Columbia River Project Water Use Plan

Middle Columbia River
White Sturgeon Spawning Monitoring

Implementation Year 8

Reference: CLBMON-23A

Year 8 Data Report (2014)

Study Period: July – September 2014

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May 25, 2015

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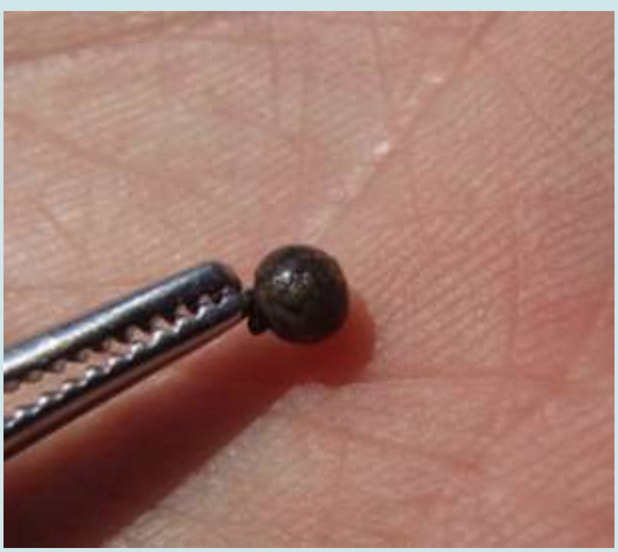

Submitted to:
BC Hydro

Submitted by:
AMEC Environment & Infrastructure
Nelson, BC

May 25, 2015

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Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23A)

Year 8 Data Report - 2014

Submitted to:

BC Hydro

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EXECUTIVE SUMMARY

A small component of the endangered Columbia White Sturgeon population resides in Arrow Lakes Reservoir (ALR), between Hugh L. Keenleyside (HLK) and Revelstoke (REV) dams. Spawning has been documented intermittently since 1999, primarily in an area approximately 5 km downstream of REV adjacent to the Revelstoke Golf Course. The Columbia River White Sturgeon Management program was initiated to address flow management issues with respect to impacts on White Sturgeon (*Acipenser transmontanus)* spawning events, timing, frequency, egg deposition, and habitat conditions. Monitoring conducted in 2014 was Year 8 of 10 of the middle Columbia River White Sturgeon spawning monitoring study program (CLBMON-23A).

White Sturgeon spawn monitoring in the middle Columbia River was conducted between July 22 and September 11, 2014 between river Km 227.4 and 230.5. White Sturgeon eggs and free embryos were captured using egg mats and larval drift nets, consistent with methods used in previous years. Egg mats were inspected weekly for the presence of White Sturgeon eggs and/or free embryos. In total, 20,502 hours of egg mat sampling effort resulted in the capture of 18 White Sturgeon eggs and one free embryo in 2014. Larval drift nets were set weekly during the day (average of 2.8 hours per set) as well as overnight between August 6 and September 11 (average of 15.2 hours per set). In total, 376 hours of larval drift net sampling effort resulted in the capture of 26 White Sturgeon eggs and 12 free embryos in 2014. Three spawning events were estimated to occur on July 29, July 30 and August 24, 2014 based on the developmental stage of the eggs at the time of capture and the water temperatures recorded over the spawning grounds.

Discharge from REV reached a peak during the monitoring period of 2,145 m^3/s which was lower than the peak discharge observed in 2012, (2,573 m^3/s), but higher than maximum discharge observed prior to the installation of a fifth unit at REV in late 2010 (1757 m^3/s). Backwatering of ALR occurred in the spawning area during the initiation of field sampling, but was not observed after July 29, 2014 resulting in riverine conditions for the majority of the sampling period. The current state of knowledge for White Sturgeon spawning below Revelstoke Dam with respect to BC Hydro's management questions for CLBMON-23a is provided below.

Management Question	Status
Where are the primary White Sturgeon incubation sites below Revelstoke Dam?	Based on White Sturgeon spawning studies conducted below Revelstoke Dam since 1999, the primary White Sturgeon incubation area is located within a 2.2 km river section between Km 227.9 and 230.1, which encompasses the area adjacent to the Revelstoke golf course. All 290 eggs and 50 free embryos collected since 1999 were located in this primary incubation area. Sampling has been conducted between approximately Km 223.5 and 234; REV is located at Km 235. White sturgeon eggs have consistently been documented in this relatively small area despite past sampling at other potentially suitable areas between Revelstoke Dam and the Illecillewaet River. The boundaries of this small spawning/incubation area may shift slightly depending on flows and ALR elevation, but remains

	relatively similar between years.
How do dam and reservoir operations affect egg and free embryos survival in this area? Specifically, do significant numbers of eggs become dewatered as a result of operations?	Estimates of egg or larval survival are difficult to calculate for sturgeon species, even in systems where more data are available. In this program, the ability to estimate survival of early life stages is not possible due to the low number of eggs/larvae that have been collected. The effect of reservoir operations within the REV egg incubation area has been investigated further under CLBMON-54. It is unknown whether a significant number of eggs become dewatered as a result of operations based on the limited sampling that has been conducted at this time. However the increase in minimum flows and overall capacity has increased the estimated permanently wetted river bed area in the middle Columbia River, which should reduce the exposure of shallow gravel bars within the egg incubation area and therefore the severity of egg and larval stranding during periods of minimum flow.
What is the most effective method for monitoring spawning of White Sturgeon?	Based on the biology of the species, the most effective method for monitoring White Sturgeon spawning in the mid-Columbia River is a combination of egg mats and drift nets. Egg mats sample continuously to collect eggs from spawning adults while drift nets are more efficient in identifying the downstream dispersal of larvae, especially once spawning has been identified and time of hatch has been estimated. During the past 7 years of this program, an average of 120 egg mats have been deployed per spawning season for approximately 20,502 hours which resulted in an average catch-rate of 0.01 eggs/free embryos per hour. In contrast, an average of 29 drift nets have been deployed per spawning season for approximately 142 hours which resulted in an average catch-rate of 0.2 eggs/free embryos per hour. Although drift nets seem to have higher catch-rates, they do not fish continuously like egg mats and may miss downstream dispersal of free embryos after hatch occurs. In 2014, both eggs and free embryos were collected on egg mats and in drift nets.
Can modifications be made to operation of Revelstoke Dam and Arrow Lakes Reservoir to protect or enhance White Sturgeon incubation habitat?	It is unknown at this time whether additional modifications to REV/ALR operations can be made to protect or enhance White Sturgeon incubation habitat. Flow modifications have already occurred with the addition of REV5. Preliminary information collected during this monitoring program before and after REV5 suggests that recent operational modifications may reduce White Sturgeon egg stranding. In addition, spawning has been consistently observed in the past three years since REV5 came online and a 142 m^3/s minimum flow requirement was implemented. The influence of REV operations and ALR elevation on physical conditions observed at the spawning area is

	currently being assessed during concurrent BC Hydro WUP programs, which may provide insights into whether additional operational modifications are necessary to protect or enhance White Sturgeon incubation habitat. These programs include: CLBMON-15a (Middle Columbia River Physical Habitat Monitoring), CLBMON-20 (Middle Columbia River White Sturgeon Spawning Habitat Assessment), CLBMON-27 (Middle Columbia River Sturgeon Incubation and Rearing Study) and CLBMON-54 (Middle Columbia River Effects of Flow Changes on Incubation and Early Rearing Sturgeon).

1.0 INTRODUCTION

White Sturgeon (*Acipenser transmontanus*) have experienced reduced population abundance in the Canadian portion of the Columbia River due to recruitment failure, altered food resources, and degradation or lack of access to suitable habitats (Porto 2008) and were listed as endangered under federal Species at Risk Act (SARA) legislation in 2006. The Columbia River population is considered at significant risk of extinction in the wild given strong evidence that, for several decades, natural recruitment has been too low to sustain this population (Hildebrand and Parsley 2013).

A small component of the Columbia River population resides in the area between Revelstoke Dam (REV) and Hugh L. Keenleyside Dam (HLK), which includes the Arrow Lakes Reservoir (ALR; Figure 1). This population component, referenced as the mid-Columbia River population, is comprised of approximately 52 adult White Sturgeon (population estimate ranges between 37 - 92 individuals at 95% confidence level) that are older than the 1969 age class (Golder 2006); construction of HLK Dam was completed in 1969. This small segment of the Columbia White Sturgeon population has experienced total recruitment failure (Hildebrand and Parsley 2013) even though natural spawning has been documented downstream of REV, near the Revelstoke Golf Course since 1999 (R.L. & L. Environmental Services Ltd. 2000). Spawning has been intermittent and naturally produced juvenile White Sturgeon have never been captured (Hildebrand and Parsley 2013). Spawning investigations occurred in 1999, 2000, 2001, 2003, 2006 through 2014 with spawning events documented in 1999, 2003, 2006, 2008, 2009, and 2011 through 2014 (Golder 2012a, AMEC 2014). Spawn timing has been estimated to occur from late July through August and this area represents the only known spawning area for White Sturgeon in the ALR (BC Hydro 2012) and has been designated, under the Species at Risk Act, as Critical Habitat for White Sturgeon by Fisheries & Oceans Canada (2014).

Revelstoke Dam was built in 1984 and its operations are a function of discharges from the Mica Dam and local inflows to Revelstoke reservoir combined with electricity demand. REV is a hydropeaking facility and since early 2011 discharges within a 24 hour period have varied between the operational minimum of 142 m^3/s to approximately 2100 m^3/s (BC Hydro 2012, Golder 2012a). Prior to the installation of a fifth turbine unit in December 2010, referred to as 'REV5', flows could be varied from zero to approximately 1700 m^3/s (Golder 2012a). The effect of hydropeaking operations at REV is a constant variation in flow rates at the White Sturgeon spawning area downstream of the REV tailrace, approximately 5 km from Revelstoke Dam. Further adding to the complex flow regime is a backwatering effect observed as far upstream as REV when ALR water levels exceed 437 meters above sea level, which generally occurs before and during the White Sturgeon spawning period.

BC Hydro and others have funded a number of White Sturgeon investigations in ALR since 1995, which has included spawn monitoring downstream of REV since 1999. Annual spawn monitoring below REV is required under the terms of the Columbia River Project Water Licence (WLR) Order to document spawning events, timing, frequency, egg deposition, and habitat conditions (BC Hydro 2012). Spawn monitoring studies under BC Hydro's WLR process were carried out from 2007 to 2011 below REV (CLBMON-23A) with concurrent studies that assessed the feasibility of sonar techniques for detecting adult White Sturgeon within the spawning area (CLBMON-23B; as cited in Golder 2012a; Crossman et al. 2011).

An additional five years of spawning investigations were initiated to document spawning events, timing, frequency and egg deposition to inform future management decisions. AMEC has been conducting these additional spawning investigations since 2012.

1.1 Objectives

The primary objectives of this monitoring program are to (BC Hydro 2012):

1. Assess sturgeon incubation sites and conditions downstream of Revelstoke Dam;
2. Relate egg stranding risk to discharge from the dam and water elevation of Arrow Reservoir;
3. Assess the feasibility of underwater videography or other remote sensing techniques for monitoring presence of White Sturgeon spawners (already covered under CLBMON-23B);
4. Select and implement the most effective method (egg mats or videography or other remote sensing) for ongoing monitoring of spawning of White Sturgeon (already covered during previous studies conducted under CLBMON-23A and 23B); and
5. Provide input to recommendations for the water allocation schedule for White Sturgeon spawning and incubation.

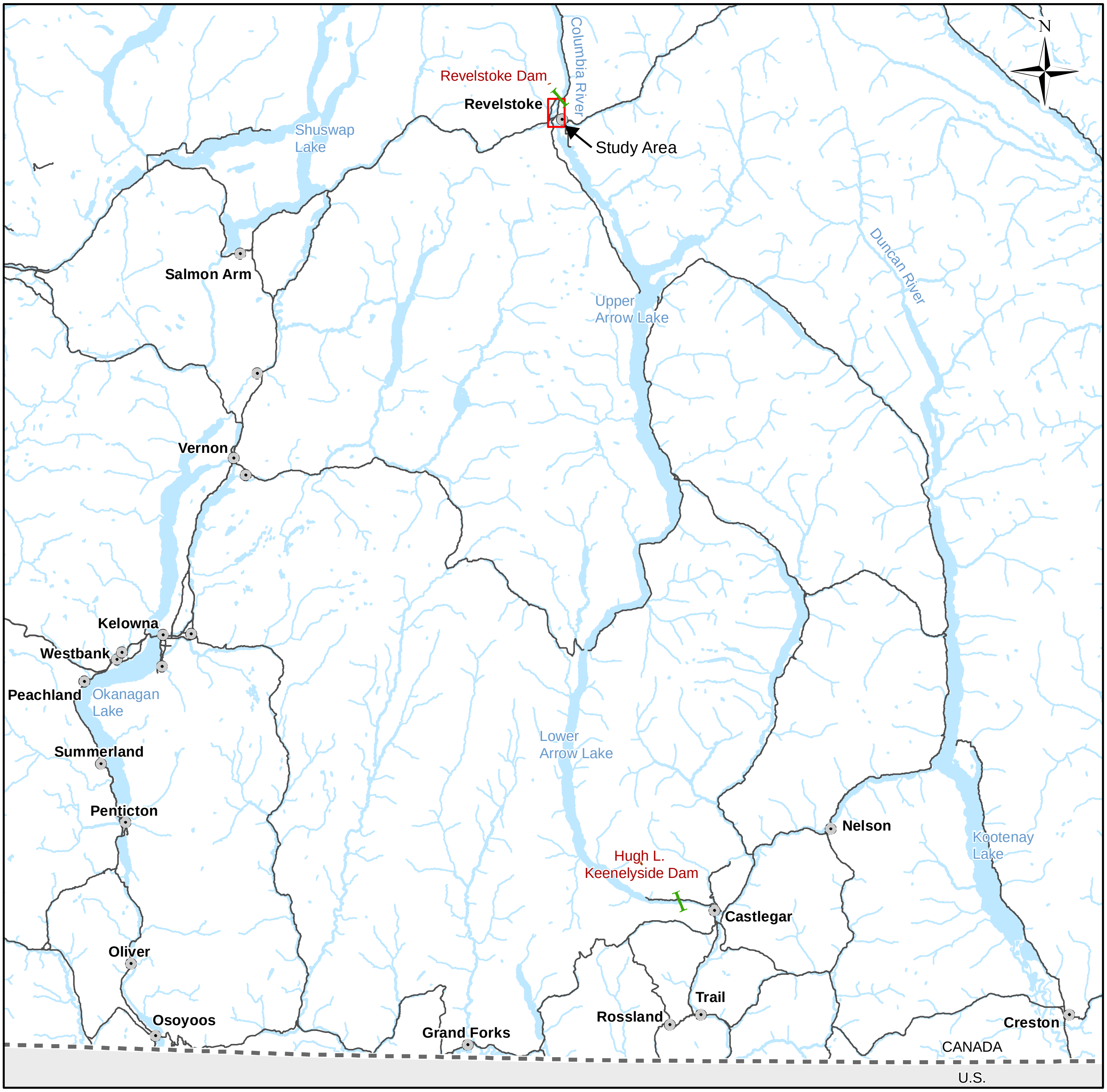
The fundamental Management Questions to be addressed through this study are (BC Hydro 2012):

1. Where are the primary White Sturgeon incubation sites below Revelstoke Dam?
2. How do dam and reservoir operations affect egg and larvae/free embryos survival in this area? Specifically, do significant numbers of eggs become dewatered as a result of operations?
3. Can underwater videography or other remote sensing methods be used to effectively monitor staging and spawning of White Sturgeon?[1]
4. What is the most effective method for monitoring spawning of White Sturgeon?
5. Can modifications be made to operation of Revelstoke Dam and Arrow Lakes Reservoir to protect or enhance White Sturgeon incubation habitat?

1.2 Purpose

The following report fulfills AMEC's commitment to provide BC Hydro with a data report for studies conducted in 2014 and adds to the dataset collected in previous years.

[1] This management question was addressed under a different program (CLBMON-23B Mid-Columbia River White Sturgeon underwater videography feasibility study; Johnson et al. 2009) and will not be further addressed by the present program.



Legend

- Dams
- City/Town
- Highway
- Stream
- Waterbody
- Study Area

Reference
BC Government Data Distribution

Scale: 1:1,400,000

0 15 30 60
Kilometers

CLIENT:	BC Hydro
PROJECT:	CLBMON-23 Mid-Columbia River White Sturgeon Spawn Monitoring
TITLE:	Overview Map of the Middle Columbia River Depicting Hydroelectric Facilities
DATE: April, 2015	ANALYST: KA
JOB No: VE52241	QA/QC: MY
GIS FILE: 01-50-001_v4.mxd	PDF FILE: 01-50-001_v4.pdf
PROJECTION: UTM Zone 11	DATUM: NAD83

Figure 1

amec

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2.0 METHODS

2.1 Study Area

Since spawn monitoring was initiated in 1999, sampling has been conducted from approximately 1 Km downstream of Revelstoke Dam (Km 235) to the mouth of the Illecillewaet River (Km 223.5) (R.L. & L. Environmental Services Ltd. 2001, Golder 2008). Based on the results of egg and larval captures, the sampling area has been continually refined over time to focus on the primary spawning habitats identified. The 2014 study area was concentrated in between Km 227 and 230.5 (Figure 2) which incorporated the area where 100% of White Sturgeon eggs have been captured since 1999 (Golder 2012a.

2.2 Environmental Parameters

In order to help answer Management Questions 2 and 4 pertaining to operations and risk of egg dewatering, environmental parameters were monitored during the program. Hourly discharge (m^3/s) from REV, separated by turbine and spillway flow, and water surface elevation (meters above sea level) of ALR at Nakusp were obtained from BC Hydro Power Records. Water temperature (℃) and water surface elevation data collected under CLBMON-15a Middle Columbia River Physical Habitat Modelling at 10 minute intervals were obtained for Station 2 (“Reach 4 downstream”), which is located at river Km 231.1 on the left downstream bank (UTM Zone 11U, Easting 414925, Northing 5653213). A thermograph station, using Onset TidbiT v2 loggers accurate to 0.2℃, was deployed to provide a backup of hourly water temperature data within the spawning area (Km 229.7L; Figure 2).

2.3 Sample Timing

The sampling period occurred from July 22 to September 10, 2014 during the known White Sturgeon spawning period below Revelstoke Dam. A summary of field sample sessions is provided in Table 1.

Table 1: Sample effort for CLBMON-23 Middle Columbia River White Sturgeon spawn monitoring, 2014.

Date	Activities
July 22-23	Deployed ten mid-channel and ten near shore egg mat/drift net sample stations. Drift net sampling
July 29-30	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 6-7	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 13-14	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 20-21	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 27-28	Retrieved, checked and redeployed egg mats. Drift net sampling.
September 3-4	Retrieved, checked and redeployed egg mats. Drift net sampling.
September 9-11	Retrieved and checked egg mats. Drift net sampling. Removed sample stations.

2.4 Spawn Monitoring

2.4.1 Egg Collection Mats

In order to maintain consistency in sampling methods across years, standard egg mats were used to collect White Sturgeon eggs/free embryos. This method has been successfully used in the middle Columbia River to monitor White Sturgeon spawning (e.g., Golder 2012a, AMEC 2014) and has been used throughout the Columbia basin in both Canada and the US to monitor other White Sturgeon populations (e.g., McCabe and Beckman 1990).

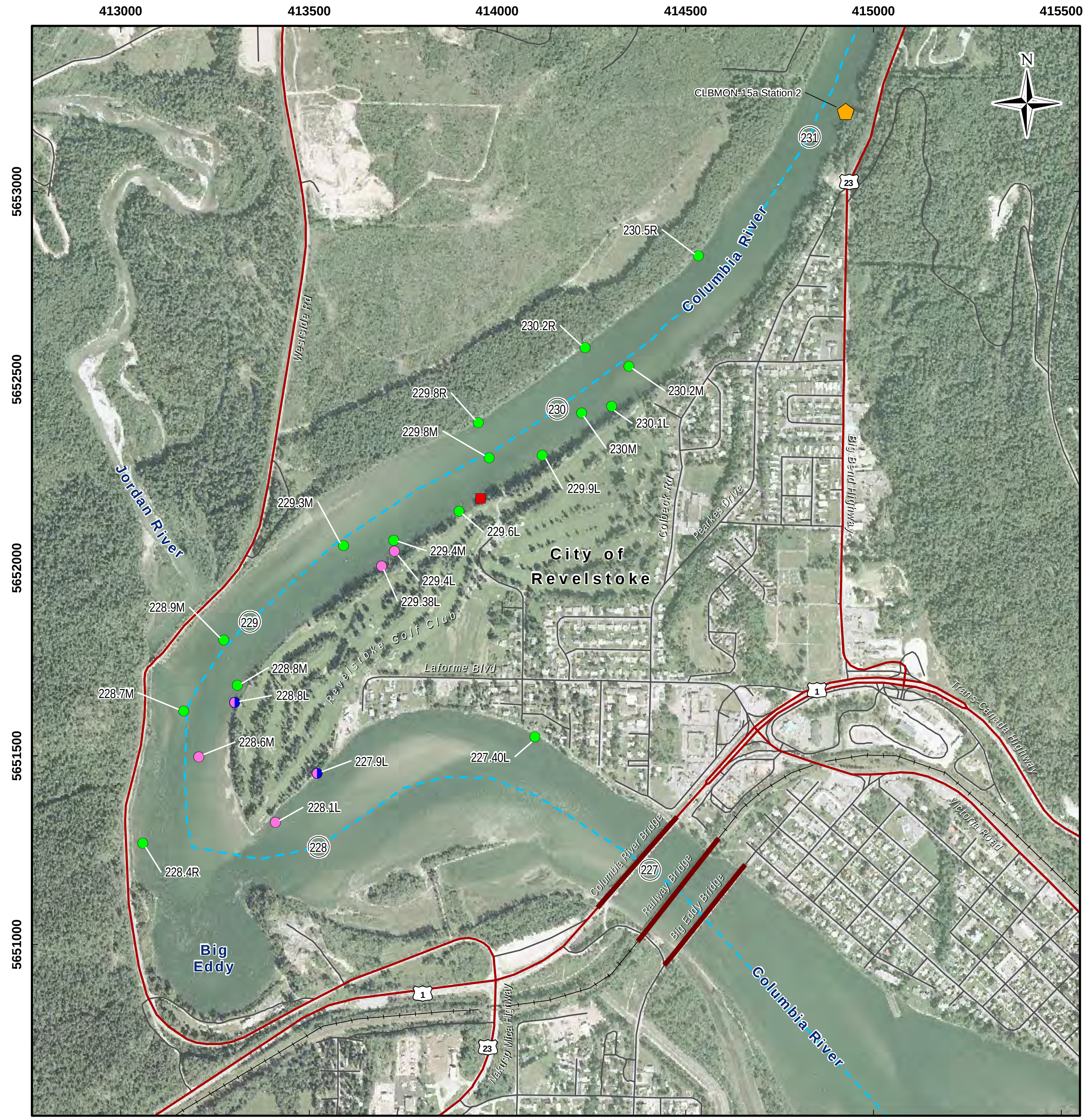
Discharge from Revelstoke Dam, along with substrate conditions in the area, limit where egg mats can be deployed due to high water water velocities (>2 m/s; Golder 2014) that can result in gear displacement. Egg mats were retrieved/deployed from a boat as per BC Hydro's Specific Work Instructions. Between 17 and 20 egg mat stations were deployed (half set to shore and the other half anchored middle channel sets) weekly. Mats were deployed between Km 227.4 and 230.5. The number of egg mat stations deployed depended on station displacement and gear availability. Egg mats were also deployed overnight during the two days of weekly sampling when drift nets were not being set overnight at those locations (Section 2.4.2). A combination of nearshore and mid-channel egg mat sets have been used below REV during the past eight years of this program in an attempt to cover potential spawning areas across the river channel. Nearshore sets included stations on both left and right banks of the spawning area, whereas effort prior to 2007 was mainly concentrated along the left downstream bank. In 2013 and 2014, water levels were lower and allowed for more mid-channel set coverage compared to 2012, when only 3 mid-channel sets could be deployed.

Each egg mat was comprised of a steel frame that enclosed latex covered animal hair filter material. The filter material was present on both sides of the frame, so when deployed, one side of the filter material was always sitting upward where drifting eggs and free embryos could lodge and attach. Egg mat dimensions were approximately 0.77 m by 0.92 m.

The egg mat system consisted of two 30 kg claw anchors attached to one another with an approximately 6 m galvanized steel chain and a float line which attached to the front anchor; a 10 m rope attached the rear anchor to the egg mat with a second float line (15 to 45 m) coming off the rear of the egg mat for retrieval. The lengths of rope used depended on depth and degree of flow fluctuations that were encountered.

Egg mats had a rope bridle system attached to each end, so that one end was attached to the rope/chain/anchor and the other bridle had a separate float line for retrieval. The retrieval float line was pulled up by the field crew, wrapped around the winch of the boat (which was permanently affixed to the bow) and used to pull the egg mat up. The egg mat was detached from the rope system and a spare egg mat was attached to the rope system and deployed. The boat operator drove to the shore and the field crew inspected the egg mat. Near shore egg mat sample locations were tied to shore instead of having a second float line. Having two float lines on mid-channel sets allowed the field crew to pull up the egg mat directly, but also the float line attached to the anchor provided a secondary means to pull up the egg mat set, should there have been a problem with the egg mat float line.

Data collected at each egg mat included: station name (e.g., J30 = retrieval buoy labelled J30); UTM; channel location (L= left bank when facing downstream, R = right bank and M = mid-channel); set and pull date and time; water temperature; set depth; number of eggs; number of free embryos; number of eggs/free embryos preserved; other species/observations; and, any relevant comments. If egg mats drifted significantly, they were moved back to their original location and noted in the comments; no new site designation was required. Data was recorded on standard data sheets set up for this program (see AMEC 2013). A photograph of each data sheet was taken during each field session to provide a backup. In the office, all data sheets were additionally scanned and then entered into MS Excel. GIS was used to convert each site UTM collected in the field to a river kilometre with channel location designation (e.g. 229.0L = river Km 229.0; L = left downstream bank). QA/QC was completed by a separate person who checked entered data for errors by comparing to field data sheets. The locations of egg mat stations are provided (Figure 2). Catch-per-unit effort (CPUE) was calculated for each egg mat (number of White Sturgeon eggs/hour of effort) for comparison between sampling locations and years (Appendix A).



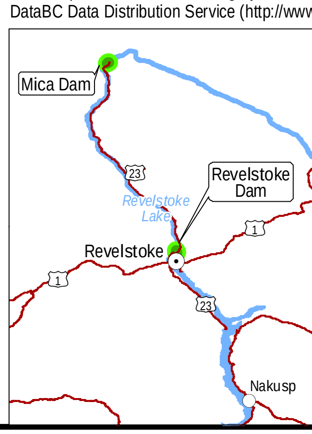
CLBMON-15a Station 2
Thermologger
River Kilometre
Highway
Bridge
Existing Road
Railway
River Centre Line
Dam

White Sturgeon Sample Locations 2014

No eggs or free embryos captured
Eggs captured
Free embryos captured
Eggs and free embryos captured

Reference
River Kilometre: Measured upstream from Hugh L. Keenleyside Dam
Base Map: British Columbia Imagery WMS
DataBC Data Distribution Service (http://www.data.gov.bc.ca/)

Scale: 1:15,000
0 50 100 200 300 400 500
Metres



CLIENT: BC hydro

PROJECT: Study Area for White Sturgeon Spawn Monitoring Below Revelstoke Dam, 2014

DATE: December, 2014	ANALYST: WR	Figure 2
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PROJECTION: UTM Zone 11	DATUM: NAD83	amec

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2.4.2 Larval Drift Nets

Previous studies have determined that the most effective method for monitoring White Sturgeon spawning in the study area (Management Question 4) is a combination of egg mat and drift net sampling (Golder 2012a). White Sturgeon eggs/free embryos were collected using larval drift nets (referred hereafter as drift nets). This method has been successfully used to collect White Sturgeon eggs/free embryos in the middle and lower Columbia rivers in Canada as well as throughout the Columbia River in the US. Drift nets consist of a D-shaped metal frame (0.8 m wide by 0.6 m high) with an attached net (3.6 m long, 0.16 cm knotless mesh, 11.4 cm diameter collection bottle). In addition, a flow meter (e.g., General Oceanics) was fixed to the D-ring frame at the top of the opening to measure the volume of water sampled; this method has been used during the past eight years for drift net sampling in the middle Columbia River.

Drift net sites were selected to cover the upper, middle and lower portion of the spawn monitoring area during each field survey. A minimum of three and maximum of fifteen drift net sets were deployed weekly and concentrated in the spawning area between Km 227.4 and 230.1. Drift nets used egg mat anchor and shoreline sites established during the first field session, with site 228.8L used as a consistent weekly set and other sites used over the study period to distribute effort to additional potential deposition areas. Egg mat sites were removed on the first sampling day, checked for eggs/free embryos and replaced with drift nets. Drift nets were removed after 2 to 4.5 hours (depending on time available) and replaced with egg mats which soaked overnight or remained for a week, depending if the site was to be resampled the following day. This was repeated on the second sampling day but once drift nets were pulled the egg mat remained in situ for a week. Therefore, drift nets were set on two consecutive days per week within the study area as per the past eight years of study in the middle Columbia River. In 2012, drift nets were only set during the first sample day and overnight sets were not possible due to higher water levels than experienced during this program in the past (AMEC 2013). However, conditions in 2013 and 2014 permitted the use of overnight sets (i.e. gear was able to withstand overnight debris loading). In 2014, drift nets were set overnight once per week August 6 through September 11. Overnight drift nets sampled for 14-17 hours from late afternoon until the next morning.

Two 30 kg claw anchors were used for drift net sites. Anchors had approximately 6 m of galvanized steel chain between them. The first anchor had a float line attached and the second anchor had a section of chain then rope to attach the drift net. The bottom end of the drift net frame was clipped onto this chain/rope line. The drift net was weighted at the front corners (approximately 4.5 kg lead weight attached to each corner) to ensure it remained upright in the water in order to more effectively sample drifting debris/aquatic life (e.g., Howell and McLellan 2006 as cited in Golder 2012a; personal observations). A second float line for retrieval was attached to the top of the drift net frame. Retrieval of the drift net was similar to the egg mat in that the float line was retrieved and the winch used to pull the drift net into the boat. The drift net was detached and the float line reattached. Drift nets were set on the same anchor systems and/or rope used for egg mat sampling (Section 2.4.1). Upon retrieval of the drift nets, the contents of the bottle and drift net were emptied into a white bucket. The contents of the bucket were further diluted with river water into small white wash basins and field crew members sorted through the debris to find and collect any White Sturgeon eggs/free embryos using tweezers.

Data recorded for drift net sampling included: station name (similar to egg mats); river km and channel location; set and pull date and time; water temperature; set depth; start/end readings of the flow meter for calculation of water volume sampled; number of eggs/ free embryos; number preserved; other species observed; and, relevant comments (e.g., drifting of station, quantity of debris, whether eggs/free embryos were alive/dead). Data recording, entry and QA/QC followed that outlined for egg mats above. Locations for drift nets are provided in Figure 2. Catch-per-unit effort (CPUE) was calculated for each drift net (number of White Sturgeon/hour and number/100 m^3 water volume) for comparison with other sampling years.

2.5 Egg Incubation, Staging & Spawn Timing Estimation

White Sturgeon eggs were immediately staged on the boat upon capture. Standard egg staging procedures were used as described in Dettlaff et al. (1993) and Wang et al. (1985). If this was not possible, eggs were to be preserved in Prefer and staged by dissection microscope in the office. Eggs staged in the field were placed in incubation trays that were anchored in the river in a location close to the point of capture. Eggs were incubated *in situ* until hatch. Incubation trays consisted of flat plastic trays with wells for approximately 100 individual eggs covered by a top plate. All free embryos, including those hatched in incubation trays as well as those collected in drift nets, were preserved in 90% ethanol to be used in future genetic analyses (e.g. parentage assignment; Jay et al. 2014).

Egg and free embryo stages were used with mean water temperatures observed during sampling to estimate the number and timing of spawning events based on developed relationships (Wang et al. 1985). The total number of eggs/free embryos, status (alive/dead/damaged), spawn timing and number of estimated spawning events were summarized. In the case of any free embryo stages falling between those noted by Wang et al. 1985, a range was calculated to cover the possible spawn timing.

2.6 Egg Stranding

In order to address Management Question 2 (Section 1.1), egg stranding surveys are to be conducted when White Sturgeon spawning event(s) are observed, depending on water levels. White Sturgeon eggs have been previously observed to dewater at a cobble/gravel bar across from the mouth of the Jordan River (~Km 228; Figure 2).

3.0 RESULTS

3.1 Environmental Parameters –Elevation, Discharge and Temperature

Arrow Lake Reservoir elevation steadily increased between April and June, reaching a peak elevation of 439.05 m above sea level (masl) in early July and gradually decreased through the remaining study period (Figure 3). Surface elevation at Nakusp above 437 masl backwaters ALR to the spawning area (Golder 2011) and was observed between June 19 and July 29, 2014 (Figure 3).

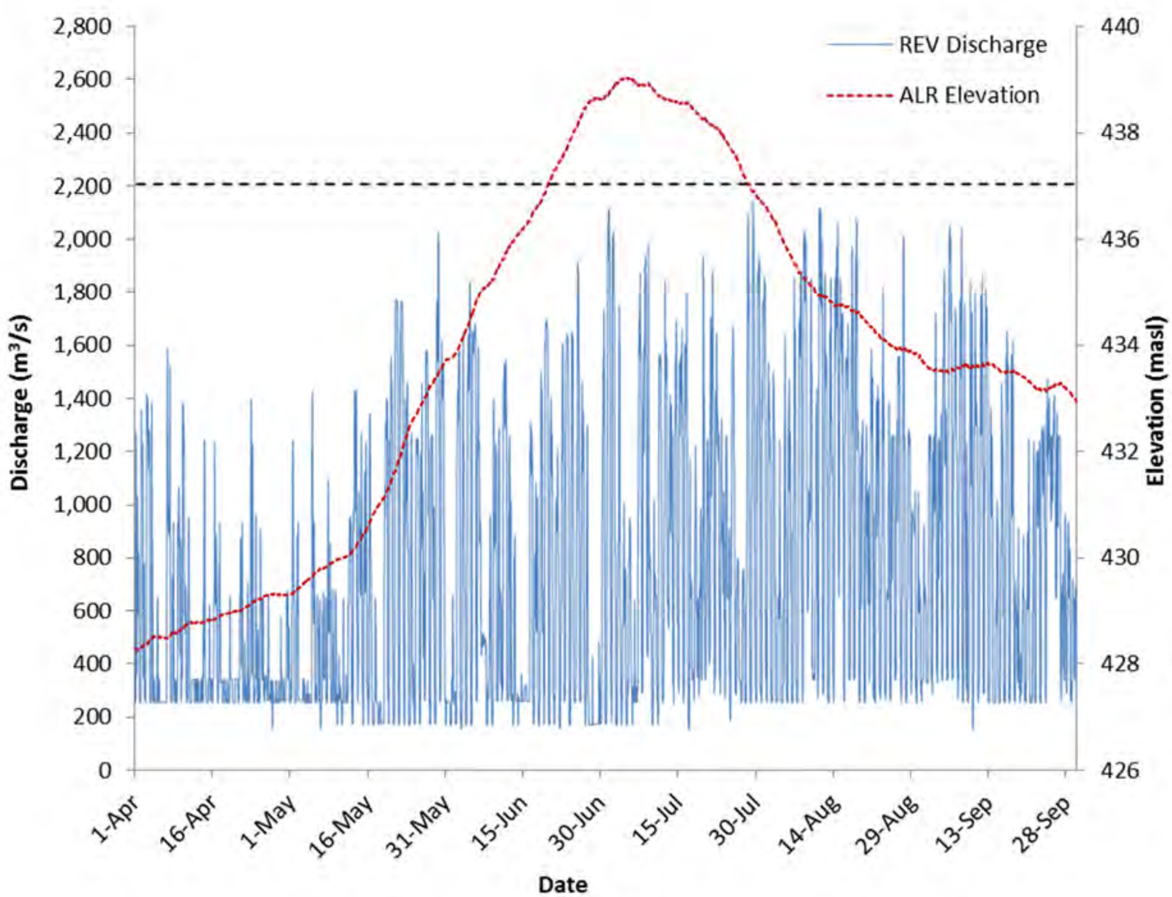


Figure 3: ***Hourly total discharge (m^3/s) from Revelstoke Dam (REV) and hourly water level elevation (meters above sea level) of Arrow Lakes Reservoir (ALR) as measured in Nakusp, BC, April 1 to September 30, 2014. The black dotted line represents 437 masl elevation when ALR backwaters the spawning area.***

Water level elevation over the spawning area reached its summer maximum during early July with the highest elevation of 441.4 masl (as measured at CLBMON-15a Station 2 level logger at Km 231.1) on July 1 at 15:00 (Figure 4). Minimum elevation of 437.4 masl was observed on September 10 at 01:00 (Figure 4). Water levels did not lower to seasonal minimums until the end of July, likely due to the backwatering effect of ALR (Figures 3 and 4). Daily fluctuations in elevation ranged between 0.6 and 3.5 m/day for the duration of the study period (Figure 4). Water elevation at the spawning area followed the discharge release pattern from REV over the duration of the study period (Figure 4).

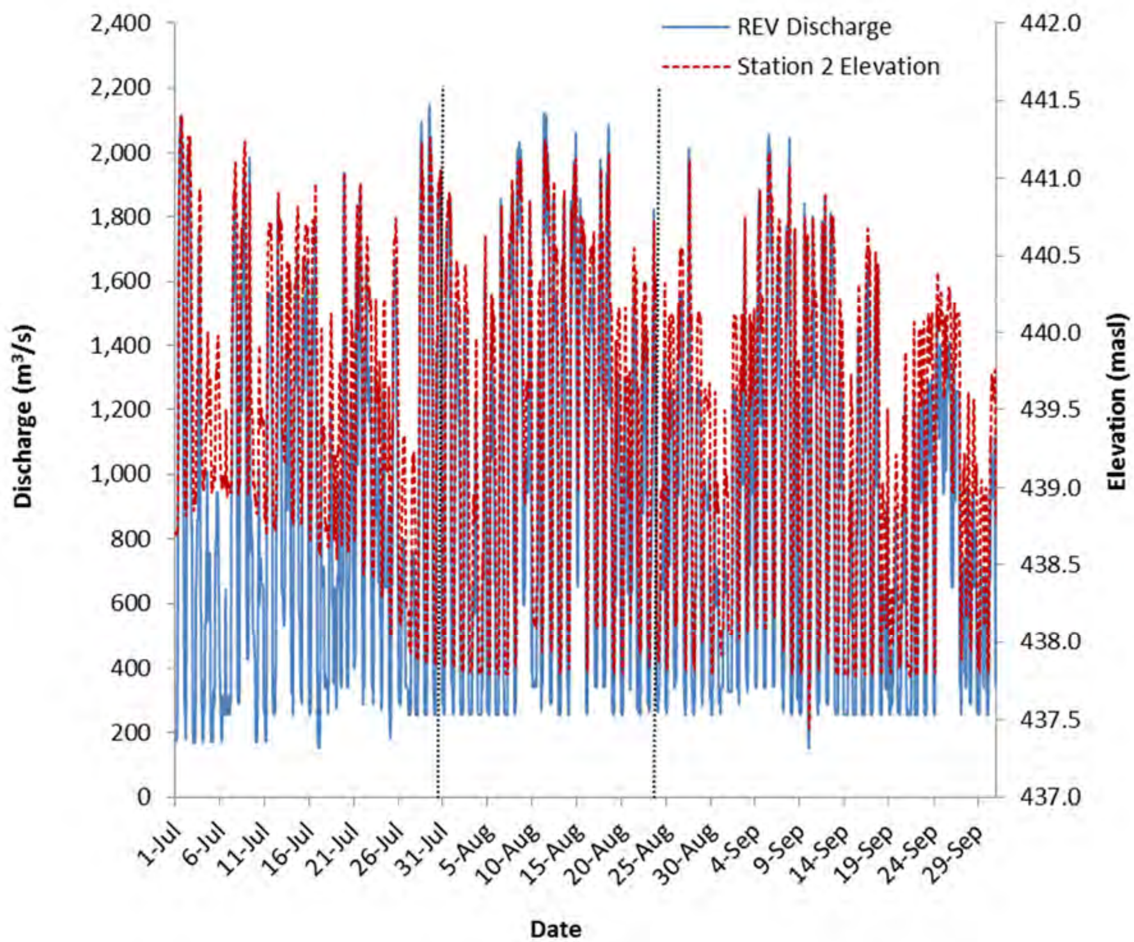


Figure 4: ***Hourly total discharge (m^3/s) from Revelstoke Dam (REV) and hourly water surface elevation (meters above sea level) measured at CLBMON-15a Station 2 at Km 227.8, July 1 to September 30, 2014. The dotted bars indicate estimated spawn timing.***

Discharge from Revelstoke Dam exhibited daily fluctuation between April 1 and September 30, 2014 due to the hydropeaking operations at the facility (Figure 3). Peak discharge was observed in late July (2,145 m^3/s on July 29 at 12:00); similar peaks were also observed in early July and mid-August (Figure 4). The maximum daily discharge sporadically reached levels up to approximately 2,000 m^3/s through September 5, 2014 (Figure 4). Discharge did not drop below 152 m^3/s during July through September 2014 (Figure 4). Spill gates were used briefly on July 25 between 1:00 and 5:00 at which time a coordinated reduction in turbine flow occurred (unpublished data, BC Hydro Power Records, 2014).

Water temperatures at the spawning area are the result of a combination of thermal conditions in the REV forebay, REV discharge volume and the backwater effect from ALR

(Golder 2011). In 2014, water temperature fluctuated between 8.5°C and 12.6°C during the late July through mid-September study period (Figure 5).

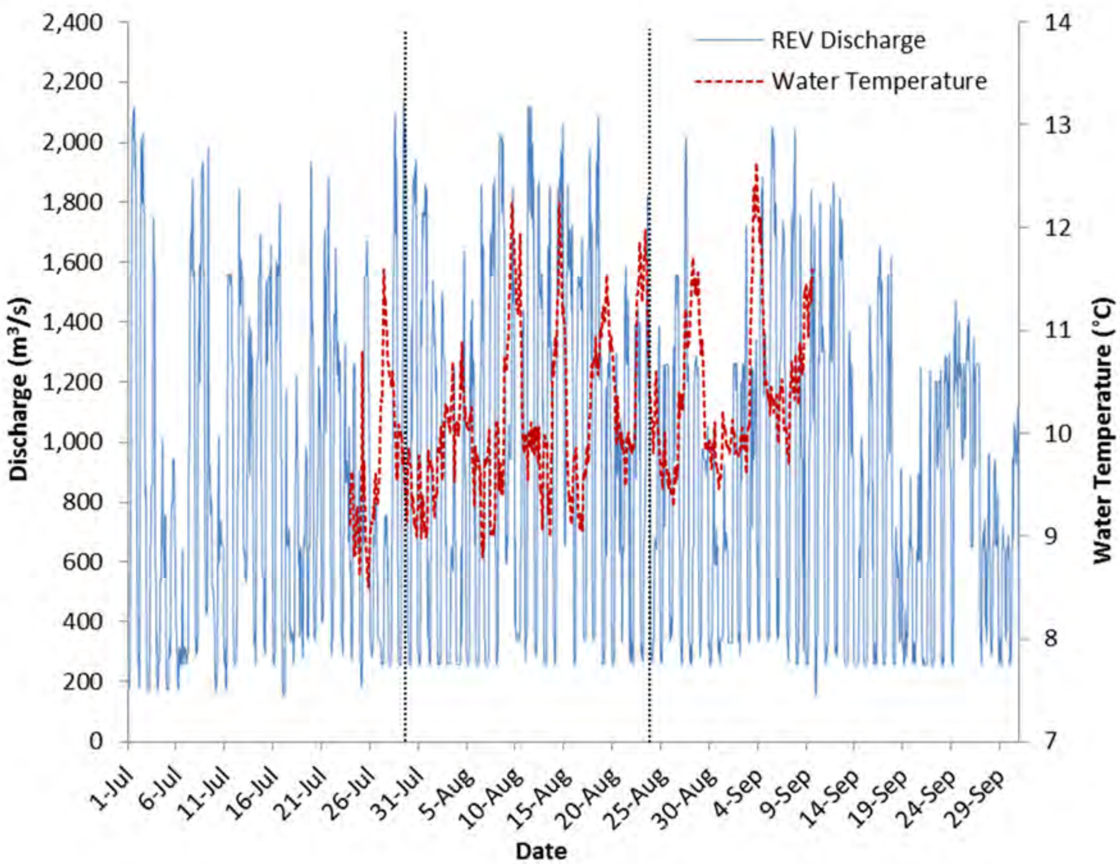


Figure 5: ***Hourly total discharge (m³/s) from Revelstoke Dam and hourly water temperature (°C) measured at 229.7L, July 1 to September 30, 2014. The dotted bar indicates estimated timing of White Sturgeon spawning events.***

3.2 White Sturgeon Egg & Free Embryo Collection

3.2.1 Egg Collection Mats

In total, 18 White Sturgeon eggs and one free embryo were collected by egg mats at stations 227.4L, 228.6M, 228.8L, 229.38L, 229.4L, on July 30, August 6, 27, 28 and September 4, 2014 (Table 2; Appendix A). In total, 20,850 mat-hours of effort (mean sample duration per egg mat = 178.2 hours; SD = 55.2) were spent during the 2014 sampling period (Table 2 and Table 3; Appendix A). A summary of effort by year(2007-2014) and sampling method is provided in Table 3 and illustrated in Figure 6.

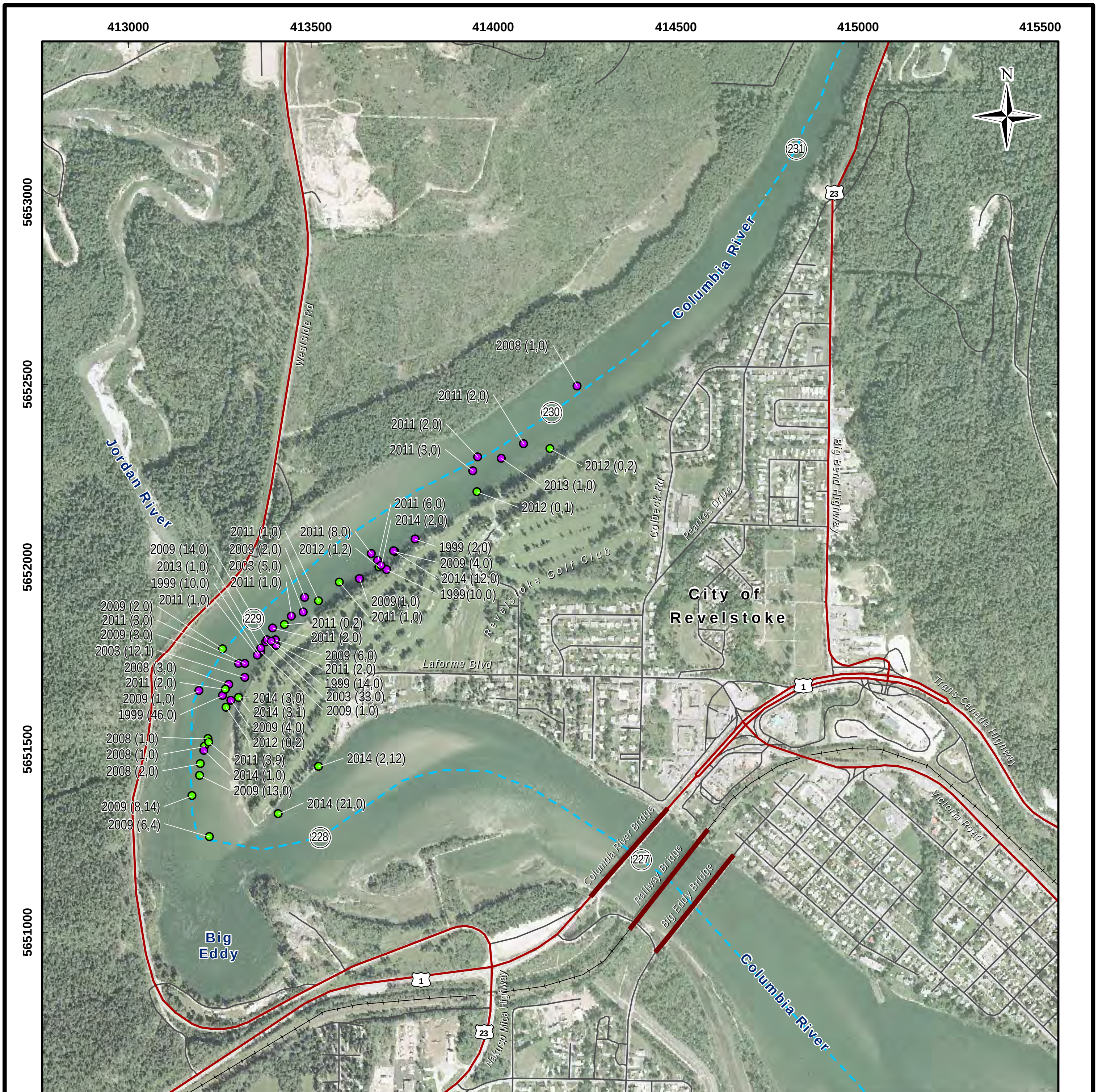
Table 2: Summary of egg collection mat sampling, July 22 to September 10, 2014.

Session	Date	No. Mats Deployed	No. Mats Retrieved	Effort (Mat-Hours)	No. Eggs /Free Embryos	Catch-Per-Unit-Effort (CPUE)[a]	Notes
1	July 22 - 23	20	0	0	0	NA	
2	July 29 - 30	19	19	3215.9	3	0.0009	
3	August 6 - 7	14	14	2776.2	1	0.0004	6 mats not retrieved until following week due to mechanical issues
4	August 14 - 15	19	20	4460.6	0	0	
5	August 20 - 21	17	18	1850.5	0	0	
6	August 27 - 28	18	18	3158.4	14	0.004	
7	September 3 - 4	16	16	2788.9	1	0.0004	
8	September 9 - 10	0	17	2599.4	0	0	
Totals		***123***	***122***	***20850.0***	***19***	***0.0009***	

[a] CPUE = no. White Sturgeon eggs/24 mat-hours.

Table 3: Summary of egg collection mat and drift net sampling by study year, 2007-2014.

Year	Egg Mats				Drift Nets				Reference
	No. Deployed	Total Effort (hrs)	No. Eggs/Free Embryos Captured	CPUE	No. Deployed	Total Effort (hrs)	No. Eggs/Free Embryos Captured	CPUE	
2014	123	20,850	19	0.0009	64	375.9	38	0.10	Current Study
2013	135	20,019	2	0.0001	67	424.3	0	0	AMEC 2014
2012	61	8,773	0	0	28	106.8	8	0.07	AMEC 2013
2011	128	22,169	30	0.03	23	61.2	18	0.30	Golder 2012
2010	96	20,514	0	0	15	67.4	0	0	Golder 2011
2009	115	18,860	36	0.05	22	65.3	47	0.70	Golder 2010
2008	164	27,009	4	0.004	6	12.6	4	0.30	Golder 2009
2007	136	25,818	0	0	8	24.7	0	0	Golder 2008
Mean	**120**	**20,502**	**11**	**0.01**	**29**	**142.3**	**14**	**0.18**	
Standard Deviation	31	5529	15	0.02	24	162.2	19	0.24	



River Kilometre
Highway
Bridge
Existing Road
Railway
River Centre Line
Dam

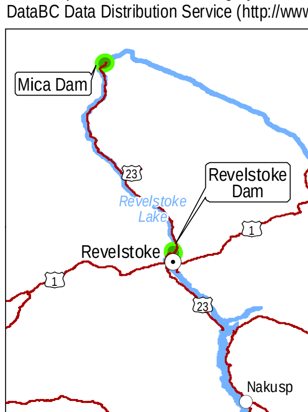
Capture Methods

Larval Drift Net
Egg Collection Mat

2014 (7, 3)
Year Captured
Eggs
Free Embryos

Reference
River Kilometre: Measured upstream from Hugh L. Keenleyside Dam
Base Map: British Columbia Imagery WMS
DataBC Data Distribution Service (http://www.data.gov.bc.ca/)

Scale: 1:15,000
0 50 100 200 300 400 500
Metres



CLIENT: BC hydro

PROJECT:
CLBMON-23a Egg Collection Mat and Drift Net Sampling Location Where White Sturgeon Eggs and/or Free Embryos Were Collected Below Revelstoke Dam, 1999, 2003, 2008, 2009, 2011, 2012, 2013 and 2014

DATE:	ANALYST:	
December, 2014	WR	**Figure** 6
JOB No: VE52241	QA/QC: MY	PDF FILE: 01-50-003_v10_field1.pdf
GIS FILE: 01-50-003_v10.mxd		amec
PROJECTION: UTM Zone 11	DATUM: NAD83	

Y:\GIS\Projects\VE\VE52200\VE52241_White_Sturgeon\Mapping\01-50-003_v10.mxd

3.2.2 Drift Nets

In total, 26 White Sturgeon eggs and 12 free embryos were captured by drift nets at stations 227.9L, 229.1L and 228.8L which were set for a total of 376 hours in 2014 (Table 3 and Table 4; Appendix B). Drift nets were set during the day (n=48) for a total of 133 hours (mean sample duration = 2.8 hours; SD = 0.52) and overnight (n=16) for a total of 243 hours (mean sample duration = 15.2 hours; SD = 0.7; Appendix B). Total water volume sampled during daytime drift net sets was 105,043 m^3 and the mean water volume per daytime drift net set was 2,235 m^3 (SD = 1,843) and velocity was 47.2 cm/s (SD=46.5; Appendix B). Volume and velocity measurements were not analyzed for overnight sets as the instruments potentially reset themselves over the duration of the set. A summary of sample effort by year and sampling method is provided in Table 3 and illustrated in Figure 6.

Table 4: Summary of drift net sampling, July 22 to September 10, 2014.

Session	Date	No. Drift Nets Deployed	Sample Effort		White Sturgeon Eggs			White Sturgeon Free Embryos			Notes
			Duration (hr)	Estimated Volume (m^3)	No.	Catch-Per-Unit-Effort (CPUE) No./hr	Catch-Per-Unit-Effort (CPUE) No./ 100 m^3	No.	Catch-Per-Unit-Effort (CPUE) No./hr	Catch-Per-Unit-Effort (CPUE) No./ 100 m^3	
1	July 22 - 23	3	8.98	13038	0	0.00	0.00	0	0.00	0.00	3 sets per day
2	July 29 - 30	6	17.21	14444	23	1.34	0.00	0	0.00	0.00	3 sets per day
3	August 6 - 7	8	47.72	13050	1	0.02	0.00	0	0.00	0.00	3 sets per day; 2 overnight
4	August 14 - 15	8	47.75	-	0	0.00	-	1	0.02	-	3 sets per day; 2 overnight
5	August 20 - 21	9	59.33	-	0	0.00	-	0	0.00	-	3 sets per day; 3 overnight
6	August 27 - 28	8	45.75	-	2	0.04	-	0	0.00	-	3 sets per day; 2 overnight
7	September 3 - 4	9	60.91	-	0	0.00	-	0	0.00	-	3 sets per day; 3 overnight
8	September 9 - 10	13	88.20	-	0	0.00	-	11	0.12	-	3 sets day one; 2 sets night one; 6 sets day two; 2 sets night two
	Totals	***64***	***375.85***	-	***26***	***0.07***	-	***12***	***0.03***	-	

"-" Drift nets set overnight and velocity meter readings could not be determined as meters zeroed themselves an unknown number of times.

3.3 Egg Incubation

Eggs collected July 29-30, 2014 were incubated at Km 229.1L, checked on August 6 at which time eggs had not yet hatched and rechecked on August 14 at which time eggs were covered in algae and no longer viable. Eggs collected August 27-28, 2014 were incubated at Km 227.8L and inspected the following week (September 4) at which time eggs were close to hatch. Following discussion with the BC Hydro contract authority and project manager, the incubation trays and eggs were transported back to the AMEC office in Nelson, BC in a bucket of oxygenated middle Columbia River water. Egg condition and water temperature were monitored daily and all viable eggs had hatched by September 6, 2014.

3.4 Staging & Estimated Spawn Timing

Based on egg stages and water temperatures, three spawning events were identified during the 2014 spawning period; July 29, July 30 and August 24-25.

Seventeen White Sturgeon eggs were captured on July 29, 2014 very soon after spawning occurred. The eggs were all staged as being very recently fertilized (stages 12 and 13; <3 hours since spawning) and spawn timing was estimated to have occurred on July 29 at 16:00 hours (Table 5). Eggs were also captured the following day, July 30, with stages suggesting two recent spawning events had occurred: eggs were captured throughout the day at various stages of cleavage (third through late) suggesting they were from the spawning event observed the day previous (July 29 at 16:00); and, freshly fertilized eggs were also captured and staging suggested that spawning had occurred July 30 at 10:00 (Table 5). It is possible these eggs originated from the same female as the mean spawning duration of females in the lower Columbia River downstream of HLK dam is 1.9 days (SD = 1.1; Jay et al. 2014). However, in the absence of genetic analysis these are considered two separate spawning events. One free embryo was collected in a drift net on August 14, 2014 which likely was a hatch from the July 29 or 30 spawning events; an average water temperature of 10°C was observed at the spawning area during incubation suggesting hatching occurred approximately 333 hours after fertilization (Wang et al. 1985), on approximately August 12-13. Another free embryo captured on an egg mat on August 28 likely originated from the July 29 or 30 event; however, this free embryo was very decayed at the time of capture which confounded determination of developmental stage (Table 5).

An additional 15 eggs were captured on August 27 and 28, 2014, two of which were dead (Table 5). Predominant features of the 13 viable eggs included the large yolk plug formation where the light area covers two thirds of the egg (stage 21; n=1) and the small yolk plug where the lateral sides merge to form a slit-like blastopore (stage 22; n=12; Table 5). Based on Wang et al. (1985), the time for White Sturgeon eggs to reach stages 21 and 22 is approximately 58 and 78 hours, respectively; this resulted in an estimated spawn time of August 24 at 16:00 or August 25 at 07:00 (Table 5). One pre-hatch egg (stage 28) was captured the following week (September 4) and was likely to have been spawned during the same event. Hatch occurs 293 hours after spawning when water temperature is 11°C so the calculated spawning date for this egg was August 23, however, temperature fluctuations occurred during the incubation period making exact spawning date determinations of later staged eggs less reliable (Wang et al. 1985; K. Jay, Jay Environmental, pers. comm. 2014). Free embryos (n=11) from the August 23 to 25 spawning event were captured in drift nets between September 9 and 11, 2014 (Table 5).

Table 5: Estimated timing of spawning events based on the developmental stages of captured White Sturgeon eggs and free embryos, 2014.

Collection Date	Sample Location[a]	Egg/Free Embryo (Number)	Stage	Spot Water Temperature (°C) When Collected	Estimated Spawn Date[b]	Description
29-Jul-14	230.2M	Egg (17)	12/13	9.2	7/29/2014 16:00	Light crescent forming - all similar
30-Jul-14	228.8L	Egg (2)	16	9.4	7/29/2014 16:00	Numerous micromeres (4th-6th cleavage)
30-Jul-14	228.6M	Egg (1)	15	9.4	7/29/2014 16:00	Third cleavage
30-Jul-14	228.1L	Egg (4)	12	9.3	7/30/2014 10:00	Dark bullseye, recently fertilized
			17	9.3	7/29/2014 16:00	Numerous small micromeres
			29	9.3	n/a	Dead
30-Jul-14	228.8L	Egg (2)	12/13	9.8	7/30/2014 10:00	Dark bullseye and light cresent
6-Aug-14	229.4L	Egg (1)	29	8.9	n/a	Dead
14-Aug-14	227.9L	Free Embryo (1)	38	11.5	7/29/2014	11 mm; mouth forming but no fin development
27-Aug-14	229.38L	Egg (2)	21/22	11.1	8/25/2014 7:00	Large and small yolk plug formation
27-Aug-14	229.4L	Egg (10)	22	11	8/24/2014 16:00	Small yolk plug/slit-like blastospore
27-Aug-14	227.9L	Egg (2)	22	10.9	8/24/2014 16:00	Small yolk plug/slit-like blastospore
			29	10.9	n/a	Dead
28-Aug-14	228.8L	Egg (1)	29	12.2	n/a	Dead
28-Aug-14	228.8L	Free Embryo (1)	Dead	12.2	n/a	Stage 41 at death; 15mm, pectoral fins and mouth developed
4-Sep-14	229.4M	Egg (1)	28	11.9	8/23/2014	Close to hatch - embryo moving in egg
9 to 11-Sep-14	227.9L	Free Embryo (11)	37-38	11.6 - 12.3	8/23/2014 to 8/25/2014	12-14 mm; mouth and pectoral fin development beginning

[a] See Figure 2 for locations.

[b] Based on Wang et al. 1985 and Dettlaff et al. 1993.

3.5 White Sturgeon Spawning and Physical Parameters

A summary of White Sturgeon spawning events and physical parameters observed below Revelstoke Dam during the spawning period (July-August) in years when spawn monitoring was conducted is provided in Table 6. The number of White Sturgeon spawning events recorded between 1999 and 2014 has varied from zero to three (Table 6). Maximum discharges were higher in 2011, 2012, 2013 and 2014 compared to other years when spawning monitoring was conducted. Minimum discharge was also higher during the past four years (i.e., zero discharge did not occur in 2011, 2012, 2013 and 2014; Table 6); spawning was observed in all four of those years.

3.6 Egg Stranding Surveys

Three opportunistic stranding surveys were conducted during the 2014 spawning period. The first survey was conducted on July 30 between 09:10 and 09:20 at Km 228.2 at the downstream end of a gravel bar which was immediately upstream of a drift net station (228.1L) where eggs had been collected the previous day. REV discharge was approximately 1000 m^3/s at the time and increasing from an overnight low of 255 m^3/s (BC Hydro Power Records, unpublished). Pools and interstitial spaces were surveyed visually in a 10 m^2 area and no eggs were observed. The second survey was conducted on August 6 between 17:10 and 17:40 at a mid-channel gravel bar at Km 227.6, about 600 m upstream of the Highway 1 bridge (Figure 1). REV discharge was approximately 1000-1600 m^3/s at the time and dropping to reach an overnight low of 255 m^3/s (BC Hydro Power Records, unpublished). An approximately 50 m^2 area was surveyed interstitially and no eggs or free embryos were observed. The final survey was conducted on August 28 between 11:15 and 11:45 at the upstream end of a gravel bar between Km 228.6 and 228.8 along the left downstream bank. REV discharge varied between 600 and 1200 m^3/s at the time and increasing from an overnight low of 255 m^3/s (BC Hydro Power Records, unpublished). Approximately 30 m^2 were surveyed for interstitial and pool stranding and no eggs or free embryos were observed.

Table 6: White Sturgeon spawning events and physical parameters observed below Revelstoke Dam (July-September) during spawn monitoring programs, 1999 to 2014. Note that spawn monitoring was not conducted in 2002, 2004 and 2005. Table updated from Golder (2012a).

Parameter		1999	2000	2001	2003	2006	2007	2008	2009	2010	2011	2012	2013	2014
No. Spawning Events		3	0	0	2	1	0	2	3	0	3	1	1	3
No. Eggs Captured		82	0	0	50	1	0	8	65	0	37	1	2	44
No. Free Embryos Captured		0	0	0	1	0	0	0	18	0	11	7	0	13
Discharge (m^3/s)	**Mean**	1230	1139	682	901	939	1185	712	744	540	957	1506	862	945
	Min.	0	0	0	0	0	0	0	0	0	145	150	253	152
	Max	1838	1635	1612	1667	1630	1773	1752	1715	1757	2140	2573	2118	2145
Water Temperature (°C)	**Mean**	10.3[a]	-[b]	9.8	9.5	10	9.7	9.2	10.9	11	10.6	10.8	10.5	10.2
	Min.	9.2[a]		6.4	6.9	8	4.5	6.7	7.6	7.5	8	7.8	9.1	8.5
	Max	11.6[a]		13.1	13.6	13.1	12.9	11.8	16.2	14.2	12.5	13.5	12.6	12.6
ALR Water Surface Elevation at Nakusp (m above sea level)	**Mean**	438	438.9	429.4	438	438.1	437.5	439.2	436.5	437.7	439	439.5	435.0	435.0
	Min.	437.2	437.6	427.3	436.2	435.2	435.3	438.7	435.8	436.1	438	436.6	432.9	433.5
	Max	440	444	430.4	439	439.8	438.6	439.9	437.5	439.3	439.5	440.5	437.6	437.9
No. Zero Flow Events		25	8	36	36	12	8	49	42	39	0	0	0	0

[a] Temperature data were only available from August 4-31.
[b] Data not available.

4.0 DISCUSSION

The following discussion is structured in accordance with the management questions outlined in the terms of reference for this monitoring program. As mentioned previously, management question 3 (underwater videography) was addressed under a different monitoring program (CLBMON-23B Middle Columbia River White Sturgeon underwater videography feasibility study; Johnson et al. 2009) and will not be further addressed by the present program.

4.1 Management Question 1: Where are the primary White Sturgeon incubation sites below Revelstoke Dam?

Columbia River White Sturgeon typically spawn in high velocity areas that have hydraulic complexity (e.g. turbulence) and coarse substrates such as areas below dams (e.g., Parsley et al. 1993 and references cited in Hildebrand and Parsley 2013). Spawning in the mid-Columbia River below Revelstoke Dam has been identified in 9 of 13 years that monitoring has been conducted despite the small population estimated for this area (approximately 52 individuals; Golder 2006) and the fact that mature females may not be available every year to spawn. Based on the spawning studies conducted below Revelstoke Dam since 1999, the primary White Sturgeon egg incubation area is located within a 2.2 km river section between Km 227.9 and 230.1, which encompasses the area adjacent to the Revelstoke golf course (Figure 6); REV is located at Km 235 (R.L. & L. Environmental Services Ltd. 2001, Golder 2008, AMEC 2012). White sturgeon eggs have consistently been documented in this relatively small area despite past sampling at other potentially suitable areas between Revelstoke Dam and the Illecillewaet River (Hildebrand et al. 2014).

The boundaries of this small spawning/incubation area may shift slightly depending on flows and ALR elevation, but remains relatively similar between years. During past study reviews, the primary incubation area was identified as a smaller 0.8 km area that began from the mouth of the Jordan River at Km 228.8 to 229.6 (Golder 2012a). However, additional years of study suggest this area now extends further up and downstream than previously identified. It was suggested that in years when ALR elevation was above 437 masl at Nakusp, the backwatering effect at the spawning area may redistribute spawners slightly upstream (Golder 2012a). This may be supported by data collected in 2008, 2011 and 2012 when eggs/free embryos were captured up to 1 km upstream of the primary incubation area during ALR backwatering. However in 2013, an egg was captured slightly upstream (Km 229.8) without this backwatering effect (Golder 2012a, AMEC 2013). The majority of eggs (23 of 44) and free embryos (12 of 13) were captured downstream of this area in 2014 (Figure 6). Limited sampling effort has been expended in this lower area during previous surveys (e.g., Golder 2012a, AMEC 2014), but is now being included during ongoing efforts.

4.2 Management Question 2: How do dam and reservoir operations affect egg and larval survival in this area? Specifically, do significant numbers of eggs become dewatered as a result of operations?

Estimates of egg or larval survival are difficult to calculate for sturgeon species, even in systems where more data are available. In this program, the ability to estimate survival of early life stages is not possible due to the low number of eggs/larvae that have been collected. Based on other spawning areas, successful White Sturgeon egg and larval survival requires suitable substrate (gravels/cobbles/boulders) with intermediate interstitial spaces, near bottom water velocity >1 m/s, depth range of 3-25 m and temperature conditions from 10 to 18°C. Conditions modelled within the REV egg incubation area under CLBMON-20 and CLBMON-54 indicate that maximum depths in the thalweg typically range from 5 to 6 m (though they are reduced to 2-3 m during minimum flows); near bottom water velocities of >1.0 m/s are observed approximately 55% of the time during the egg incubation period; and, substrates within the study area consist of coarse materials such as gravels, cobbles and boulders (Hildebrand et al. 2014). Hourly water temperatures in the Revelstoke spawning area are typically below 12°C, with maximum temperatures occasionally reaching 16.1°C (Hildebrand et al. 2014).

It is unknown whether a significant number of eggs become dewatered as a result of operations based on the limited sampling that has been conducted at this time. However the increase in minimum flows and overall capacity has increased the estimated permanently wetted river bed area in the middle Columbia River by approximately 37% when ALR elevation is below 425 m (Golder 2012b). Therefore, this should reduce the severity of egg and larval stranding during periods of minimum flow (Hildebrand et al. 2014) and exposure of gravel bars as observed prior to enactment of minimum flows is less likely. During this program, comprehensive egg stranding surveys have been conducted twice to investigate dewatering of incubation areas, once in 2009 when minimum REV flow was zero and once in 2011 when minimum REV flow was 145 m^3/s (Golder 2012a). In 2009, seven White Sturgeon eggs were recorded in the 29 m^2 of exposed gravel bar surveyed, which resulted in a density estimate of 0.24 stranded eggs/m^2 and a potential estimated 7,600 stranded eggs over the entire 31,600 m^2 area assuming egg density was the same over the entire gravel bar (Golder 2010). In 2011, no eggs were observed in the 30 m^2 of exposed gravel bar surveyed when approximately 8000 m^2 of the bar was dewatered (Golder 2012a). Between 2012 and 2014, water levels did not expose this area sufficiently during spawning monitoring to warrant extensive investigations (i.e. minimum flows were not observed during the White Sturgeon egg incubation period).

4.3 Management Question 4: What is the most effective method for monitoring spawning of White Sturgeon?

The most effective method for monitoring White Sturgeon spawning in the mid-Columbia River is a combination of egg mats and drift nets. Other methods for monitoring White Sturgeon spawning in this area have included acoustic telemetry and DIDSON monitoring (Golder 2009, Crossman et al. 2011). Although these methods were effective for observing sturgeon in the spawning area, they were ineffective for monitoring spawning.

During the past 8 years of this program, an average of 120 egg mats have been deployed per spawning season for approximately 20,502 hours which resulted in an average catch-rate of 0.01 eggs/free embryos per hour. In contrast, an average of 29 drift nets have been deployed per spawning season for approximately 142 hours which resulted in an average catch-rate of 0.2 eggs/free embryos per hour. Although drift nets do have higher catch-rates, they are more labour intensive and do not monitor continuously like egg mats. Research conducted on sturgeon free embryos has identified a downstream dispersal following hatch, when endogenous yolk reserves are used (Crossman and Hildebrand 2012). Accordingly, it is important to ensure drift nets are deployed during the period surrounding estimated hatch dates. Other work also found that the cooler water temperatures observed in the mid-

Columbia River results in free embryos hatching over a protracted period over several days instead of all at once (Parsley et al. 2011). Therefore, drift nets fished twice per week may have a better chance to overlap with larval downstream dispersal. In 2014, egg mats sampled continuously for approximately 51 days, whereas drift nets covered one third of that time (16 days). Therefore, both methods should be used together during sampling to ensure timing and frequency of spawning is captured.

4.4 Management Question 5: Can modifications be made to operations of Revelstoke Dam and ALR to protect or enhance White Sturgeon incubation habitat?

It is unknown at this time whether additional modifications to REV/ALR operations can be made to protect or enhance White Sturgeon incubation habitat. Flow modifications have already occurred with the addition of REV5 and the implementation of a REV 142 m^3/s minimum discharge (see Section 4.2). Preliminary information collected during this monitoring program before and after REV5 suggests that recent operational modifications may reduce White Sturgeon egg stranding and spawning has been consistently observed in the past four years since REV5 came online concurrently with the implementation of minimum flow requirements (see Section 4.2).

The REV discharge regime, along with ALR elevation may influence the physical conditions (depth, velocity, substrate and thermal regime) observed at the spawning area. Physical changes observed from REV5 operational modifications includes greater diel variation in water level and less diel variation in temperature, but this was based on only two post-project years and is considered preliminary (Golder 2013). Hildebrand et al. (2014) indicated that the results of modelled effects of REV discharge and ALR water levels on velocity, depth and substrate are within the ranges observed in successfully recruiting White Sturgeon populations. However, a high degree of uncertainty still remains for recommending protection/enhancement flows for White Sturgeon in the middle Columbia River (Hildebrand et al. 2014). Past analyses did not find any discernable short or long term relationships between spawning and physical parameters (discharge, increasing or declining temperatures, ALR elevations and the frequency of zero flow events) (Golder 2012a), though the sample size was small due to the low mean number of spawning events per year.

The influence of REV operations and ALR elevation on physical conditions observed at the spawning area is currently being assessed during concurrent BC Hydro WUP programs, which may provide further insight into whether additional operational modifications are necessary to protect or enhance White Sturgeon incubation habitat. These programs include: CLBMON-15a (Middle Columbia River Physical Habitat Monitoring), CLBMON-20 (Middle Columbia River White Sturgeon Spawning Habitat Assessment), CLBMON-27 (Middle Columbia River Sturgeon Incubation and Rearing Study) and CLBMON-54 (Middle Columbia River Effects of Flow Changes on Incubation and Early Rearing Sturgeon).

5.0 RECOMMENDATIONS

1. Repeat 2014 sampling for the upcoming 2015 period, if conditions permit. That is, commence surveys during the fourth week of July and continue sampling through early September. Spawning events have been documented between July 25 and August 28.
2. Use overnight drift netting as per 2014 sampling protocols when flow conditions are appropriate.
3. Incubate eggs to hatch so that tissue samples are available for future genetic analyses.

6.0 REFERENCES

AMEC. 2013. Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23a). Year 6 Data Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: AMEC Environment & Infrastructure Ltd. 23 pp + 3 App.

AMEC. 2014. Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23a). Year 7 Data Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: AMEC Environment & Infrastructure Ltd. 23 pp + 3 App.

BC Hydro. 2012. Columbia River Project Water Use Plan Monitoring Program Terms of Reference. CLBMON-23 Mid Columbia River White Sturgeon Spawn Monitoring.

Crossman, J. A., Martel, G., Johnson, P. N. and Bray, K. 2011. The use of dual-frequency identification sonar (DIDSON) to document white sturgeon activity in the Columbia River, Canada. Journal of Applied Ichthyology 27: 53-57.

Dettlaff, T.A., A.S. Ginsburg and O.I. Schmalhausen. 1993. Sturgeon fishes. Developmental biology and aquaculture. Springer-Verlag, Berlin, Germany, 300 pp.

Fisheries and Oceans Canada. 2014. Recovery strategy for White Sturgeon (Acipenser transmontanus) in Canada [Final]. In Species at Risk Act Recovery Strategy Series. Ottawa: Fisheries and Oceans Canada. 252 pp.

Golder Associates Ltd. 2006. A synthesis of White Sturgeon investigations in Arrow Lakes Reservoir, B.C. 1995 – 2003. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 041480016F: 61 p. + plates + 11 app.

Golder Associates Ltd. 2008. Middle Columbia River White Sturgeon spawn monitoring: 2007 investigations data report. Report prepared for BC Hydro, Revelstoke, B.C. Golder Report No. 07-1480-0053F: 12 p. + plates + 2 app.

Golder Associates Ltd. 2009. Middle Columbia River White Sturgeon spawn monitoring: 2008 investigations data report. Report prepared for BC Hydro, Revelstoke, B.C. Golder Report No. 08-1480-0029F: 24 p. + 2 app.

Golder Associates Ltd. 2010. Middle Columbia River White Sturgeon spawn monitoring: 2009 investigations data report. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 09-1480-0040F: 20 p. + 2 app.

Golder Associates Ltd. 2011. Middle Columbia River White Sturgeon spawn monitoring: 2010 investigations. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 10-1492-0061F: 17 p. + 1 app.

Golder Associates Ltd. 2012a. Middle Columbia River White Sturgeon spawn monitoring: 2011 investigations. Report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 11-1492-0071F: 21 p. + 1 app.

Golder Associates Ltd. 2012b. Middle Columbia River physical habitat monitoring. CLBMON-15a. Annual technical report – 2011. Report prepared for BC Hydro, Castlegar, BC. Golder Report No. 11-1492-0084. 44 p. + 6 app.

Golder Associates Ltd. 2013. CLBMON-15a Mid-Columbia River Physical Habitat Monitoring. Synthesis Report (Years 1 – 6). Report prepared for BC Hydro, Revelstoke, BC. 27 January 2014. Golder Report No. 12-1492-0084. 44 p. + 6 app.

Hildebrand, L. R. and M. Parsley. 2013. Upper Columbia White Sturgeon Recovery Plan – 2012 Revision. Prepared for the Upper Columbia White Sturgeon Recovery Initiative. 129p. + 1 app. Available at: www.uppercolumbiasturgeon.org

Hildebrand, L. R., A. Lin, M. C. Hildebrand, and D. Fissel. 2014. Effects of Flow Changes on White Sturgeon Spawning, Incubation, and Early Rearing Habitats in the Middle Columbia River (CLBMON-20 and CLBMON-54). Prepared for BC Hydro, Castlegar, BC by Golder Associates Ltd, Castlegar, BC and ASL Environmental Sciences Inc., Victoria, BC. 64 pp. + 3 app and 1 Attachment.

Jay, K., J. Crossman and K. Scribner. 2014. Estimates of effective number of breeding adults and reproductive success for White Sturgeon. Transactions of the American Fisheries Society 143: 1204-1216.

Johnson, P. N., M.H. Tiley, S. LeBourdais and R.C. Bocking. 2009. Monitoring Study No. CLBMON-23b. Mid-Columbia River White Sturgeon underwater videography feasibility study 2008-2009 final Report.

McCabe, G.T., and L.G. Beckman. 1990. Use of an artificial substrate sampler to collect white sturgeon eggs. California Fish and Game 76:248–250.

Parsley, M.J., L.G. Beckman and G.T. McCabe, Jr. 1993. Spawning and rearing habitat use by white sturgeons in the Columbia River downstream from McNary Dam. Transactions of the American Fisheries Society 122: 217-227.

Parsley, M.J., E. Kofoot, and T.J. Blubaugh. 2011. Mid Columbia Sturgeon Incubation and Rearing Study (Year 2 – 2010). Report prepared for BC Hydro, Castlegar, B.C. 23 p + 1 app.

Porto, L. 2008. White Sturgeon populations in the BC Hydro dam footprint impacts area. Report prepared for the Columbia Basin Fish and Wildlife Program, Columbia Basin, Nelson, BC. 45 p. + 1 app.

R.L. & L. Environmental Services Ltd. 2000. White sturgeon investigations in Arrow Reservoir and Columbia River, B.C., 1999 study results. Report prepared for B.C. Ministry of Environment, Lands and Parks, Nelson, B.C. R.L. & L. Report No. 754F: 38 p. + 4 app.

R.L. & L. Environmental Services Ltd. 2001. White sturgeon investigations in Arrow Reservoir and the Columbia River, B.C., 2000 study results. Report prepared for B.C. Ministry of Environment, Lands and Parks, Nelson, B.C. R.L. & L. Report No. 840F: 23 p. + 4 app.

Wang, Y.L., F.P. Binkowski and S.I. Doroshov. 1985. Effect of temperature on early development of white and lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. Environ. Biol. Fishes.

APPENDIX A
Egg Collection Mat Sampling

Table A1. Egg collection mat sampling data collected during middle Columbia River White Sturgeon spawning monitoring, July 22 to September 10, 2014.

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2014)	Time	Water Temp (°C)	Date (2014)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
230.1L	2.9	22-Jul	18:30	9.0	29-Jul	17:00	9.5	166:30	166.5	0	0	0
230.2M	2.3	22-Jul	17:05	9.0	30-Jul	11:42	9.4	186:37	186.62	0	0	0
230.0M	2.7	22-Jul	17:10	9.0	29-Jul	16:49	9.5	167:39	167.65	0	0	0
229.8M	3.5	22-Jul	17:19	9.0	30-Jul	11:16	9.4	185:57	185.95	0	0	0
229.4M	5.1	22-Jul	17:26	9.0	30-Jul	11:03	9.6	185:37	185.62	0	0	0
229.3M	2.9	22-Jul	17:35	9.0	30-Jul	10:37	9.6	185:02	185.03	0	0	0
229.8R	3.8	22-Jul	18:13	9.0	6-Aug	17:44	9.0	359:31	359.52	0	0	0
229.9L	2.1	22-Jul	18:35	9.0	30-Jul	11:52	9.5	185:17	185.28	0	0	0
229.6L	3.8	22-Jul	18:42	9.0	30-Jul	12:03	9.3	185:21	185.35	0	0	0
229.38L	4.3	22-Jul	18:47	9.0	29-Jul	16:37	9.5	165:50	165.83	0	0	0
228.8L	2.4	22-Jul	18:54	9.0	30-Jul	9:18	9.4	182:24	182.4	2	0	0.011
228.9M	5.0	22-Jul	18:57	9.0	30-Jul	10:25	9.5	183:28	183.47	0	0	0
230.2R	4.1	23-Jul	10:55	9.6	29-Jul	17:24	9.4	150:29	150.48	0	0	0
228.1L	3.4	23-Jul	11:05	9.6	29-Jul	16:12	9.5	149:07	149.12	0	0	0
228.4R	2.8	23-Jul	11:23	9.6	29-Jul	17:46	9.9	150:23	150.38	0	0	0
228.7M	2.4	23-Jul	13:07	9.6	29-Jul	17:53	9.9	148:46	148.77	0	0	0
228.6M	2.9	23-Jul	13:17	9.2	30-Jul	10:03	9.4	164:46	164.77	1	0	0.0061
228.8M	3.9	23-Jul	13:22	9.2	30-Jul	9:46	9.6	164:24	164.4	0	0	0
229.4L	4.2	23-Jul	13:38	9.2	29-Jul	16:24	9.5	146:46	146.77	0	0	0
230.5R	3.1	23-Jul	13:50	9.2	29-Jul	17:14	9.4	147:24	147.4	0	0	0
229.4L	6.0	29-Jul	16:25	9.5	6-Aug	18:15	8.9	193:50	193.83	1	0	0.0052
230.0M	3.9	29-Jul	16:50	9.5	6-Aug	15:25	8.8	190:35	190.58	0	0	0
230.5R	3.4	29-Jul	17:15	9.4	6-Aug	15:55	8.7	190:40	190.67	0	0	0
230.2R	3.4	29-Jul	17:25	9.4	6-Aug	17:35	9.0	192:10	192.17	0	0	0
228.4R	2.7	29-Jul	17:46	9.9	7-Aug	10:34	10.6	208:48	208.8	0	0	0
228.7M	4.0	29-Jul	17:53	9.9	14-Aug	9:51	11.2	375:58	375.97	0	0	0
228.1L	3.1	29-Jul	18:53	9.2	30-Jul	9:00	10.3	14:07	14.12	0	0	0
229.38L	3.6	29-Jul	19:17	9.1	7-Aug	10:19	9.5	207:02	207.03	0	0	0
230.1L	2.9	29-Jul	19:29	9.1	6-Aug	15:41	8.8	188:12	188.2	0	0	0
228.6M	3.1	30-Jul	10:04	9.4	14-Aug	10:05	11.4	360:01	360.02	0	0	0
228.9M	5.1	30-Jul	10:26	9.5	14-Aug	9:35	44.2	359:09	359.15	0	0	0
229.3M	3.0	30-Jul	10:39	9.6	14-Aug	10:45	44.2	360:06	360.1	0	0	0
229.4M	5.3	30-Jul	11:03	9.6	13-Aug	17:53	9.7	342:50	342.83	0	0	0

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2014)	Time	Water Temp (°C)	Date (2014)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
229.8M	4.0	30-Jul	11:17	9	6-Aug	17:59	8.8	174:42	174.7	0	0	0
230.2M	2.8	30-Jul	11:42	9.4	6-Aug	15:10	8.7	171:28	171.47	0	0	0
229.9L	1.4	30-Jul	12:00	9.4	7-Aug	10:02	9.6	190:02	190.03	0	0	0
229.6L	4.6	30-Jul	12:08	9.4	6-Aug	15:08	8.8	171:00	171	0	0	0
228.8M	4.0	30-Jul	12:27	9.8	14-Aug	10:35	11.3	358:08	358.13	0	0	0
228.8L	3.0	30-Jul	13:12	9.3	6-Aug	14:40	8.9	169:28	169.47	0	0	0
228.1L	2.5	30-Jul	13:40	9.3	6-Aug	14:25	9.0	168:45	168.75	0	0	0
230.0M	3.2	6-Aug	15:25	8.8	13-Aug	17:15	9.4	169:50	169.83	0	0	0
230.1L	3.2	6-Aug	15:41	8.8	13-Aug	16:22	9.1	168:41	168.68	0	0	0
230.5R	3.6	6-Aug	15:55	8.7	13-Aug	16:48	9.2	168:53	168.88	0	0	0
230.2M	2.5	6-Aug	16:12	8.7	13-Aug	16:56	9.4	168:44	168.73	0	0	0
228.8L	1.8	6-Aug	17:13	8.9	14-Aug	9:20	11.2	184:07	184.12	0	0	0
229.6L	4.0	6-Aug	17:35	9.1	13-Aug	15:50	9.0	166:15	166.25	0	0	0
230.2R	3.1	6-Aug	17:37	9	13-Aug	17:07	9.4	167:30	167.5	0	0	0
229.8M	3.9	6-Aug	17:59	8.8	14-Aug	11:22	11.3	185:23	185.38	0	0	0
229.4L	5.5	6-Aug	18:19	8.9	14-Aug	11:05	11.5	184:46	184.77	0	0	0
229.38L	3.1	7-Aug	10:19	9.5	13-Aug	15:39	9.0	149:20	149.33	0	0	0
228.4R	2.1	7-Aug	10:34	9.6	13-Aug	17:38	10.0	151:04	151.07	0	0	0
228.1L	2.9	7-Aug	12:36	9.1	13-Aug	15:27	9.1	146:51	146.85	0	0	0
227.9L	3.8	7-Aug	12:54	9.0	13-Aug	15:15	9.7	146:21	146.35	0	0	0
229.9L	2.2	7-Aug	13:19	9.0	13-Aug	16:01	9.1	146:42	146.7	0	0	0
227.4LB	2.2	13-Aug	12:03	11.4	20-Aug	15:40	10.5	171:37	171.62	0	0	0
229.6L	5.4	13-Aug	15:50	9.0	20-Aug	17:00	9.9	169:10	169.17	0	0	0
229.9L	1.5	13-Aug	16:02	9.1	20-Aug	16:52	9.9	168:50	168.83	0	0	0
230.1L	2.5	13-Aug	16:22	9.2	20-Aug	16:11	9.9	167:49	167.82	0	0	0
230.5R	3.4	13-Aug	16:48	9.4	20-Aug	16:29	9.9	167:41	167.68	0	0	0
230.2M	2.1	13-Aug	16:57	9.4	20-Aug	16:20	9.9	167:23	167.38	0	0	0
230.2R	1.9	13-Aug	17:08	9.4	20-Aug	16:37	9.9	167:29	167.48	0	0	0
230.0M	2.5	13-Aug	17:15	9.4	20-Aug	16:43	9.9	167:28	167.47	0	0	0
228.4R	1.6	13-Aug	17:38	10.0	20-Aug	17:45	10.8	168:07	168.12	0	0	0
229.38L	3.1	13-Aug	18:30	9.6	21-Aug	9:51	9.4	183:21	183.35	0	0	0
228.7M	3.6	14-Aug	9:52	11.2	-	-	-	-	-	-	-	-
228.6M	3.9	14-Aug	10:06	11.4	20-Aug	17:40	10.0	151:34	151.57	0	0	0
228.8M	3.7	14-Aug	10:36	11.3	28-Aug	9:15	12.0	334:39	334.65	0	0	0
230.1L	2.5	20-Aug	16:15	10.0	27-Aug	17:19	10.9	169:04	169.07	0	0	0

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2014)	Time	Water Temp (°C)	Date (2014)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
230.2M	2.0	20-Aug	16:21	9.9	27-Aug	17:34	11.0	169:13	169.22	0	0	0
230.5R	3.7	20-Aug	16:32	9.9	28-Aug	10:29	12.1	185:57	185.95	0	0	0
230.2R	3.6	20-Aug	16:41	9.9	28-Aug	10:18	12.1	185:37	185.62	0	0	0
230.0M	2.2	20-Aug	16:44	9.9	27-Aug	17:08	11.0	168:24	168.4	0	0	0
229.9L	1.6	20-Aug	16:55	9.9	27-Aug	16:56	11.0	168:01	168.02	0	0	0
229.6L	5.0	20-Aug	17:05	9.9	28-Aug	10:01	12.2	184:56	184.93	0	0	0
229.4L	5.1	20-Aug	17:14	9.9	27-Aug	17:49	11.0	168:35	168.58	10	0	0.0593
229.3M	2.8	20-Aug	17:25	9.9	27-Aug	16:01	11.1	166:36	166.6	0	0	0
228.8M	2.8	20-Aug	17:32	9.9	27-Aug	15:51	11.2	166:19	166.32	0	0	0
228.6M	2.9	20-Aug	17:41	9.9	27-Aug	15:33	11.1	165:52	165.87	0	0	0
228.4R	1.2	20-Aug	17:52	10.9	27-Aug	15:41	11.4	165:49	165.82	0	0	0
227.4L	2.8	21-Aug	9:12	9.9	27-Aug	14:54	11.5	149:42	149.7	0	0	0
228.1L	3.0	21-Aug	9:37	9.5	27-Aug	15:22	11.1	149:45	149.75	0	0	0
227.9L	2.9	21-Aug	12:11	9.5	27-Aug	15:12	11.3	147:01	147.02	0	0	0
228.8L	2.7	21-Aug	12:25	9.5	28-Aug	9:45	12.2	165:20	165.33	1	1	0.006
229.38L	4.3	21-Aug	12:35	9.5	27-Aug	16:09	11.1	147:34	147.57	2	0	0.0136
228.6M	3.9	27-Aug	15:33	11.1	3-Sep	16:11	12.4	168:38	168.63	0	0	0
228.4R	2.6	27-Aug	15:46	11.4	3-Sep	16:04	12.2	168:18	168.3	0	0	0
228.8M	3.9	27-Aug	15:51	11.2	3-Sep	15:56	12.4	168:05	168.08	0	0	0
229.3M	3.5	27-Aug	16:02	11.1	3-Sep	17:04	12.3	169:02	169.03	0	0	0
229.38L	4.8	27-Aug	16:26	11.1	3-Sep	9:56	12.1	161:30	161.5	0	0	0
229.9L	2.0	27-Aug	17:05	11.0	3-Sep	17:17	12.3	168:12	168.2	0	0	0
230.0M	3.4	27-Aug	17:08	11.0	3-Sep	17:24	12.3	168:16	168.27	0	0	0
230.1L	2.8	27-Aug	17:30	10.9	3-Sep	17:30	12.3	168:00	168	0	0	0
230.2M	2.7	27-Aug	17:35	11.0	3-Sep	17:49	12.2	168:14	168.23	0	0	0
229.4L	5.5	27-Aug	17:49	11.0	10-Sep	10:51	11.6	329:02	329.03	0	0	0
227.4L	2.8	27-Aug	18:19	10.9	4-Sep	10:24	11.9	184:05	184.08	1	0	0.0054
227.9L	2.4	28-Aug	9:34	12.2	3-Sep	15:28	12.5	149:54	149.9	0	0	0
228.1L	1.7	28-Aug	9:43	12.2	3-Sep	15:36	12.4	149:53	149.88	0	0	0
230.2R	1.3	28-Aug	10:23	12.1	3-Sep	17:45	12.2	151:22	151.37	0	0	0
230.5R	1.3	28-Aug	10:41	12.1	4-Sep	10:11	11.9	167:30	167.5	0	0	0
228.8L	2.2	28-Aug	12:17	11.5	3-Sep	15:45	12.4	147:28	147.47	0	0	0
229.38L	3.1	28-Aug	12:30	11.5	4-Sep	9:40	12.0	165:10	165.17	0	0	0
229.6L	3.5	28-Aug	12:43	11.4	4-Sep	10:01	11.9	165:18	165.3	0	0	0
228.8M	3.0	3-Sep	15:56	12.4	9-Sep	15:12	11.4	143:16	143.27	0	0	0

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2014)	Time	Water Temp (°C)	Date (2014)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
228.4R	1.2	3-Sep	16:08	12.2	9-Sep	15:23	11.3	143:15	143.25	0	0	0
228.6M	2.7	3-Sep	16:11	12.4	10-Sep	9:58	11.5	161:47	161.78	0	0	0
229.3M	2.2	3-Sep	17:05	12.3	10-Sep	10:25	11.5	161:20	161.33	0	0	0
229.9L	1.1	3-Sep	17:18	12.3	9-Sep	16:45	11.5	143:27	143.45	0	0	0
230.0M	2.1	3-Sep	17:25	12.3	10-Sep	11:15	11.5	161:50	161.83	0	0	0
230.1L	2.1	3-Sep	17:38	12.3	9-Sep	15:55	11.4	142:17	142.28	0	0	0
230.2R	1.3	3-Sep	17:48	12.2	9-Sep	15:37	11.4	141:49	141.82	0	0	0
230.2M	2.1	3-Sep	17:50	12.2	9-Sep	16:05	11.4	142:15	142.25	0	0	0
228.1L	2.7	4-Sep	9:36	12.0	10-Sep	12:35	12.4	146:59	146.98	0	0	0
229.6L	2.1	4-Sep	10:09	11.9	10-Sep	9:40	11.6	143:31	143.52	0	0	0
230.5R	1.9	4-Sep	10:18	11.8	9-Sep	15:36	11.4	125:18	125.3	0	0	0
227.4L	2.5	4-Sep	10:34	12.0	9-Sep	17:58	11.4	127:24	127.4	0	0	0
227.9L	3.5	4-Sep	12:18	11.6	9-Sep	14:55	11.4	122:37	122.62	0	0	0
229.38L	3.7	4-Sep	12:33	11.6	10-Sep	9:36	11.4	141:03	141.05	0	0	0
228.8L	2.7	4-Sep	12:47	11.5	9-Sep	15:03	11.4	122:16	122.27	0	0	0

[1] WSG = White Sturgeon; CPUE = Catch per Unit Effort (no. eggs/hour of effort)

"-" = no data available

APPENDIX B
Drift Net Sampling

Table B1. Drift net sampling data collected during middle Columbia River White Sturgeon spawning monitoring, July 22 to September 11, 2014.

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	Estimated Volume Sampled (m^3)	White Sturgeon Catch Summary[1]					
		Date (2014)	Time	Water Temp (°C)	Date (2014)	Time	Water Temp (°C)				Eggs	Free Embryos	CPUE Eggs (No./hr)	CPUE Free Embryos (No./hr)	CPUE Eggs (No./ 100 m^3)	CPUE Free Embryos (No./100 m^3)
228.8M	3.9	23-Jul	10:18	9.6	23-Jul	13:21	9.2	3:03	3.05	3897.78	0	0	0	0	0	0
229.4L	5.0	23-Jul	10:30	9.6	23-Jul	13:38	9.2	3:08	3.13	5611.45	0	0	0	0	0	0
230.5R	1.5	23-Jul	10:46	9.6	23-Jul	13:34	9.2	2:48	2.8	3528.97	0	0	0	0	0	0
228.1L	1.7	29-Jul	16:12	9.5	29-Jul	18:16	9.2	2:04	2.07	436.51	17	0	8	0	1.88	0
229.38L	2.1	29-Jul	16:39	9.5	29-Jul	19:03	9.1	2:24	2.4	1803.07	0	0	0	0	0	0
230.1L	2.7	29-Jul	17:00	9.5	29-Jul	19:20	9.1	2:20	2.33	3005.82	0	0	0	0	0	0
228.1L	2.8	30-Jul	9:01	10.2	30-Jul	13:18	9.3	4:17	4.28	702.48	4	0	1	0	0.13	0
228.8L	1.5	30-Jul	9:20	9.4	30-Jul	12:49	9.8	3:29	3.48	3163.66	2	0	1	0	0.02	0
228.8M	3.8	30-Jul	9:48	9.6	30-Jul	12:27	9.8	2:39	2.65	5332.56	0	0	0	0	0	0
228.1L	2.1	6-Aug	14:30	9.0	6-Aug	16:32	8.7	2:02	2.03	11288.44	0	0	0	0	0	0
228.8L	1.8	6-Aug	14:43	8.9	6-Aug	16:40	8.7	1:57	1.95	2356.40	1	0	1	0	0.02	0
229.6L	2.1	6-Aug	15:10	8.8	6-Aug	17:28	8.7	2:18	2.3	1144.62	0	0	0	0	0	0
228.1L	2.7	6-Aug	16:35	8.7	7-Aug	9:33	10.6	16:58	16.97	-	0	0	0	0	-	-
227.9L	1.6	6-Aug	18:40	8.9	7-Aug	9:47	9.9	15:07	15.12	-	0	0	0	0	-	-
228.1L	2.4	7-Aug	9:33	10.6	7-Aug	12:35	9.1	3:02	3.03	1489.42	0	0	0	0	0	0
227.9L	1.7	7-Aug	9:47	9.9	7-Aug	12:53	9.0	3:06	3.1	2694.87	0	0	0	0	0	0

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	Estimated Volume Sampled (m^3)	White Sturgeon Catch Summary[1]					
		Date (2014)	Time	Water Temp (°C)	Date (2014)	Time	Water Temp (°C)				Eggs	Free Embryos	CPUE Eggs (No./hr)	CPUE Free Embryos (No./hr)	CPUE Eggs (No./ 100 m^3)	CPUE Free Embryos (No./100 m^3)
229.9L	1.0	7-Aug	10:04	9.6	7-Aug	13:17	9.0	3:13	3.22	1650.78	0	0	0	0	0	0
227.9L	2.5	13-Aug	15:15	9.7	13-Aug	18:08	9.7	2:53	2.88	1637.20	0	0	0	0	0	0
228.1L	2.8	13-Aug	15:27	9.1	13-Aug	18:21	9.7	2:54	2.9	333.47	0	0	0	0	0	0
229.38L	2.2	13-Aug	15:40	9.0	13-Aug	18:30	9.6	2:50	2.83	1408.68	0	0	0	0	0	0
227.9L	1.6	13-Aug	18:18	9.7	14-Aug	8:53	11.2	14:35	14.58	-	0	0	0	0	-	-
228.1L	2.5	13-Aug	18:25	9.6	14-Aug	9:09	11.2	14:44	14.73	-	0	0	0	0	-	-
227.9L	1.5	14-Aug	9:07	11.2	14-Aug	12:11	11.5	3:04	3.07	2106.52	0	1	0	0	0	0.02
228.1L	2.2	14-Aug	9:16	11.2	14-Aug	12:35	11.8	3:19	3.32	71.06	0	0	0	0	0	0
228.8L	1.1	14-Aug	9:20	11.2	14-Aug	12:47	12.0	3:27	3.45	4105.47	0	0	0	0	0	0
227.4L	1.5	20-Aug	15:49	10.5	20-Aug	18:24	9.9	2:35	2.58	254.20	0	0	0	0	0	0
227.9L	2.3	20-Aug	15:58	10.2	20-Aug	18:08	9.9	2:10	2.17	1630.62	0	0	0	0	0	0
228.1L	2.5	20-Aug	16:05	10.0	20-Aug	18:00	10.1	1:55	1.92	732.09	0	0	0	0	0	0
228.1L	2.5	20-Aug	18:00	10.0	21-Aug	9:31	9.4	15:31	15.52	-	0	0	0	0	-	-
227.9L	2.3	20-Aug	18:16	9.9	21-Aug	9:15	9.5	14:59	14.98	-	0	0	0	0	-	-
227.4L	1.5	20-Aug	18:32	9.9	21-Aug	8:55	10.0	14:23	14.38	-	0	0	0	0	-	-
227.9L	2.6	21-Aug	9:28	9.5	21-Aug	12:08	9.5	2:40	2.67	-	0	0	0	0	-	-
228.8L	1.3	21-Aug	9:46	9.4	21-Aug	12:15	9.5	2:29	2.48	2567.85	0	0	0	0	0	0

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	Estimated Volume Sampled (m^3)	White Sturgeon Catch Summary[1]					
		Date (2014)	Time	Water Temp (°C)	Date (2014)	Time	Water Temp (°C)				Eggs	Free Embryos	CPUE Eggs (No./hr)	CPUE Free Embryos (No./hr)	CPUE Eggs (No./ 100 m^3)	CPUE Free Embryos (No./100 m^3)
229.38L	2.7	21-Aug	9:52	9.4	21-Aug	12:30	9.6	2:38	2.63	1801.75	0	0	0	0	0	0
227.4L	1.2	27-Aug	15:09	11.2	27-Aug	18:09	10.9	3:00	3	2485.91	0	0	0	0	0	0
227.9L	1.4	27-Aug	15:20	11.1	27-Aug	18:21	10.9	3:01	3.02	2752.17	2	0	1	0	0.02	0
228.1L	2.1	27-Aug	15:28	11.1	27-Aug	18:41	10.9	3:13	3.22	156.90	0	0	0	0	0	0
227.9L	1.6	27-Aug	18:39	10.9	28-Aug	9:20	12.0	14:41	14.68	-	0	0	0	0	-	-
228.1L	2.9	27-Aug	18:48	10.9	28-Aug	9:34	12.0	14:46	14.77	-	0	0	0	0	-	-
228.8L	1.2	28-Aug	9:56	12.1	28-Aug	12:10	11.6	2:14	2.23	1116.13	0	0	0	0	0	0
229.38L	1.7	28-Aug	9:59	12.1	28-Aug	12:20	11.5	2:21	2.35	1838.19	0	0	0	0	0	0
229.6L	1.5	28-Aug	10:04	12.2	28-Aug	12:33	11.5	2:29	2.48	1134.99	0	0	0	0	0	0
227.9L	1.6	3-Sep	15:34	12.4	3-Sep	18:25	12.2	2:51	2.85	649.07	0	0	0	0	0	0
228.1L	2.4	3-Sep	15:43	12.4	3-Sep	18:35	12.3	2:52	2.87	1979.17	0	0	0	0	0	0
228.8L	1.2	3-Sep	15:54	12.4	3-Sep	18:44	12.2	2:50	2.83	3010.59	0	0	0	0	0	0
227.9L	1.4	3-Sep	18:31	12.3	4-Sep	9:15	12.3	14:44	14.73	-	0	0	0	0	-	-
228.1L	2.3	3-Sep	18:42	12.3	4-Sep	9:30	12.1	14:48	14.8	-	0	0	0	0	-	-
228.8L	1.8	3-Sep	18:51	12.2	4-Sep	9:44	11.9	14:53	14.88	-	0	0	0	0	-	-
227.9L	1.5	4-Sep	9:30	12.3	4-Sep	12:05	11.5	2:35	2.58	1454.68	0	0	0	0	0	0
229.38L	1.6	4-Sep	9:41	12.0	4-Sep	12:23	11.6	2:42	2.7	3046.34	0	0	0	0	0	0

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	Estimated Volume Sampled (m^3)	White Sturgeon Catch Summary[1]					
		Date (2014)	Time	Water Temp (°C)	Date (2014)	Time	Water Temp (°C)				Eggs	Free Embryos	CPUE Eggs (No./hr)	CPUE Free Embryos (No./hr)	CPUE Eggs (No./ 100 m^3)	CPUE Free Embryos (No./100 m^3)
228.8L	1.5	4-Sep	9:56	11.9	4-Sep	12:36	11.6	2:40	2.67	2377.84	0	0	0	0	0	0
227.9L	1.4	9-Sep	15:00	11.4	9-Sep	17:41	11.6	2:41	2.68	1399.54	0	1	0	0	0	0.03
228.8L	1.3	9-Sep	15:10	11.4	9-Sep	17:30	11.6	2:20	2.33	2431.33	0	0	0	0	0	0
228.8M	3.5	9-Sep	15:13	11.4	9-Sep	17:16	11.6	2:03	2.05	3508.94	0	0	0	0	0	0
228.8L	1.3	9-Sep	17:36	11.6	10-Sep	9:20	11.6	15:44	15.73	-	0	0	0	0	-	-
227.9L	2.0	9-Sep	17:52	11.6	10-Sep	9:00	11.6	15:08	15.13	-	0	3	0	0	-	-
227.9L	2.2	10-Sep	9:18	11.6	10-Sep	12:15	12.3	2:57	2.95	1011.21	0	1	0	0	0	0.03
229.38L	2.0	10-Sep	9:38	11.6	10-Sep	13:33	12.7	3:55	3.92	3411.60	0	0	0	0	0	0
229.6L	2.2	10-Sep	9:47	11.8	10-Sep	13:00	12.5	3:13	3.22	2340.25	0	0	0	0	0	0
227.9L	2.9	10-Sep	12:32	12.3	10-Sep	16:06	12.3	3:34	3.57	856.83	0	3	0	1	0	0.10
229.6L	2.8	10-Sep	13:14	12.3	10-Sep	15:50	12.3	2:36	2.6	1782.62	0	0	0	0	0	0
229.38L	2.2	10-Sep	13:48	12.8	10-Sep	15:32	12.3	1:44	1.73	1543.08	0	0	0	0	0	0
227.9L	1.8	10-Sep	16:30	13.2	11-Sep	8:52	NA	16:22	16.37	-	0	2	0	0	-	-
227.9L	2.1	10-Sep	16:40	13.2	11-Sep	8:35	NA	15:55	15.92	-	0	1	0	0	-	-

[1] CPUE = Catch per Unit Effort (number of eggs or free embryos / hour of effort or 100 m^3 of water sampled).
"-" Drift nets set overnight and velocity meter readings could not be determined as meters zero'ed themselves an unknown number of times.

APPENDIX C
Station Location Coordinates

Table C1. UTM coordinates of sample locations during White Sturgeon spawning monitoring in the middle Columbia River, 2014.

Station Name	UTM Coordinates		
	Zone	Easting	Northing
230.5R	11	414535.9	5652828.1
230.2M	11	414351.0	5652534.8
230.2R	11	414233.9	5652582.9
230.1L	11	414305.2	5652426.3
230M	11	414224.3	5652410.1
229.9L	11	414120.3	5652298.2
229.8R	11	413949.7	5652384.1
229.8M	11	413978.2	5652290.6
229.6L	11	413899.0	5652149.6
229.4M	11	413726.0	5652070.0
229.4L	11	413728.1	5652043.1
229.38L	11	413692.5	5652003.1
229.3M	11	413591.2	5652057.3
228.9M	11	413274.2	5651805.4
228.8M	11	413309.0	5651686.0
228.8L	11	413303.1	5651640.6
228.7M	11	413166.5	5651618.2
228.6M	11	413207.8	5651495.4
228.4R	11	413059.3	5651265.8
228.1L	11	413410.0	5651322.1
227.40L	11	414101.0	5651548.0
227.9L	11	413522.0	5651452.0