Columbia River Project Water Use Plan

Columbia River White Sturgeon Management Plan

Middle Columbia River White Sturgeon Spawning Monitoring

Implementation Year 12

Reference: CLBMON-23A

Year 12 Data Report (2018)

Study Period: July – September 2018

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May 31, 2019

MIDDLE COLUMBIA RIVER WHITE STURGEON SPAWNING MONITORING
(CLBMON-23A)
Year 12 Data Report – 2018

Submitted to:

BC Hydro
Castlegar, British Columbia

Submitted by:

Wood Environment & Infrastructure Solutions
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Nelson, British Columbia

31 May 2019

VE52241-2018

Recommended Citation: Wood. 2019. Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23A). Year 12 Data Report. Report Prepared for: BC Hydro, Castlegar. 32 pp + 3 App.

Key Words: Middle Columbia River, White Sturgeon, Spawning, Eggs, Free Embryos, Revelstoke Dam, Columbia Water Use Plan

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ACKNOWLEDGEMENTS

The following people are gratefully acknowledged for assistance and information contributions during this study:

BC Hydro

James Crossman, Castlegar
Margo Sadler, Burnaby
Guy Martel, Burnaby
Karen Bray, Revelstoke
James Baxter, Castlegar
Katy Jay, Burnaby
Dean Den Biesen, Castlegar

Ktunaxa Nation (formerly Canadian Columbia River Intertribal Fisheries Commission)

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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 2018 was the 12th consecutive year 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 18 and September 7, 2018. Effort and methodology were consistent with previous years and sampling was focused between river Km 227.4 and 230.3. Egg mats were deployed for the duration of sampling and inspected weekly for the presence of White Sturgeon eggs and/or free embryos. Drift nets were set weekly during the day (average of 3.3 hours per set) as well as overnight (average of 15.1 hours per set) between July 25 and September 6. In total, 23,068 hours of egg mat sampling effort and 387.2 hours of drift net sampling effort was expended in 2018. A total of six White Sturgeon eggs were captured on egg mats and 88 eggs and five free embryos were captured in drift nets; this was the highest number of eggs collected since monitoring began in 1999.

Discharge from REV reached a peak of 2,072 m^3/s during the monitoring period, which was lower than the peak discharge observed during this study (2,573 m^3/s in 2012), but higher than the maximum discharge observed prior to the installation of a fifth unit at REV in late 2010 (1,757 m^3/s). Backwatering of ALR in the spawning area occurred from June 2 to August 18, throughout the majority of the spawning period in 2018. 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 393 eggs and 56 free embryos collected since 1999 have been captured in this area. White Sturgeon eggs have consistently been documented in this relatively small area despite past sampling at other potentially suitable areas between 1 km downstream of Revelstoke Dam (Km 234) and the Illecillewaet River (Km 223.5). Revelstoke Dam is located at Km 235. 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 was not possible due to the low number of eggs/larvae that were collected. The effect of reservoir operations on physical parameters within the REV egg incubation area has been investigated further under CLBMON-20 and 54. Minimim flows implemented following the addition of a 5th turbine at REV in 2011 have increased the permanently wetted river bed area in the middle Columbia River and reduced the exposure of shallow gravel bars within the egg incubation area to the extent that egg and larval stranding is likely minimal. Stranding surveys were conducted in 2009, 2011 and 2014, with stranded eggs located on an exposed gravel bar only observed in 2009 before minimum flows were implemented. A desktop assessment of stranding risk over the duration of this monitoring program found the proportion of time that flows were below a threshold where incubating eggs or larvae would be at risk (between 0 and 142 m^3/s) was 0% since the implementation of the minimum flow. The evaluation also indicated that since 2016, minimum flows have not been below 250 m^3/s when early life stages were in the study area. Results demonstrate low stranding risk under current operations that include the minimum flow with less of the spawning grounds exposed when eggs are incubating and recently hatched embryos are hiding in the substrate. Additional field verification may be warranted for operations during the spawning period (July-September) where flows are less than 142 cms.
What is the most effective method for monitoring spawning of White Sturgeon?	Based on the broadcast spawning 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 and can identify the duration of spawning with less intensive effort compared to drift nets. Drift nets are more efficient in collecting eggs and larvae and they can be placed downstream of the known spawning site. In addition they identify the downstream dispersal of larvae, especially once spawning has been identified and time of hatch has been estimated. During the past 12 years of this program, an average of 126 egg mats have been deployed per spawning season for approximately 21,223 hours which resulted in an average catch-rate of 0.01 eggs/free embryos per hour. In contrast, an average of 40 drift nets have been deployed per spawning season for approximately 213 hours which resulted in an average catch-rate of 0.14 eggs/free embryos per hour. Although drift nets seem to have higher catch-rates, they do not fish continuously like egg mats.

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. For example, a 142 m^3/s minimum flow requirement was initiated concurrent with REV5 coming online (December 2010). Preliminary information collected during this monitoring program before and after REV5 suggests that operational modifications have reduced White Sturgeon egg and larval stranding due to an increase in minimum flow. In addition, spawning has been recorded 7 of the 8 years following the addition of REV5. The influence of REV operations and ALR elevation on physical conditions observed at the spawning area was also assessed during concurrent BC Hydro WUP programs including: 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). Results of these studies related to White Sturgeon incubation habitats are briefly discussed.

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1 INTRODUCTION

White Sturgeon (*Acipenser transmontanus*) have experienced reduced population abundance in the Canadian portion of the Columbia River due to recruitment failure and were listed as endangered under federal Species at Risk Act (SARA) legislation in 2006 (Fisheries & Oceans Canada 2014). The Columbia River population has been considered at significant risk of extirpation in the wild given strong evidence that, for several decades, natural recruitment has been too low to sustain this population (Porto 2008, Hildebrand and Parsley 2013, Fisheries & Oceans Canada 2014). While conservation aquaculture is being used to prevented extripation, research into hypotheses related to recruitment failure is ongoing, including monitoring of spawning adults to describe the timing, frequency, and locations used for spawning.

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 observed in most years, but naturally produced juvenile White Sturgeon have never been captured (Hildebrand and Parsley 2013). Spawning investigations occurred in 1999, 2000, 2001, 2003, and 2006 through 2018 with spawning events documented in 12 of 17 years (Golder 2012a, Amec Foster Wheeler 2017). Spawn timing has been estimated to occur from late July to late 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 seven years of spawning investigations were undertaken from 2012 to 2018 to document spawning events, timing, frequency and egg deposition to inform future management decisions.

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.

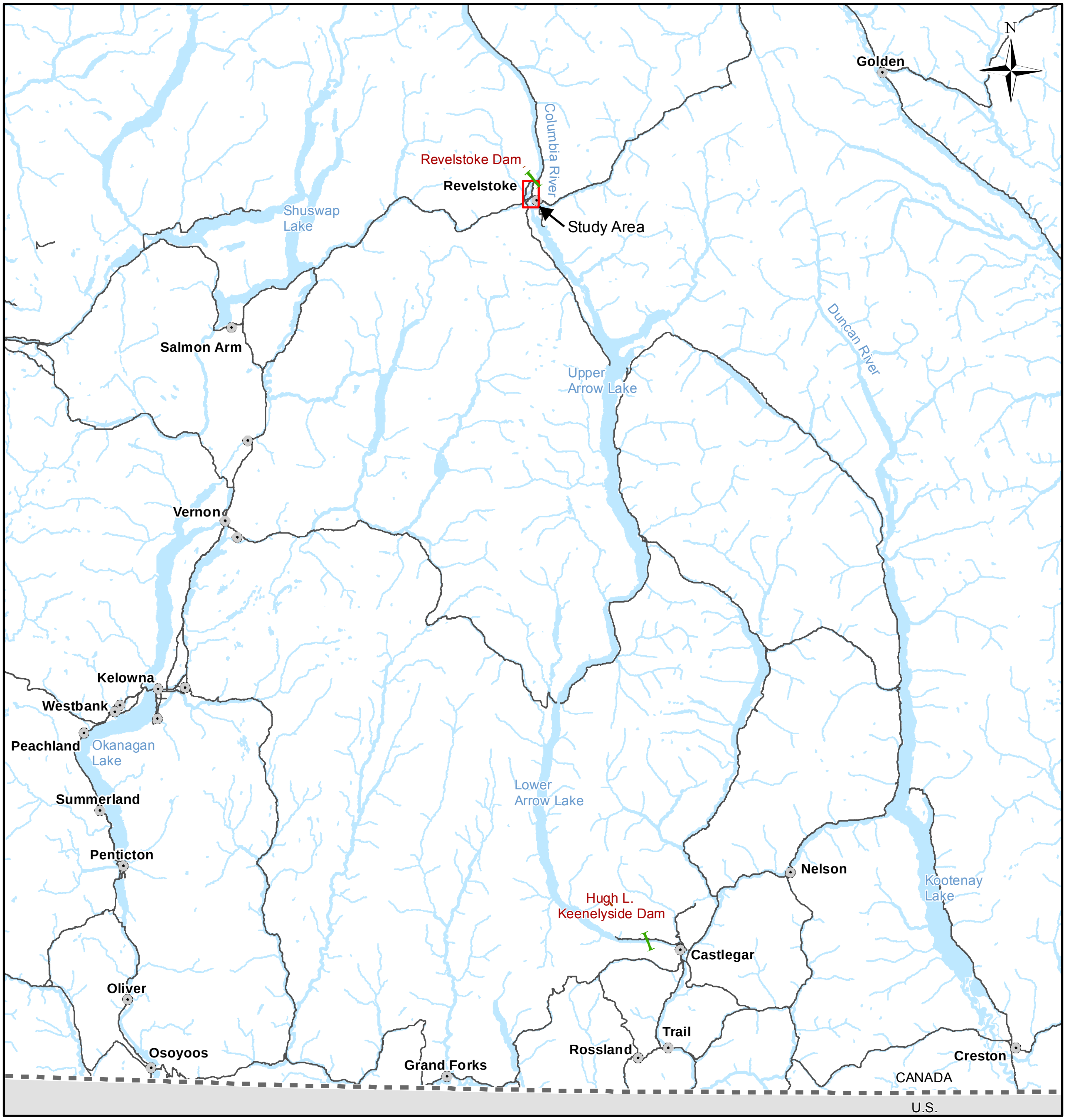
The Management Questions to be addressed through this study are (BC Hydro 2012):

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 Wood's commitment to provide BC Hydro with a data report for studies conducted in 2018 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

Scale: 1:1,400,000

0 5 10 20 30 40 50

Kilometers

Reference:

DataBC Data Distribution Service
Open Government License
(http://www.data.gov.bc.ca/)

Geogratis/Geobase
Open Government License - Canada
(http://data.gc.ca/eng/about-datagcca)

CLIENT:
Prepared for BC Hydro

PROJECT:
CLBMON-23 Mid-Columbia River
White Sturgeon Spawn Monitoring

TITLE:
Overview Map of the Middle Columbia River Depicting Hydroelectric Facilities

DATE:	
January, 2019	Figure 1

GIS FILE: 01-50-001_Overview_v6

COORDINATE SYSTEM:	JOB No:	ANALYST:	QA/QC:
NAD 1983 UTM Zone 11N	VE52241	MY	CL

wood.

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2 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 2018 study area was concentrated in between Km 227.4 and 230.3 (Figure 2), which incorporated the area where all White Sturgeon eggs have been captured since 1999 (Golder 2012a, Amec Foster Wheeler 2016).

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 covering a time period of April through September to cover the pre-spawning through incubation period and be consistent with previous reporting. Water temperature (°C) 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°C, was deployed to provide a backup of hourly water temperature data within the spawning area (Km 229.6L; Figure 2).

2.3 Sample Timing

Sampling was conducted between July 19 and September 7, 2018 during the documented White Sturgeon spawning period below Revelstoke Dam. A summary of field sample sessions is provided in Table 1.

Table 1: Sampling effort for CLBMON-23 Middle Columbia River White Sturgeon spawn monitoring, 2018.

Date	Activities
July 18-19	Deployed ten mid-channel and ten near shore egg mat/drift net sample stations.
July 25-26	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 1-2	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 8-9	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 15-17	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 22-23	Retrieved, checked and redeployed egg mats. Drift net sampling.
August 29-30	Retrieved, checked and redeployed egg mats. Drift net sampling.
September 5-7	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, 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 Foster Wheeler 2016) 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).

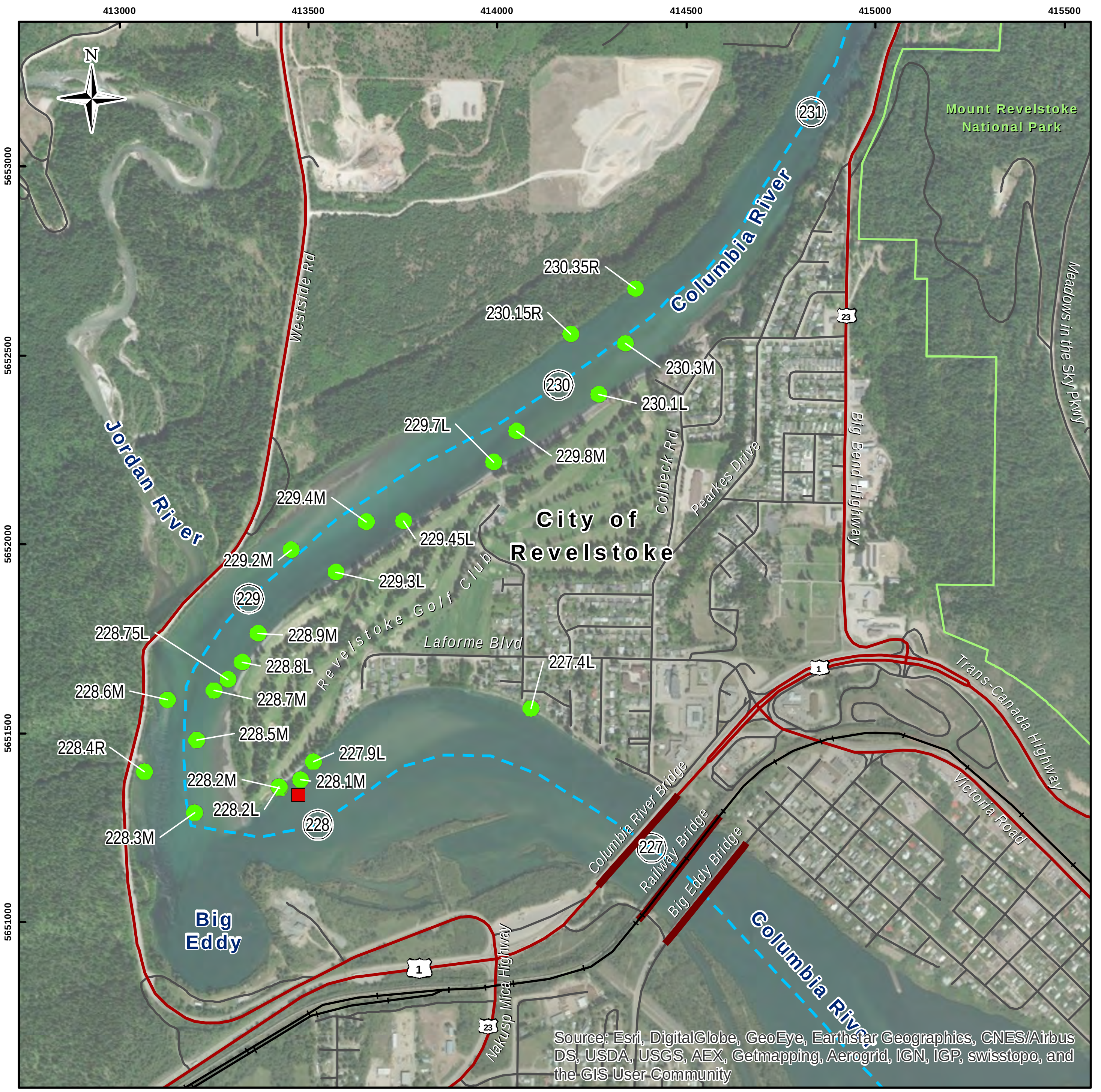
Discharge from Revelstoke Dam, along with substrate conditions in the area, limit where egg mats can be deployed due to high water velocities (>2 m/s; Golder 2014) that can result in gear displacement. Egg mats were retrieved/deployed from a boat as per BC Hydro's Specific Work Instructions and is described herein. Between 20 and 22 egg mat stations were deployed (half set to shore and the other half anchored middle channel sets) weekly. Mats were deployed between Km 227.8 and 230.3 which incorporated the area where all White Sturgeon eggs have been captured since 1999. 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 nine 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.

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).

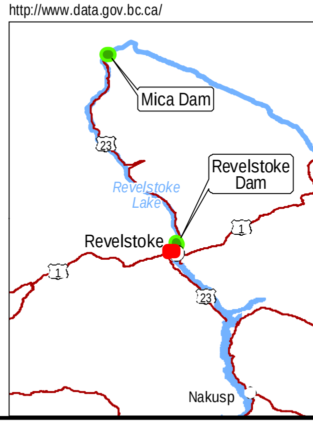


Legend

- 2018 Sample Locations
- Thermologger
- 288 River Kilometre
- River Centre Line
- Highway
- Bridge
- Existing Road
- Railway
- Contour (25m)
- Dam
- National Park

0 125 250 500
Meters
Scale: 1:15,000

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/



CLIENT:
Prepared for BC Hydro

PROJECT:
CLBMON-23a Mid-Columbia River White Sturgeon Spawn Monitoring

TITLE:
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DATE: January, 2019	Figure 2	
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COORDINATE SYSTEM: NAD 1983 UTM Zone 11N		

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2.4.2 *Drift Nets*

Previous years of work under this program 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, Amec Foster Wheeler 2016). Accordingly, White Sturgeon eggs/free embryos were collected using drift net sampling (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 six and maximum of 19 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 227.9L 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 2.1 to 6.0 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 years since have permitted the use of overnight sets (i.e. gear was able to withstand overnight debris loading). In 2018, two to four drift nets were set overnight once per week August 1 through September 6. Overnight drift nets sampled for 14-16 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 and basters.

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

The following are standard egg processing methods used during this program. White Sturgeon eggs were immediately staged on the boat upon capture. Standard egg staging procedures were used as described in Jay et al. (2016), Dettlaff et al. (1993) and Wang et al. (1985). 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. Incubation trays consisted of flat plastic trays with wells for approximately 100 individual eggs covered by a top plate. Eggs were then either incubated *in situ* until hatch or transferred to the Kootenay Trout Hatchery in Fort Steele, BC. If incubated *in situ*, eggs remained in incubation trays until hatch at which time all free embryos, including 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). If transferred to the Kootenay Trout Hatchery, eggs and/or free embryos were transferred to large ziploc bags half filled with fresh river water and half filled with air at the end of the weekly sample session. The ziploc bag was then packed securely in a cooler with ice packs and transferred to the Kootenay Trout Hatchery.

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 (Parsley at al. 2011; 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 Sampling Effort Maps

Maps were created to illustrate total effort by 500 m river section from Km 235 (Revelstoke Dam) to Km 223.5 (downstream of the Illecillewaet River). One version of this map was created using data collected between 2012 and 2018 that compiled the total combined egg mat and drift net sampling hours expended in each river section and identified the locations where eggs and/or free embryos were captured during that period. A second version was created identifying how many sampling years have occurred in each river section between 1999 and 2018 and identified the locations where eggs and/or free embryos have been captured over the duration of the entire program.

2.7 Egg and Free Embryo Stranding Risk Evaluation

In order to address Management Question 2, egg stranding surveys were conducted when White Sturgeon spawning event(s) were detected and crews could access the exposed portions of the river bed safely. Discussions with BC Hydro determined whether egg stranding surveys were required based on the water level forecast. 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; Golder 2010).

Egg and free embryo stranding risk was evaluated by reviewing water levels following spawning events between 2007 and 2018. An at-risk period was identified that includes the period when egg and free embryos may be present over the primary spawning area. The at-risk period following a spawning event was set at 50 days (1,200 hours) based on the time from egg fertilization to hatch (19 days as identified by Parsley et al. 2011) and from hatch through pre-feeding/hiding to dispersal (30 days as identified by Crossman and Hildebrand 2012). For years with multiple spawning events, the at-risk period included the time span from the first spawning event to 50 days (1,200 hours) after the final spawning event. The proportion of the at-risk period that discharge reached a minmum of two thresholds was evaluated. The two thresholds selected were zero (discharge = 0 m^3/s) and below the operational minimum established in 2010 (discharge < 142 m^3/s). The minimum discharge observed during the at-risk period was also identified.

Egg stranding surveys were not conducted during the 2018 spawning period because water levels did not expose the area sufficiently to warrant extensive field investigations.

3 RESULTS

3.1 Environmental Parameters – Elevation, Discharge and Temperature

Arrow Lake Reservoir elevation steadily increased between April and July, reaching a peak elevation of 439.7 m above sea level (masl) in mid-July and gradually decreased through the study period (Figure 3). Surface elevation at Nakusp above 437 masl backwaters ALR to the spawning area (Golder 2011). ALR reached this elevation between June 2 and August 18 in 2018; therefore ARL was backwatering the spawning area for the majority of the spawning period in 2018 (Figure 3).

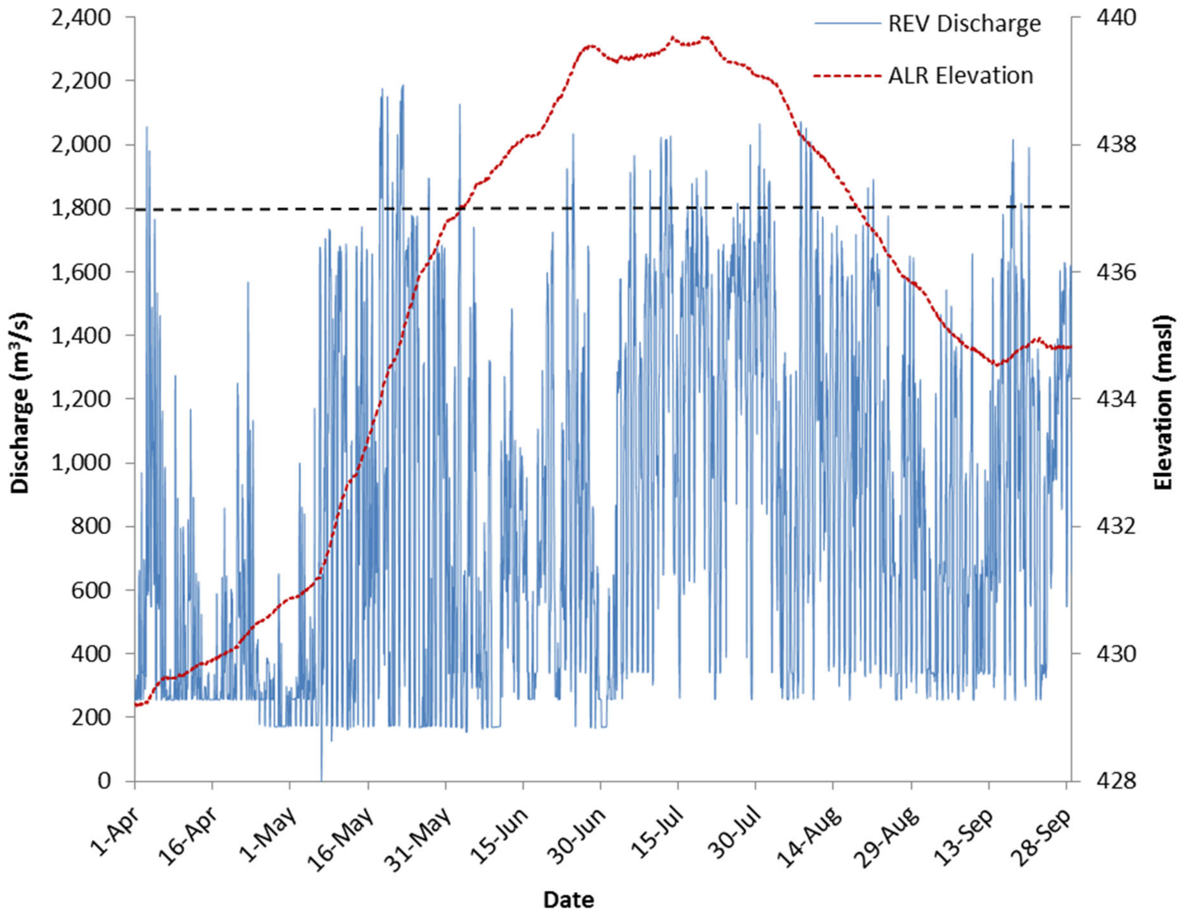


Figure 3: **Hourly discharge (m^3/s) from Revelstoke Dam (REV) and hourly water level elevation (meters above sea level) of Arrow Lakes Reservoir (ALR) as measured in Nakusp, BC, April 1 to September 30, 2018. The black dotted line represents 437 masl elevation when ALR backwaters the spawning area.**

Water level elevation downstream of REV reached a summer maximum of 443.5 masl (as measured at the REV tailrace) at various times between July and September (Figure 4). Minimum elevation of 439.4 masl was observed on August 26 and througout the remainder of August and September (Figure 4). Daily fluctuations in elevation ranged between 0.2 and 3.7 m/day for the duration of the study period (Figure 4). Water elevation in the REV tailrace followed the discharge release pattern from REV over the duration of the study period (Figure 4). Water surface elevation over the spawning area was not available during the 2018 monitoring period because the Station 2 water level monitoring station maintained during CLBMON-15a was removed in May 2018 (Michael Zimmer, Okanagan Nation Alliance, pers. comm. 2018). In previous years, Station 2 has been used to describe water level over the spawning area.

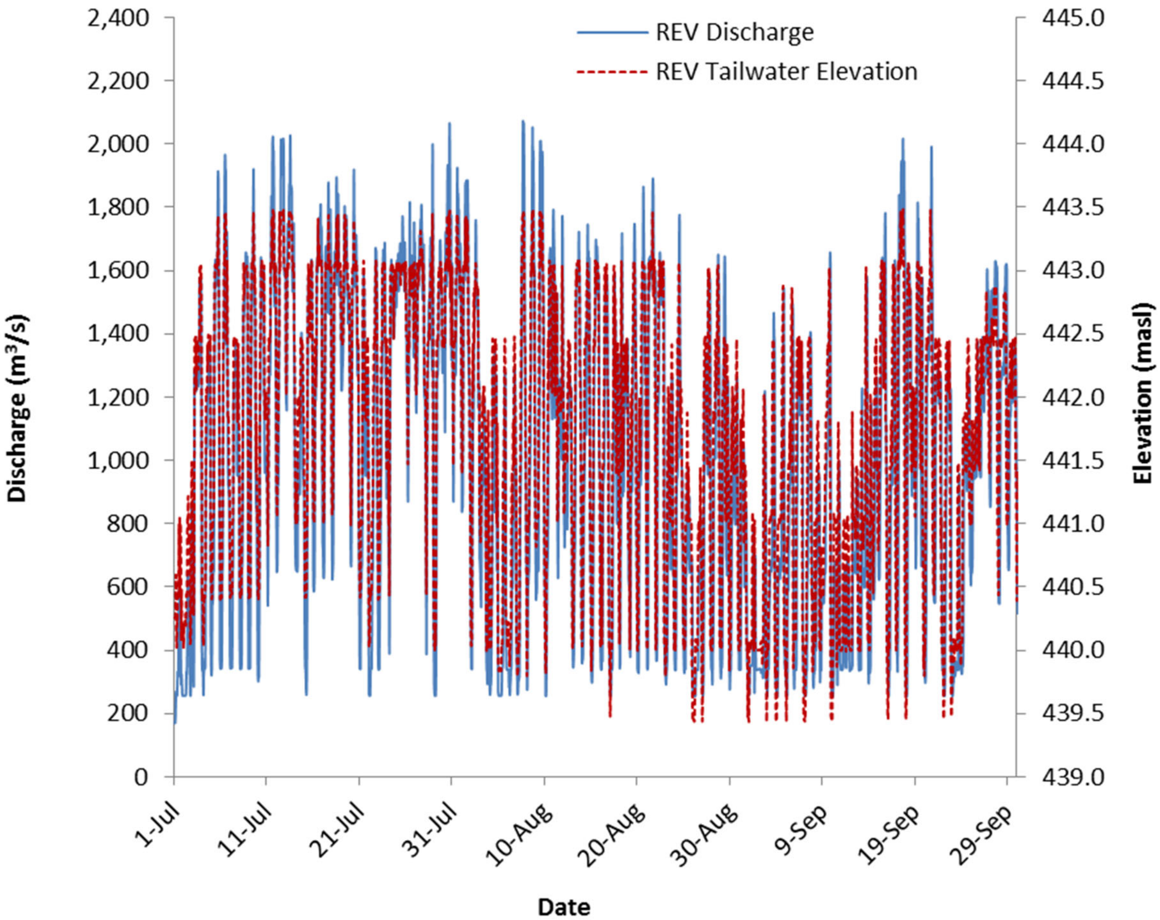


Figure 4: **Hourly total discharge (m^3/s) from Revelstoke Dam (REV) and REV tailwater hourly water surface elevation (meters above sea level), July 1 to September 30, 2018.**

Discharge from Revelstoke Dam exhibited daily fluctuations due to the hydropeaking operations at the facility (Figure 3). Peak discharge during the sturgeon spawning period was observed in early-August (2,072 m^3/s on August 7 at 16:00) (Figure 5). Discharge did not drop below 254 m^3/s between July and September 2018 (Figure 5). Spill gates were used sporadically January through June, but not during the spawning period in 2018 (unpublished data, BC Hydro Power Records, 2018).

Water temperatures at the spawning area are the result of a combination of thermal conditions in the REV forebay, REV discharge volume and the presence or absence of a backwater effect from ALR (Golder 2011). During the 2018 spawning monitoring study period, water temperature fluctuated between 8.9°C and 12.9°C (Figure 5).

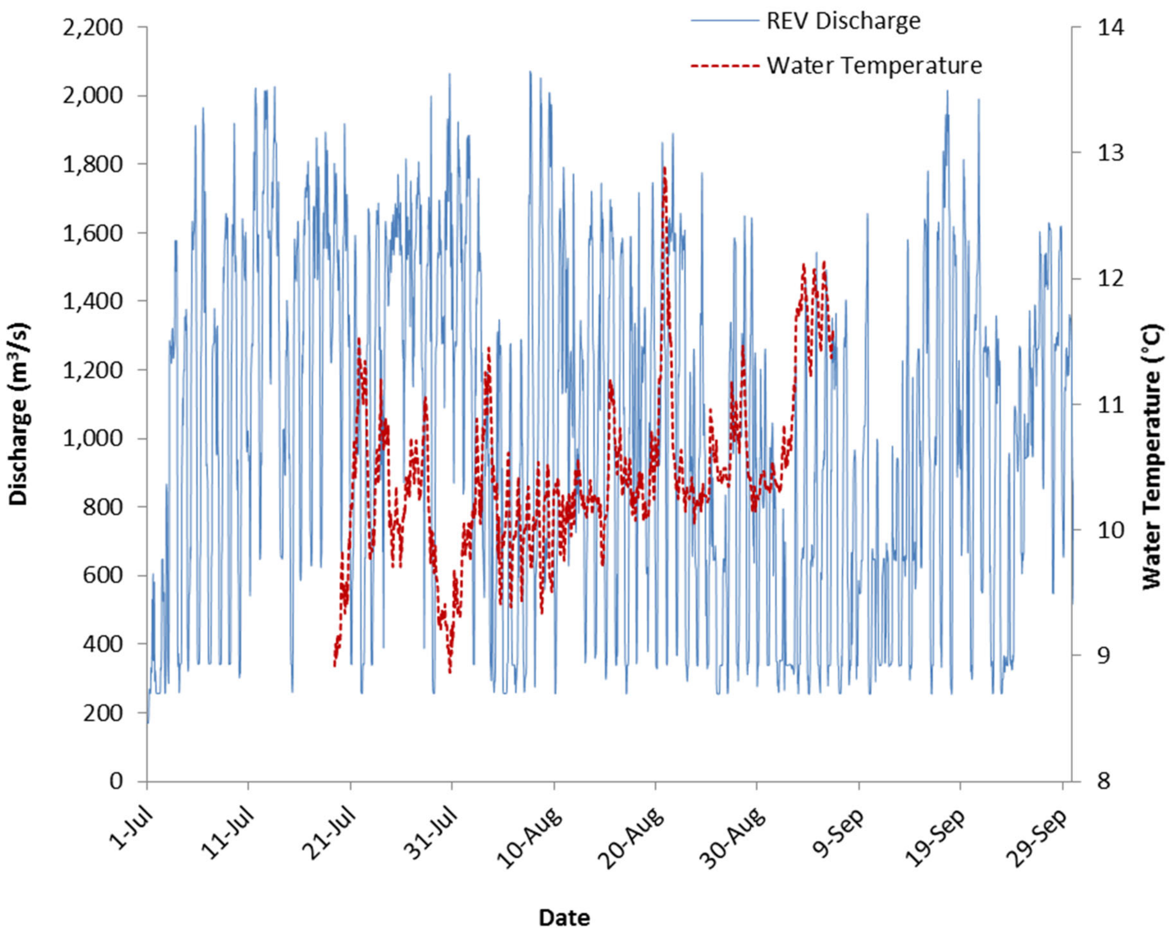


Figure 5: **Hourly total discharge (m^3/s) from Revelstoke Dam and hourly water temperature (°C) measured at Km 228.1, July 1 to September 30, 2018.**

3.2 White Sturgeon Egg & Free Embryo Collection

3.2.1 *Egg Collection Mats*

Six White Sturgeon eggs were collected on egg mats in 2018 (Table 2; Appendix A). No free embryos were collected on egg mats in 2018. In total, 23,068 mat-hours of effort (mean sample duration per egg mat = 161 hours; SD = 26.9) were spent during the 2018 sampling period (Table 2 and Table 3; Appendix A). A summary of effort by year (2007-2018) and sampling method is provided in Table 3.

Table 2: Summary of egg collection mat sampling, July 18 to September 7, 2018.

Session	Date	No. Mats Deployed	No. Mats Retrieved	Effort (mat-hours)	No. Eggs /Free Embryos	Catch-Per-Unit-Effort (CPUE)[a]
1	July 18 - 19	20	0	0	0	0
2	July 25 - 26	20	20	3,320	0	0
3	August 1 - 2	20	20	3,169	0	0
4	August 8 - 9	20	20	3,314	5	0.04
5	August 15 - 17	20	20	3,320	1	0.01
6	August 22 - 23	20	20	3,212	0	0
7	August 29 - 30	20	20	3,291	0	0
8	September 5 - 7	0	20	3,441	0	0
Totals		***140***	***140***	***23,068***	***6***	***0.01***

[a] CPUE = no. white sturgeon eggs and free embryos/24 mat-hours

Table 3: Summary of egg collection mat and drift net sampling by study year, 2007-2018.

Year	Egg Mats				Drift Nets			
	No. Deployed	Total Effort (hours)	No. Eggs/Free Embryos Captured	Catch-Per-Unit-Effort (CPUE)[a]	No. Deployed	Total Effort (hours)	No. Eggs/Free Embryos Captured	Catch-Per-Unit-Effort (CPUE)[a]
2018	140	23,068	6	0.01	71	387.2	93	0.24
2017	143	23,263	7	0.01	66	379.5	2	0.01
2016	140	22,771	1	0.001	55	341.6	0	0
2015	132	21,560	0	0	60	311	0	0
2014	123	20,850	19	0.02	64	375.9	38	0.10
2013	135	20,019	2	0.002	67	424.3	0	0
2012	61	8,773	0	0	28	106.8	8	0.07
2011	128	22,169	30	0.03	23	61.2	18	0.30
2010	96	20,514	0	0	15	67.4	0	0
2009	115	18,860	36	0.05	22	65.3	47	0.70
2008	164	27,009	4	0.004	6	12.6	4	0.30
2007	136	25,818	0	0	8	24.7	0	0
Mean	**126**	**21,223**	**9**	**0.010**	**40**	**213**	**18**	**0.14**
Standard Deviation	26	4555	13	0.016	25	167	29	0.21

[a] CPUE for egg mats = captures/24 mat-hours; CPUE for drift nets = captures/hour

3.2.2 *Drift Nets*

Five White Sturgeon free embryos and 88 eggs were captured by drift nets in 2018 (Table 4; Appendix B). Drift nets were set during the day (n=58) for a total of 191 hours (mean sample duration = 3.3 hours; SD = 0.9) and overnight (n=13) for a total of 196 hours (mean sample duration = 15.0 hours; SD = 0.3; Appendix B). Total water volume sampled during daytime drift net sets was 99,992 m^3, the mean water volume per daytime drift net set was 1,818 m^3 (SD = 1,905) and velocity was 31.2 cm/s (SD = 32.8; 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.

Table 4: Summary of drift net sampling, July 18 to September 7, 2018.

Session	Date	No. Drift Nets Deployed	Sample Effort		White Sturgeon Eggs			White Sturgeon Free Embryos			Notes
					No.	Catch-Per-Unit-Effort (CPUE)		No.	Catch-Per-Unit-Effort (CPUE)		
			Duration (hours)	Estimated Volume (m^3)[a]		No. /hour	No./ 100 m^3		No./ hour	No./ 100 m^3	
1	July 18 - 19	0	0.0	0	0	0	0	0	0	0	Initial trip
2	July 25 - 26	6	18.2	6,289	0	0	0	0	0	0	3 sets per day
3	August 1 - 2	8	48.3	8,954	0	0	0	0	0	0	3 sets per day; 2 overnight sets
4	August 8 - 9	6	20.6	13,186	83	4.03	0.63	0	0	0.00	3 sets per day
5	August 15 - 17	19	88.2	48,513	5	0.06	0.01	0	0	0.00	4 sets first day; 9 sets second day; 4 sets third day; 2 overnight sets
6	August 22 - 23	11	69.3	19,262	0	0	0	5	0.07	0.03	4 sets per day; 3 overnight sets
7	August 29 - 30	10	53.4	18,787	0	0	0	0	0	0.00	4 sets per day; 2 overnight sets
8	September 5 - 7	11	89.4	21,215	0	0	0	0	0	0.00	7 day sets; 3 overnight sets
Totals		***71***	***387.2***	***136,206***	***88***	***0.227***	***<0.001***	***5***	***0.013***	***<0.001***	

Notes: [a] Does not include volume of overnight drift net sets as meters zero'ed themselves an unknown number of times.

3.3 Egg Incubation

Eggs collected on August 8, 2018 (n=88) were not incubated and were transferred to the Kootenay Trout Hatchey on August 9, 2018 (Table 5).

The three viable eggs collected on August 15 and 16, 2018 were incubated at Km 229.1L. Upon inspection the following week (August 23) the eggs had matured to near hatch but died prior to hatching. The eggs were collected and preserved in ethanol for future analysis, as were four dead free embryos collected on August 23, 2018 (Table 5). The one viable free embryo collected on August 23, 2018 was transferred to the Kootenay Trout Hatchery that same day (Table 5).

Between 2012 and 2018, three viable eggs, 21 dead eggs and 40 free embryos were preserved for future genetic analysis.

3.4 Staging & Estimated Spawn Timing

Based on egg stages and water temperatures, six spawning events were estimated in 2018 (Table 5). Spawning events were estimated to have occurred on August 3, 6, 7, 8, 10 and 12 in 2018 (Table 5).

Eighty eight eggs with stages ranging from 4-26 were collected on August 8, 2018 (Table 5). Four groups of stages were identified (4-5, 7-9,15 and 26). Based on these egg stages, time of collection and average water temperature (10°C) over the previous 5 days, four spawning events were identified estimated to have occurred at approximately 17:00 on August 3, 5:00 on August 6, between 18:00 on August 7 and 0:00 on August 8, and 14:30 on August 8 (Table 5).

Three additional eggs were captured at similar locations the following week, on August 15 (stages 18 and 30) and August 16 (stage 33). Water temperature over the previous 10 days was approximately 10°C suggesting fertilization occurred approximately 128 hours (stages 30-33) and 75 hours (stage 18) prior to egg collection and one spawning event occurred between 10:00 on August 10 and 1:30 on August 11 while the other occurred at approximately 15:30 on August 12 (Table 5). Cool thermal regimes such as those observed in the middle Columbia River have been found to slow egg development (Parsley et al. 2011). In addition, temperature fluctuations occurred during the incubation period making exact spawning date determinations of later staged eggs less reliable (Wang et al. 1985) and it is likely the stage 30 and 33 eggs were from the same spawning event. Therefore, eggs collected on August 15/16 were from two spawning events that occurred after the four identified on August 8 (Table 5).

One viable free embryo (stage 38) was collected on August 23. At 12.5°C, approximately 48 hours are required post-hatch to reach this stage; cooler water regimes were not evaluated (Jay 2014). Assuming a minimum of 48 hours post hatch and 256 hours from fertilization to hatch, the free embryo had been spawned at minimum 304 hours prior. Backcalculation suggests the latest it might have been fertilized was during the August 10 spawning event, however, as noted above the cool thermal regime may have slowed development and it may have been from one of the earlier spawning events.

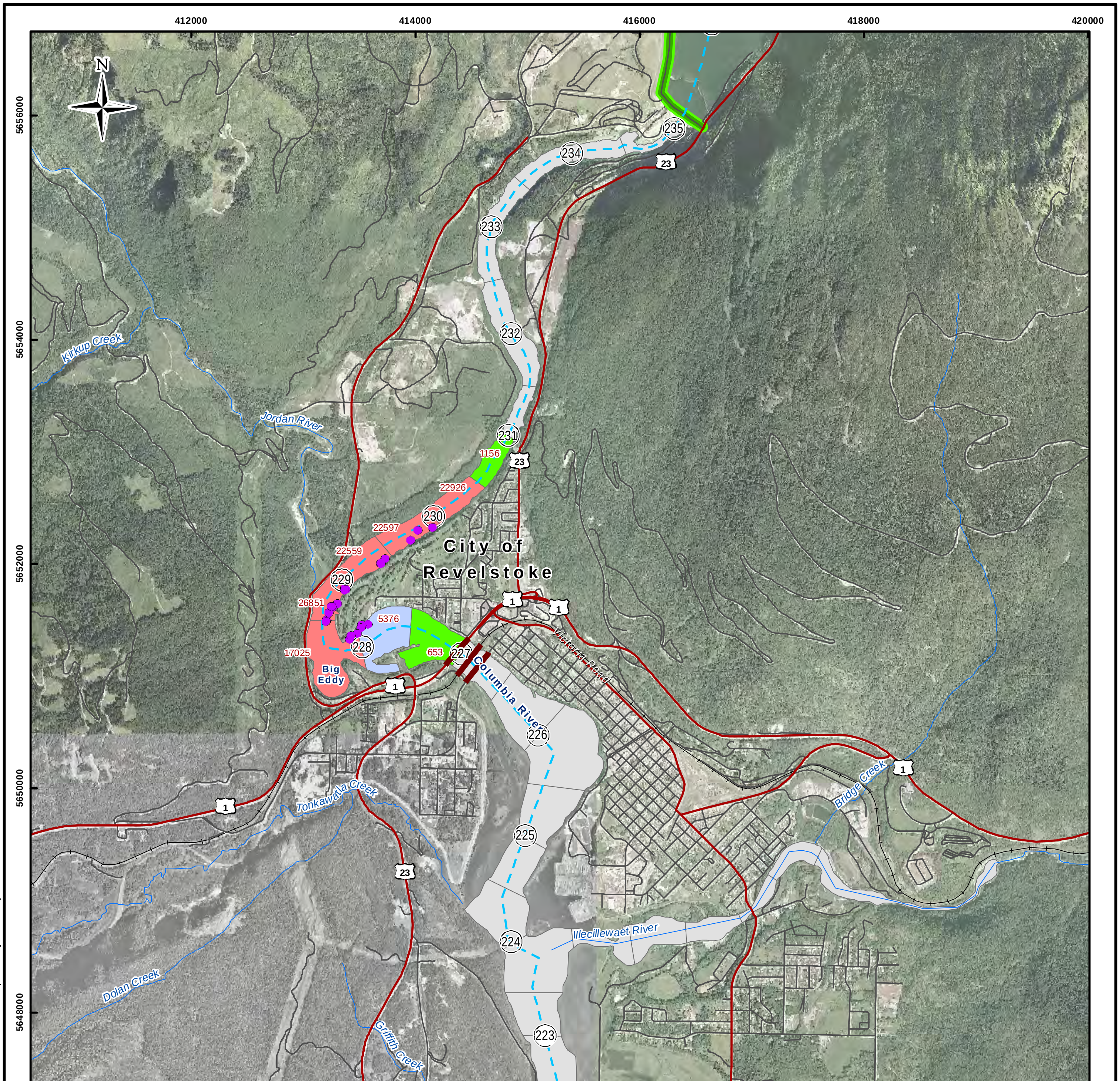
Table 5: Estimated timing of spawning events based on the developmental stages of captured White Sturgeon eggs and free embryos, 2018.

Spawning Event	Collection Date and Time	Sample Location	Egg/Free Embryo (Number)	Stage	Spot Water Temperature (°C) When Collected	Estimated Spawn Date and Time	Description
1	8/8/2018 14:55	228.5M	Egg (1)	26	10.2	8/3/2018 17:00	Egg stage suggests 118 hours post-spawn; transferred to hatchery
2	8/8/2018 14:55	228.5M	Egg (1)	15	10.2	8/6/2018 5:00	Egg stage suggests 58 hours post-spawn; transferred to hatchery
3	8/8/2018 16:04	228.9M	Egg (1)	9	9.7	8/7/2018 18:00	Egg stage suggests 22 hours post-spawn; transferred to hatchery
3	8/8/2018 15:35	228.7M	Egg (1)	8	11	8/8/2018 0:00	Egg stage suggests 15 hours post-spawn; transferred to hatchery
3	8/8/2018 14:55	228.5M	Egg (1)	8	10.2	8/8/2018 0:00	Egg stage suggests 15 hours post-spawn; transferred to hatchery
2, 3, 4	8/8/2018 17:32	228.1M	Egg (74)	4-15	9.4	8/6/2018 7:30 8/8/2018 14:30	Egg stage suggests 3-58 hours post-spawn; transferred to hatchery
2, 3, 4	8/8/2018 18:52	227.9L	Egg (9)	7-15	9.2	8/6/2018 9:00 8/8/2018 4:00	Egg stage suggests 15-58 hours post-spawn; transferred to hatchery
5	8/15/2018 18:00	228.1M	Egg (1)	30	11.1	8/10/2018 10:00	Egg stage suggests 128 hours post-spawn; incubated and preserved
5	8/16/2018 9:36	228.7M	Egg (1)	33	10.5	8/11/2018 1:30	Egg stage suggests 128 hours post-spawn; incubated and preserved
6	8/15/2018 18:30	227.9L	Egg (1)	18	11.1	8/12/2018 15:30	Egg stage suggests 75 hours post-spawn; incubated and preserved
-	8/16/2018 17:20	227.9L	Egg (2)	Dead	10.4	-	Dead
-	8/16/2018 18:02	228.2L	Egg (1)	Dead	10.2	-	Dead
-	8/23/2018 8:28	228.2L	Free Embryo (2)	Dead	10.1	-	Dead
-	8/23/2018 11:30	227.9L	Free Embryo (1)	Dead	10.6	-	Dead
-	8/23/2018 11:57	228.2L	Free Embryo (1)	38	10.2	-	Transferred to hatchery
-	8/23/2018 11:53	228.7M	Free Embryo (1)	Dead	10.2	-	Dead

Notes: “-“ = unknown spawn time

3.5 Sampling Effort Maps

A summary of effort by sampling hours between 2012 and 2018 is illustrated in Figure 6 and a summary of effort by years of sampling is illustrated in Figure 7.



Legend

- Egg or Free Embryo Collected
- 288 River Kilometre
- 16 Highway
- Bridge
- Railway
- River Centre Line
- Dam

Sampling Effort (hours)

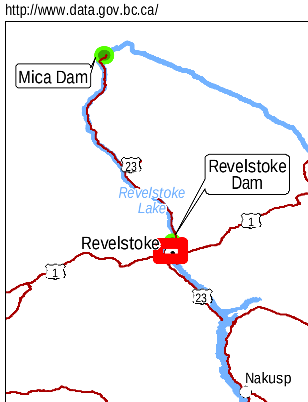
- Not Sampled 2012-2018
- <5000
- 5000 - 10000
- 10000 - 15000
- 15000 - 20000
- >20000

0 0.5 1

Kilometers

Scale: 1:50,000

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/



CLIENT:

Prepared for BC Hydro

PROJECT:

CLBMON-23a Mid-Columbia River White Sturgeon Spawn Monitoring

TITLE:

Mid-Columbia River Substrate Mat and Drift Net Sampling Effort (Hours) Identifying Where White Sturgeon Eggs and/or Free Embryos were Collected 2012-2018

DATE: January, 2019

Figure 6

JOB No: VE52241

ANALYST: MY

QA/QC: CL

GIS File: 01-50-015_2012_2018_Effort

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

wood.

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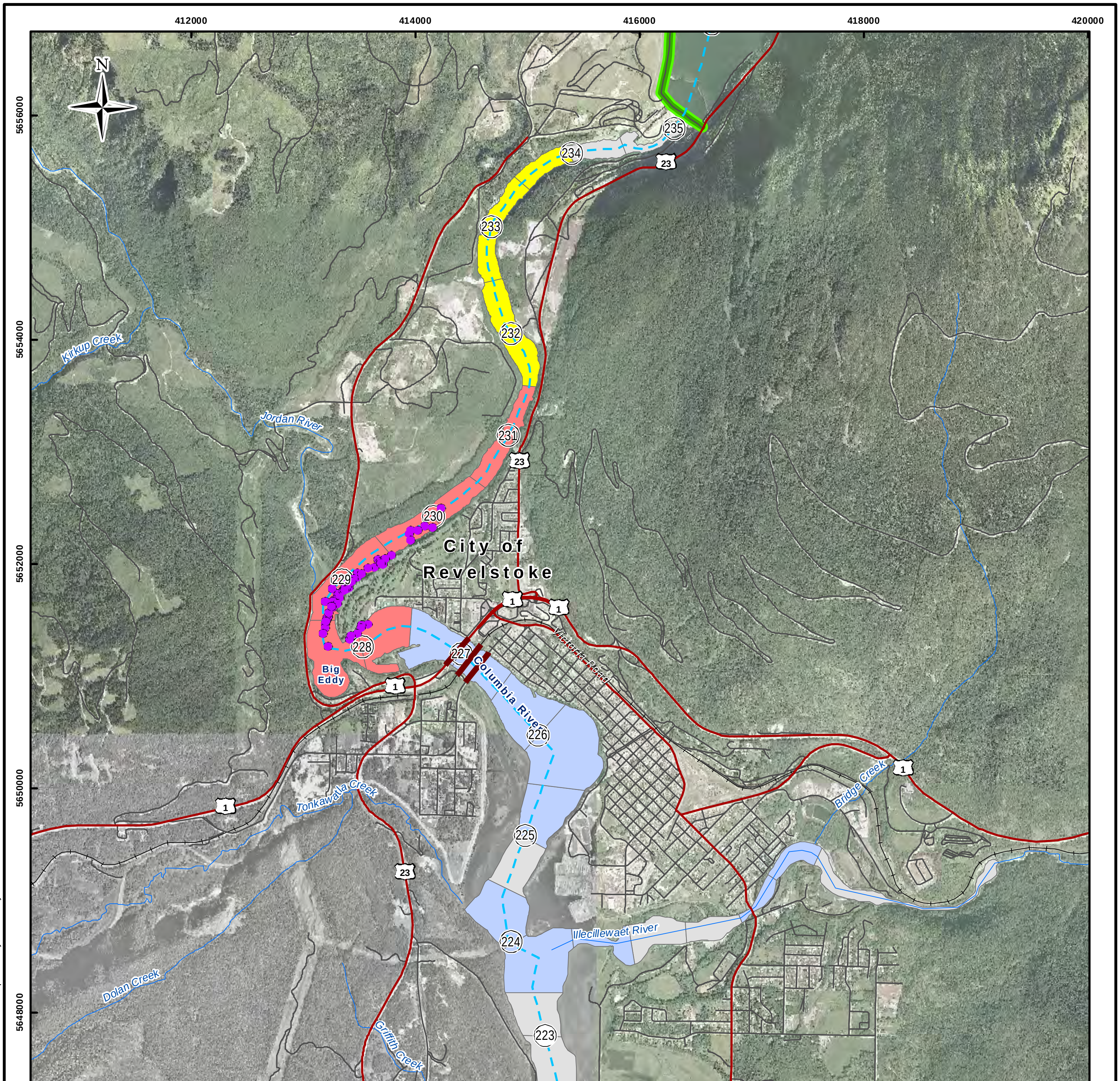


Legend

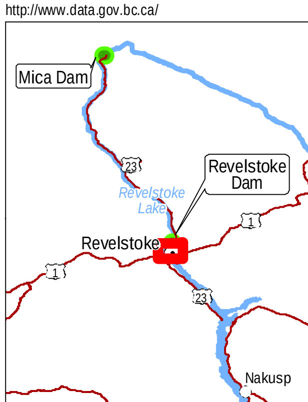
- Egg or Free Embryo Collected
- 288 River Kilometre
- 16 Highway
- Bridge
- Railway
- River Centre Line
- Dam

Years of Sampling

- 0
- 1
- 2-5
- >5

0 0.5 1
Kilometers
Scale: 1:50,000

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/



CLIENT: Prepared for BC Hydro

PROJECT: CLBMON-23a Mid-Columbia River White Sturgeon Spawn Monitoring

TITLE: Mid-Columbia River Substrate Mat and Drift Net Sampling Effort (Number of Years) Identifying Where White Sturgeon Eggs and/or Free Embryos were Collected 1999-2018

DATE: January, 2019

Figure 7

JOB No: VE52241 | ANALYST: MY | QA/QC: CL

GIS File: 01-50-014_1999_2018_Effort

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

wood.

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3.6 White Sturgeon Spawning and Physical Parameters

Dates of spawning events during years that spawn monitoring was conducted are summarized in Figure 8. A summary of White Sturgeon spawning events and physical parameters observed below Revelstoke Dam during the spawning period (July to September) in years when spawn monitoring was conducted is provided in Table 6.

Spawning events occurred between July 20 and August 28 in years that spawn monitoring was conducted from 1999 to 2018 (Figure 8). The number of White Sturgeon spawning events recorded between 1999 and 2018 has varied from zero to six (Table 6).

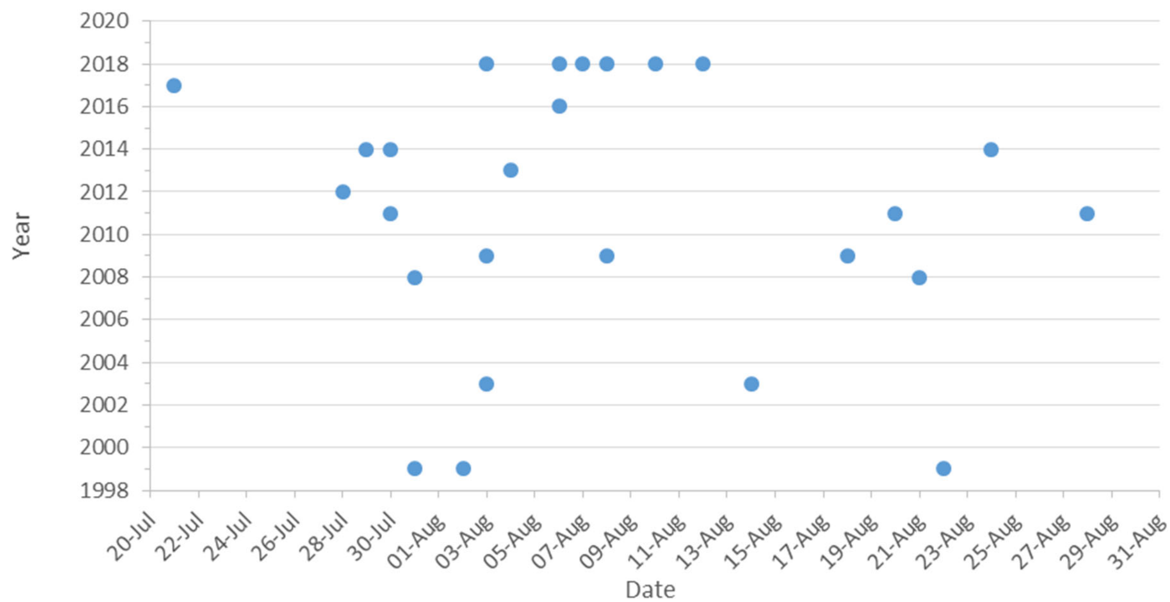

Figure 8: **Timing of White Sturgeon spawning events in the mid-Columbia River during years that spawn monitoring was conducted, 1999 to 2018. Note that spawn monitoring was not conducted in 2002, 2004 and 2005. Spawn timing is not available for the one spawning event documented in 2006.**

Table 6: White Sturgeon spawning events and physical parameters observed below Revelstoke Dam (July-September) during spawn monitoring programs, 1999 to 2018. 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	2015	2016	2017	2018
No. Spawning Events		3	0	0	2	1	0	2	3	0	3	1	1	3	0	1	1	6
No. Eggs Captured		82	0	0	50	1	0	8	65	0	37	1	2	44	0	1	8	94
No. Free Embryos Captured		0	0	0	1	0	0	0	18	0	11	7	0	13	0	0	1	5
Discharge (m^3/s)	**Mean**	1230	1139	682	901	939	1185	712	744	540	957	1506	862	945	1387	1026	1059	1034
	Min.	0	0	0	0	0	0	0	0	0	145	150	253	152	254	258	254	255
	Max	1838	1635	1612	1667	1630	1773	1752	1715	1757	2140	2573	2118	2145	2182	2118	1899	2072
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	10.5	10.5	9.8	10.4
	Min.	9.2[a]		6.4	6.9	8	4.5	6.7	7.6	7.5	8	7.8	9.1	8.5	8.5	8.8	8.5	8.9
	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	12.2	12.5	13.4	12.9
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	430.7	432.1	438.4	437.6
	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	428.9	430.3	436.3	435
	Max	440	444	430.4	439	439.8	438.6	439.9	437.5	439.3	439.5	440.5	437.6	437.9	432.9	434.3	439.5	439.7
No. Zero Flow Events		25	8	36	36	12	8	49	42	39	0	0	0	0	0	0	0	0

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

3.7 Egg and Free Embryo Stranding Risk

Between 2007 and 2018, discharge of 0 m^3/s and discharge less than 142 m^3/s during the at-risk period following spawning events were only observed in 2008 and 2009 prior to REV5 coming online (Figure 9). The highest proportion of the at-risk period when discharge was at or below the two thresholds was observed in 2008 when discharge of 0 m^3/s was observed during approximately 21% of the at-risk period and discharge less than 142 m^3/s was observed during approximately 27% of the at-risk period (Figure 9). In 2008 and 2009, discharge was below 142 m^3/s for an average of 25% of the at-risk period. Between 2011 and 2014 the minimum flow observed during the at-risk period was approximately 150 m^3/s and between 2016 and 2018 it increased to approximately 255 m^3/s (Figure 9).

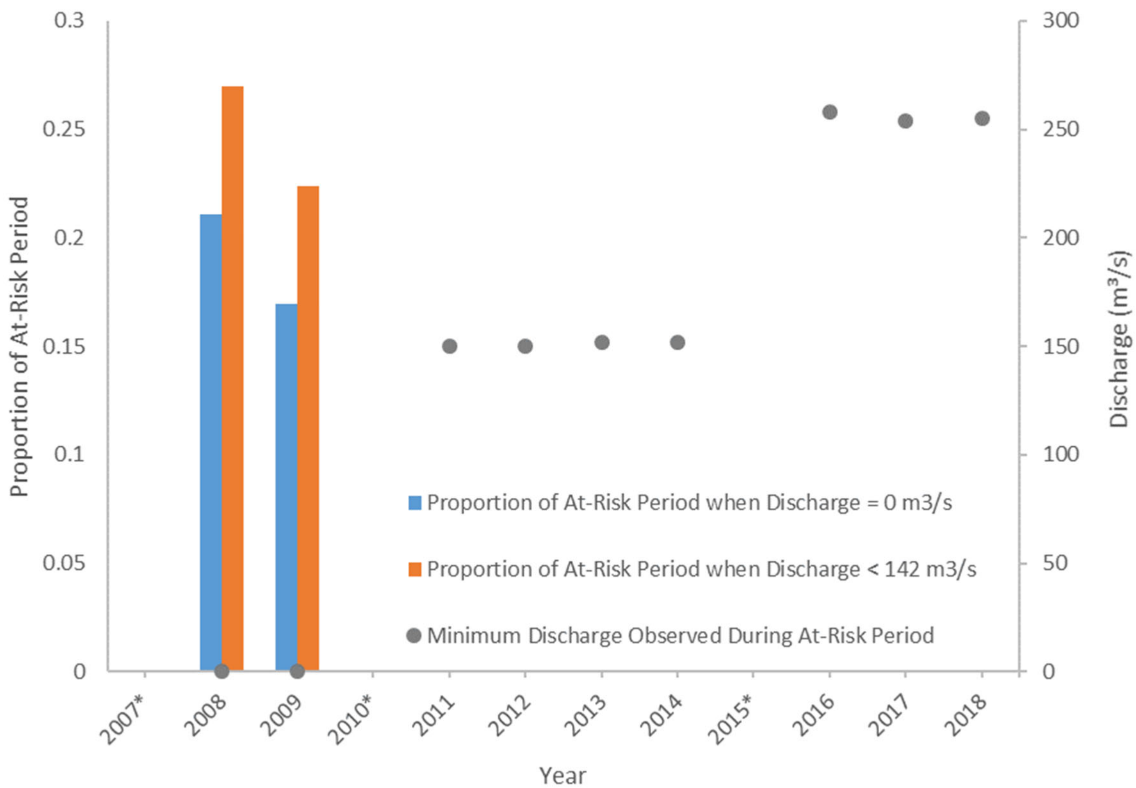

Figure 9: Proportion of the Middle Columbia River White Sturgeon spawning at-risk period (50 days) that discharge was at zero (0 m^3/s) or below the current operational minimum (142 m^3/s). Minimum discharge observed during the at-risk period is also identified. * Denotes years no spawning was recorded.

4 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 (e.g., Parsley et al. 1993 and references cited in Hildebrand and Parsley 2013). Spawning in the mid-Columbia River below Revelstoke Dam occurred from late July to late August and was identified in 12 of 17 years that monitoring has been conducted. It is not surprising that spawning has not been identified every year as the small population estimated for this area (approximately 52 individuals; Golder 2006) could result in mature females not being available every year to spawn given they spawn intermittently and the time between spawning years increases with age. The sex ratio for the population segment below HLK Dam is 1:1 and females are thought to typically spawn once every 3 to 4 years, whereas males may be capable of spawning every year (Hildebrand and Parsley 2013). Assuming a 1:1 sex ratio applies to the mid-Columbia River segment of the population, there may be spawners of each sex available annually but based on the spawning studies conducted below Revelstoke Dam since 1999, the primary White Sturgeon spawing location is a small area and sampling has been consistent across all monitoring years so it is expected that spawning would be detected if it occured. The 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 2); 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 although sampling outside this main area has been less frequent. For example, only 1 year of sampling has occurred between the area downstream of the Hwy #1 Bridge (Km 227) and the Illecillewaet River (Figure 6 and Figure 7).

The boundaries of this small spawning/incubation area may shift slightly depending on flows and ALR elevation, but remain relatively similar between years based on results of this work that incorporates the area where all White Sturgeon eggs have been captured since 1999. The 94 White Sturgeon eggs and five free embryos collected in 2018 were between Km 227.9 and Km 228.9, within this primary incubation area.

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 (e.g. Lake Sturgeon; Caroffino et al. 2010; Duong et al. 2011; Forsythe et al. 2013). Caroffino et al. (2010) estimated overall mortality from the egg stage to larval stage for Lake Sturgeon in the Peshtigo River, Wisconsin, USA at 99% and from egg stage to age-0 juvenile life stage at over 99.9%. In this program, the ability to estimate survival of early life stages was not possible due to the low number of eggs/larvae that were collected and uncertainty in the number of spawning adults (e.g., Jay et al. 2014). Based on spawning studies in other areas, successful White Sturgeon egg and larval survival require 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). These findings suggest habitat conditions within the White Sturgeon egg incubation area are suitable for egg and larval survival if habitat requirements are similar to those identified for White Sturgeon in other areas.

Comprehensive egg stranding surveys were conducted to investigate dewatered incubation areas when spawning was documented. They were conducted once in 2009 when minimum REV flow was zero and repeated in 2011 and 2014 when minimum REV flow was 145 m^3/s (Golder 2012). 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 8,000 m^2 of the bar was dewatered (Golder 2012). In 2014, no eggs or free embryos were observed in the 10 m^2, 50 m^2, and 30 m^2 of exposed gravel bar surveyed when stranding surveys were conducted on 30 July, 6 August and 28 August, respectively. Water levels did not expose this area sufficiently during spawning monitoring conducted in other years post-REV5 to warrant extensive investigations (i.e. minimum flows were not observed during the White Sturgeon egg incubation period). In 2018, the ALR backwatered the area over the majority of the spawning and incubation period, no zero flow events occurred and exposure of gravel bars was not observed.

In addition to the comprehensive stranding surveys conducted prior to 2018, the risk of eggs or larvae becoming dewatered as a result of operations was based on a limited number of field surveys conducted when exposed substrates were observed. As part of the 2018 study, egg dewatering was further evaluated by determining the proportion of time eggs or larvae were at-risk of being stranded during the 2007-2018 sampling period (Figure 9). This desktop assessment of stranding risk found the proportion of time that flows were between 0 and 142 m^3/s during the at-risk period was 0% since the implementation of the minimum flow. The evaluation also indicated that since 2016, flows during the at-risk period have not been below 250 m^3/s. This has resulted in low stranding risk because less of the river bed area is exposed when eggs are incubating and recently hatched embryos are hiding in the substrate. The increase in minimum flows attributed to REV5 has increased the estimated permanently wetted river bed area in the middle Columbia River by approximately 32%

when ALR elevation is below 425 m; when ALR is higher than 425 m the effect is lessened (Dashti et al. 2016). Additional field verification may be warranted for operations during the spawning period (July-September) where flows are less than 142 cms.

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 (i.e., could not detect/confirm spawning events).

During the past 12 years of this program, an average of 126 egg mats have been deployed per spawning season for approximately 21,223 hours which resulted in an average catch-rate of 0.01 eggs/free embryos per 24 mat-hours. In contrast, an average of 40 drift nets have been deployed per spawning season for approximately 213 hours which resulted in an average catch-rate of 0.14 eggs/free embryos per hour. Although drift nets do have higher catch-rates, they require more frequent inspection and do not monitor continuously like egg mats. Research conducted on sturgeon free embryos has identified a downstream dispersal period 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. Parsley et al. 2011 also report that the cooler water temperatures observed in the mid-Columbia River result in free embryos hatching over a protracted period over several days instead of all at once. Therefore, drift nets fished twice per week may have a better chance to overlap with larval downstream dispersal. In 2018, egg mats sampled continuously for approximately 50 days, whereas drift nets covered one third of that time (15 days).

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 observed in six of the seven 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 include greater diel variation in water level and flows, but there was no evidence that this has led to increased seasonal variation (Plate et al. 2015). In addition, less diel variation in water temperature was observed post-WUP flow, but the change in variation observed (0.1-0.4°C) was not ecologically significant nor was this variation seasonal (Golder 2014, Plate et al. 2014, Plate et al. 2015). 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. In addition, there may be benefits of these minimum flows on benthic invertebrate biomass, since substrates submerged for longer daytime periods had greatest availability of preferred fish food items (Larratt et al. 2017). However, other confounding variables such as duration of daily high flows, ALR backwatering and tributary inflows also influence the total abundance, biomass and diversity of benthic communities (Laratt et al. 2017).

5 RECOMMENDATIONS

The following recommendations are a result of the technical forum held for the Mid-Columbia White Sturgeon Management Plan in December 2018 (BC Hydro 2018):

- Continue spawning monitoring in the middle Columbia River (to 2023) to track the timing, frequency and location of spawning events to aid in ongoing research into hypotheses related to recruitment failure for the Upper Columbia White Sturgeon population. The middle Columbia population is unique in that it has the latest temporal spawning period of all Columbia River White Sturgeon populations.
- Collection of wild spawn progengy from the middle Columbia River is critical for capturing the genetic diversity of this population segment in the conservation aquaculture program.
    - Accordingly, transport eggs and/or larvae that are alive to the Kootenay Trout Hatchery (KTH) for rearing and future release into ALR in order to increase the genetic diversity of the supplemetal progreny. Obtain a hatchery transport protocol from KTH and develop/maintain a transport kit with key supplies.
- Collect a tissue sample for genetic analyses from all progeny collected. This includes both juveniles at the time of release from a fin clip as well as preserving all mortailites in both the field and hatchery. Tissue samples will be used to estimate the number of contributing adults spawning in each year and assist in evaluating the genetic diversity of the aquaculture program.
- Conduct additional egg stranding surveys in years where spawning has been detected and operations are forecasted to be below minimum flows. This will require discussion with BC Hydro and could include night sampling.
- In years where spawning is detected, consider drift net sampling later in the year and further downstream than has been conducted to date to capture estimated time of larval dispersal, when possible.

6 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.

AMEC. 2015. Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23a). Year 8 Data Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: AMEC Environment & Infrastructure Ltd. 24 pp + 3 App.

Amec Foster Wheeler. 2016. Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23a). Year 9 Data Report. Report Prepared for: BC Hydro, Castlegar. Prepared by: Amec Foster Wheeler Environment & Infrastructure Ltd. 22 pp + 3 App.

Amec Foster Wheeler. 2017. Middle Columbia River White Sturgeon Spawning Monitoring (CLBMON-23A). Year 10 Data Report. Report Prepared for: BC Hydro, Castlegar. 24 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.

BC Hydro. 2018. Mid Columbia River White Sturgeon Technical Forum – Summary and Action Items. Memo produced by BC Hydro, 4pp.

Caroffino, D.C., Sutton, T.M., Elliott, R.F. and Donofrio, M.C. 2010. Early life stage mortality rates of lake sturgeon in the Peshtigo River, Wisconsin. North American Journal of Fisheries Management 30: 295-304.

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.

Crossman, J. A. and L. R. Hildebrand. 2012. Evaluation of spawning substrate enhancement for White Sturgeon in a regulated river: Effects on larval retention and dispersal. River Research and Applications. Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/rra.2620

Dashti, S., K. Healey, Y. Iman, N. Wright, E. Plate and M. Zimmer. 2016. CLBMON-15a Mid-Columbia River Physical Habitat Monitoring Project, 2015 (Year 9). Prepared for: BC Hydro, Revelstoke, BC. Prepared by: Okanagan Nation Alliance, LGL Limited and Ecofish Research Limited. 43 p. + 5 app.

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

Duong, T.Y., Scribner, K.T., Crossman, J.A., Forsythe, P.S., Baker, E.A., Kanefsky, J., Homola, J.J. and Davis, C. 2011. Relative larval loss among females during dispersal of Lake Sturgeon (*Acipenser fulvescens*). Environmental Biology of Fishes 91: 459-469.

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.

Forsythe, P.S., Scribner, K.T., Crossman, J.A., Ragavendran, A. and Baker, E.A. 2013. Experimental assessment of the magnitude and sources of lake sturgeon egg mortality. Transactions of the American Fisheries Society 142: 1005-1011.

Golder Associates Ltd. 2001. White sturgeon investigations in Arrow Reservoir and the Columbia River, B.C., 2001 study results. Draft data report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 0128994D: 19 p. + 4 app.

Golder Associates Ltd. 2004. White sturgeon investigations in Arrow Lakes Reservoir, B.C., 2002 - 2003 study results. Data report prepared for BC Hydro, Castlegar, B.C. Golder Report No. 031480045/0228056/0228047F: 27 p. + 4 app.

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. 2012. 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. 2014. 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. 2014. Estimating effective number of breeding adults, reproductive success, and spawning duration for White Sturgeon in the Upper Columbia River, Canada. M.Sc. Thesis. Michigan State University, USA.

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.

Jay, K., J. Crossman and M. Webb. 2016. Developmental Staging for Sturgeon Embryos and Yolk-Sac Larvae. Prepared for the 2016 NASPS Annual Meeting Workshop, Hood River, OR. 21 p.

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.

Larratt, H., R. Plewes, J. Schleppe, and A. Duncan. 2017. CLBMON-15b. Middle Columbia River ecological productivity monitoring, 2007-2016. Report Prepared for BC Hydro. Prepared by Ecoscape Environmental Consultants with Okanagan Nation Alliance. June 2017. 61 pp. + 4 app.

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.

Plate, E.M., Y. Imam, S. Dasht, L. Walker, N. Wright and M. Zimmer. 2014. CLBMON-15a Mid-Columbia Physical Habitat Monitoring Project. Implementation Year 7. (April 2014) Prepared for BC Hydro, Burnaby, BC by ONA, LGL Limited and Ecofish Research Limited. 46 pp. + 6 App.

Plate, E.M., Y. Imam, S. Dasht, L. Walker, N. Wright and M. Zimmer. 2015. CLBMON-15a Mid-Columbia Physical Habitat Monitoring Project. Implementation Year 8. (June 2015) Prepared for BC Hydro, Burnaby, BC by ONA, LGL Limited and Ecofish Research Limited. 51 pp. + 6 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.

Tiley, M. 2006. Habitat use of Arrow Lakes Reservoir pre-spawning and spawning adult white sturgeon (Acipenser transmontanus) timing of spawning and embryo and larval survival. Prepared for World Wildlife Fund Canada Endangered Species Recovery Fund. 14 p.

UCWSRI. 2017. Upper Columbia White Sturgeon Recovery Initiative. Operational Plan 2013-2017. Prepared by the UCWSRI-TWG. 28 pp.

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 18 to September 6, 2018.

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2018)	Time	Water Temp (°C)	Date (2018)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
230.3M	3.7	18-Jul	15:33	8.7	25-Jul	15:15	10.8	167:42	167.70	0	0	0
229.8M	4.3	18-Jul	15:42	8.7	25-Jul	15:37	9.9	167:55	167.92	0	0	0
229.4M	5.6	18-Jul	15:50	8.7	26-Jul	8:42	10.0	184:52	184.87	0	0	0
230.15R	3.2	18-Jul	16:00	8.7	25-Jul	15:28	10.0	167:28	167.47	0	0	0
230.35R	3.5	18-Jul	16:07	8.7	25-Jul	15:17	10.4	167:10	167.17	0	0	0
228.9M	5.4	18-Jul	16:58	9.0	26-Jul	9:21	9.9	184:23	184.38	0	0	0
228.6M	3.8	18-Jul	17:05	8.7	26-Jul	9:53	10.0	184:48	184.80	0	0	0
229.2M	4.5	18-Jul	17:13	8.7	26-Jul	8:53	9.9	183:40	183.67	0	0	0
229.7L	3.5	18-Jul	17:18	8.8	25-Jul	15:47	9.9	166:29	166.48	0	0	0
230.1L	3.1	18-Jul	17:23	8.8	25-Jul	15:26	10.0	166:03	166.05	0	0	0
228.1M	5.0	19-Jul	8:54	9.2	26-Jul	8:13	11.2	167:19	167.32	0	0	0
228.5M	4.3	19-Jul	9:02	9.1	26-Jul	9:43	9.9	168:41	168.68	0	0	0
228.75L	3.5	19-Jul	9:10	8.9	25-Jul	14:51	10.3	149:41	149.68	0	0	0
229.3L	4.4	19-Jul	9:15	8.9	26-Jul	8:17	10.7	167:02	167.03	0	0	0
229.45L	4.2	19-Jul	9:21	9.1	25-Jul	15:55	9.9	150:34	150.57	0	0	0
228.7M	4.5	19-Jul	10:50	9.1	26-Jul	9:31	9.9	166:41	166.68	0	0	0
228.2M	4.9	19-Jul	10:58	8.9	25-Jul	14:45	10.8	147:47	147.78	0	0	0
227.9L	4.9	19-Jul	11:02	8.9	25-Jul	14:48	10.4	147:46	147.77	0	0	0
228.4R	3.8	19-Jul	11:08	9.1	26-Jul	8:22	10.4	165:14	165.23	0	0	0
228.8L	3.0	19-Jul	11:14	9.0	25-Jul	16:04	9.9	148:50	148.83	0	0	0
230.3M	3.4	25-Jul	15:16	10.8	1-Aug	14:24	10.1	167:08	167.13	0	0	0
230.35R	4.0	25-Jul	15:19	10.4	1-Aug	14:30	10.1	167:11	167.18	0	0	0
230.1L	3.1	25-Jul	15:28	10.0	2-Aug	8:34	10.4	185:06	185.10	0	0	0
230.15R	2.0	25-Jul	15:36	9.9	1-Aug	15:46	9.9	168:10	168.17	0	0	0
229.8M	4.3	25-Jul	15:39	9.9	1-Aug	14:39	9.9	167:00	167.00	0	0	0
229.7L	3.5	25-Jul	15:52	9.9	1-Aug	15:40	9.9	167:48	167.80	0	0	0
229.45L	4.2	25-Jul	16:00	9.9	2-Aug	8:48	10.3	184:48	184.80	0	0	0
228.8L	4.2	25-Jul	16:13	9.9	2-Aug	8:19	10.2	184:06	184.10	0	0	0
228.2M	4.5	25-Jul	17:38	10.3	-	-	-	-	-	-	-	-
227.9L	3.5	25-Jul	17:54	9.8	1-Aug	14:07	11.6	164:13	164.22	0	0	0

Appendix Table A1 Continued

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2018)	Time	Water Temp (°C)	Date (2018)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
228.75L	3.2	25-Jul	18:03	9.9	2-Aug	8:16	10.2	182:13	182.22	0	0	0
229.4M	4.5	26-Jul	8:44	10.0	2-Aug	8:52	10.4	168:08	168.13	0	0	0
229.2M	4.0	26-Jul	8:55	9.9	1-Aug	15:54	9.8	150:59	150.98	0	0	0
228.9M	4.8	26-Jul	9:21	9.9	2-Aug	9:01	10.6	167:40	167.67	0	0	0
228.7M	4.0	26-Jul	9:33	9.9	2-Aug	9:15	10.5	167:42	167.70	0	0	0
228.5M	4.0	26-Jul	9:45	9.9	2-Aug	9:18	10.5	167:33	167.55	0	0	0
228.6M	2.2	26-Jul	9:55	10.0	2-Aug	9:04	10.6	167:09	167.15	0	0	0
228.1M	4.7	26-Jul	11:13	10.2	1-Aug	14:09	10.9	146:56	146.93	0	0	0
229.3L	2.8	26-Jul	11:29	10.3	1-Aug	14:13	10.5	146:44	146.73	0	0	0
228.4R	3.2	26-Jul	11:44	10.4	1-Aug	16:02	10.1	148:18	148.30	0	0	0
230.3M	3.4	1-Aug	14:26	10.1	9-Aug	10:05	10.2	187:39	187.65	0	0	0
230.35R	3.7	1-Aug	14:34	9.9	9-Aug	10:09	10.2	187:35	187.58	0	0	0
229.8M	5.0	1-Aug	15:38	9.9	9-Aug	9:48	10.3	186:10	186.17	0	0	0
229.7L	3.5	1-Aug	15:42	9.9	9-Aug	9:39	10.4	185:57	185.95	0	0	0
230.15R	3.7	1-Aug	15:48	9.9	9-Aug	9:55	10.3	186:07	186.12	0	0	0
229.2M	4.8	1-Aug	15:56	9.8	08-Aug	16:18	9.6	168:22	168.37	0	0	0
228.4R	3.4	1-Aug	17:05	10.6	08-Aug	14:47	10.7	165:42	165.70	0	0	0
228.1M	4.5	1-Aug	17:17	9.9	08-Aug	14:22	12.5	165:05	165.08	0	0	0
227.9L	4.2	2-Aug	8:08	10.5	08-Aug	14:27	11.5	150:19	150.32	0	0	0
229.3L	5.3	2-Aug	8:31	10.2	09-Aug	9:32	10.4	169:01	169.02	0	0	0
229.45L	4.1	2-Aug	8:50	10.3	09-Aug	9:35	10.4	168:45	168.75	0	0	0
228.3M	4.9	2-Aug	8:53	10.4	08-Aug	14:42	10.8	149:49	149.82	0	0	0
228.9M	4.6	2-Aug	9:03	10.6	08-Aug	16:04	9.7	151:01	151.02	1	0	0.007
228.6M	1.8	2-Aug	9:06	10.6	08-Aug	14:58	10.0	149:52	149.87	0	0	0
228.7M	3.5	2-Aug	9:17	10.5	08-Aug	15:35	11.0	150:18	150.30	1	0	0.007
228.5M	4.0	2-Aug	9:20	10.5	08-Aug	14:55	10.2	149:35	149.58	3	0	0.020
228.2M	4.0	2-Aug	10:09	10.5	09-Aug	7:56	11.2	165:47	165.78	0	0	0
228.75L	3.0	2-Aug	11:34	10.7	08-Aug	14:29	10.8	146:55	146.92	0	0	0
228.8L	3.1	2-Aug	11:42	10.6	09-Aug	7:59	10.7	164:17	164.28	0	0	0
230.1L	3.0	2-Aug	11:57	10.5	09-Aug	9:51	10.3	165:54	165.90	0	0	0
228.3M	4.0	08-Aug	14:44	10.8	16-Aug	9:58	10.5	187:14	187.23	0	0	0
228.4R	2.5	08-Aug	14:53	10.5	16-Aug	9:40	10.5	186:47	186.78	0	0	0

Appendix Table A1 Continued

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2018)	Time	Water Temp (°C)	Date (2018)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
228.5M	3.8	08-Aug	14:56	10.2	16-Aug	10:11	10.6	187:15	187.25	0	0	0
228.6M	1.9	08-Aug	14:59	10.0	16-Aug	10:23	10.6	187:24	187.40	0	0	0
228.7M	3.2	08-Aug	15:37	11.0	16-Aug	9:36	10.5	185:59	185.98	1	0	0.005
228.9M	4.7	08-Aug	16:05	9.7	09-Aug	8:05	10.5	16:00	16.00	0	0	0
229.2M	4.0	08-Aug	16:19	9.6	15-Aug	15:48	11.0	167:29	167.48	0	0	0
228.1M	5.0	08-Aug	17:34	9.4	15-Aug	15:22	11.6	165:48	165.80	0	0	0
227.9L	3.0	08-Aug	19:27	9.2	15-Aug	15:23	11.0	163:56	163.93	0	0	0
228.75L	2.3	08-Aug	20:12	9.1	15-Aug	17:45	11.0	165:33	165.55	0	0	0
229.3L	2.0	09-Aug	9:34	10.4	16-Aug	10:26	10.5	168:52	168.87	0	0	0
229.45L	4.0	09-Aug	9:36	10.4	16-Aug	10:42	10.5	169:06	169.10	0	0	0
229.7L	3.0	09-Aug	9:48	10.3	15-Aug	17:34	11.0	151:46	151.77	0	0	0
229.8M	3.4	09-Aug	9:49	10.3	15-Aug	17:32	11.0	151:43	151.72	0	0	0
230.1L	2.0	09-Aug	9:52	10.3	15-Aug	16:42	11.0	150:50	150.83	0	0	0
230.15R	3.0	09-Aug	10:04	10.2	15-Aug	15:52	11.1	149:48	149.80	0	0	0
230.3M	2.1	09-Aug	10:06	10.2	15-Aug	16:30	11.0	150:24	150.40	0	0	0
230.35R	3.0	09-Aug	10:14	10.2	15-Aug	16:33	11.0	150:19	150.32	0	0	0
228.2M	3.5	09-Aug	10:25	10.6	16-Aug	9:04	10.5	166:39	166.65	0	0	0
228.8L	3.1	09-Aug	10:55	10.2	15-Aug	15:38	11.1	148:43	148.72	0	0	0
228.9M	3.8	09-Aug	10:57	10.2	15-Aug	15:35	11.2	148:38	148.63	0	0	0
228.8L	2.0	15-Aug	15:45	11.0	16-Aug	12:55	10.7	21:10	21.17	0	0	0
229.2M	3.5	15-Aug	15:48	11.0	22-Aug	16:34	10.5	168:46	168.77	0	0	0
230.15R	2.0	15-Aug	16:28	10.9	22-Aug	15:50	10.4	167:22	167.37	0	0	0
230.3M	3.0	15-Aug	16:30	11.0	22-Aug	15:33	10.8	167:03	167.05	0	0	0
230.35R	4.0	15-Aug	16:38	11.0	22-Aug	15:42	10.5	167:04	167.07	0	0	0
230.1L	2.6	15-Aug	17:28	11.0	22-Aug	15:55	10.3	166:27	166.45	0	0	0
229.8M	4.4	15-Aug	17:32	11.0	22-Aug	16:02	10.3	166:30	166.50	0	0	0
229.7L	3.4	15-Aug	17:38	11.0	22-Aug	16:08	10.3	166:30	166.50	0	0	0
228.9M	4.5	15-Aug	17:42	11.1	17-Aug	8:30	10.3	38:48	38.80	0	0	0
228.1M	4.5	15-Aug	18:01	11.1	22-Aug	14:23	11.4	164:22	164.37	0	0	0
228.75L	1.9	16-Aug	9:33	10.4	22-Aug	14:41	10.8	149:08	149.13	0	0	0
228.4R	1.7	16-Aug	9:56	10.7	23-Aug	9:35	10.2	167:39	167.65	0	0	0
228.3M	3.2	16-Aug	9:59	10.5	23-Aug	9:45	10.1	167:46	167.77	0	0	0

Appendix Table A1 Continued

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2018)	Time	Water Temp (°C)	Date (2018)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
228.5M	3.5	16-Aug	10:11	10.6	23-Aug	9:32	10.1	167:21	167.35	0	0	0
228.6M	1.0	16-Aug	10:23	10.6	22-Aug	14:58	10.5	148:35	148.58	0	0	0
229.3L	3.0	16-Aug	10:40	10.4	22-Aug	16:41	10.2	150:01	150.02	0	0	0
229.45L	3.2	16-Aug	10:49	10.4	22-Aug	16:16	10.3	149:27	149.45	0	0	0
228.7M	3.5	16-Aug	12:39	10.9	23-Aug	8:38	10.2	163:59	163.98	0	0	0
228.2M	3.6	16-Aug	13:05	10.5	23-Aug	9:51	10.1	164:46	164.77	0	0	0
228.8L	2.0	17-Aug	8:30	10.4	22-Aug	14:44	10.5	126:14	126.23	0	0	0
227.9L	2.9	17-Aug	12:08	10.4	22-Aug	14:25	11.0	122:17	122.28	0	0	0
228.9M	3.7	17-Aug	12:12	10.6	23-Aug	9:26	10.0	141:14	141.23	0	0	0
228.1M	4.3	22-Aug	14:23	11.4	23-Aug	8:18	10.8	17:55	17.92	0	0	0
228.6M	1.6	22-Aug	14:58	10.4	29-Aug	16:08	10.2	169:10	169.17	0	0	0
230.3M	2.7	22-Aug	15:33	10.8	29-Aug	15:06	10.3	167:33	167.55	0	0	0
230.35R	3.0	22-Aug	15:54	10.4	29-Aug	15:13	10.3	167:19	167.32	0	0	0
230.15R	3.0	22-Aug	15:51	10.3	29-Aug	15:09	10.3	167:18	167.30	0	0	0
230.1L	2.3	22-Aug	16:00	10.3	29-Aug	15:04	10.2	167:04	167.07	0	0	0
229.8M	4.4	22-Aug	16:02	10.3	29-Aug	15:57	10.2	167:55	167.92	0	0	0
229.7L	2.9	22-Aug	16:12	10.3	29-Aug	14:49	10.4	166:37	166.62	0	0	0
229.45L	3.0	22-Aug	16:31	10.2	29-Aug	14:45	10.4	166:14	166.23	0	0	0
229.2M	3.2	22-Aug	16:34	10.2	29-Aug	16:03	10.2	167:29	167.48	0	0	0
229.3L	2.8	22-Aug	16:53	10.1	30-Aug	8:45	10.8	183:52	183.87	0	0	0
228.75L	2.4	22-Aug	17:44	10.3	29-Aug	14:41	10.5	164:57	164.95	0	0	0
228.8L	2.2	23-Aug	8:34	10.3	30-Aug	8:42	10.8	168:08	168.13	0	0	0
228.9M	3.3	23-Aug	9:26	10.0	30-Aug	9:40	10.6	168:14	168.23	0	0	0
228.5M	2.9	23-Aug	9:32	10.1	29-Aug	16:22	10.2	150:50	150.83	0	0	0
228.4R	2.0	23-Aug	9:41	10.3	29-Aug	16:24	10.2	150:43	150.72	0	0	0
228.3M	3.5	23-Aug	9:45	10.2	29-Aug	16:20	10.1	150:35	150.58	0	0	0
228.2M	3.4	23-Aug	9:54	10.1	30-Aug	9:45	10.7	167:51	167.85	0	0	0
228.1M	3.7	23-Aug	11:28	10.5	30-Aug	9:48	10.7	166:20	166.33	0	0	0
227.9L	3.0	23-Aug	11:48	10.1	29-Aug	14:34	10.6	146:46	146.77	0	0	0
228.7M	2.4	23-Aug	11:53	10.4	29-Aug	16:25	10.3	148:32	148.53	0	0	0
229.7L	3.0	29-Aug	15:03	10.0	05-Sep	16:58	12.4	169:55	169.92	0	0	0
230.1L	1.6	29-Aug	15:06	10.2	05-Sep	16:52	12.4	169:46	169.77	0	0	0

Appendix Table A1 Continued

Station Name	Set Depth (m)	Set Data			Pull Data			Total Time	Hours of Effort	WSG Catch Summary[1]		
		Date (2018)	Time	Water Temp (°C)	Date (2018)	Time	Water Temp (°C)			Eggs	Free Embryos	CPUE Eggs (No./hr)
230.3M	1.4	29-Aug	15:08	10.3	05-Sep	14:58	12.3	167:50	167.83	0	0	0
230.15R	2.0	29-Aug	15:10	10.3	05-Sep	15:28	12.0	168:18	168.30	0	0	0
230.35R	2.8	29-Aug	15:35	10.1	05-Sep	15:26	12.0	167:51	167.85	0	0	0
229.8M	2.9	29-Aug	15:59	10.2	06-Sep	10:24	11.4	186:25	186.42	0	0	0
229.2M	2.0	29-Aug	16:04	10.2	06-Sep	10:47	11.5	186:43	186.72	0	0	0
228.6M	1.0	29-Aug	16:09	10.2	05-Sep	15:42	12.1	167:33	167.55	0	0	0
228.4R	1.0	29-Aug	16:17	10.1	05-Sep	17:08	12.2	168:51	168.85	0	0	0
228.3M	2.3	29-Aug	16:21	10.1	06-Sep	11:08	11.5	186:47	186.78	0	0	0
228.5M	2.5	29-Aug	16:23	10.2	06-Sep	13:15	12.4	188:52	188.87	0	0	0
228.7M	1.7	29-Aug	16:26	10.3	06-Sep	13:26	12.0	189:00	189.00	0	0	0
228.75L	1.7	29-Aug	17:49	10.3	05-Sep	14:40	12.7	164:51	164.85	0	0	0
229.45L	3.0	29-Aug	17:55	10.3	06-Sep	11:01	11.6	185:06	185.10	0	0	0
228.9M	3.8	30-Aug	9:41	10.6	06-Sep	13:40	12.0	171:59	171.98	0	0	0
228.2M	3.3	30-Aug	9:45	10.7	06-Sep	11:45	11.7	170:00	170.00	0	0	0
228.1M	3.6	30-Aug	9:48	10.7	06-Sep	11:30	11.8	169:42	169.70	0	0	0
227.9L	2.8	30-Aug	11:25	10.3	05-Sep	14:33	13.4	147:08	147.13	0	0	0
228.8L	2.6	30-Aug	11:41	10.4	05-Sep	14:47	12.3	147:06	147.10	0	0	0
229.3L	2.8	30-Aug	11:55	10.3	06-Sep	10:55	11.5	167:00	167.00	0	0	0

Notes: [1]CPUE = Catch-per-unit-effot; "-" mat not retrievable and no data available

Appendix B
Drift Net Sampling

Table B1. D-Ring larval drift net sampling data collected during middle Columbia River White Sturgeon spawning monitoring, July 25 to September 7,

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 (2018)	Time	Water Temp (°C)	Date (2018)	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)
228.2M	4.8	25-Jul	14:46	10.8	25-Jul	17:36	10.3	2:50	2.83	14.270566	0	0	0	0	0	0
227.9L	4.2	25-Jul	14:50	10.4	25-Jul	17:51	9.8	3:01	3.02	1.579618	0	0	0	0	0	0
228.75L	3.0	25-Jul	14:53	10.3	25-Jul	18:01	9.9	3:08	3.13	2277.3366	0	0	0	0	0	0
228.1M	4.4	26-Jul	8:13	11.2	26-Jul	11:11	10.2	2:58	2.97	2502.6415	0	0	0	0	0	0
229.3L	3.2	26-Jul	8:18	10.7	26-Jul	11:24	10.3	3:06	3.1	1488.5807	0	0	0	0	0	0
228.4R	2.8	26-Jul	8:23	10.4	26-Jul	11:32	10.4	3:09	3.15	4.4283309	0	0	0	0	0	0
227.9L	4.1	1-Aug	14:08	11.6	1-Aug	17:08	10.1	3:00	3	3.3617512	0	0	0	0	0	0
228.1M	5.0	01-Aug	14:11	10.9	01-Aug	17:15	9.9	3:04	3.07	2482.7275	0	0	0	0	0	0
229.3L	2.1	1-Aug	14:15	10.5	1-Aug	17:32	9.9	3:17	3.28	1294.6117	0	0	0	0	0	0
227.9L	4.2	1-Aug	17:14	9.9	2-Aug	8:01	11.3	14:47	14.78	1.8226362	0	0	0	0	0	0
229.3L	2.0	01-Aug	17:37	9.8	02-Aug	8:28	10.2	14:51	14.85	658.68721	0	0	0	0	0	0
228.75L	2.6	02-Aug	8:18	10.2	02-Aug	11:10	11.3	2:52	2.87	2732.0641	0	0	0	0	0	0
228.8L	3.5	02-Aug	8:21	10.2	02-Aug	11:36	10.6	3:15	3.25	1.2150908	0	0	0	0	0	0
230.1L	2.7	02-Aug	8:37	10.4	02-Aug	11:46	10.2	3:09	3.15	1779.676	0	0	0	0	0	0
228.1M	3.9	08-Aug	14:24	12.5	08-Aug	17:32	9.4	3:08	3.13	136.41419	74	0	23.64	0	17.33	0

Appendix Table B1 Continued

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 (2018)	Time	Water Temp (°C)	Date (2018)	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)
227.9L	3.4	08-Aug	14:28	11.5	08-Aug	18:52	9.2	4:24	4.4	1680.43	9	0	2.05	0	0.12	0
228.75L	2.5	08-Aug	14:31	10.8	08-Aug	19:30	9.3	4:59	4.98	5727.9515	0	0	0	0	0	0
228.2M	3.0	09-Aug	7:58	11.2	09-Aug	10:24	10.6	2:26	2.43	2830.203	0	0	0	0	0	0
228.8L	2.6	09-Aug	8:00	10.7	09-Aug	10:50	10.3	2:50	2.83	529.57707	0	0	0	0	0	0
228.9M	3.3	09-Aug	8:06	10.5	09-Aug	10:56	10.2	2:50	2.83	2281.576	0	0	0	0	0	0
227.4L	2.5	15-Aug	15:18	11.7	15-Aug	18:45	11.0	3:27	3.45	402.99161	0	0	0	0	0	0
228.1M	4.5	15-Aug	15:22	11.6	15-Aug	18:00	11.1	2:38	2.63	2723.9905	1	0	0.38	0	0.01	0
227.9L	2.8	15-Aug	15:25	11.4	15-Aug	18:30	11.1	3:05	3.08	399.98088	1	0	0.32	0	0.08	0
228.9M	4.5	15-Aug	15:35	11.2	15-Aug	17:42	11.1	2:07	2.12	3458.8099	0	0	0	0	0	0
228.75L	1.8	15-Aug	17:55	11.0	16-Aug	9:12	10.5	15:17	15.28	5697.3987	0	0	0	0	0	0
227.4L	1.9	16-Aug	8:55	10.6	16-Aug	12:08	10.7	3:13	3.22	2729.7014	0	0	0	0	0	0
227.9L	2.8	16-Aug	9:01	10.5	16-Aug	12:10	10.7	3:09	3.15	1717.8548	0	0	0	0	0	0
228.2M	2.8	16-Aug	9:05	10.5	16-Aug	12:35	10.7	3:30	3.5	2681.9484	0	0	0	0	0	0.0
228.7M	2.3	16-Aug	9:36	10.5	16-Aug	12:39	10.9	3:03	3.05	9799.1941	0	0	0	0	0	0
227.4L	2.0	16-Aug	12:09	10.7	16-Aug	17:05	10.4	4:56	4.93	3705.7299	0	0	0	0	0	0

Appendix Table B1 Continued

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 (2018)	Time	Water Temp (°C)	Date (2018)	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)
227.9L	2.6	16-Aug	12:31	10.6	16-Aug	17:20	10.4	4:49	4.82	1389.9693	2	0	0.41	0	0.03	0
228.2M	3.1	16-Aug	12:35	10.7	16-Aug	13:05	10.5	0:30	0.5	661.1579	0	0	0	0	0	0
228.8L	2.8	16-Aug	12:55	10.7	16-Aug	17:44	10.2	4:49	4.82	3939.6348	0	0	0	0	0	0
228.2L	3.0	16-Aug	13:27	10.7	16-Aug	18:02	10.2	4:35	4.58	1106.6912	1	0	0.22	0	0.02	0
228.8L	3.0	16-Aug	17:45	10.2	17-Aug	8:24	10.4	14:39	14.65	1278.154	0	0	0	0	0	0
227.4L	3.5	17-Aug	8:14	10.4	17-Aug	11:45	10.8	3:31	3.52	10.787306	0	0	0	0	0	0
228.2L	2.1	17-Aug	8:17	10.2	17-Aug	11:50	10.6	3:33	3.55	2027.5815	0	0	0	0	0	0
227.9L	2.6	17-Aug	8:21	10.5	17-Aug	12:00	10.6	3:39	3.65	432.86934	0	0	0	0	0	0
228.9M	2.6	17-Aug	8:32	10.3	17-Aug	12:12	10.6	3:40	3.67	4348.4454	0	0	0	0	0	0
227.9L	3.2	22-Aug	14:25	11	22-Aug	17:20	10.3	2:55	2.92	1.9171432	0	0	0	0	0	0
228.2L	2.5	22-Aug	14:37	10.5	22-Aug	17:29	10.1	2:52	2.87	209.13062	0	0	0	0	0	0
228.75L	2.0	22-Aug	14:41	10.8	22-Aug	17:39	10.1	2:58	2.97	2707.4248	0	0	0	0	0	0
228.8L	2.7	22-Aug	14:44	10.8	22-Aug	17:46	10.3	3:02	3.03	1364.5605	0	0	0	0	0	0
227.9L	2.8	22-Aug	17:27	10.1	23-Aug	8:23	10.4	14:56	14.93	0.1215091	0	0	0	0	0	0
228.2L	3.5	22-Aug	17:35	10.1	23-Aug	8:28	10.2	14:53	14.88	2387.8424	0	2	0	0.13	0	0.08

Appendix Table B1 Continued

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 (2018)	Time	Water Temp (°C)	Date (2018)	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	2.9	22-Aug	17:53	10.1	23-Aug	8:38	10.2	14:45	14.75	3824.4712	0	0	0	0	0	0
228.1M	3.0	23-Aug	8:19	10.8	23-Aug	11:27	10.5	3:08	3.13	5766.0648	0	0	0	0	0	0
227.9L	2.8	23-Aug	8:26	10.6	23-Aug	11:30	10.5	3:04	3.07	4.9548702	0	1	0	0.33	0	20.18
228.2L	3.0	23-Aug	8:30	10.2	23-Aug	11:57	10.4	3:27	3.45	2793.0752	0	1	0	0.29	0	0.04
228.7M	1.8	23-Aug	8:38	10.2	23-Aug	11:53	10.4	3:15	3.25	202.0696	0	1	0	0.31	0	0.49
227.9L	2.5	29-Aug	14:36	10.9	29-Aug	17:31	10.2	2:55	2.92	2767.6393	0	0	0	0	0	0
227.4L	3.0	29-Aug	14:39	10.6	29-Aug	17:36	10.2	2:57	2.95	-	0	0	0	0	0	0
228.75L	2.0	29-Aug	14:43	10.5	29-Aug	17:44	10.3	3:01	3.02	2.1736624	0	0	0	0	0	0
229.45L	2.0	29-Aug	14:46	10.4	29-Aug	17:51	10.4	3:05	3.08	2339.1173	0	0	0	0	0	0
227.9L	2.4	29-Aug	17:33	10.2	30-Aug	8:30	10.9	14:57	14.95	12140.377	0	0	0	0	0	0
227.4L	2.7	29-Aug	17:42	10.1	30-Aug	8:36	10.8	14:54	14.9	-	0	0	0	0	0	0
227.9L	2.6	30-Aug	8:33	10.9	30-Aug	11:23	10.3	2:50	2.83	1050.473	0	0	0	0	0	0
227.4L	3.3	30-Aug	8:39	10.8	30-Aug	11:27	10.4	2:48	2.8	-	0	0	0	0	0	0
228.8L	2.6	30-Aug	8:43	10.8	30-Aug	11:39	10.4	2:56	2.93	304.43425	0	0	0	0	0	0
229.3L	2.1	30-Aug	8:46	10.8	30-Aug	11:44	10.4	2:58	2.97	183.03317	0	0	0	0	0	0

Appendix Table B1 Continued

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 (2018)	Time	Water Temp (°C)	Date (2018)	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)
227.9L	1.5	05-Sep	14:34	13.4	05-Sep	17:15	12.0	2:41	2.68	1.552616	0	0	0	0	0	0
228.2L	3.2	05-Sep	14:38	12.8	05-Sep	17:19	12.0	2:41	2.68	80.776535	0	0	0	0	0	0
228.75L	2.1	05-Sep	14:46	12.1	05-Sep	17:33	12.0	2:47	2.78	2757.9726	0	0	0	0	0	0
228.8L	2.4	05-Sep	14:49	12.3	05-Sep	17:37	12.0	2:48	2.8	-	0	0	0	0	0	0
227.9L	2.0	05-Sep	17:17	12.0	06-Sep	8:54	11.5	15:37	15.62	1.552616	0	0	0	0	0	0
228.2L	3.2	05-Sep	17:29	11.9	06-Sep	8:57	11.5	15:28	15.47	2807.6023	0	0	0	0	0	0
228.75L	2.0	05-Sep	17:34	12.0	06-Sep	9:03	11.5	15:29	15.48	7416.3336	0	0	0	0	0	0
228.8L	2.8	05-Sep	17:45	11.9	06-Sep	9:11	11.5	15:26	15.43	-	0	0	0	0	0	0
227.9L	2.5	06-Sep	8:56	11.5	06-Sep	14:50	12.0	5:54	5.9	32.604936	0	0	0	0	0	0
228.75L	2.1	06-Sep	9:06	11.5	06-Sep	14:23	11.2	5:17	5.28	5034.5936	0	0	0	0	0	0
228.8L	2.7	06-Sep	9:15	11.5	06-Sep	14:31	11.4	5:16	5.27	3082.0508	0	0	0	0	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 sampling locations during middle Columbia River White Sturgeon spawning monitoring, 2018.

Station Name	UTM Coordinates		
	Zone	Easting	Northing
227.4L	11	414089	5651566
227.9L	11	413514	5651425
228.1M	11	413479	5651377
228.2L	11	413422	5651358
228.2M	11	413423	5651354
228.3M	11	413199	5651289
228.4R	11	413066	5651399
228.5M	11	413204	5651482
228.6M	11	413127	5651589
228.75L	11	413287	5651641
228.7M	11	413251	5651614
228.8L	11	413324	5651688
228.9M	11	413366	5651764
229.2M	11	413454	5651985
229.3L	11	413572	5651926
229.45L	11	413752	5652060
229.4M	11	413651	5652059
229.7L	11	413989	5652218
229.8M	11	414050	5652299
230.15R	11	414193	5652557
230.1L	11	414267	5652397
230.35R	11	414364	5652677
230.3M	11	414339	5652533
Temperature Logger	11	413479	5651377