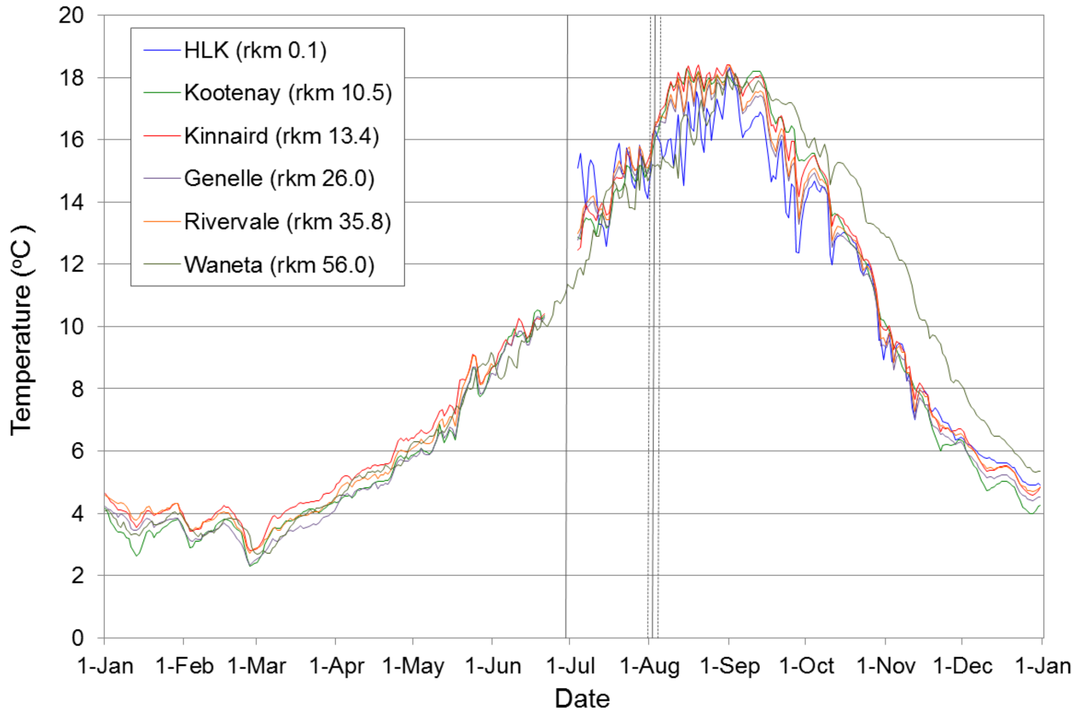

Figure 7. Mean daily water temperature (°C) of the LCR in 2011. Data was recorded at locations of HLK (rkm 0.1), Kootenay (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid lines represent estimated first and last spawning dates at the Waneta spawning area while vertical dashed lines represent estimated first and last spawning dates at the ALH spawning area. Estimated spawning days were either based on the collection of fertilized eggs or larvae.

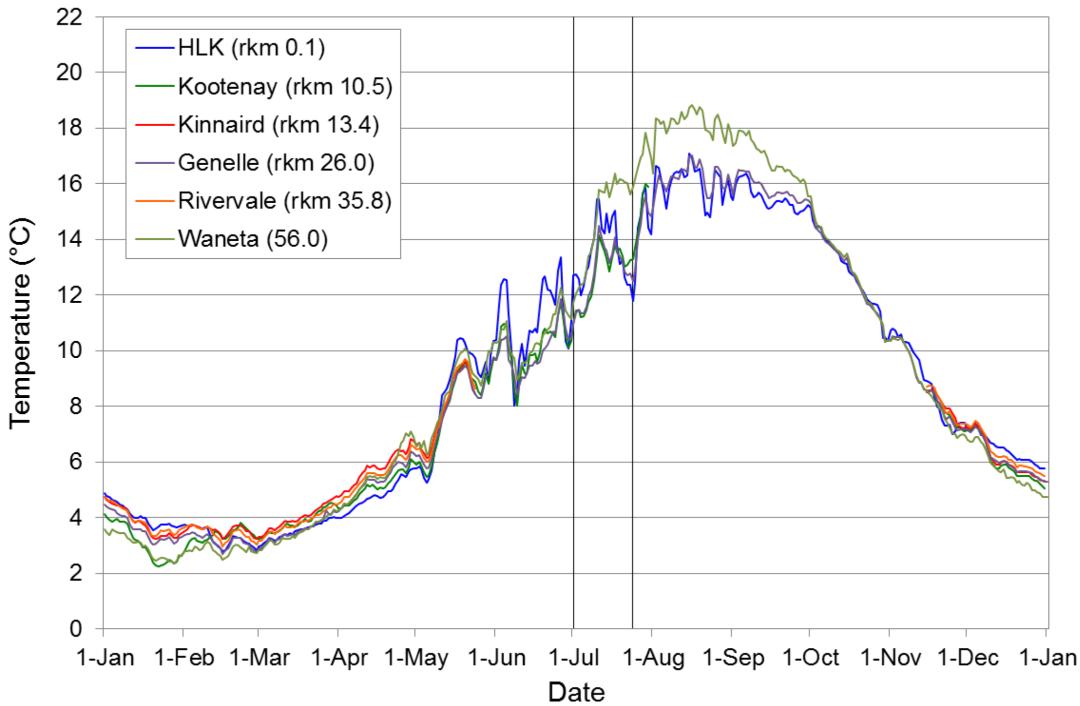

Figure 8. Mean daily water temperature (^{o}C) of the LCR in 2012. Data was recorded at locations of HLK (rkm 0.1), Kootenay Eddy (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid lines represent estimated spawning days at the Waneta spawning area, either based on the collection of fertilized eggs or larvae. Despite sampling effort, estimated spawning dates were not calculated for the upstream locations.

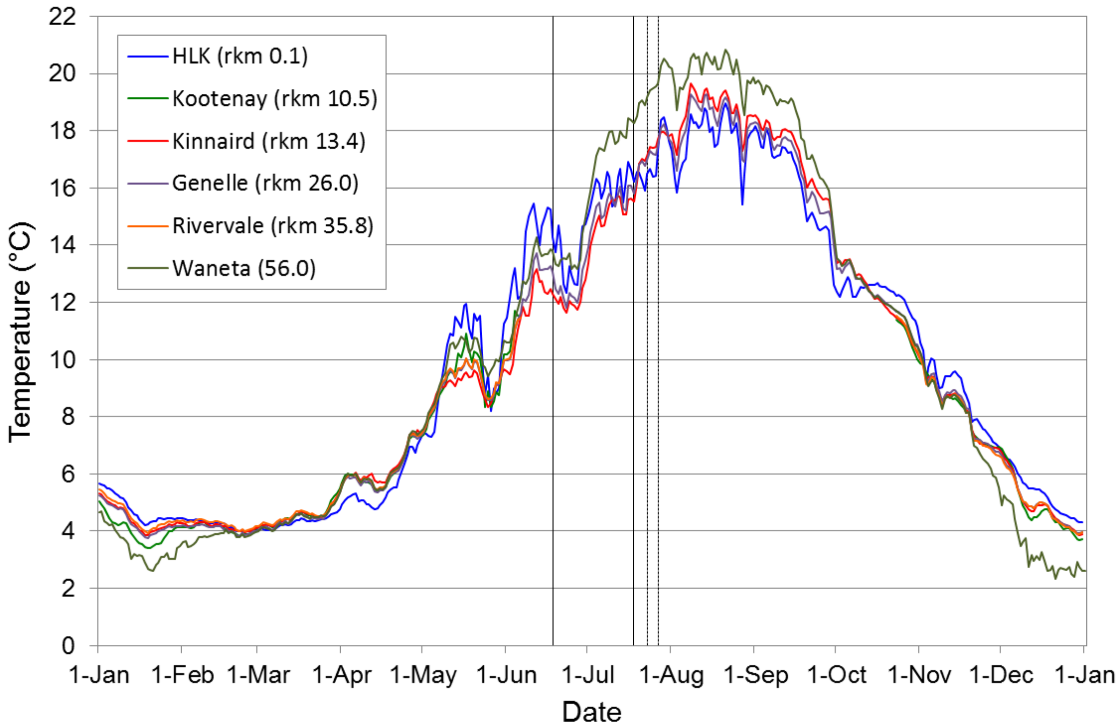

Figure 9. Mean daily water temperature (°C) of the LCR in 2013. Data was recorded at locations of HLK (rkm 0.1), Kootenay (rkm 10.5), Kinnaird (rkm 13.4), Genelle (rkm 26.0), Rivervale (rkm 35.8) and Waneta (rkm 56.0). Missing data is due to lost or damaged temperature loggers. Vertical solid lines represent estimated spawning days at the Waneta spawning area while vertical dashed lines represent estimated spawning events near Kinnaird. Estimated spawning days were either based on the collection of fertilized eggs or larvae.

3.1.3 Erosion

On July 13, 2012 a boat based erosion survey was conducted on the lower Columbia River from Hugh Keenleyside Dam to the US border. The flows at this date were 87,000 cfs from Arrow, 105,300 cfs from Brilliant and 194,800 cfs at Birchbank. The survey date occurred just prior to an increase of flows near the third week of July, and peak Birchbank flow of 213,400 cfs on July 21.

In total 33 sites were surveyed (see Appendix I), with some bank erosion and property flooding noted in several areas (see Appendix I). General results from the survey identified several areas where there was inundated and flooded land and property, and in some cases where high water levels may have accelerated bank erosion.

3.2 Early Life Stage Monitoring

From 2011-2013, White Sturgeon spawn monitoring at the Waneta site was conducted by Golder Associates for Columbia Power Corporation as part of the Brilliant Expansion Project (Golder 2012; 2013; 2014). Data collected through this monitoring study was provided to BC Hydro through a data sharing agreement to meet requirements under the CLB MON-28 Spawn Monitoring Program. Sampling in each year started in early June and continued until early August, a sampling period which is consistent with previous efforts at this location.

3.2.1 2011 Sampling

Sampling in 2011at Waneta occurred over a period of 61 field days commencing on June 13 and ending on August 12. In total, 2,318 eggs and 9 free embryos were captured during 19,882 mat-hours (828.4 days) of egg mat sampling; and an additional 234 eggs and 16 larvae were captured during 49.8 hours (2.1 days) of drift net sampling (Table 1). In 2011, an estimated 8 discrete spawning events occurred between June 30 and August 01 (Table 2). All occurred at water temperatures above 14 °C, and 7 of 8 on the descending limb of the Pend d'Orielle hydrograph (Golder 2012).

In addition to sampling at Waneta in 2011, additional mats and nets were deployed in other areas that were suspected White Sturgeon spawning locations. In 2011, Egg mats and drift nets were strategically placed in other areas of the LCR (HLK, ALH, rkm 13.5, rkm 18.2, Kootenay River) in an effort to potentially locate alternate spawning locations. Egg mat sampling occurred at ALH over a period of 37 field days between June 28 and August 3, and drift net sampling occurred over a period of 26 field days between July 11 and August 17. At HLK, rkm 13.5, rkm 18.2, and Kootenay River, drift net sampling occurred over a period of 26 field days between July 11 and August 17. In total, 3,614 mat-hours (150.6 days) of egg collection mat sampling; and 5,546 hours (231.1 days) of drift net sampling resulted in the capture of 187 eggs and 340 larvae (Table 1). 493 were captured by both egg mats and drift nets in the ALH tailrace site and 34 were captured in a drift net at rkm 18.2 (Table 1).

3.2.2 2012 Sampling

In 2012 at Waneta, egg sampling began on June 11 and sampling continued until August 3 with water temperatures ranging from 9.6 to 18.3°C. Total sampling effort for egg mats and drift nets were 16,627.2 hours (692.8 days) and 48.2 hours (2.0 days), respectively, for a cumulative effort of 16,675.4 hours (694.8 days) (Table 1). A total of 360 eggs and 17 larvae were captured at Waneta between the dates of July 4 and July 27 (Table 1). It is estimated that 18 spawning events occurred at Waneta (Table 2).

Sampling at the upstream locations was delayed until July 26 due to high water flows (50 year flood level) that prevented gear deployment. Once permitted, drift nets were deployed for 24-hour sets at ALH (n=8) on July 26 and on August 12 at rkm 18.2 (n=2) with water temperatures ranging from 13.1 to 16.7 °C. Sampling was terminated at both sites on August 16. Across all sites, the cumulative effort for entire study period was 3,126.0 hours (130.3 days) (Table 1). Total sampling effort completed at ALH and rkm 18.2 was 2,929.2 hours (122.1 days) and 196.8 hours (8.2 days), respectively. Six dead eggs were captured at ALH, however, there were no live eggs or larvae collected and preserved at ALH or rkm 18.2 (Table 1).

3.2.3 2013 Sampling

In 2013 at Waneta, egg mats were deployed on June 17 and sampling continued until July 31 with daily mean water temperatures ranging from 13.1 to 20.5°C. Total sampling effort for egg mats was 14,739 hours (614.1 days) (Table 1). Additional details and results are summarized in Golder and LGL (2014). Spawning was first detected on June 21 on the descending arm of the first freshet peak that occurred on May 9. Flows increased in June and spawning was not detected again until the descent of the second peak after June 23. Over the sampling period, a total of 410 White Sturgeon eggs were captured at Waneta (Table 1). It is estimated that a total of 12 spawning events occurred at Waneta (Table 2).

At other locations, egg and larval sampling was conducted from July 11 to August 9 with water temperatures ranging from 13.9 to 19.4 °C. Across all upstream sites, the cumulative effort for entire study period was 1,197.9 hours (49.9 days) (Table 1). Sampling at ALH occurred between July 11 and August 9. Total sampling effort conducted at ALH was 680.4 hours (28.4 days). Cumulative sampling effort at rkm 14.5 was 154.3 hours (6.4 days) between the dates of July 18 and August 9. Sampling at rkm 18.2 occurred through the dates of July 15 and August 9 for a total effort of 363.2 hours (15.1 days).

A total of 5 yolk-sac larvae were collected and preserved at the upstream locations (Table 1). No eggs were collected at any of the three monitoring sites. Zero yolk-sac larvae were collected at ALH (CPUE = 0), 1 yolk-sac larvae was collected at rkm 14.5 (CPUE= 0.006) on July 29, and 4 yolk-sac larvae were collected at rkm 18.2 (CPUE = 0.011) between the dates of July 29 and August 2.

Table 1. The number of White Sturgeon eggs and larvae collected by sampling effort, sampling location, and year on the lower Columbia River, 2008-2013. Reproduced from BC Hydro 2015a.

		Egg Mats			Drift Nets		
Year	**Location**	**Eggs**	**Larvae**	**Effort (Hrs)**	**Eggs**	**Larvae**	**Effort (Hrs)**
2008	Waneta	3,456	7	19,428	494	220	72
	rkm 18.2	0	0	16,493	0	1	164
2009	Waneta	1,715	2	21,964	77	39	90.1
	rkm 18.2	0	0	0	0	5	976.1
	Robson	0	0	0	0	0	3091.3
2010	Waneta	4,003	16	18,204	888	89	113.4
	rkm 18.2	0	0	10,600	1	8	2,104
	ALH**	12	0	3,608	30	115	2,084
2011	Waneta	2,318	9	19,882	234	16	49.8
	rkm 18.2	0	0	0	2	32	1,400
	rkm 13.5	0	0	0	0	0	154
	Kootenay	0	0	0	0	0	993
	HLK*	0	0	0	0	0	461
	ALH	2	0	3,614	183	308	2,538
2012	Waneta	226	2	16,627	134	15	48
	rkm 18.2	-	-	-	0	0	197
	ALH	-	-	-	6	0	2,929
2013	Waneta	410	0	14,739	-	-	-
	rkm 18.2	-	-	-	0	4	363
	rkm 14.5	-	-	-	0	1	154
	ALH	-	-	-	0	0	680

*Hugh Keenlyside Dam
**Arrow Lakes Generating Station

Table 2. Estimated number of annual spawning events at the Waneta Spawning area from 2001-2013. Total numbers of White Sturgeon eggs and the estimated number of spawning events (based on staged embryos) is also presented as a comparison by year. Grey highlighted rows represent years where flows exceeded 200 kcfs at the international border on the Columbia River.

Year	Peak Discharge (cfs)	Peak Freshet Date	Total Number Eggs Sampled	Estimated Minimum Number of Spawning Events	% of Spawning Events Occurring on Descending Limb of Freshet Hydrograph
1997*	302,452	6-Jun	N/A	N/A	N/A
2001	114,651	26-May	620	7	100
2002	230,412	30-Jun	2058	9	56
2003	150,526	05-Jun	3829	9	100
2004	135,089	14-Jun	2038	9	100
2005	166,521	10-Jun	4815	12	100
2006*	227,250	25-May	N/A	N/A	N/A
2007	185,984	09-Jun	1528	10	100
2008	216,651	04-Jun	3456	17	100
2009	173,948	02-Jun	1715	15	100
2010	181,245	21-Jun	4891	18	63
2011	267,000	14-Jun	2552	8	88
2012	280,400	28-Jun	360	18	100
2013	202,000	1-Jul	410	12	100

* monitoring of White Sturgeon spawning at Waneta was not conducted

3.3 Juvenile Stage Monitoring

Results for juvenile monitoring are reported under the CLBMON 29 monitoring program (BC Hydro 2015b). To date, wild origin juvenile represent < 0.5% of all captures. Juvenile White Sturgeon in the lower Columbia recruit to sampling gear used in these monitoring programs at approximately 3-4 years of age (BC Hydro 2015b). If the high flow years were successful in promoting survival from the egg stage through to the juvenile stage we would expect to see these wild origin individuals start to recruit to the sampling gear by fall of 2015 at the earliest. Additional years of monitoring are required.

3.4 Adult Life Stage Monitoring and Movements

In 2011, 2012, and 2013 a total of 24, 18, and 4 tags respectively, were deployed in male and female adult White Sturgeon in the lower Columbia River (see Table 3). As there were a number of tags already deployed within the five zones from previous sampling in past years (see Table 3), and the number of tags deployed in the system is greater than 100, the focus of the tags in 2011, 2012, and 2013 was on wild adults at advanced maturity stages (females: F3; Males: F2), and on fish taken to the hatchery and used for broodstock (Table 3).

Table 3. Acoustic tags implanted by year for wild caught female and male adult White Sturgeon in the LCR, 2007-2013.

Year	Wild		Broodstock		Total
	Female	Male	Female	Male	
2007	0	0	5	6	11
2008	0	0	8	7	15
2009	11	8	10	12	41
2010	0	0	9	10	19
2011	3	1	9	11	24
2012	0	0	8	10	18
2013	0	2	2	0	4
Total	14	11	51	56	132

3.4.1 2011

The movements of 78 adults, 43 females and 35 males, tagged with acoustic transmitters were examined during the period of spring 2008 through December of 2011. Only adults with movements detected in all years were included in the analyses. Analysis of the movements of all individuals resulted in the mean proportion of time spent at a single location (residency time) was 0.65 ± 0.21 (mean ± 1 SD). Though not significantly different (df = 75, t = 1.99, P = 0.30), females had slightly higher residency time (0.67 ± 0.20) compared to males (0.62 ± 0.22). Habitat use for fish tracked as part of this work was highest in the upper section of the river and there were only marginal differences between females and males.

A number of adult White Sturgeon (n=44) were identified to have made movements that appeared to be spawning related during June-August from 2008 to 2011. Spawning related movements tended to remain within the section of river the individual was originally detected in (Table 4). However, a proportion of individuals in each river section exhibited putative spawning migrations to adjoining river sections (Table 4). Individuals suspected to spawn in the middle section of the LCR (Kootenay-Columbia confluence to Trail BC) travelled further to spawning areas compared to those spawning in the upper (Robson Reach) or lower (e.g., Waneta) sections (Table 5). Time spent on the spawning grounds was similar across the different suspected spawning sites and averaged about a month in duration (Table 5).

Table 4. The proportion of White Sturgeon adults (n=44) with acoustic transmitters that undertook suspected spawning movements (June to August) within and outside the river section they were originally detected in within the lower Columbia River, Canada, 2008-2011.

	River Section (Known or Suspected Spawning Area)		
River Section where Movement Originated[a]	**Upper** (Keenleyside)	**Middle** (Suspected – Kinnaird)	**Lower** (Waneta)
Upper	0.80	0.20	0.00
Middle	0.06	0.59	0.35
Lower	0.08	0.00	0.92

[a] Upper = HLK to Kootenay River mouth; Middle = Downstream of Kootenay R. mouth to Birchbank; Lower = Trail to Waneta

Table 5. Summary of movements made to suspected spawning sites for adult sturgeon detections originating in three different river sections. The mean (± 1 SD) distance travelled (km) to suspected spawning sites, the travel time (days) it took the individual to arrive at the site, and the total time (days) spent at the site are presented for movements made in the lower Columbia River during the period of June to August, 2008-2011.

River Section*	Distance Travelled	Travel Time	Time Spent on Location
Upper	6.20 ± 5.35	6.73 ± 10.35	27.69 ± 24.92
Mid	12.78 ± 13.35	6.13 ± 7.38	34.50 ± 25.66
Lower	6.68 ± 14.06	1.44 ± 1.74	30.56 ± 18.05
Overall	9.08 ± 11.57	5.30 ± 8.04	31.24 ± 22.35

*Upper = HLK to Kootenay River mouth; Middle = Downstream of Kootenay R. mouth to Birchbank; Lower = Trail to Waneta

3.4.2 2012 and 2013

The movements of 98 adults (50 females and 48 males) tagged with acoustic transmitters were examined during 2008 through 2013. Only adults with movements detected in all years were included in the analyses. A total of 50,058 detections were recorded with a mean (± SD) of 572.9 ± 81.0 and 445.3 ± 64.3 detections for females and males, respectively. Habitat use was highest in the upper section of the river (e.g., Robson reach, rkm 0.1, 2.5, and 6.5) with marginal differences between females and males (Figure 10).

In 2012 and 2013, 16 (8 males, 7 females; Figure 11) and 20 (9 males, 11 females; Figure 12) adults were identified for suspected spawn related movements, respectively. In 2012, the highest proportion of adults identified at a suspected spawning location was detected at rkm 56.0 (0.31) followed by rkm

16.9 (0.25). The majority of males were detected at rkm 56.0 (0.63) and rkm 16.9 (0.25). The highest proportion of females was detected at rkm 26.0 (0.29) while the other detected females were evenly distributed between rkm 0.1, 9.0, 10.5, 16.9, and 53.8 (0.14). In 2013, the majority of adults identified at a suspected spawning location were detected at rkm 13.4 (0.45) and rkm 56.0 (0.20). Most males were detected at rkm 13.4 (0.56) and rkm 26.0 (0.22). The majority of females were evenly distributed between rkm 13.4 and 56.0 (0.36).

A high proportion of fish residing in the Upper section (0.71; HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)) and Middle section (0.65; downstream Kootenay River Confluence to Birchbank (rkm 29)) migrated to adjoining downstream river sections during suspected spawn related movements (Table 19). Individuals detected in the Lower section (downstream Birchbank to Waneta (rkm 56.0)) tended to remain within the Lower section for spawn related movements (proportion of 0.67; Table 6). Individuals suspected to have spawned in the Lower section travelled further (25.8 ± 13.3 km; mean ± SD) from the suspected residency location compared to those suspected to spawn in the Upper (10.9 ± 4.4 km) and Middle (8.1 ± 8.6 km) sections (Table 7). Time spent on the suspected spawning grounds was greater within the Middle section (43.0 ± 40.1 days) than the Upper (7.9 ± 4.3 days) and Lower (29.2 ± 25.6 days) sections (Table 7).

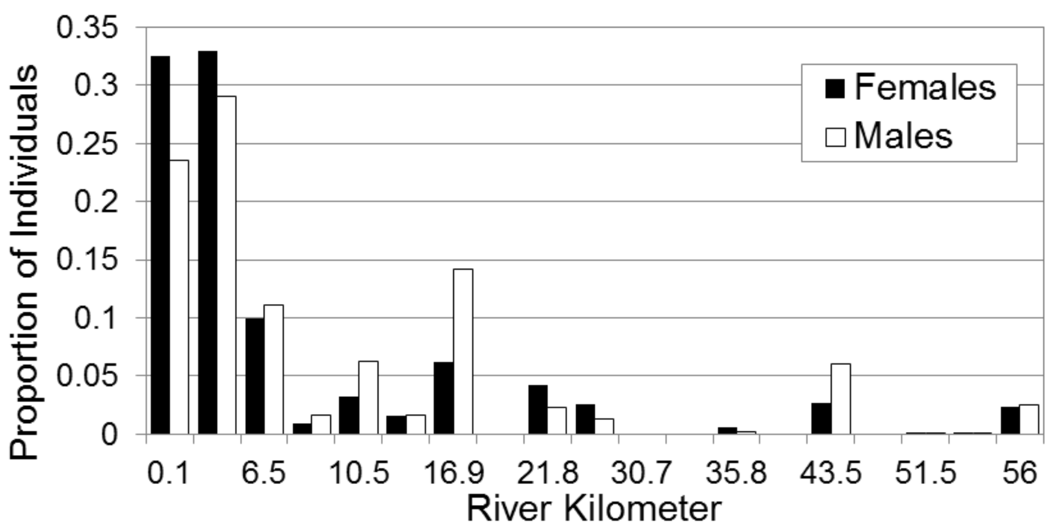

Figure 10. The proportion of detections by river kilometer of female (n = 50) and male (n = 48) adult White Sturgeon implanted with acoustic transmitters in the LCR, 2008-2013.

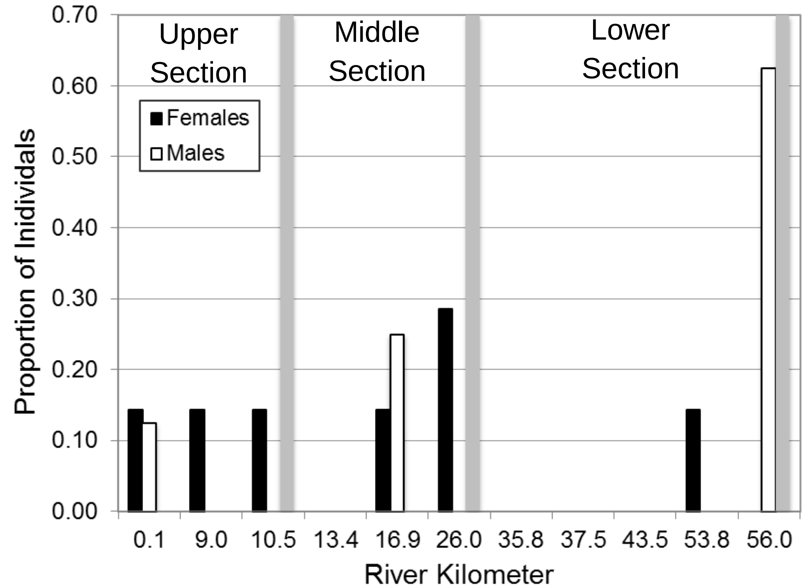

Figure 11. Proportion of detections by river kilometer of acoustically tagged female and male adult White Sturgeon identified for suspected spawn related movements in the LCR in 2012. LCR was divided into three sections including: Upper (HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)), Middle (downstream Kootenay River Confluence to Birchbank (rkm 29)), and Lower (downstream Birchbank to Waneta (rkm 56.0)).

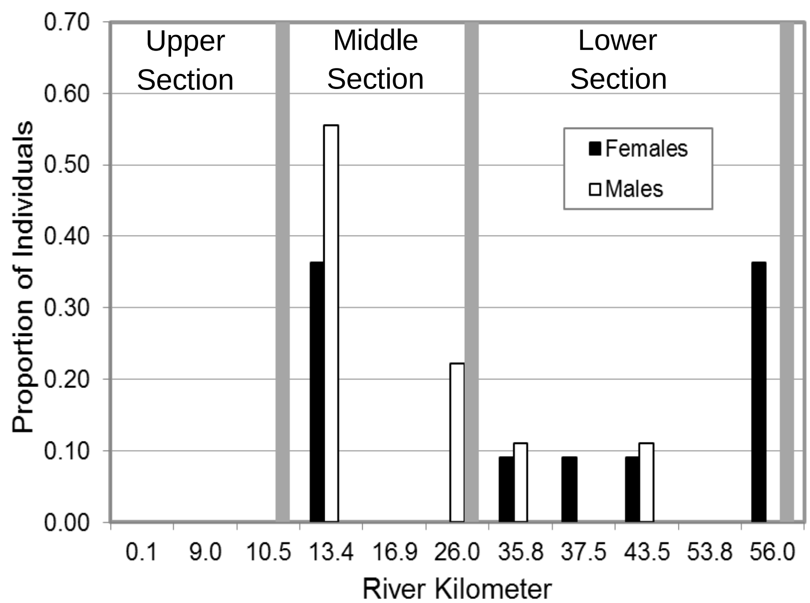

Figure 12. Proportion of detections by river kilometer of acoustically tagged female and male adult White Sturgeon identified for suspected spawn related movements in the LCR in 2013. LCR was divided into three sections including: Upper (HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)), Middle (downstream Kootenay River Confluence to Birchbank (rkm 29)), and Lower (downstream Birchbank to Waneta (rkm 56.0)).

Table 6. The proportion, by river section, of adult White Sturgeon (n=36) implanted with acoustic transmitters identified for suspected spawn related movements in the LCR in 2012 and 2013. LCR was divided into three sections including: Upper (HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)), Middle (downstream Kootenay River Confluence to Birchbank (rkm 29)), and Lower (downstream Birchbank to Waneta (rkm 56.0)).

Suspected Residency	Suspected Spawning Area		
	Upper	Middle	Lower
Upper	0.14	**0.71**	0.14
Middle	0.10	0.25	**0.65**
Lower	0.00	0.33	**0.67**

Table 7. Mean (± SD) distance travelled (km), travel time (days), and total time on site (days) for suspected spawn related movements for adult White Sturgeon implanted with acoustic tags in the LCR in 2012 and 2013. LCR was divided into three sections including: Upper (HLK (rkm 0.1) to Kootenay River Confluence (rkm 10.5)), Middle (downstream Kootenay River Confluence to Birchbank (rkm 29)), and Lower (downstream Birchbank to Waneta (rkm 56.0)).

River Section	Distance Travelled (km)	Travel Time (Days)	Time Spent on Site (Days)
Upper	10.9 ± 24.2	24.2 ± 43.1	7.9 ± 4.3
Middle	8.1 ± 8.6	12.4 ± 17.9	43.0 ± 40.1
Lower	25.8 ± 13.3	18.4 ± 21.7	29.2 ± 25.6
Overall	16.6 ± 13.6	16.5 ± 22.6	32.7 ± 32.8

4.0 DISCUSSION

Historical freshet levels, as defined in this study as 200 kcfs at the international border on the lower Columbia River were exceeded in 2011 and 2012. Freshet flows have only reached levels greater than 200 kcfs three times since 2001 (Figure 13) and the duration these flows have been maintained above 200 kcfs has been relatively short (Table 8). However, in both 2011 and 2012, flows were above 200 kcfs for 50 and 56 days, respectively. Further, peak flows reached highs of 267,000 (2011) and 280,000 (2012) which is comparable to the 1997 flow year when recruitment was detected. These two high flow years will serve as important test years in the long-term dataset that is being compiled for White Sturgeon under this program and discussed below.

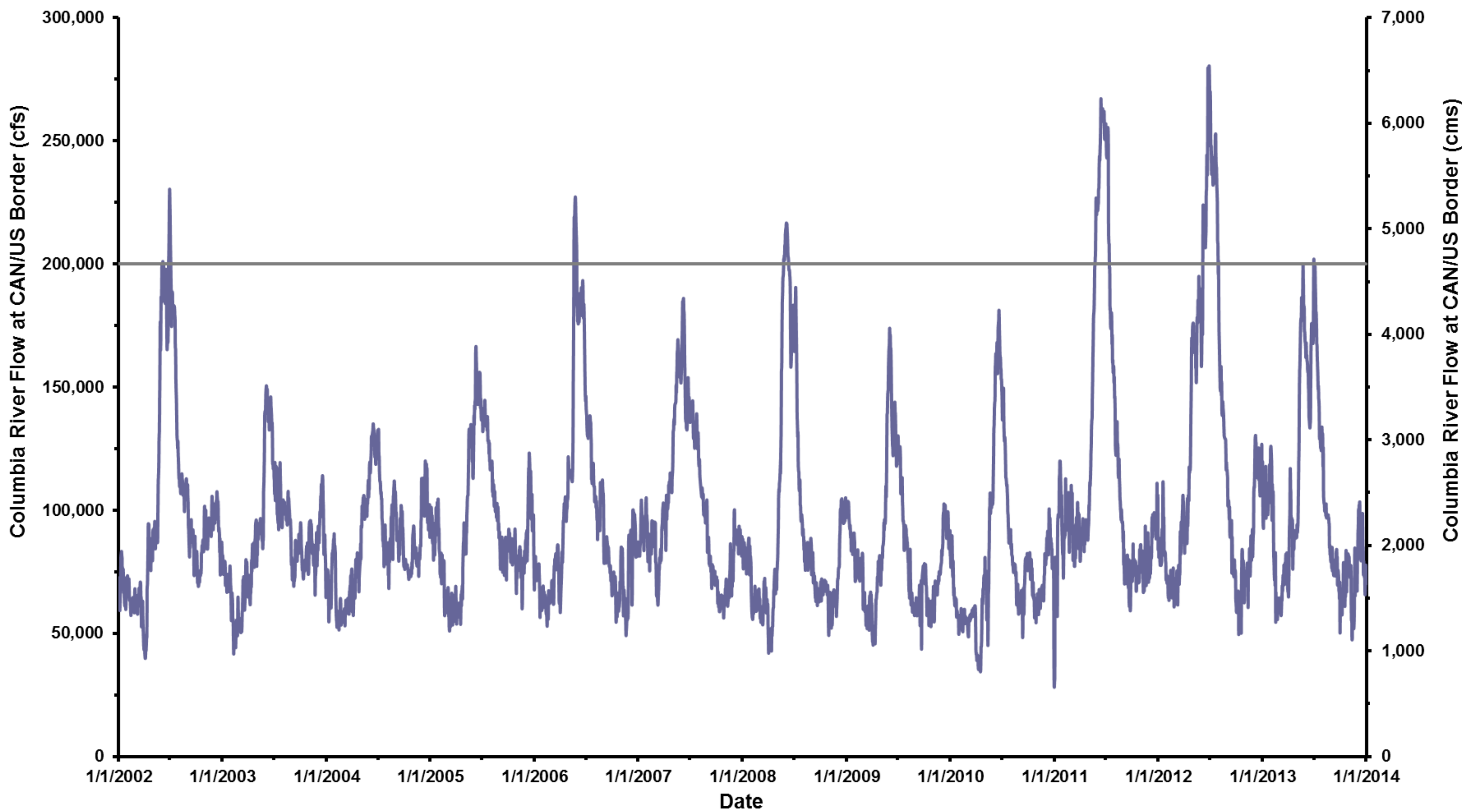

Figure 13. Mean daily discharge (cms and cfs) measured at the Canada/U.S. International Border on the Columbia River for each year from January 01, 2002 – December 31, 2013. Vertical dashed bars represent the predicted annual White Sturgeon spawning period based on egg and larval collections, suitable water temperatures, and river flows. The solid horizontal line represents 200 kcfs, which is the sustained target flow (minimum duration of one month) that is used to characterize a high flow event.

Table 8. Summary of the last nine years where the combined Columbia River flows at the Canada/U.S. border exceeded 200 kcfs. Maximum flow by year is presented in cfs and cms. Duration is presented as the total number of consecutive days that 200 kcfs was exceeded in each of the three years. Note: Flows at the Canada/U.S. border were not recorded until 2002. 1997 border flows were estimated using Columbia and Pend D'Orielle River flows and are within 5% of the true value.

Year	Max (cfs)	Max (cms)	Duration >200 kcfs (Days)
1997	302,452	8565	51
2002	230,411	6,525	9
2006	227,250	6,435	11
2008	216,651	6,135	17
2011	267,000	7560.6	50
2012	280,400	7940.04	56
2013	202,000	5720	1

Management questions for this program related to adult White Sturgeon center around how movements are influenced by flows. Specifically, they are focused on describing any unidentified spawning sites in the lower Columbia River that are used during years of higher flows and determining the level of interaction among adults residing in different locations (e.g. upper and lower sections of the LCR). White Sturgeon have a unique life history and given their longevity require long-term databases when describing characteristics related to their biology. This program was developed to ensure adequate data would be collected over a 10 year period to evaluate White Sturgeon movements in relation to operations of the LCR within the same period. This has been accomplished to date through the deployment of acoustic transmitters in adult male and female White Sturgeon that were predicted to spawn within 1-3 years of tagging. These long term tags will serve as an important tool to monitor movements in relations to flows within and across the years of this study (2008-2018). For example, examination of individual fish movements have resulted in spawning being confirmed at the HLK/ALH location in both 2010 and 2011, a site that was previously unknown. Further, it appears that many fish that are making presumed spawning migrations remain within the river section where they primarily reside year-round. A number of these adults appear to make movements to the Kinnaird area during the known spawning period and this area is an important focus of the early life stage monitoring. General habitat use does not appear to change among years examined to date. Adults tend to spend a large majority of their time at a specific location and only make movements during the summer and fall periods, regardless of operations. Individuals tend to return to the same location of residency after making movements for spawning or feeding. In the early years of this program, acoustic tags were deployed during the late spring and early summer months. Fish predicted to spawn in the same year (e.g. female stage F4) as tag application occurred were avoided due to the conservation aquaculture program requiring them as broodstock. In future years, having the ability to track fish in known spawning condition to the location where they spawned would provide additional confidence when evaluating spawning related movements that are assumed for other adults where sex is known.

While this program is focused on providing a comparative analysis of the effects of different flow regimes on probabilities of survival, adult reproduction, and subsequent recruitment in the lower Columbia River, determining the effects of discharge on spawning metrics (e.g. number of events, number of eggs) is challenging due to a number of factors. Though spawning related data has been collected from the Waneta area annually since 1993, there is no correlation between numbers of eggs collected and annual discharge. This type of relationship is even more complex at spawning areas where there are fewer early life stage captures and the geographical areas of egg deposition are uncertain. Further, early life stage assessments in years of high flows add further complication as sampling becomes very challenging and meaningful sampling is not possible outside of the margins of the thalweg. For example, due to high flows in 2012 (50 year flood level), nets were deployed three weeks later compared to the 2011 spawn-monitoring program as a result of safety, equipment, and other concerns (e.g. elevated debris). Despite this, it is believed spawning activity did not occur prior to deployment, as equipment was still deployed prior to water temperatures hitting optimal levels for spawning (14°C). Despite sampling challenges and comparing relative metrics of spawning activity among years, spawning has been shown to occur almost exclusively on the descending limb of the hydrograph. Interestingly, this was even true in years like 2013 where there were two descending limbs as a result of peaked discharges from Arrow later in the summer (Figure 5). All documented spawning events in that year were estimated to occur on either the first or second descending limb. While determining a peak threshold might be difficult for White Sturgeon spawning, the shape of the hydrograph is likely of equal importance with higher peak flows scouring the substrate and allowing spawning to occur over a protracted descending limb. Future collection efforts that expand on data collected known spawning areas in the lower Columbia River (e.g. Kinnaird) will be important to determining the effects of varying annual flows on both habitats used and spawning related success. Pairing known spawning in years with adult movements to those areas will be important going forward as monitoring at one life stage is not adequate to evaluate the larger complexities of flows.

Juvenile monitoring is one of the key aspects of this program to determine if wild recruitment has occurred, or specifically, if higher flows years have a positive effect on larval to juvenile survival in the lower Columbia River. This is due to difficulties in relating early life stage success (egg and larval captures) to environmental conditions in a given year. Although, spawning has been documented at the Waneta site in all years examined and spawning has been confirmed through the capture of both eggs and larvae at other sites in the Canadian portion of the lower Columbia River, the ability to detect successful recruitment pulses are unlikely through this monitoring as recruitment failure is hypothesized to be occurring somewhere between the early larval stage and juvenile stages. Recruitment signals are most likely to be detected through the juvenile monitoring program of CLBMON 29. Flows in 2011 and 2012 were above normal and it is expected that any natural recruitment due to these high sustained flow events would not be evident in the juvenile program until 4-5 years later (2015 at the earliest) as this is the age when juvenile sturgeon start to recruit to the sampling equipment.

This report summarizes information collected in the first 5 years of this program but serves as a general overview of how the management questions are being addressed. More complex analyses will be undertaken when sufficient data is available to evaluate adult movements over several operational scenarios. Importantly, determining if the 2011 or 2012 flow years resulted in a change in movements will be important, as limited years for comparison currently exist.

5.0 RECOMMENDATIONS

The following are recommendations for the monitoring study:

- Continue to describe erosion on the lower Columbia River during years of higher flows.
- Further identification of alternate spawning sites through early life stage monitoring and the use of egg mats and drift nets. Continual adaptation of this work in relation to new information in the upper sections of the river will be important. Particular focus should be given to the Kinnaird site.
- Evaluate deploying additional acoustic transmitters in adult White Sturgeon that are predicted to spawn within the same year (i.e. stage F4) in order to track their movements to spawning locations.
- Evaluate the feasibility of using a fine scale acoustic positioning system to describe seasonal movements in relation to operations or other environmental factors. This acoustic positioning system could be tested near spawning areas or downstream of facilities on the lower Columbia River.
- Continuation of fall juvenile monitoring to detect any wild recruitment that may have resulted in the higher flow years of 2011 and 2012.

6.0 REFERENCES

Apperson, K.A. and P.J. Anders. 1991. Kootenai River White Sturgeon investigations and experimental culture. Annual Progress Report to Bonneville Power Administration, Portland Or. FY 1990: 67 p.

BC Hydro 2011a. Lower Columbia River adult White Sturgeon monitoring: 2009 & 2010 investigations data report. Report prepared by BC Hydro Water License Requirements, Castlegar, B.C.

BC Hydro 2011b. Lower Columbia River White Sturgeon early life stage monitoring and juvenile detection: 2009 & 2010 investigations data report. Report prepared by BC Hydro Water License Requirements, Castlegar, B.C.

BC Hydro. 2015a. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Years 5 and 6 Data Report. Reported by BC Hydro, Castlegar, BC. 83 pp.

BC Hydro. 2015b. Lower Columbia River Juvenile White Sturgeon Detection Program (CLBMON-29). Years 4 and 5 Data Report. Reported by BC Hydro, Castlegar, BC. 82 pp + 1 Appendix.

BC Hydro. 2015c. Lower Columbia River Adult White Sturgeon Monitoring Program (CLBMON-28). Year 7 Data Report. Reported by BC Hydro, Castlegar, BC. 53 pp.

Bruch, R.M., T.A. Dick, and A. Choudhury. 2001. A field guide for the identification of stages of gonad development in lake sturgeon, (*Acipenser fulvescens* Rafinesque) with notes on lake sturgeon reproductive biology and management implications. 38 p.

Columbia River Water Use Plan Consultative Committee. 2005. Consultative Committee Report; Columbia River Water Use Plan. pp 8-30.

Elliot, J.C. and R.C. Beamesderfer. 1990. Comparison of efficiency and selectivity of three gears used to sample White Sturgeon in a Columbia River reservoir. California Fish and Game. 76:174-180.

Gadomski, D.M., and M.J. Parsley. 2005. Effects of Turbidity, Light Level, and Cover on Predation of White Sturgeon Larvae by Prickly Sculpins. Transactions of the American Fisheries Society 134(2):369-374.

Golder Associates Ltd. 2002b. Upper Columbia River White Sturgeon Broodstock Investigations, 2001 study results. Report prepared for B.C. Ministry of Environment, Lands and Parks, Nelson, B.C. Golder Associates Ltd. Report No. 012-8920F: 52p. + 7app.

Hildebrand, L., C. McLeod, and S. McKenzie. 1999. Status and management of White Sturgeon in the Columbia River in British Columbia, Canada: an overview. Journal of Applied Ichthyology 15: 164-172.

Howell, M., and J. McLellan. 2006. Lake Roosevelt White Sturgeon Recovery Project Annual Progress Report, January2004-March 2005. Wash. Dept. Fish and Wildlife, Spokane.

Irvine, R.L., D.C., Schmidt, and L.R. Hildebrand. 2007. Population Status of White Sturgeon in the Lower Columbia River within Canada. Transactions of the American Fisheries Society 136(6):1472-1479.

Ligon FK, Dietrich WE, Trush WJ. 1995. Down-stream ecological effects of dams, a geomorphic perspective. BioScience 45: 183-192.

McAdam SO, Walters CJ, Nistor C. 2005. Linkages between White Sturgeon recruitment and altered bed substrates in the Nechako River, Canada. Transactions of the American Fisheries Society 134: 1448-1456.

Nigro, A.A., B.E. Rieman, J.C. Elliot, and D.R. Engle. 1988. Status and habitat requirements of White Wturgeon populations in the Columbia River downstream from McNary Dam. Annual Progress Report (July 1987-March 1988) to Bonneville Power Administration, Portland, Or. 140 p.

O'Riordan, Chair of the Water Use Plan Steering Committee. 2001. Guidance letter to Peace and Columbia River Water Use Plan Consultative Committees of 19 February 2001. In: Executive Summary. 2004. Consultative Committee Report Columbia River Water Use Plan. June 2004. 15 pp.

Paragamian, V.L., R.C.P., Beamesderfer, and S.C., Ireland. 2005. Status, Population Dynamics, and Future Prospects of the Endangered Kootenai River White Sturgeon Population with and without Hatchery Intervention. Transactions of the American Fisheries Society 134(2):518-532.

R.L. & L. Environmental Services Ltd. 1996. Columbia River White Sturgeon investigations. 1995 study results. Report Prepared for B.C. Hydro, Kootenay Generation, Vancouver, B.C. and BC Ministry of Environment, Lands and Parks, Nelson Region. R.L. & L. Report No. 96-377F: 94 p. + 6 app.

Stevens, D.L. and A.R. Olsen, 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99 (465): 262-278.

Upper Columbia White Sturgeon Recovery Initiative. 2002. Upper Columbia River White Sturgeon Recovery Plan. Prepared for the Upper Columbia White Sturgeon Recovery Initiative. 88 pp + app.

Upper Columbia White Sturgeon Recovery Initiative. 2006. Upper Columbia River Adult White Sturgeon Capture Transport and Handling Manual. Prepared for the Upper Columbia White Sturgeon Recovery Initiative. 20 pp + app.

van Poorten, B.T., and S. O. McAdam. 2010. Estimating Differences in Growth and Metabolism in Two Spatially Segregated Groups of Columbia River White Sturgeon Using a Field-Based Bioenergetics Model. The Open Fish Science Journal *3:* 132-141.

7.0 Appendix 1: 2012 High Flow Erosion Survey

October 24, 2012

Note to file: High water erosion survey on lower Columbia River, July 13, 2012

On July 13, 2012 a boat based erosion survey was conducted on the lower Columbia River from Hugh Keenleyside Dam to the US border. The flows at this date were 87,000 cfs from Arrow, 105,300 cfs from Brilliant and 194,800 cfs at Birchbank. The survey date occurred just prior to an increase of flows near the third week of July, and peak Birchbank flow of 213,400 cfs on July 21. The primary objective of this survey was to identify sites where high water discharges may be causing abnormal bank erosion. A secondary objective was to identify sites where there were potential flooding issues with the high water. At all sites that were surveyed, digital photos were taken, a location was recorded as either a key site, river kilometer or UTM location, and comments were made about the issues. In total 33 sites were surveyed (see Appendix I and II), with some bank erosion and property flooding noted in several areas (see Appendix I and II).

General results from the survey identified several areas where there was inundated and flooded land and property, and in some cases where high water levels may have accelerated bank erosion. The area of highest impact was in the Genelle area near the trailer park. Several claims have been made for damages during this period.

For further information on this survey please contact:

James Baxter (James.Baxter@bchydro.com)

Appendix I. Summary of Erosion Survey of Lower Columbia River on July 13, 2012.

Photo	Location	UTM 1	UTM 2	Comments
1	HLK LUB	444099	5465327	HLK Dam face and downstream
2	HLK LUB	444099	5465327	HLK Dam face and downstream
3	HLK LUB	444099	5465327	HLK Dam face and downstream
4	HLK LUB	444099	5465327	HLK Dam face and downstream
5	ALGS RUB	444402	5465735	ALGS Gazebo and downstream
6	ALGS RUB	444402	5465735	ALGS Gazebo and downstream
7	ALGS RUB	444402	5465735	ALGS Gazebo and downstream
8	ALGS RUB	444402	5465735	ALGS Gazebo and downstream
9	D/S HLK Log sort LUB	445039	5465567	Log sort area that may flood in higher waters
10	D/S HLK Log sort LUB	445039	5465567	Log sort area that may flood in higher waters
11	Below Balfour Bay RUB	447064	5465620	Shed and Garden that will flood
12	Below Balfour Bay RUB	447064	5465620	Shed and Garden that will flood
13	RUB	447233	5465550	Truck in water
14	RUB	447309	5465536	Shed, boats and other in water
15	Norns Creek DCP	N/A	N/A	N/A
16	Millenium Park LUB	452668	5463502	Proposed pool area
17	Millenium Park LUB	452668	5463502	Proposed pool area
18	Millenium Park LUB	452668	5463502	Proposed pool area
19	Millenium Park Bridge LUB	452517	5463105	Bridge underwater
20	Millenium Park Bridge LUB	452517	5463105	Bridge underwater
21	Kootenay River RUB below Trailer Park	453616	5462651	House
22	Kootenay River RUB below Trailer Park	453616	5462651	House
23	Kootenay River LUB below Brilliant Bridg	453992	5462930	Slumping bank
24	Kootenay River LUB below Brilliant Bridg	453992	5462930	Slumping bank
25	Kootenay River LUB below Brilliant Bridg	453992	5462930	50 m d/s slumping bank
26	Kootenay Oxbow RUB	453233	5462570	
27	Kootenay Oxbow RUB	453233	5462570	
28	Kootenay eddy at confluence RUB	N/A	N/A	N/A
29	Kootenay eddy at confluence LUB	N/A	N/A	N/A
30	Kootenay eddy at confluence LUB	N/A	N/A	N/A
31	RKM 16.9 LUB	N/A	N/A	N/A
32	U/S Blueberry Creek LUB	452553	5454840	Shacks underwater
33	U/S Blueberry Creek LUB	452553	5454840	Shacks underwater
34	Sandbar Eddy LUB	451427	5453427	N/A
35	Sandbar Eddy LUB	451427	5453427	N/A
36	Sandbar Eddy LUB	451427	5453427	N/A
37	Whispering Pines LUB	N/A	N/A	Various
38	Whispering Pines LUB	N/A	N/A	Various
39	Whispering Pines LUB	N/A	N/A	Various
40	Whispering Pines LUB	N/A	N/A	Various
41	Whispering Pines LUB	N/A	N/A	Various
42	Whispering Pines LUB	N/A	N/A	Various
43	Whispering Pines LUB	N/A	N/A	Various
44	Whispering Pines LUB	N/A	N/A	Various
45	Whispering Pines LUB	N/A	N/A	Various
46	Whispering Pines LUB	N/A	N/A	Various
47	Recountoured Area Genelle U/S	N/A	N/A	N/A
48	Recountoured Area Genelle D/S	N/A	N/A	N/A
49	Genelle Eddy D/S	448600	5450227	D/S
50	Genelle Eddy D/S	448600	5450227	D/S
51	Eroding Bank at Railway LUB	448023	5449519	LUB
52	Eroding Bank at Railway LUB	448023	5449519	LUB
53	Eroding Bank at Railway LUB	448023	5449519	LUB
54	Genelle Island Looking U/S	448023	5449519	Island
55	Genelle Island Looking U/S	448023	5449519	Island
56	Genelle Island Looking U/S	448023	5449519	Island
57	Birchbank LUB	447398	5446101	Eroding bank
58	Birchbank LUB	447398	5446101	Eroding bank
59	Rivervale LUB	446253	5441809	Sheds, gazebos and other structures under water
60	Rivervale LUB	446253	5441809	Sheds, gazebos and other structures under water
61	Rivervale LUB	446253	5441809	Sheds, gazebos and other structures under water
62	Rivervale LUB	446253	5441809	Sheds, gazebos and other structures under water
63	Rivervale LUB	446253	5441809	Sheds, gazebos and other structures under water
64	Rivervale RUB	446253	5441809	Eroding bank
65	Rivervale RUB	446253	5441809	Eroding bank
66	Gyro Park Beach RUB	448170	5439556	N/A
67	Gyro Park Beach RUB	448170	5439556	N/A
68	Across Gyro Park Beach LUB at Teck	447955	5439141	Outhouse in water
69	Across Gyro Park Beach LUB at Teck	447955	5439141	Outhouse in water
70	Gyro Park Boat Launch RUB	448322	5439016	Launch underwater
71	Gyro Park Boat Launch RUB	448322	5439016	Launch underwater
72	RUB	450350	5438377	Eroding bank
73	RUB	450350	5438377	Eroding bank
74	Building above Rock Point Rapids RUB	452439	5438351	Building flooded (pumphouse?)
75	LUB at Waneta	454569	5428469	Eroding bank
76	LUB at Waneta	454569	5428469	Eroding bank
77	RUB D/S Waneta	454187	5427976	Eroding bank
78	RUB D/S Waneta	454187	5427976	Eroding bank

Appendix II. Photos from Erosion Survey of Lower Columbia River on July 13, 2012.


Genelle Bar Fish Habitat
Enhancement