Duncan Dam Project Water Use Plan

Lower Duncan River Kokanee Spawning Monitoring

Reference: DDMMON-4

Year 5 Data Report (2012)

Study Period: September - October 2012

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Lower Duncan River Kokanee Spawning Monitoring (DDMMON-4)

Year 5 Data Report (2012)

Submitted to:
BC Hydro
Burnaby, BC

Submitted by:
AMEC Environment & Infrastructure
Nelson, BC

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EXECUTIVE SUMMARY

The Duncan Dam (DDM) Water Use Planning (WUP) project was initiated to address flow management issues with respect to impacts on competing resources in the area. During this process, several data gaps were identified with respect to kokanee spawning in the Lower Duncan River (LDR). Monitoring studies under the Duncan Dam (DDM) Water Use Plan (WUP) were initiated in September 2008 to enumerate kokanee and collect information on spawning habitats and use, as well as biological sampling of kokanee morphology in the LDR and the Lardeau River. A synthesis report was prepared following Year 4 (2011) monitoring which details information collected to address BC Hydro's management questions for DDMMON-4 (AMEC 2012).

This report presents data collected during the 2012 (Year 5) spawning period. Overall, the management questions are being answered and the program objectives are being met under the existing study plan. This study recommends that the Action Plan to Minimize Stranding of Kokanee Spawning in Lower Duncan River Sidechannels program (DDMWORKS-4) utilize the information herein and in AMEC (2012) to develop a long term strategy to optimize kokanee productivity in the lower Duncan River. Responses to BC Hydro's management questions for DDMMON-4 are provided in the following table, including contributions from this year's study.

Management Question	Status
What is the spawn run timing, fry emergence timing, and relative intensity of kokanee spawning in the Lower Duncan River? What potential operational/environmental cues affect this variable?	Spawn run timing for kokanee in the LDR occurs from late August to late October, with peak spawning estimated between September 20 and October 10. Preliminary analyses conducted under DDMMON-7 indicated that the drop in discharge that occurs in the LDR in late September may have an effect on the distribution of spawning kokanee as this is affiliated with the change in proportion of kokanee observed on the left and right banks. That is, after the drop occurs, more kokanee are proportionally seen on the right bank than before the drop. No pattern was observed between discharge at DRL assessed from early to mid-September and the timing of the kokanee spawn timing (AMEC and Poisson 2012). No trend for spawn timing and LDR water temperatures were observed (AMEC and Poisson 2012). Information on fry emergence timing is provided in the Year 4 synthesis report and was not directly studied in Year 5 (AMEC 2012). As discussed in AMEC (2012), fry emergence timing in the LDR occurred in December/January, with ponding estimated in February/March. Fry emergence was approximately 3 months earlier in the LDR than that estimated for the Lardeau River and Meadow Creek. Fry emergence timing is dependent on water temperature, which is influenced by DDM operations. It is unknown whether earlier emergence is disadvantageous to LDR kokanee fry at this time.

	Relative Intensity: The majority of kokanee in the Duncan River system were observed to spawn in Meadow Creek (52%), followed by the Lardeau River (45%) and lastly the LDR (3%); this was similar to what has been observed from 2002 to 2011 though the proportion of spawners in Meadow Creek was lower and Lardeau higher than in most years. The regulation of the LDR has caused substrate compaction and reduced the amount of spawning habitat for kokanee compared to that available historically, but it is unknown whether this is why lower proportions of spawners are observed in the LDR versus Meadow Creek and the Lardeau River. Relative intensity of kokanee spawning in the LDR is also highly influenced by in-lake adult and fry survival, lake fertilization, predation, density dependence, angling pressure and general lake conditions.
What are the timing/cues of kokanee spawners in Meadow Creek and Lardeau River systems?	Information is provided in the Year 4 synthesis report and was not directly studied in Year 5 (AMEC 2012). As per AMEC (2012), spawning in Meadow Creek occurs from mid-August to late October with peak spawning during mid- to third week of September. Previous research suggests that water temperature may not influence spawn timing/arrival. In the Lardeau River, spawning occurs from early September to mid-October with peak during last week of September. There is a lack of information on cues in the Lardeau River.
What are the relative distribution of kokanee spawners in the Lower Duncan River, Meadow Creek and Lardeau River? What potential operation/environmental/physical cues (e.g., temperature, velocity, depth, cover, substrate) affect this variable?	LDR: Spawning has been observed in the upper 9 km of the LDR likely because these areas have more suitable spawning gravels present compared to lower regions of the river, which are largely comprised of fines due to the regulation of Kootenay Lake. The regulation of the LDR has also caused substrate compaction and reduced the amount of spawning habitat for kokanee compared to that available historically, but it is unknown whether this is why lower proportions of spawners are observed in the LDR versus Meadow Creek and the Lardeau River (see above). Observations suggest that early spawning begins in side channel habitats, but by the peak of spawning kokanee are in side channel and mainstem habitats with approximately equal frequency. Kokanee move into side channels earlier than the mainstem likely because they are seeking out low velocity, cooler (shadowed) areas to minimize energy expenditure as has been observed for kokanee in Meadow Creek. Preliminary analyses conducted under DDMMON-7 indicated that the drop in discharge that occurs in the LDR in late September may have an effect on the distribution of spawning kokanee as this is affiliated with the change in proportion of kokanee observed on the left and right banks. That is, after the drop occurs, more kokanee are

	proportionally seen on the right bank than before the drop. No pattern was observed between discharge at DRL assessed from early to mid-September and the timing of the kokanee spawn timing (AMEC and Poisson 2012). No trend for spawn timing and LDR water temperatures were observed (AMEC and Poisson 2012). Meadow Creek: As per AMEC (2012), the majority of spawning occurs in the 3 km spawning channel. Areas upstream and downstream of the spawning channel (SC) fence are also used when kokanee are no longer able to enter the channel (i.e., channel is closed due to maximum channel loading). Distribution is affected by the presence of the spawning fence, the waterfall barrier (2 km upstream of the SC) and silt substrates that are not well suited for spawning in the lower section of the river. The spawning channel likely provides more suitable spawning substrates, since it was specifically built in 1967 to compensate for half of the kokanee run lost due to DDM construction and now provides 3 km of spawning gravels specific to kokanee spawning. Lardeau River: As per AMEC (2012), spawning occurs along the length of the river with most preferred areas in the uppermost side channels. Suitable spawning substrates are found in the Lardeau River based on the intensity of spawning observed (see above). In addition, the Lardeau River experiences a natural hydrograph and flushing flows aid in removing fine sediments that may build-up within substrate interstices. Genetic analysis has determined that kokanee spawners from the LDR, Lardeau River and Meadow Creek were not genetically distinct and can be considered from the same stock (AMEC 2012; Lemay and Russello 2011).
What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended kokanee spawning operations?	A summary of physical works or operational constraints that could be implemented with rationale/benefits for kokanee spawning protection was provided in AMEC (2012) and has not been included herein. Suggestions in AMEC (2012) have the potential to reduce the estimated annual dewatering of 0.14% of kokanee eggs deposited in the entire Duncan River system under baseline operations.

1.0 INTRODUCTION

Duncan Dam (DDM) was built in 1967 as a storage facility under the Columbia River Treaty (CRT). Prior to the DDM Water Use Plan (WUP) implementation in 2007, flow management in the Lower Duncan River (LDR) below DDM was dictated by seasonal operating targets set by the CRT and, to a lesser degree, by water level requirements for Kootenay Lake set by the International Joint Commission. A number of flow management issues (e.g., CRT, fisheries, and recreational users) impose significant challenges for the operation of DDM. Four unregulated tributaries also influence the flow regime in the LDR (i.e., Lardeau River, Meadow Creek, Cooper Creek, and Hamill Creek; Figure 1). The DDM Water Use Planning (WUP) project was initiated to address flow management issues with respect to impacts on competing resources in the area. The DDM WUP Consultative Committee (CC) identified kokanee (*Oncorhynchus nerka*) spawning success in the LDR as an issue that could be impacted by DDM operations (BC Hydro 2007).

BC Hydro commitments to the DDM WUP and to meeting flow management targets set under the Columbia River Treaty restrict the timing and amount of flow that can be delivered in the fall during the kokanee spawning period (August to October). Flow targets set out by the DDM WUP specify a maximum target of 73 m^3/s flow from October 1 to 22 and increasing discharge hereafter as measured at the Water Survey of Canada (WSC) gauge (08N118) below the confluence of the Duncan and Lardeau rivers (BC Hydro 2007). Kokanee spawn monitoring studies under the Duncan Dam (DDM) Water Use Plan (WUP) were completed each fall from 2008 to 2011. The following report presents data collected during the 2012 (Year 5) spawning period, which focused on a subset of the objectives, management questions and hypotheses listed below.

2.0 OBJECTIVES

The following are objectives and management questions related to DDMMON-4 program. Those illustrated in ***bolded italics*** were covered during Year 5 (2012) and the remaining were covered during the four year program that was conducted between 2008 and 2011 (AMEC 2012).

Specific objectives of the Lower Duncan River Kokanee Monitoring program as summarized from the Terms of Reference (TOR) were to:

1. ***Document the annual kokanee escapement to the Lower Duncan River***, Lardeau River, Meadow Creek, and the Meadow Creek Spawning Channel;
2. ***Document kokanee spawning in the Lower Duncan River within and outside of operational constraints***; and,
3. Define kokanee spawning habitat preferences, timing and kokanee morphology between spawning runs in the Lower Duncan River, Lardeau River and Meadow Creek for consideration of future decision analyses.

Management questions outlined in the TOR include:

1. ***What is the spawn run timing***, fry emergence timing, and relative intensity of ***kokanee spawning in the Lower Duncan River***? What potential operational/environmental cues affect this variable?

2. What are the timing/cues of kokanee spawners in Meadow Creek and Lardeau River systems?
3. ***What are the relative distribution of kokanee spawners in the Lower Duncan River, Meadow Creek and Lardeau River?*** What potential operation/environmental/physical cues (e.g., temperature, velocity, depth, cover, substrate) affect this variable?; and
4. What physical works or operational constraints could be implemented to minimize operational conflicts associated with recommended kokanee spawning operations?

2.1 Purpose

The following report fulfills AMEC's commitment to provide BC Hydro with a data report for the 2012 (Year 5) kokanee spawning period and adds to the dataset collected to support BC Hydro's specific objectives and management questions as indicated above.

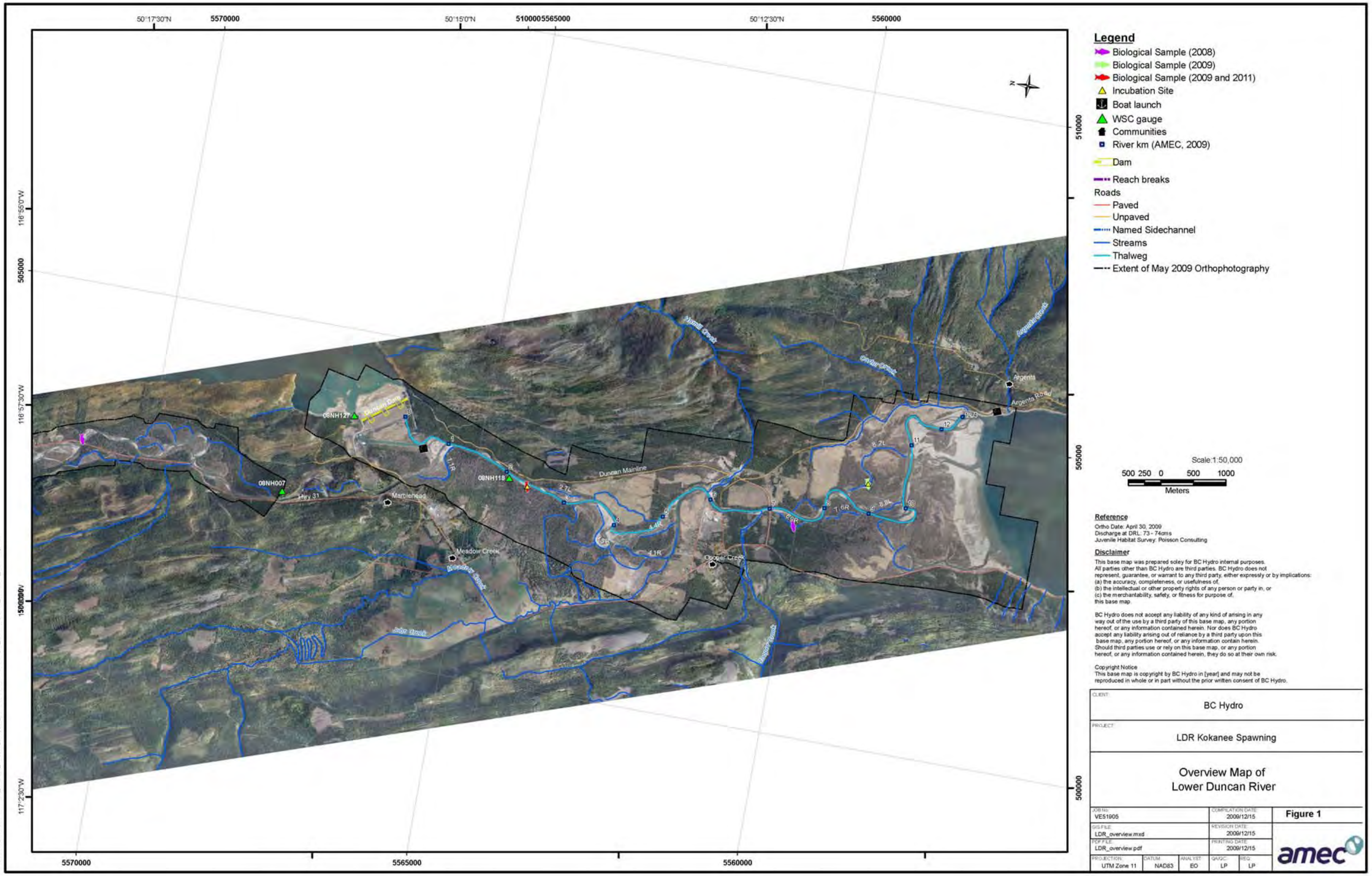

Figure 1: ***Overview of the Lower Duncan River and its major tributaries depicting sample sites, 2008-2011. Biological sampling was not conducted in 2012, only helicopter enumeration.***

3.0 METHODS

3.1 Study Area

The Duncan River flows into the northern end of Kootenay Lake, north of Nelson in south-eastern British Columbia. The river drains both the Selkirk and Purcell mountains into Kootenay Lake. The study area for the Kokanee Spawning Monitoring program included the entire LDR from Duncan Dam (River Km 0.0) to Kootenay Lake (Km 12.4) and its associated side channels (Figure 1).

3.2 Environmental Parameters

Hourly discharge and water temperature records were obtained for the LDR from the Water Survey of Canada (WSC) gauge (No: 08N118) below the Lardeau and Duncan rivers confluence (DRL) from BC Hydro's Access database.

3.3 Sample Timing

A summary of sampling dates for 2012 LDR kokanee spawn monitoring studies conducted is provided in Table 1. Sampling included helicopter enumeration and mapping. A test flight occurred on September 21, 2012 to assess the feasibility of using a single engine 206 Long Ranger; the use of this aircraft required enumeration surveys to be conducted at or above 500 ft. above ground level (A. Simpson, BC Hydro Aircraft Operations, pers. comm., 2012). It was determined that enumeration of kokanee in the LDR at this height was not feasible due to the abundance of debris in the system and small size of the fish. Due to the poor visibility at this elevation and potential for inaccurate enumeration, counts from September 21 were not included in analyses. This method was trialed as it was successful on the lower Columbia River for the enumeration of spawning rainbow trout and the helicopter provided better visibility for two observers (J. Baxter, Owner, Mountain Water Research, pers. comm., 2012). Further details for each sample method are provided below.

Table 1: Sample timing and survey type for DDMMON-4 LDR kokanee spawn monitoring, 2012.

Date	Survey Type	Helicopter Type
21 September	LDR Enumeration; test flight	206 LongRanger; Highland Helicopters, Castlegar, BC
26 September	LDR Enumeration; side channel spawn mapping	BO105LS (Twin); Dam Helicopters, Castlegar, BC
3 October	LDR Enumeration; side channel spawn mapping	BO105LS (Twin); Dam Helicopters, Castlegar, BC
10 October	LDR Enumeration; mainstem spawn mapping	BO105LS (Twin); Dam Helicopters, Castlegar, BC

3.4 Helicopter Enumeration Surveys

Helicopter enumeration surveys were conducted to collect data specifically related to Specific Objectives #1 and #2, Hypotheses H01 and to obtain information to help answer Management Questions #1 through #3 for this program (Section 2.0). The following standardized methods were used to enumerate kokanee in the LDR system and follow those used for the past five years.

Helicopter surveys were used to enumerate adult kokanee in the LDR. Enumeration surveys covered the entire 12.4 km length of the LDR starting from the delta (confluence with Kootenay Lake) to approximately 0.6 km downstream of DDM (Figure 1). All side channels in the LDR were also surveyed and enumerated for kokanee. Enumeration surveys were not conducted in the DDM tailrace section between DDM and Km 0.6 as kokanee have not been historically observed to use this area for spawning. However, this area was surveyed during the September 24, 2008 and October 9, 2010 flights to confirm presence/absence of kokanee spawners in the discharge channel; kokanee were not observed during these two surveys (AMEC 2012). During the previous four years, it was decided that the DDM discharge channel would not be included in regular enumeration surveys and this was followed in 2012 (AMEC 2012).

In previous years, eight helicopter surveys were conducted to determine the peak spawning period. However, in 2012 four helicopter surveys were conducted during the peak spawning period, mid-September to mid-October, to concentrate efforts around this time as recommended in AMEC (2012). The helicopter used for the initial survey on 21 September 2012 was a 206 Long Ranger piloted by Mark Homis from Highland Helicopters (Castlegar/Nakusp, BC). This carrier/pilot has previously conducted kokanee enumeration surveys in tributaries of Arrow Lakes Reservoir. Flight elevation requirements when using this aircraft were not appropriate for kokanee enumeration in the LDR (Section 3.3.). The helicopter used for the three remaining flights was a BO105LS twin engine piloted by Duncan Wassick from Dam Helicopters (Castlegar, BC). This aircraft and pilot conducted the kokanee spawning surveys of the LDR in 2011.

Standard 1:4,000 detailed maps were used to conduct enumeration surveys as per previous years (AMEC 2012). These maps were divided into mainstem and side channel areas and location markings delineated every 100 m to identify areas where kokanee and spawning areas were present. Counters marked the location, number of kokanee, and spawning behaviour within 100 m sections on the orthophoto maps during each survey. Kokanee spawning behaviour was recorded as follows:

- **Holding** – Kokanee observed in a group/school that were stationary;
- **Migrating** – Kokanee observed in a group/school that were moving in an upstream direction (may include single fish moving upstream);
- **Spawning** – Kokanee observed in relatively stationary pairs and distributed evenly throughout an area; and,
- **Dead** – Kokanee were observed floating/drifting at the surface belly up.

Counts were separately conducted by two individuals sitting on the left-hand side of the helicopter (one in front and one directly behind). The helicopter was flown in a manner, which permitted the main counters to view the entire width of the channel. The pilot also manoeuvred the aircraft as necessary to maximize the river view for the main counters. The flight on 21 September was conducted approximately 155 m above the ground while the remaining flights were conducted at approximately 20 m above the ground. All flights were conducted between 10 to 18 km/hr depending on the terrain, safety hazards, and weather conditions. Each flight divided the LDR between the mainstem and its side channels, so that the entire mainstem was surveyed first (in an upstream direction) followed by individual side channels. This method allowed for systematic surveys to be conducted and counters could better determine the spawning/fish locations. Counts were conducted by the same crew used during the past five years (AMEC 2012). These helicopter methods are similar to those standards used for salmonid aerial counts throughout the Pacific Northwest (e.g., Jones et al. 2007).

3.5 Helicopter Spawn Mapping Surveys in the LDR

Spawn mapping surveys were conducted to obtain information to address Hypotheses H02 through H04, Specific Objective #2 and to help answer Management Question #3 (Section 2.0). Also, the TOR specified that a spawning success measure for the entire LDR be obtained to evaluate DDM flow management with respect to the kokanee spawning period.

As per previous years, spawn mapping was conducted throughout the entire LDR using 1:500 orthophoto maps to delineate kokanee spawning locations during the spawning period (AMEC 2012). Kokanee redd and areas where kokanee were actively spawning were directly drawn onto the 1:500 orthophotos. In 2012, spawn mapping was conducted in side channels before and after kokanee spawning protection flows that occurred on October 1 (September 26 and October 3, respectively). Spawn mapping was conducted in the mainstem only after the flow reduction on October 10 as there was not enough time during flights to conduct both side channel and mainstem spawn mapping and very few mainstem spawning areas became dewatered in previous years (Table 1 and 2; AMEC 2012).

Table 2: Maximum target flows as measured in the Lower Duncan River downstream of the Lardeau River at the WSC gauge (08NH118). Bolded/italicized values represents the discharge when spawn mapping surveys were conducted.

Date Range	Maximum Discharge (m^3/s)
25 August to 24 September	250
25 to 27 September	***190***
28 to 30 September	130
1 to 21 October – Kokanee Protection Flow	***73***[a]
22 October to 21 December	110
22 December to 9 April	250[b]
10 April to 15 May	120
16 May to 31 July	400

[a] Note that during this period the maximum and minimum flow targets are identical.
[b] In the event that this maximum flow target does not allow BC Hydro to meet CRT reservoir level targets, then this maximum may increase to 300 m^3/s or the variance value approved by the US Army Corps of Engineers (BC Hydro 2005).

3.6 Data Analyses

Enumeration and spawn mapping data were entered into the DDMMON-4 MS Access database developed specifically for this program (AMEC 2012). Data QA/QC was conducted via data sort and tabulation functions in MS Access and Excel and any data entry errors and/or inconsistencies in the data were verified and corrected.

3.6.1 Area Under the Curve (AUC) Abundance Estimates

To refine spawn timing and escapement estimates (Specific Objectives #1 and Management Question #1), area-under-the-curve (AUC) abundance estimates were calculated using Bayesian methods to estimate aerial observer efficiency as well as peak spawn timing and spawner abundance of kokanee in the LDR from 2008 to 2011 (AMEC 2012). An expansion factor for converting peak counts to total abundance was also calculated. These analyses were updated with data collected in 2012 where applicable (Appendix A). Note that values for 2008 – 2011 may vary from those presented in previous reports as a result of the inclusion of data collected in 2012. Detailed statistical methods are provided in AMEC (2012) and summarized in Appendix A.

3.6.2 Relative Intensity of Spawning

Peak kokanee spawner counts collected in the LDR and Lardeau River were expanded by the mean expansion factor as calculated by the AUC analysis. Abundance estimates for Meadow Creek were based on actual counts at the MCSC enumeration fence plus the estimated number of kokanee in the Meadow Creek stream proper (MOE, unpublished). Counts for Meadow Creek proper were based on one peak count per year, but this count could not be expanded since this data was not available currently for each year (MOE, unpublished). Information was not included from enumeration surveys conducted from 2002 to 2007 because fish were not distinguished between migrating, spawning and holding in the LDR as per the present study. In 2011, the peak count was observed on September 26 when only side channel enumeration was possible due to weather (Section 4.2.1). Therefore, the next highest count when both sidechannel and mainstem areas were surveyed (September 22; spawner count= 43,386) was used for the LDR peak count in 2011 to allow comparisons between systems.

3.6.3 Potential Egg Deposition & Egg Losses

As per previous studies, spawn mapping was used to determine the number of spawners and spawning area used in the LDR in 2012 (AMEC 2012). Potential egg deposition was calculated for spawn mapping conducted before and after the October 1 kokanee protection flow.

Pre-Reduction PED was calculated as:

Number Female kokanee x (Fecundity – Egg Retention).

Post-reduction PED was calculated as:

$$[(PED_{before} * Area_{after}) / Area_{before})].$$

Mean fecundity and egg retention was used as per AMEC (2012). For the LDR it was determined that a simple calculation of PED was not representative of spawning success due to the observed dewatering of spawning areas during October flow reductions. Therefore, it was necessary to determine the area used by spawning kokanee versus the spawning area dewatered to estimate the potential number of fertilized kokanee eggs that were initially deposited in the LDR and remained wetted (i.e., alive) versus the number of eggs that were dewatered (i.e., dead) and would contribute to the adult spawning population in the future. Using the number of female kokanee in an area is a better method than redd enumeration due to inherent difficulties in counting redds and redd superimposition (AMEC

2009). Helicopter mapping was effective because the entire LDR could be mapped in approximately 1 to 3 hours, depending on the aircraft, and provided a relatively accurate means to determine area, since both boat and ground surveys were not suitable for spawn mapping of the entire LDR study area (AMEC 2009).

The following assumptions were made to estimate kokanee spawning success in the LDR:

1. Areas dewatered kill 100% of eggs once they are exposed.
2. PED is based on a snapshot of the number of spawning females at a site immediately prior to flow reductions and does not consider spawning activity outside the survey period, redd superimposition, and does not include egg losses due to predation.
3. Females make one redd and spawn once in the area where they are observed. Information available on Meadow Creek kokanee indicates that females mostly construct one redd, but some may construct more (Morbey 2003, Morbey and Ydenberg 2003). Morbey and Ydenberg (2003) observed that approximately 30% of the kokanee redds in Meadow Creek were superimposed and that re-using redds likely caused a significant source of egg mortality. However, estimated mortality due to excavation was not available.
4. Sex ratios of kokanee in the LDR are similar to that reported for the MCSC (i.e., nearing 1:1), since this information was not available for the LDR (AMEC 2008). Therefore, enumeration counts can be divided evenly among the sexes.

After each spawn mapping survey, 1:500 orthophotos were scanned, digitized by GIS personnel and the digitized areas were measured. Area totals for each spawn mapping survey were used to determine spawning success in the LDR in conjunction with PED.

Since the majority of dewatering was observed to occur in side channel habitats compared to the mainstem LDR, PED was calculated separately for each habitat area (i.e., side channel versus mainstem; AMEC 2012).

4.0 RESULTS

4.1 Environmental Parameters

4.1.1 LDR Discharge and Water Temperature

Mean daily discharge and water temperature below DDM measured at DRL in 2012 is presented in Figure 2. Discharge patterns followed the maximum target flows for the kokanee spawning period. In general, discharge in 2012 was similar to 2011 in that it seemed to follow a more natural hydrograph with the larger peak in July/August, whereas in the other years of the program two smaller discharge peaks were observed between May and August (AMEC 2012). Highest maximum discharge during the 5-year study period of DDMMON-4 was observed on July 23, 2012 with a peak mean daily discharge of 571 m^3/s (AMEC 2012). This was the highest discharge recorded since 1997 (BC Hydro Duncan Dam Elevation Discharge Access Database).

In general, water temperature in the LDR reaches annual maximums in July or August and minimums during the winter period (AMEC 2012). Mean water temperature over the September/October kokanee spawning period ranged from 9°C to 12.5°C in 2012 (Figure 2). Maximum water temperature observed in 2012 was 15°C in mid-August after which time temperatures steadily declined to approximately 9°C by the end of October.

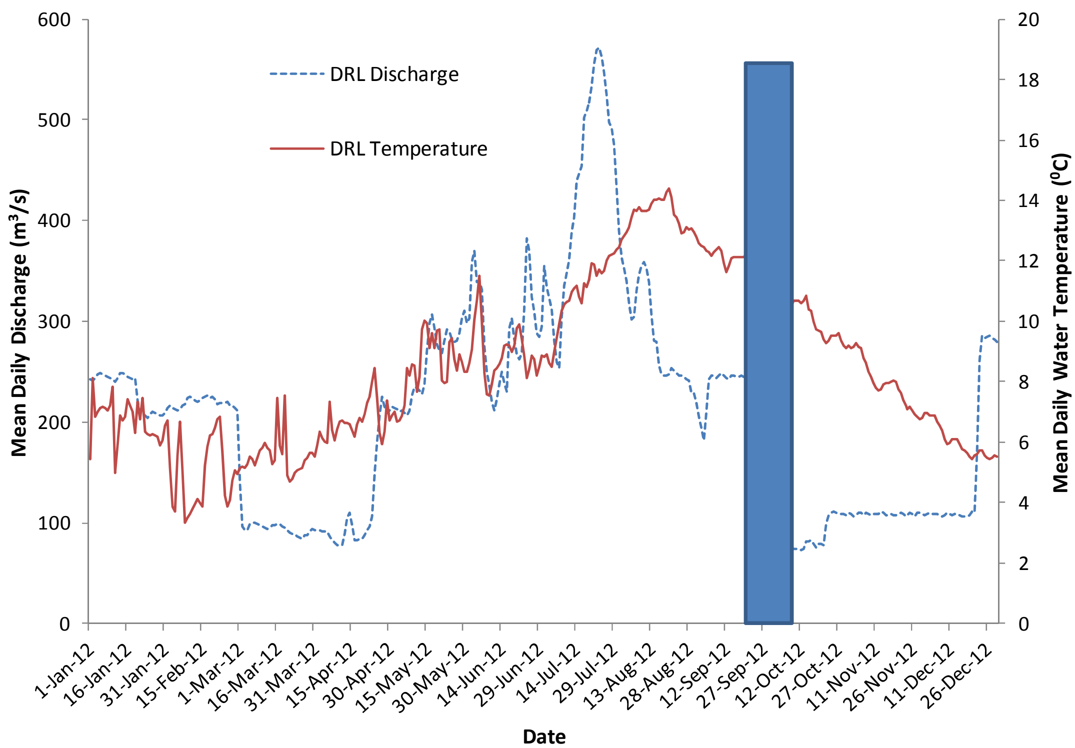

Figure 2: ***Mean daily discharge and water temperature at DRL (Water Survey of Canada gauge No: 08NH118), 2012. Shaded box represents the kokanee enumeration period.***

4.2 Kokanee Escapement

The majority of kokanee enumerated in the LDR during the initial 2012 survey were observed to be holding (Figure 3). The number of holding kokanee decreased as the fish began spawning; most fish were observed to be spawning following the October 1 flow reduction (Figure 3). The distribution of spawning kokanee was similar in side channel and mainstem areas until the final enumeration survey when the majority was observed in mainstem spawning areas (Table 3). The number of migrating fish was similar during the three enumeration surveys though increased slightly in the latter half of the enumeration period (Figure 3).

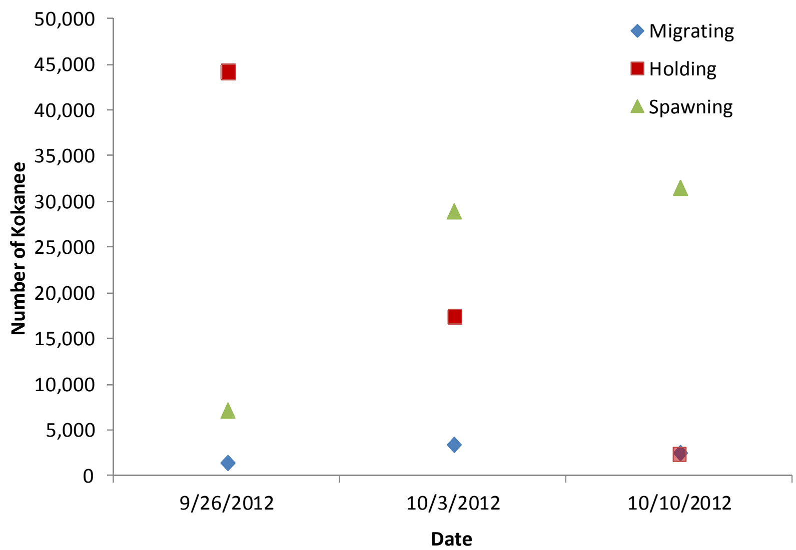

Figure 3: ***Number of migrating, holding and spawning kokanee enumerated in the lower Duncan River, 2012.***

Table 3: ***The number of spawning kokanee distributed in the side channels and the mainstem lower Duncan River, 2012.***

Date	Mainstem	Side Channels
26-Sep-12	3,228	3,933
3-Oct-12	14,785	14,157
10-Oct-12	26,688	4,828

4.2.1 Peak Counts

The number of spawning kokanee peaked in the LDR during early October 2012, which was similar to that observed since 2002 (Table 4). Peak spawning has been observed in early September at the Meadow Creek spawning channel and in late September in the Lardeau River (AMEC 2008).

Table 4: Annual peak kokanee spawner counts in the LDR study area, 2002-2012.

Year	Day	Peak Count[a]
2002	September 20	6,000
2003	October 6	26,069
2004	October 1	3,000
2005	September 27	2,200
2006	September 25	2,305
2007	September 19	24,320
2008	October 2	25,114
2009	October 7	10,220
2010	September 30	12,998
2011	September 26[b]	30,728+
2012	October 10	31,516

[a]Surveys conducted prior to 2008 did not distinguish between spawning, migrating, or holding fish and may not reflect actual number of kokanee spawning in the LDR. Surveys conducted since 2008 have counted kokanee based on spawning behaviour.
[b] The peak count is the estimated number of spawners in side channels of the LDR only, since the helicopter survey could not be carried out in the mainstem. This was the highest number of kokanee observed spawning in side channels in 2011.

4.2.2 AUC

The total aerial counts are plotted with the daily spawner abundance predicted by the hierarchical Bayesian AUC analysis in Figure 4 (Appendix A). Visibility was not found to influence spawner abundance during previous analyses (AMEC 2012). The total annual spawner abundance estimates with 95% credibility intervals are plotted in Figure 5 and tabulated in Table 5. The timing of peak spawning with 95% credibility intervals is plotted in Figure 6. The ratios of the expected annual spawner abundance to peak counts by year is plotted in Figure 7.

In summary, the results of the AUC analyses suggest that:

- approximately 112,000 kokanee spawned in the LDR in 2012 compared to 92,000 in 2011, 25,000 in 2010 and 2009 and 35,000 in 2008;
- peak spawning occurs between September 20 and October 10;
- the mean expansion factor for converting the peak count into the total spawner abundance is 1.5 although it could be as low as 0.8 or as high as 3.0 depending on the year.

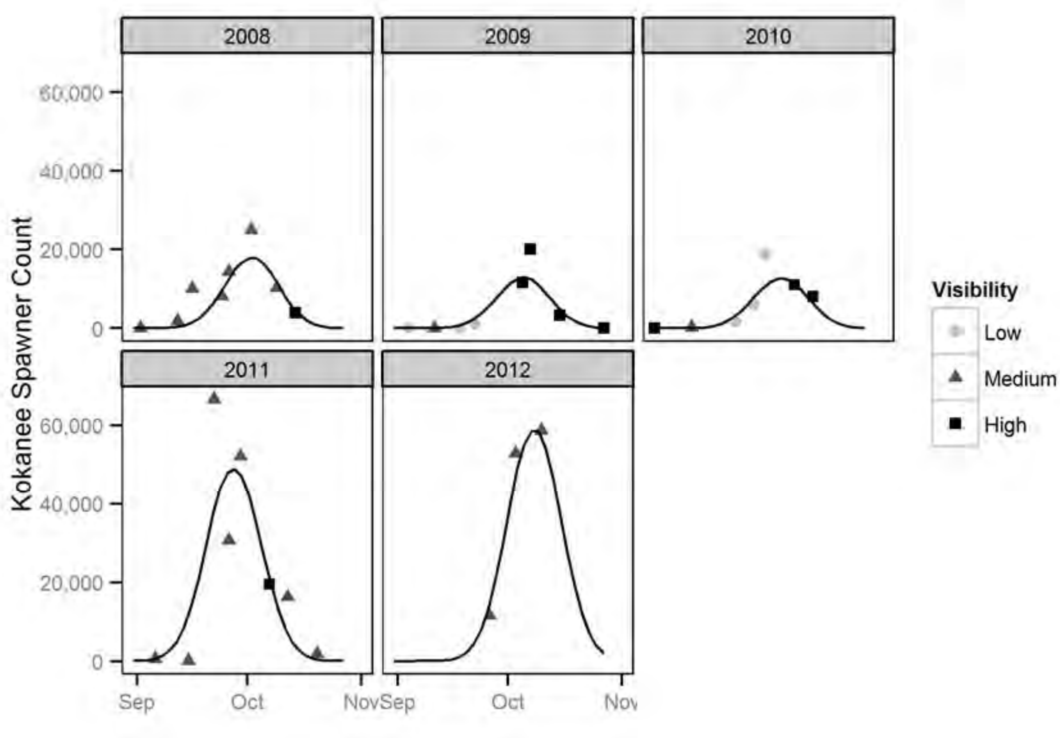

Figure 4: ***Aerial spawner counts by year in the LDR, 2008-2012. The solid line is the expected count as predicted by the AUC model.***

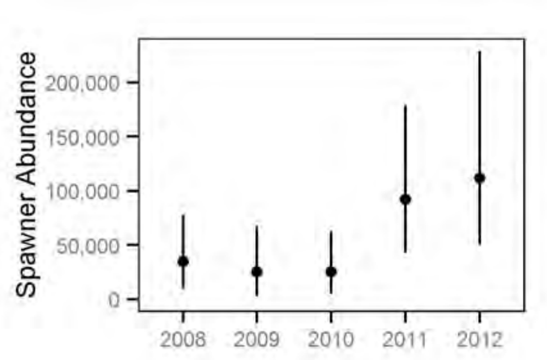

Figure 5: ***Estimated annual kokanee spawner abundance with 95% credibility intervals by year in the LDR, 2008-2012.***

Table 5: ***The estimated annual kokanee spawner abundance with 95% credibility intervals by year in the LDR, 2008-2012.***

Year	Spawner Abundance	Lower 95% CI	Upper 95% CI
2008	35,000	10,000	78,000
2009	25,000	3,000	67,000
2010	25,000	5,000	62,000
2011	92,000	43,000	179,000
2012	112,000	50,000	229,000

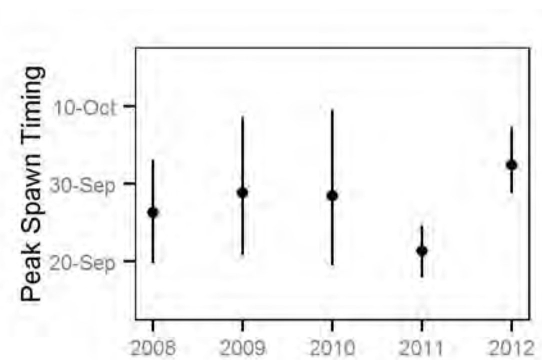

Figure 6: ***Estimated timing of peak kokanee spawning with 95% credibility intervals for the LDR, 2008-2012.***

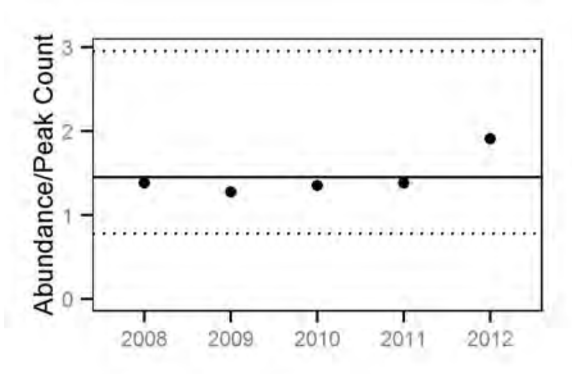

Figure 7: ***Ratios of the estimated annual spawner abundance to peak counts by year for kokanee in the LDR, 2008-2012. The solid line is the expected peak count expansion factor and the dotted lines are 95% credibility intervals.***

4.2.3 Relative Intensity of Kokanee Spawning in the Duncan River System

Meadow Creek accounted for approximately 52% of the observed total escapement within the Duncan River system in 2012 followed by the Lardeau River (45%) and the LDR (3%; Figure 8).

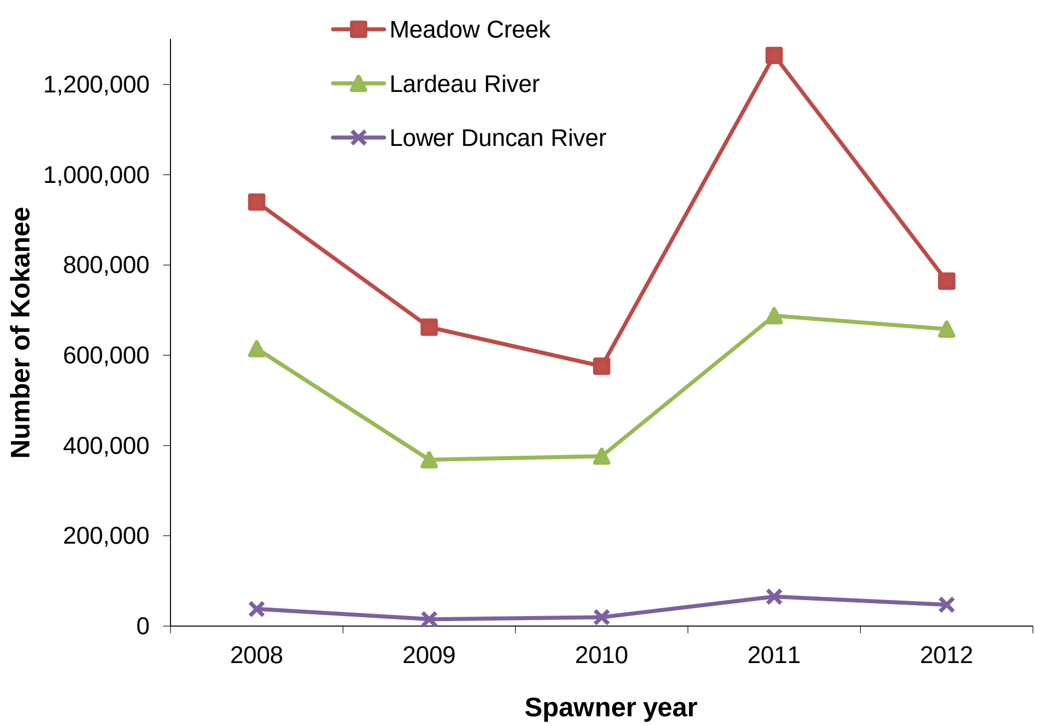

Figure 8: ***Estimated abundance of kokanee spawning in Meadow Creek, Lardeau River, and the Lower Duncan River, 2008 to 2012.***

4.3 Migration, Holding & Spawning Behaviour

In 2012, four surveys were conducted during the peak kokanee spawning period, so information for the entire spawning period was not collected. The following information is based on the previous four years of study (AMEC 2012) that has been updated with any new information collected during the 2012 peak spawning period.

Kokanee can be observed migrating from Kootenay Lake into the LDR in early or mid-August (M. Pearson, per. comm., 2011). In 2011, silver and red kokanee were observed throughout the LDR on August 19 and some spawning was observed during surveys conducted under DDMMON-7 (AMEC 2012). At the onset of helicopter enumeration surveys conducted from 2008 to 2011 (late August/early September) there were generally higher numbers of holding/migrating fish in the LDR compared to the number observed spawning. For example, in 2010 almost 80,000 kokanee were holding in the LDR and no fish were spawning during the first survey conducted on August 31. Most of these holding fish were located at the mouth of Meadow Creek at this time. Migrating and holding behaviour was observed to decline as spawning behaviour began to increase from mid- to late September each year. Fish observed holding near Meadow Creek during early September surveys, likely migrated and spawned there. Some fish observed holding in early and mid-September in the upper LDR may have also migrated and spawned in the Lardeau River.

Early spawning behaviour was usually observed after the first week of September each year, but varied slightly. For example, in 2009 spawning was first observed 1.5 weeks later compared to 2008, 2010 and 2011. The number of spawners observed in the LDR increased over the duration of the enumeration surveys to reach a peak in late September/early October. Helicopter enumeration was completed in mid- to late-October each year when lower numbers of kokanee were observed. In 2009, kokanee were not observed in the LDR during the final enumeration survey conducted on October 27; this was the latest survey conducted over the five year study period. However, low numbers of kokanee were still often observed spawning in the LDR after the completion of helicopter enumeration at the end of October and even into early November during other years (observations taken during DDMMON-2 field sampling; Thorley et al. 2012).

4.4 Spawner Distribution & Habitat Use in the LDR

Kokanee were observed to spawn in the upper 7 km of the LDR mainstem and in all side channels that remained wetted as per other study years (AMEC 2012). Spawning kokanee were usually not observed downstream of Km 7.0 or upstream of Km 0.6 in the LDR mainstem (including the discharge channel). However, a few spawners have been observed along the left bank at Km 8.0, 8.3 and 10.2 during years with high numbers of kokanee (i.e., 2008, 2011 and 2012); in 2012 kokanee were also observed along the right bank at Km 8.0 and between Km 8.9 and 9.6. Very few kokanee have been observed at the lowermost portion of the discharge channel during snorkel surveys conducted under DDMMON-2 in mid-September, but these fish were not spawning (Thorley et al. 2012); kokanee have never been observed at this location during helicopter enumeration. In 2009 and 2010, kokanee were not observed in side channel 6.9R, since this area was not wetted during the kokanee spawning period in an attempt to prevent egg losses. In all other years this side channel remained wetted during the enumeration surveys and resulted in dewatering of spawning habitat (AMEC 2012, Section 4.5).

A higher proportion of kokanee spawners were observed in LDR side channel habitats (90%) compared to mainstem areas prior to the peak spawning periods enumerated from 2008 to 2011. However, this finding changed during and after peak spawning where higher numbers of kokanee were observed spawning in mainstem habitats (60%) compared to side channels (40%) in 2008 and 2009. In 2010, the opposite occurred with a higher proportion of kokanee spawners enumerated in side channels (60%) versus the mainstem (40%) during peak spawning. Direct comparisons could not be made for data collected in 2011 as weather conditions prevented counts in both mainstem and side channel habitats on two occasions: i) September 15 only mainstem habitats were surveyed; and, ii) September 26 only side channels were enumerated. As discussed previously, in 2012 enumeration surveys were only conducted during the peak spawning period.

4.5 Kokanee Spawn Mapping, PED & Egg Losses

The total area used by spawning kokanee in the LDR mainstem was approximately 20,992 m^2 following the flow reduction and it is estimated that 2,713,272 eggs were deposited in that area (Table 6). As mentioned above, the mainstem was not mapped prior to the flow reduction. However, it is estimated that no redds were dewatered in mainstem spawning areas as none were observed during the post flow reduction survey. Dewatering of mainstem redds has been zero or minimal compared to dewatering in side channels of the LDR in previous years (Table 6; AMEC 2012).

Approximately 760 m^2 of the spawning area observed in side channels prior to the October 1 flow reduction was dewatered following the flow reduction (Table 6). The estimated number of eggs dewatered in these areas was 76,016 (Table 6). Additional spawning areas (3,556 m^2) were observed following the flow reduction; therefore total side channel spawning area was an estimated 8,220 m^2 in 2012.

Dewatering of redds following the October 1 flow reduction included areas in side channels 3.5R, 6.9R, 7.6R and 8.2L (Appendix B).

Table 6: Total spawning area, area dewatered, Potential Egg Deposition (PED), number of eggs dewatered and spawning success for side channel (SC) and mainstem areas (MS) within the LDR study area before (Pre) and after (Post) Kokanee Protection Flows, 2009 to 2012.

Year	Period	Area (m^2)		PED	
		SC	MS	SC	MS
2012	Pre[a]	4,734	N/A	473,172	2,713,272
	Post[b]	3,973	20,922	397,156	2,713,272
	Difference	760	0	76,016	0
2011	Pre	6,902	88,172	3,253,621	2,372,672
	Post	5,902	88,172	2,781,955	2,372,672
	Difference	1,001	0	471,666	0
2010	Pre	4,041	8,055	830,540	642,948
	Post	3,784	8,632	777,601	640,852
	Difference	258	-577	52,939	2,096
2009	Pre	399	0	48,732	-
	Post[c]	267	4,219	32,667	-
	Difference	132	-	16,065	-

[a] Mainstem mapping was not conducted prior to the flow reduction. However, no dewatered redds were observed in the mainstem during post-reduction mapping.
[b] Additional spawning areas were observed post-reduction (3556 m^2) because kokanee moved into side channels but the information presented reflects the original spawning area dewatered and changes to PED.
[c] Larger area was observed post-reduction because kokanee moved into side channels to spawn. Only 132m^2 of area was dewatered from the original pre-reduction mapping, which is reflected in PED.
- Spawning was not observed pre-reduction. It was assumed that post-reduction spawning areas were not dewatered.

5.0 DISCUSSION

The following discussion is structured along the management questions that were applicable during the Year 5 program.

5.1 What is the spawn run timing and relative intensity of kokanee spawning in the Lower Duncan River?

5.1.1 Spawn Run Timing

Spawn run timing for kokanee in the LDR occurs from late August to late October, with peak spawning estimated between September 20 and October 10. In 2012, peak spawning was estimated to occur on October 2 though the highest spawner count during enumeration surveys occurred on October 10. Preliminary analyses conducted under DDMMON-7 indicated that the drop in discharge that occurs in the LDR in late September may have an effect on the distribution of spawning kokanee as this is affiliated with the change in proportion of kokanee observed on the left and right banks. That is, after the drop occurs, more kokanee are proportionally seen on the right bank than before the drop. This is potentially a response to availability of spawning habitats consisting of optimal depth, velocity and substrate along the right bank following the drop. No pattern was observed between discharge at DRL assessed from early to mid-September and the timing of the kokanee spawning (AMEC and Poisson 2012). No trend for spawn timing and LDR water temperatures were observed (AMEC and Poisson 2012). In addition, water temperature was not found to influence the onset of spawning for mature kokanee in Meadow Creek (Morbey and Ydenberg 2003).

5.1.2 Relative Intensity of Kokanee Spawning in the LDR

The relative intensity of kokanee spawning in the LDR has been low in comparison to Meadow Creek and the Lardeau River. Since 2002, the majority of kokanee in the Duncan River system were observed to spawn in Meadow Creek (60-65%), followed by the Lardeau River (30-35%) and lastly the LDR (only between 1-3%; AMEC 2012). The trends were the same in 2012 though the proportion of spawners in Meadow Creek was lower (52%) and the Lardeau River higher (45%) than observed in previous years.

Prior to the construction and operation of DDM, approximately 62% of the spawning escapements were from the Duncan River itself, followed by the Lardeau River (30%) and Meadow Creek (8%; Acara 1970; AMEC 2008). The change in the proportion of spawners to the Duncan River has been attributed to the construction of DDM (Acara 1970, Vonk 2001). Lower numbers of kokanee spawners began to be observed in 1966 during dam construction and likely remained at these lower levels until present (Acara 1970, Vonk 2001, AMEC 2008).

The regulation of the LDR has also caused substrate compaction (NHC 2010) and reduced the amount of spawning habitat for kokanee compared to that available historically (Vonk 2001), but it is unknown whether this is why lower proportions of spawners are observed in the LDR versus Meadow Creek and the Lardeau River. Adult returns to the Duncan River system are also highly influenced by in-lake factors such as adult and fry survival, fertilization inputs, lake conditions and angling pressure (AMEC 2008). Vonk (2001) indicated that returns to MCSC have also been negatively affected by channel conditions such as siltation, redd superimposition, predation and loss of water supply. Kokanee spawner year-class strength has also been related to other in-lake factors such as food availability and growth, density dependence and interactions between other kokanee stocks and predation (e.g., Fraley et al. 1986, Grover 2006).

5.2 What are the relative distribution of kokanee spawners in the Lower Duncan River?

Kokanee spawn in the upper 9 km of the LDR below DDM mainly from Km 0.8 to 7.1 in the mainstem and in all side channels that remained wetted during the spawning season (1.1R; 2.7L; 3.5R; 4.1R; 4.4R; 6.9R; 7.6R; 8.2L; and, 8.8L); this did not change in 2012 though some spawning was also observed in the mainstem between Km 8.0 and 9.6. It is likely that kokanee spawn within the upper river because these areas have more suitable spawning gravels compared to lower regions of the river, which are largely comprised of fines due to the regulation of Kootenay Lake (NHC 2010). The regulation of the LDR has also caused substrate compaction (NHC 2010) and reduced the amount of spawning habitat for kokanee compared to that available historically (Vonk 2001), but it is unknown whether this is why lower proportions of spawners are observed in the LDR versus Meadow Creek and the Lardeau River (Section 5.1.3). Lestelle et al. (2006) indicated that a lack of flushing flows due to river regulation may make the gravels less suitable, so fish may avoid spawning in these areas and find better habitats elsewhere.

Observations suggest that early spawning begins in side channel habitats, but by the peak of spawning kokanee are in both side channel and mainstem habitats in approximately equal proportions (AMEC 2012). Kokanee move into side channels earlier than the mainstem likely because they are seeking out low velocity, cooler (shadowed) areas to minimize energy expenditure as has been observed for kokanee in Meadow Creek (Morbey and Yedenberg 2003). Following peak spawning in 2012, the majority of spawners were located in the mainstem which was similar to previous years (AMEC 2012).

Preliminary analyses conducted under DDMMON-7 indicated that the drop in discharge that occurs in the LDR in late September may have an effect on the distribution of spawning kokanee as this is affiliated with the change in proportion of kokanee observed on the left and right banks. That is, after the drop occurs, more kokanee are proportionally seen on the right bank than before the drop. No pattern was observed between discharge at DRL assessed from early to mid-September and the timing of the kokanee spawn timing (AMEC and Poisson 2012). No trend for spawn timing and LDR water temperatures were observed (AMEC and Poisson 2012).

Side channel areas observed to dewater following the October 1 flow reduction in 2012 included areas that have dewatered in 2009 and 2011 (AMEC 2012). This includes areas of side channel 3.5R between Km 0.0 and 0.6, side channel 6.9R, side channel 7.6R and side channel 8.2L between Km 0.0 and 0.8 (AMEC 2012).

6.0 RECOMMENDATIONS

The following are recommendations for future kokanee spawning monitoring:

1. Review the results of this monitoring program to determine if kokanee egg losses/adult returns from the LDR impact the overall kokanee population in the Duncan River system.
2. Update maps used for enumeration and spawn mapping surveys with more recent imagery; updated imagery would allow more accurate determination of kokanee spawning locations due to recent changes in the river channel.
3. Conduct a minimum of three to four enumeration surveys to capture peak spawning in the LDR to monitor yearly spawner abundance. These surveys would allow for the peak spawning period (September 20 to October 10) to be covered. That is, one survey each near start (September 20) and end (October 10) of peak spawning, plus one or two additional surveys in between these dates would help to depict the abundance curve to pin point peak spawning.
4. Continue to use 20m flight elevations during LDR kokanee enumeration and spawn mapping surveys to ensure consistency in accuracy of counts, spawning area delineation and behaviour assessment.
5. Field verify changes to DDM operations predicted by the hydraulic model using observations of kokanee spawning/egg depositional areas and dewatering. Conversely, observations of kokanee habitat use changes could be analysed using the hydraulic model to test hypotheses of habitat optimization changes.
6. Use the information herein and in AMEC (2012) to develop a long term strategy to optimize kokanee productivity in the lower Duncan River through the Action Plan to Minimize Stranding of Kokanee Spawning in Lower Duncan River Sidechannels program (DDMWORKS-4).

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APPENDIX A
Area-Under-the-Curve (AUC) Analysis

LDR Kokanee Spawning Monitoring:

Area-Under-the-Curve Analysis of Kokanee Spawner Abundance in the Lower Duncan River (2008-2012)

Final Memorandum

January 10, 2013

Prepared for

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Introduction

Aerial counts of spawning kokanee have been conducted in the Lower Duncan River (LDR) every fall since 2008 as part of DDMMON-4. Spawner counts can be analysed using Area-Under-the-Curve (AUC) methods to estimate spawn timing and, if observer efficiency and spawner residence time are known, absolute spawner abundance (Hilborn et al. 1999, Su et al. 2001).

The current memorandum uses Bayesian methods to estimate the aerial observer efficiency as well as the peak spawn timing and spawner abundance of kokanee in the LDR from 2008 to 2012. The memorandum also estimates the expansion factor for converting peak counts to total abundance.

Methods

The data were provided in the form of an Excel 2007 spreadsheet by AMEC Environment & Infrastructure. The spawner abundance and timing of peak spawning were estimated using a hierarchical Bayesian AUC model (see Appendix A). The model is similar to that used by Thorley (2012) with the most notable change being that the residual variation in the spawner counts is no longer assumed to increase linearly with the expected number of spawners.

Key assumptions of the hierarchical Bayesian AUC model included:

- The mean spawner residence time (longevity) ranged between 7 and 14 days (Acara 1970, Morbey and Ydenberg 2003);
- The observer efficiency ranged between 0.56 and 1.62 (as estimated by the Bayesian efficiency analysis);
- Spawner arrival timing was normally distributed (Hilborn et al. 1999);
- The mean of the spawner arrival timing in each year is drawn from an underlying normal distribution (Su et al. 2001);
- The residual variation about the expected counts is normally distributed.

The expansion factor for converting annual peak counts into an absolute spawner abundance was estimated from the ratios of the AUC abundance to the observed peak count for each year. The expansion factor was estimated using a Bayesian model (see Appendix A).

Key assumptions of the Bayesian peak count expansion factor model included:

- The median expected abundance from the AUC analysis is the actual abundance;
- The residual variation in the ratios is log-normally distributed.

Results

The aerial counts indicate that the highest peak counts occurred in 2011 and 2012 (Figure 1). Not surprisingly, the AUC-based estimates of the absolute spawner abundance were also highest in 2011 and 2012 (Figure 2 and Table 1).

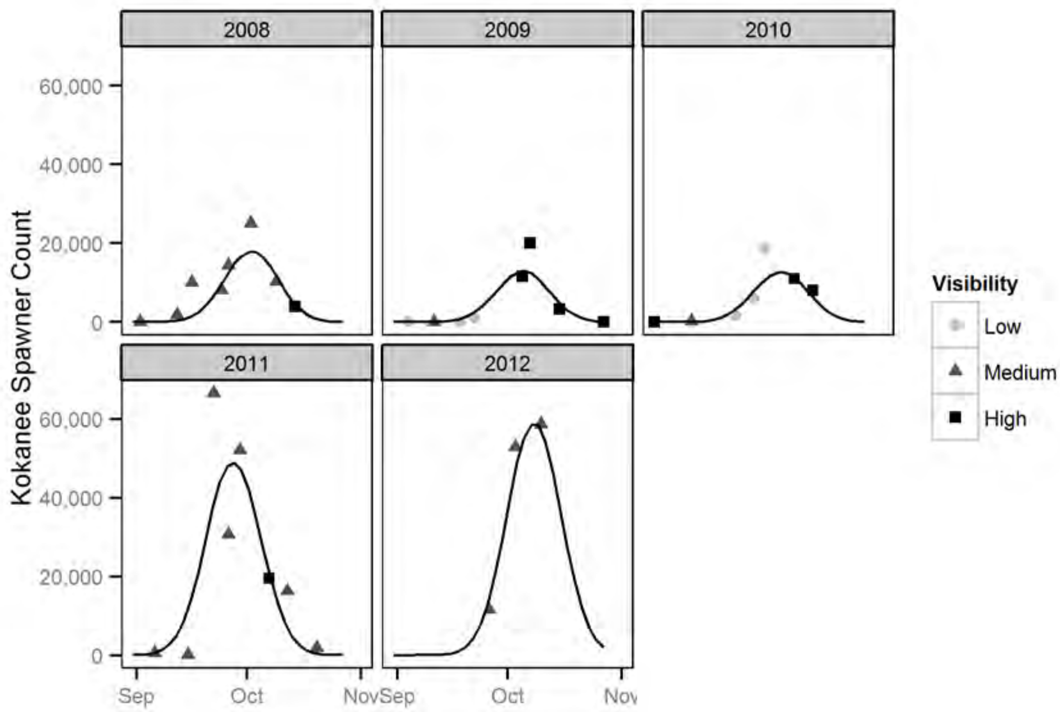

Figure 1: The aerial kokanee spawner counts in the Lower Duncan River by date and year from 2008 to 2012. The solid line is the expected count as predicted by the AUC model.

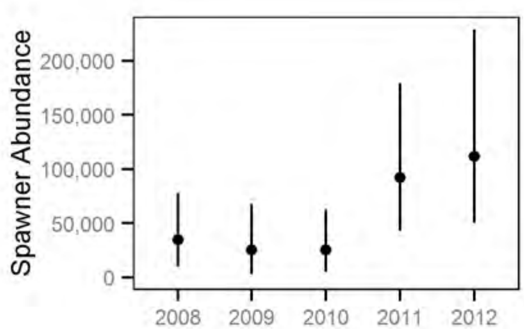

Figure 2: The estimated annual kokanee spawner abundance in the Lower Duncan River from 2008 to 2012. The vertical bars represent 95% credibility intervals.

Table 1: The estimated annual kokanee spawner abundance in the LDR with 95% credibility intervals from 2008 to 2012.

Year	Spawner Abundance	Lower 95% CI	Upper 95% CI
2008	35,000	10,000	78,000
2009	25,000	3,000	67,000
2010	25,000	5,000	62,000
2011	92,000	43,000	179,000
2012	112,000	50,000	229,000

The peak spawning timing occurs between September 20th and October 10th and can vary by as much as two weeks between years (Figure 3). In 2012 the estimated peak spawning date was October 2$^{nd.}$ The estimated abundance to peak count ratio was 1.45 but it can vary from between 0.78 and 2.95 for individual years (Figure 4).

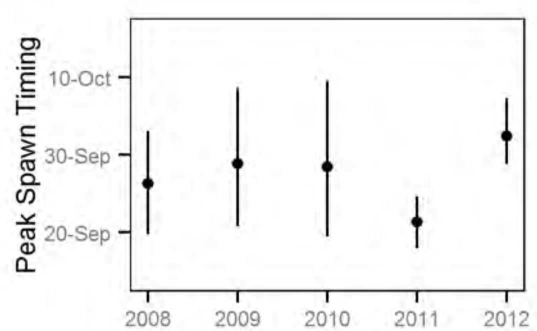

Figure 3: The estimated timing of peak kokanee spawning in the Lower Duncan River from 2008 to 2012. The vertical bars represent 95% credibility intervals.

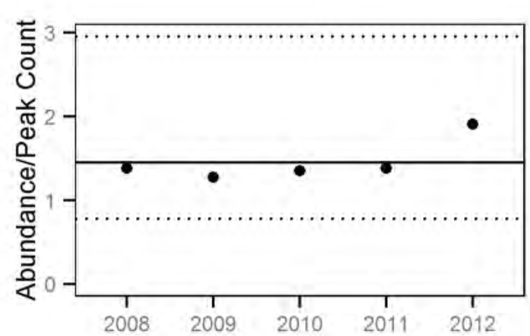

Figure 4: The ratios of the estimated annual spawner abundance to peak counts for kokanee in the Lower Duncan River from 2008 to 2012. The solid line is the expected peak count expansion factor and the dotted lines are 95% credibility intervals.

Discussion

The current memorandum updates the previous analysis of Thorley (2012) to include the 2012 data.

The results suggest that

1) approximately 112,000 kokanee spawned in the LDR in 2012 compared to 92,000 in 2011, 25,000 in 2010 and 2009 and 35,000 in 2008;
2) peak spawning occurs between September 20 and October 10;
3) the expansion factor for converting a peak count into a total spawner abundance for the Lower Duncan River is 1.5 although it could be as low as 0.8 or as high as 3.0 depending on the year.

Closure

This report is to the best of my knowledge accurate and correct. If you have any questions regarding its contents please contact the undersigned.

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References

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Appendix A

Bayesian Analyses

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Poisson Consulting Ltd.

23 November 2012

1 General Approach

Bayesian models were fitted to the data using the software packages R 2.15.2[9] and JAGS 3.3.0[7] which interfaced with each other via the rjags R package. In general the models assumed low information uniform or normal prior distributions. The posterior distributions were estimated from a minimum of 1,000 samples thinned from the second halves of three Gibbs sampling chains. Model convergence was confirmed by ensuring that R-hat (the Gelman-Rubin-Brooks potential scale reduction factor) was less than 1.1 for each of the parameters in the model[3, 5, 4]. Where relevant, the statistical significance of particular parameters was calculated using two-sided Bayesian p-values[1, 6].

Following Bradford et al. (2005)[2], the influence of particular variables was, where informative, expressed in terms of the effect size (i.e., percent change in the response variable) with 95% credibility intervals. When the variable was considered a random effect, the percent change in the response was quantified with respect to the typical value, i.e., the expected value of the underlying distribution from which the observed values represent random draws. Plots were produced using the ggplot2 R package [10].

2 JAGS Distributions, Functions and Operators

JAGS distributions, functions and operators are defined in the following two tables. For additional information on the JAGS language, which is a dialect of the BUGS language, see the JAGS User Manual[8].

JAGS Distribution	Description
dlnorm(mu, sd^-2)	Log-normal distribution
dnorm(mu, sd^-2)	Normal distribution
dunif(a, b)	Uniform distribution

JAGS Function or Operator	Description
<-	Deterministic relationship
~	Stochastic relationship
1:n	Vector of integers from 1 to n
for (i in 1:n) {...}	Repeat ... for 1 to n times incrementing i each time
log(x)	Natural logarithm of x
phi(x)	Standard normal cumulative distribution function
x[1:n]	Subset of first n values in x
x^y	Power where x is raised to the power of y

3 JAGS Models

The following sections provide the variable and parameter definitions and JAGS model code for each of the analyses.

3.1 Spawner Abundance

3.1.1 Variables and Parameters

Variable/Parameter	Description
bAbundance[yr]	Abundance in the yrth year
bAbundanceIntercept	Log abundance in a typical year
bAbundanceYear[yr]	Effect of the yrth year on log abundance
bObserverEfficiency	Observer efficiency as a proportion
bPeakTiming[yr]	Peak timing in the yrth year
bPeakTimingIntercept	Peak spawn timing in a typical year
bPeakTimingYear[yr]	Effect of the yrth year on peak spawn timing
bResidenceTime	Individual residence time in days
Count[i]	The ith count
Dayte[i]	Day of the year of the ith count
eAbundance[i]	Expected abundance for the ith count
eCount[i]	Expected ith count
ePeakTiming[i]	Expected timing of peak spawning for the ith count
nrow	Number of counts
nYear	Number of years
sAbundanceYear	SD of the effect of year on log abundance
sCount	SD of the residual variation in the spawner count
sPeakTimingYear	SD of the effect of year on peak spawn timing
sSpawnDuration	The duration of spawning as a SD
Year[i]	The year of the ith count

3.1.2 Model Code

```
model {
  sSpawnDuration ~ dunif(0, 42)

  sCount ~ dunif(0, 10000)
  sAbundanceYear ~ dunif(0, 12)
  bAbundanceIntercept ~ dunif(0, 14)

  sPeakTimingYear ~ dunif(0, 14)
  bPeakTimingIntercept ~ dunif(240, 300)

  bResidenceTime ~ dunif(7, 14)
  bObserverEfficiency ~ dunif(0.56, 1.62)

  for (yr in 1:nYear) {
    bPeakTimingYear[yr] ~ dnorm (0, sPeakTimingYear^-2)
    bPeakTiming[yr] <- bPeakTimingIntercept + bPeakTimingYear[yr]
    bAbundanceYear[yr] ~ dnorm (0, sAbundanceYear^-2)
    log(bAbundance[yr]) <- bAbundanceIntercept + bAbundanceYear[yr]
```

```
  }

  for (i in 1:nrow) {
    ePeakTiming[i] <- bPeakTiming[Year[i]]
    eAbundance[i] <- (phi((Dayte[i] - ePeakTiming[i])/sSpawnDuration)
      - phi((Dayte[i] - ePeakTiming[i] - bResidenceTime)/sSpawnDuration))
      * bAbundance[Year[i]]
    eCount[i] <- eAbundance[i] * bObserverEfficiency
    Count[i] ~ dnorm(eCount[i], sCount^-2)
  }
}
```

3.2 Spawner Abundance to Peak Count Ratio

3.2.1 Variables and Parameters

Variable/Parameter	Description
bRatio	Ratio in a typical year
bRatioInd	Ratio in a individual year
nrow	Number of years
sRatio	SD of the log ratio

3.2.2 Model Code

```
model {

    bRatio ~ dunif (0.2, 5.0)
    sRatio ~ dunif (0, 2)

    for(i in 1:nrow) {
      Ratio[i] ~ dlnorm(log(bRatio), sRatio^-2)
    }
    bRatioInd ~ dlnorm(log(bRatio), sRatio^-2)
  }
```

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[1] N. Bochkina and S. Richardson. Tail posterior probabilities for inference in pairwise and multi-class gene expression data. *Biometrics*, 63:1117–1125, 2007.

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[3] S. Brooks and A. Gelman. Alternative methods for monitoring convergence of iterative simulations. *Journal of Computational and Graphical Statistics*, 7:434–455, 1998.

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[5] A. Gelman and D. Rubin. Inference from iterative simulation using multiple sequences. *Statistical Science*, 7:457–511, 1992.

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[7] M. Plummer. Jags: A program for analysis of bayesian graphical models using gibbs sampling. In *Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003)*, Vienna, Austria, 2003.

[8] M. Plummer. *JAGS Version 3.1.0 User Manual*, 2011.

[9] R Development Core Team. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria, 2012. ISBN 3-900051-07-0.

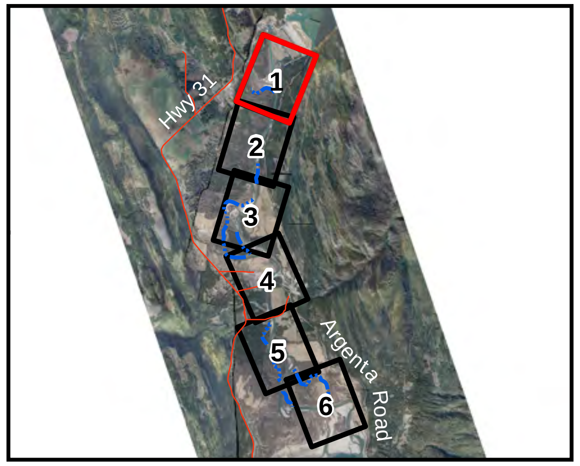
[10] H. Wickham. *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag, New York, 2009.

APPENDIX B
2012 Kokanee Spawning Locations & Areas Observed to Dewater

Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Kokanee Spawning Use
- Kokanee Spawning Use - Area Lost

Note:
Mapped areas not to scale



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Meters

Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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2012 Kokanee Spawning Areas and Areas Dewatered in the LDR

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PDF FILE: kokanee_spawning_2012_combined.pdf			PRINTING DATE: 2012/01/02	
PROJECTION: UTM Zone 11	DATUM: NAD83	ANALYST: AA	QA/QC: MY	REQ: CL

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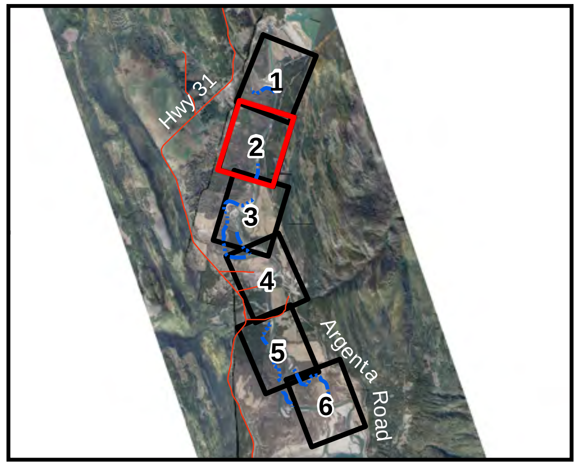
Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Kokanee Spawning Use
- Kokanee Spawning Use - Area Lost

Note:
Mapped areas not to scale



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Reference
Ortho Date: April 30, 2009
Discharge at DRL: 73 - 74cms
Kokanee Spawning: AMEC (Oct.2009)

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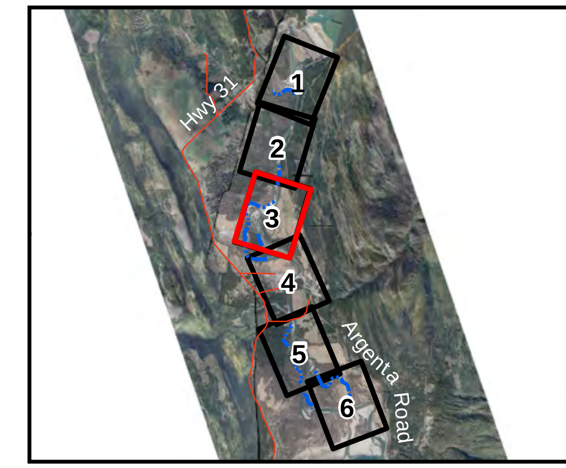

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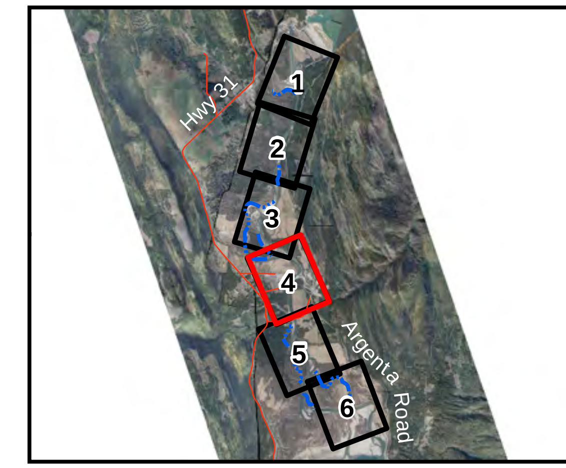

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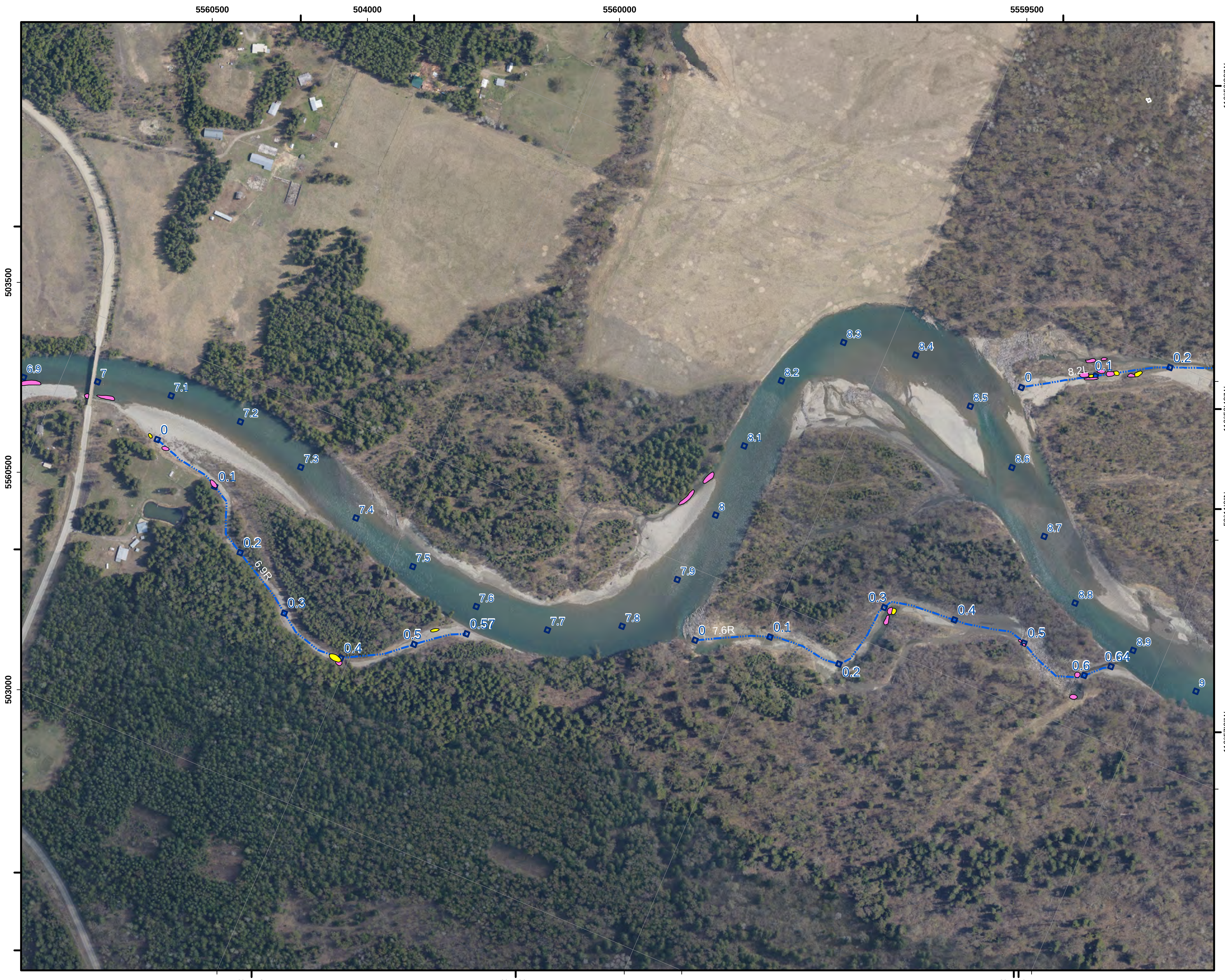

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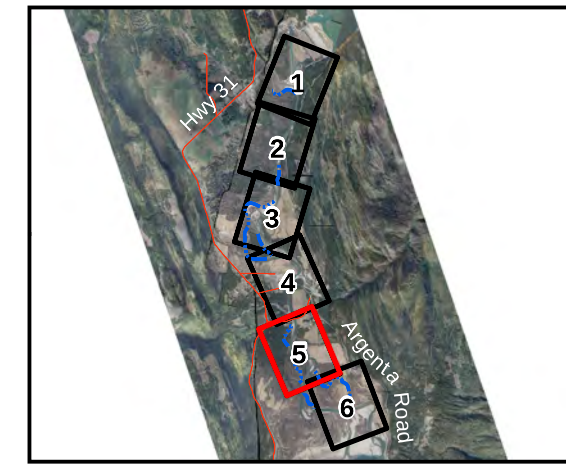

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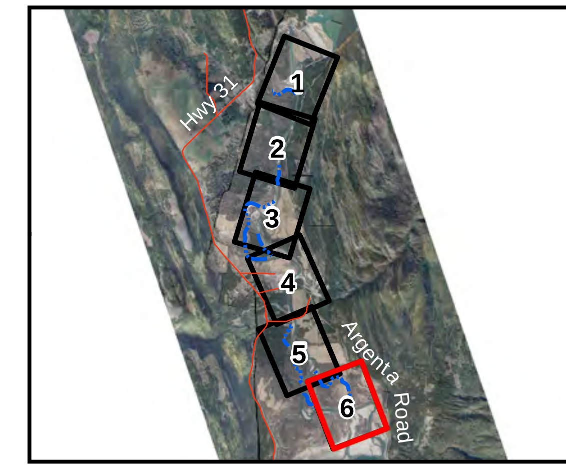

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