Duncan Dam Project Water Use Plan

Action Plan to Minimize Stranding of Kokanee Spawning in Lower Duncan River Sidechannels

Implementation Year 1

Reference: DDMWORKS-4

Study Period: June 2016 to December 2016

Amec Foster Wheeler Environment & Infrastructure
Nelson, BC

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BC Hydro

DDMWORKS-4 Lower Duncan River Kokanee Spawning/Incubation Habitat Modelling

Submitted To:

BC Hydro
Burnaby, BC

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IMPORTANT NOTICE

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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, which identified Kokanee (*Oncorhynchus nerka*) spawning success in the Lower Duncan River below DDM as an issue that could be impacted by operations (BC Hydro 2007). Kokanee migrate from Kootenay Lake and spawn in the Lower Duncan River, Meadow Creek and the Lardeau River between early August and the end of October. BC Hydro commitments to the DDM WUP and to meeting flow management targets set under the Columbia River Treaty (CRT) restrict the timing and amount of flow that can be delivered in the fall during the Kokanee spawning period. 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 below the confluence of the Duncan and Lardeau rivers (DRL). These targets were set prior to the initiation of the Lower Duncan Kokanee spawn monitoring study (DDMMON-4). This 10-year study was initiated in 2008 to document Kokanee spawning and timing, identify critical spawning/incubation habitat areas, and determine variables that may affect Kokanee spawning success in the Lower Duncan River as related to DDM operations. Amec Foster Wheeler was retained by BC Hydro to evaluate Kokanee spawning protection flows, provide a risk analysis of how different protection flows will affect Kokanee spawning success, and identify feasible operating regimes that can mitigate operational impacts within BC Hydro's control and opportunity within the CRT, the International Joint Commission's 1938 Kootenay Lake Order and the DDM WUP. To facilitate these objectives, Kokanee spawning/incubation habitat areas mapped during DDMMON-4 were used as a proxy for spawning success. Habitat area was modelled in side channels known to dewater Kokanee redds in consideration of run timing and spawning intensity over the peak spawning period to help determine alternative flow regimes that may reduce stranding. Field evaluations conducted under DDMMON-4 were used to ground truth modelled scenarios.

Flow scenarios derived from the BC Hydrotech model provided a high level overview of the total habitat area available to Kokanee in critical side channel areas under various spawning protection flows. The model was able to predict 95% of the maximum amount of spawning/incubation habitat that were mapped during DDMMON-4. However, it was less accurate at distinguishing habitat available within specific side channels, especially for 6.9R and 7.6R. The risk analysis demonstrated incremental gains in overall habitat area when protection flows increased above 75 m^3/s (as measured at DRL) and increased flows to 100 m^3/s corresponded to a 24% reduction of dewatered spawning/incubation habitat area. Flows of 125 m^3/s corresponded to a 28% reduction, only 4% better than 100 m^3/s. Although flows >150 m^3/s demonstrated over a 40% reduction in overall dewatered spawning/incubation habitat area, there would be a trade-off to holding flows too high and potentially precluding spawning in some areas because depths and velocities may no longer be suitable. The risk analysis of how different protection flows may affect Kokanee spawning success underestimated the amount of habitat area available for the modelled flows when compared to actual ground observations.

Based on key biological criteria, DDM operational constraints, and discussions with regulatory agencies, a Kokanee protection flow field trial was initiated on 25 September 2016 and included maintaining flows at 100 m^3/s through November after which time flows were increased. It was estimated that approximately 3% of spawning/incubation area within critical side channels were dewatered in 2016 compared to previous years when up to 33% of this same area dewatered

when protection flows were initiated on 1 October and dropped to 75 m^3/s. Additional monitoring with 100 m^3/s variation, if operationally feasible, beginning in late September is required for further evaluation of this alternative scenario.

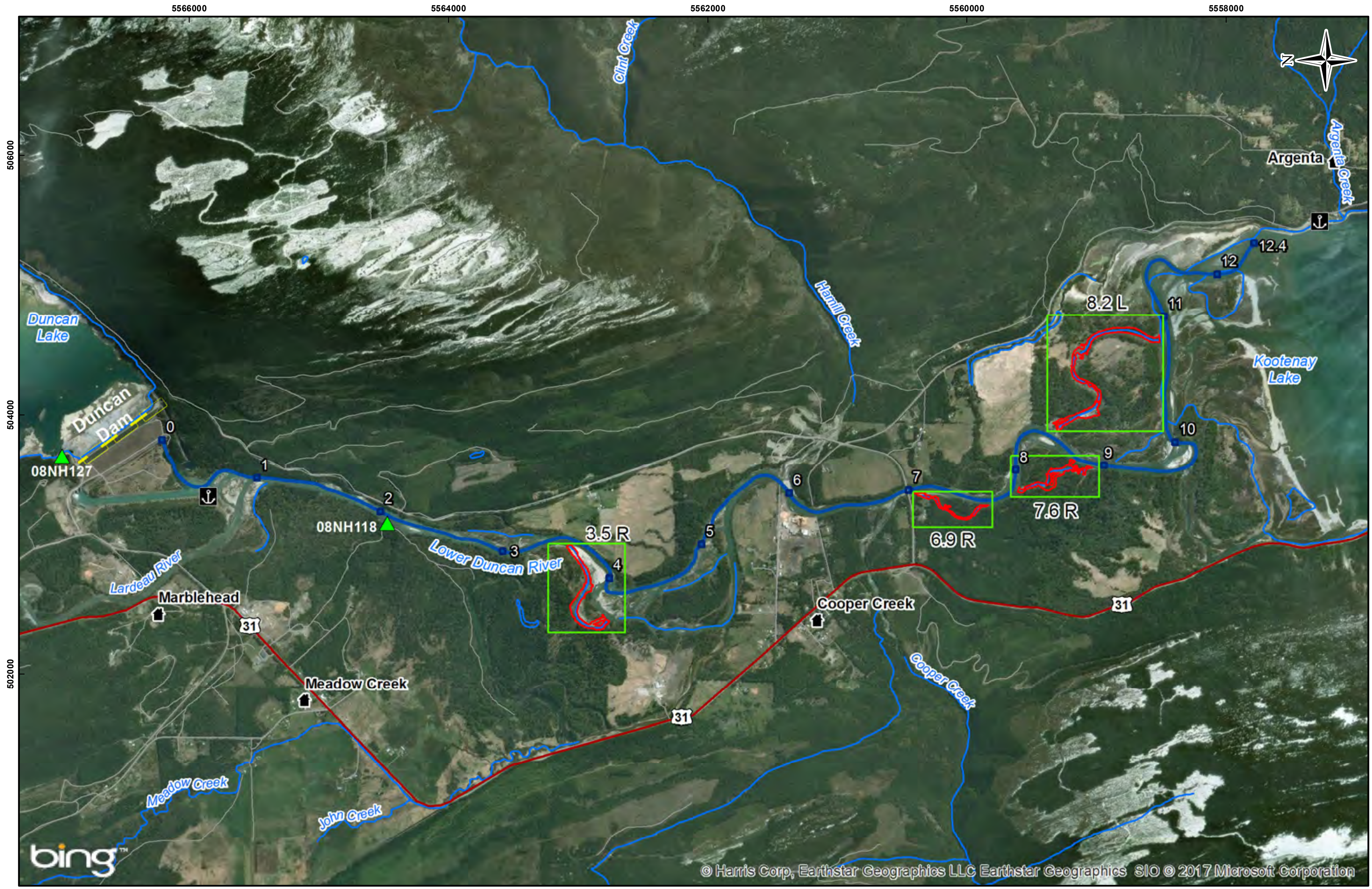
1.0 INTRODUCTION

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 (IJC) 1938 Kootenay Lake Order. 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 WUP project was initiated to address flow management issues with respect to impacts on competing resources in the area, which identified Kokanee (*Oncorhynchus nerka*) spawning success in the LDR as an issue that could be impacted by DDM operations (BC Hydro 2007).

Kokanee migrate from Kootenay Lake and spawn in the LDR, Meadow Creek and the Lardeau River between early August and the end of October. BC Hydro commitments to the DDM WUP and to meeting flow management targets set under the CRT restrict the timing and amount of flow that can be delivered in the fall during the Kokanee spawning period. 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 (DRL; BC Hydro 2007). These targets were set prior to the initiation of the Lower Duncan Kokanee spawn monitoring study (DDMMON-4). This 10-year study was initiated in 2008 to document Kokanee spawning and timing, identify critical spawning/incubation habitat areas, and determine variables that may affect Kokanee spawning success in the LDR as related to DDM operations.

Based on information collected under DDMMON-4 to date, peak of Kokanee spawning in the LDR is observed from mid-September to early October and critical habitat areas of interest include side channel (SC) habitats where Kokanee redds have been observed to dewater and become isolated from the mainstem during the CRT flow targets in October. Key side channels observed to dewater and become fully or partially isolated include 3.5R, 6.9R, 8.2L and, to a lesser extent, 7.6R (AMEC 2008-2012; ONA et al. 2016a, 2016b; **Figure 1**). Discharges <200 m^3/s can result in some level of dewatering in at least one of these critical side channels (NHC 2010). Kokanee spawning success in critical side channel areas has ranged between 67-94% during studies conducted from 2008 to 2012 when Kokanee spawner abundance was high (AMEC 2012). During that time period, Kokanee spawned in both mainstem and side channel habitats. Since this time, the overall Kokanee population in Kootenay Lake has declined due to in-lake issues (Bassett et al. 2016). Thus, lower numbers of Kokanee spawners have been observed in the LDR and spawning has been concentrated within the LDR mainstem where spawning success is usually close to 100% as redds tend not to become dewatered (AMEC 2012, ONA et al. 2016b).

Amec Foster Wheeler was retained by BC Hydro to evaluate LDR Kokanee spawning protection flows, provide a risk analysis of how different protection flows will affect Kokanee spawning success, and identify feasible operating regimes that can mitigate operational impacts within BC Hydro's control and opportunity within the CRT, Kootenay Lake IJC and the DDM WUP (BC Hydro DDMWORKS-4 Scope of Services, 22 February 2016).



Last updated by matthew.yuen

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Legend

- River km (AMEC, 2009)
- Boat Launch
- Communities
- WSC Gauge
- Dam
- Highway
- Existing Road
- Watercourse
- Waterbody
- Critical Side Channel Location

0 0.5 1
Kilometers
Scale 1:40,000

References:
DataBC Data Distribution Service
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(http://www.data.gov.bc.ca/)
Geogratis/Geobase
Open Government License - Canada
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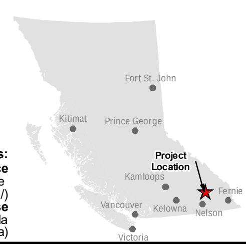

CLIENT:	PROJECT:
Prepared for BC Hydro	LDR Kokanee Spawning

TITLE:

Overview Map of Lower Duncan River depicting side channel areas of interest

DATE:	ANALYST:	QA/QC:	
April 11, 2017	MY	LP	**Figure 1**

GIS FILE: 02-01-002_Side_Channel_Overview

JOB No: VE52598

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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2.0 METHODS

Evaluation of Kokanee spawning protection flows was undertaken by conducting an information review, modelling spawning-incubation habitats under various discharge scenarios, and ground truthing the habitat model based on field data collected under DDMMON-4. Further details are provided below.

2.1 Information Review

Background information was reviewed to summarize the existing biological information on Kokanee spawning in the LDR and the impacts of operations on Kokanee spawning success. Key critical areas and flows of interest as related to spawning and incubation requirements and timing were used for model reviews. Information sources included:

- Reports from the following DDM Water Licencing Requirements (WLR) programs:
  - DDMMON-2 Lower Duncan River Habitat Use Monitoring;
  - DDMMON-3 Lower Duncan River Hydraulic Model Development;
  - DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring; and,
  - DDMMON-7 Lower Duncan River Water Quality Monitoring;
- Operations and LDR flow information available through BC Hydro Power Records.
- LDR flow modeling obtained from BC Hydrotech.
- Relevant literature for Kokanee related to hydroelectric impacts, Kootenay Lake, habitat requirements and life history.

A summary of the Kokanee population in the Duncan River watershed and background information for the LDR, Meadow Creek and the Lardeau River is also provided in AMEC (2008). A synthesis of the initial 5-year DDMMON-4 program is found in AMEC (2012).

2.1.1 Spawning, Incubation and Emergence Timing

Spawn run timing for Kokanee in the LDR between 2008 and 2016 was evaluated during DDMMON-4 (AMEC 2012, ONA et al. 2017). Kokanee spawning abundance during the final monitoring survey of the season between 2008 and 2016 was also compiled (AMEC 2008-2012, ONA et al. 2016a, 2016b, 2017).

Early life stage development for Kokanee was estimated using Accumulated Thermal Units (ATUs), which are calculated by adding the average daily water temperature cumulatively from peak of spawning. Water temperatures for the DRL staff gauge located downstream of the Lardeau River were obtained from BC Hydro's Access database maintained by Poisson Consulting Ltd that was updated to 28 February 2017. ATU's were calculated for each spawner cohort year of study to estimate Kokanee incubation, hatch and emergence timing. These life stages are highly dependent on water temperature (Murray et al. 1989), which is influenced by DDM operations (AMEC and Poisson 2012). Emergence (or swim-up) is a term applied when Kokanee become neutrally buoyant thus they emerge from the gravels and are carried downstream with the current (Acara 1970, Murray et al. 1989). In the LDR, Kokanee early life stage development was found to be similar to the ATU development stages derived for Meadow Creek and is therefore a viable method to estimate hatching and emergence in the LDR (AMEC 2010, 2011, 2012).

2.1.2 Regulatory Meeting

The key biological considerations for evaluating the effectiveness of any proposed changes to the Kokanee protection flow regime on the LDR were discussed at the Columbia Operations Fish Advisory Committee (COFAC) meeting held on 13 September 2016. Representatives of the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) and the Department of Fisheries & Oceans (DFO) were at this meeting. It was agreed that Kokanee spawning protection flows would be held at 100 m^3/s instead of 75 m^3/s during the 2016 DDMMON-4 monitoring period and that stable or increasing flows would occur throughout the incubation/emergence period.

2.2 Spawning/Incubation Habitat-Flow Matrix

Lower Duncan River Kokanee spawning areas mapped during DDMMON-4 surveys between 2008 and 2012 were compiled into an overall spawning/incubation habitat map[1] (**Appendix A**). Spawning/incubation area polygons compiled from DDMMON-4 (**Appendix A**) represent actual areas used by Kokanee to build redds and where eggs/larvae incubate, hatch and remain until emergence (i.e., habitat directly used and therefore assumed to be suitable). Habitat polygons were mapped pre- (130-190 m^3/s; 25-30 September) and post-spawning protection flows (73-75 m^3/s; 1-21 October) during DDMMON-4. Habitat areas that were most prone to dewater redds and result in egg losses (i.e., post-spawning protection flows) were determined to be “critical side channel areas” and included side channels 3.5R, 6.9R, 8.2L and, to a lesser extent, 7.6R (**Figure** 1). The total amount of actual mapped habitat area from DDMMON-4 was used as the basis for comparison with the different modelled flow scenarios (i.e., maximum spawning/incubation habitat within the model).

The LDR flow model obtained from the BC Hydrotechnical department (referenced herein as BC Hydrotech) was used to overlay a set of discharge scenarios onto the mapped habitat polygons (**Appendix A**). The BC Hydrotech flow model was available in 25 m^3/s increments (**Appendix B**) and flow model scenarios used for this evaluation included DRL discharges of 75, 100, 125, and 200 m^3/s (i.e., regular operational flows during the Kokanee spawning period). The flow at which each side channel was fully watered or ON[2] was used to calculate maximum habitat within the model to facilitate comparing discharge scenarios (

Table 1). Thus, the actual mapped habitat polygons were clipped to fit into the modelled flow scenario polygons. Differences between the actual and clipped areas were compared as part of the ground truthing exercise (Section 2.3).

[1] Note that spawn mapping was at 1:500 scale from 2009-2013, but changed to 1:2,000 from 2014-2016 under DDMMON-4. Spawn maps were also reviewed from 2013 and 2015 and areas overlapped data collected in 2008-2012.
[2] ON = fully flowing state where surface flows entering the channel and the side channel are fully connected; OFF = dewatered condition ignoring groundwater and seepage; BW = backwatered where the outlet and portion of the side channel is watered, but there is no surface flow entering the inlet (NHC 2010).

Table 1: Modelled LDR Flows when critical side channels are fully connected (ON) and habitats are maximized

Name	Flow Used (m^3/s)
3.5R	200
6.9R	375
7.6R	300
8.2L	275

A spawning/incubation habitat-flow matrix was developed to demonstrate the spawning/incubation area (m^2) available under each flow scenario. The proportion (%) of spawning/incubation areas dewatered for each flow scenario was also calculated. It was assumed that spawning and incubation areas are the same and are representative of Kokanee spawning success.

2.2.1 Side Channel Status

The LDR flow model obtained from BC Hydrotech was also used to update side channel status (i.e., ON, OFF, BW) at various discharges originally modelled under DDMMON-3 (see Table 10 in NHC 2010). Flow scenarios at 25 m^3/s increments were evaluated between 25 and 400 m^3/s. Side channel status descriptions were similar to those used by NHC (2010), with the inclusion of a fourth description: FW = water entering from the upstream end to half way down the channel, but does not reach the downstream end of the channel.

2.3 Ground Truth

Habitat area and side channel status calculated with the LDR BC Hydrotech flow model were compared to observations collected during field sampling under DDMMON-4. Area differences (m^2) between the polygons mapped in the field versus the polygons from the BC Hydrotech flow model were calculated. Side channel status was compared between the model and DDMMON-4 field sampling using direct observations and photographs/video footage. However, direct observations to update the side channel status table were only available for flows of 75, 125 and 200 m^3/s in 2010 and for 100 m^3/s in 2016 within critical side channel areas.

3.0 RESULTS

3.1 Key Biological Considerations for Kokanee Protection

The key biological considerations for evaluating the effectiveness of any proposed changes to the Kokanee protection flow regime on the LDR are highlighted below.

3.1.1 Spawn Timing

Spawn run timing for Kokanee in the LDR occurs from late August to late October/early November; spawning is estimated to peak between September 28 and October 7 (24 September to 11 October; 95% Confidence Intervals) (ONA et al. 2017[3]; **Table 2**). During years with higher Kokanee spawner abundance, spawning typically begins in side channel habitats, but by peak spawning Kokanee are in side channel and mainstem habitats with approximately equal frequency (AMEC 2008-2012). In more recent years where lower abundances of Kokanee have been observed, spawning in side channels was less frequent compared to mainstem areas during peak spawning (ONA et al. 2016b, 2017). Kokanee spawning usually tapers off by late October (AMEC 2008-2012, ONA et al. 2016a, 2016b, 2017; **Table 3**), but spawning Kokanee have been observed into early November (AMEC 2012).

Table 2: Estimated date of annual peak counts of Kokanee spawners in the LDR study area, 2008-2016 (from ONA et al. 2017)

Year	Date of Peak Spawning	Lower 95% CI	Upper 95% CI
2008	Oct 2	Sep 30	Oct 4
2009	Oct 5	Oct 2	Oct 8
2010	Oct 3	Oct 1	Oct 5
2011	Sep 28	Sep 24	Oct 5
2012	Oct 6	Oct 1	Oct 10
2013	Oct 7	Oct 4	Oct 10
2014	Oct 7	Oct 3	Oct 10
2015	Oct 6	Sept 29	Oct 11
2016	Oct 3	Sept 28	Oct 7

[3] Note that in 2016 the DDMMON-4 model was revised to allow the uncertainty in the spawner counts to vary with the annual abundance. This improvement occurred based on low spawner abundances observed after 2013 and resulted in an improvement in the estimates in years with lower counts (ONA et al. 2017).

Table 3: Number of Kokanee spawners observed during final helicopter enumeration under DDMMON-4 (AMEC 2008-2012; ONA et al. 2016a, 2016b, 2017)

Enumeration Year	Last Survey Date	Number Spawners Observed
2008	14 October	7,890
2009	27 October	0 (15 Oct = 1,753)
2010	13 October	4,258
2011	20 October	1,974
2012	10 October	36,318
2013	9 October	9,662
2014	-	-
2015	15 October	816
2016	19 October	746

Notes: Number of spawners observed represent mainstem and side channel areas combined.
"-" No data report available for 2014 and details not provided in ONA et al. (2016b).

3.1.2 Incubation & Fry Emergence Timing

A summary of the estimated developmental stage dates for Kokanee in the LDR (2008-2017) based on applicable ATUs and LDR water temperatures downstream of the Lardeau River at the DRL water gauge is provided in **Table 4**. Compiled Kokanee stages and corresponding ATUs are based direct observations collected at Meadow Creek (Acara 1970, MFLNRO unpublished) and the Kootenay Trout Hatchery (D. Koller, Kootenay Trout Hatchery, pers. comm., 2008) and are summarized in AMEC (2008).

Table 4: Estimated developmental stage dates for LDR Kokanee based on Accumulated Thermal Units (ATU) per Spawner Cohort Year, 2008-2017

	ATU	Spawning Cohort Year								
Stage		**2008/ 2009**	**2009/ 2010**	**2010/ 2011**	**2011/ 2012**	**2012/ 2013**	**2013/ 2014**	**2014/ 2015**	**2015/ 2016**	**2016/ 2017**
Peak Spawn Date		2-Oct	5-Oct	3-Oct	28-Sep	6-Oct	7-Oct	7-Oct	6-Oct	3-Oct
Eyed	333	6-Nov-08	3-Nov-09	2-Nov-10	29-Oct-11	8-Nov-12	8-Nov-13	6-Nov-14	5-Nov-15	1-Nov-16
Hatch	700-780	21-Jan-09	23-Dec-09	27-Dec-10	20-Dec-11	4-Jan-13	2-Jan-14	2-Jan-15	30-Dec-15	16-Dec-16
Emergence Start	735	5-Feb-09	2-Jan-10	3-Jan-11	26-Dec-11	11-Jan-13	8-Jan-14	10-Jan-15	9-Jan-16	22-Dec-16
Emergence End	890	23-Mar-09	9-Feb-10	9-Feb-11	11-Feb-12	13-Feb-13	13-Feb-14	13-Feb-15	10-Feb-16	26-Jan-17

Notes: Water temperatures are inclusive of both the Lardeau River and DDM releases (DRL Water Gauge).

In the LDR, Kokanee hatch out of the egg stage between late December and late January (**Table** 4). Depending on water temperatures experienced during the incubation period, emergence has been estimated to start in late December and mostly ends by mid-February, but in some year's emergence may not be completed until late March (**Table 4**). For example in 2008, the emergence period was estimated to occur later compared to other years (early February to late March) because winter water temperatures were colder (AMEC 2012).

3.2 Spawn/Incubation Habitat-Flow Matrix

The total amount of available Kokanee spawning/incubation area (m^2) mapped under DDMMON-4 was used as the basis for modelled flow comparisons (**Table 5**). The proportion (%) of this area dewatered for each modelled flow scenario is provided in **Table 6**.

Table 5: Kokanee spawning/incubation habitat area (m^2) available at modelled DRL flows in LDR critical side channels

Name	Max Habitat within Model	DRL Flows (m^3/s)					
		75	100	125	150	175	200
3.5R	2,160	299	1,835	2,099	2,140	2,151	2,160
6.9R	540	0	0	0	0	0	0
7.6R	801	0	0	0	13	510	598
8.2L	2,942	0	4	21	668	846	903
Total	**6,443**	**299**	**1,839**	**2120**	**2,822**	**3,507**	**3,662**

Notes: Max Habitat within Model = Total amount of mapped spawning/incubation habitat observed during DDMMON-4. Wetted habitat is not available in SC6.9R until >300 m^3/s.

Table 6: The proportion (%) of Kokanee spawning/incubation habitat dewatered at modelled DRL flows in LDR critical side channels

Name	Max Habitat within Model	DRL Flows (m^3/s)					
		75	100	125	150	175	200
3.5R	2,160	86	15	3	1	0	0
6.9R	540	-	-	-	-	-	-
7.6R	801	-	-	-	98	36	25
8.2L	2,942	-	100	99	77	71	69
Total	**6,443**	**95**	**71**	**67**	**56**	**46**	**43**

Notes: Max Habitat within Model = Total amount of mapped spawning/incubation habitat observed during DDMMON-4. Wetted habitat is not available in SC6.9R until >300 m3/s. (-) Habitats were not wetted for these flows and therefore nothing to dewater.

Based on the modelling, it was estimated that 3.5R had spawning/incubation habitat at flows >75 m^3/s, whereas 8.2L required flows >100 m^3/s and 7.6R required flows >150 m^3/s for spawning habitat to be available; no spawning/incubation habitat was predicted for 6.9R at any of the modelled flows (**Table 5**). Habitat area increased substantially from 299 to 1835 m^2 in 3.5R when flows increase from 75 to 100 m^3/s because the channel transitioned from BW to ON over this range of discharge (Table 8**, Section 3.3.1**). The highest proportion (95%) of dewatered spawning/incubation habitat area was modelled for the base case scenario of 75 m^3/s, with less dewatering predicted at flows >100 m^3/s (**Table 6**).

3.3 Ground Truth

3.3.1 <u>BC Hydrotech Model & Spawn/Habitat Flow-Matrix</u>

Overall, the BC Hydrotech model was able to predict 95% of the maximum amount of spawning/incubation habitat that were mapped during DDMMON-4 (**Table 7**). However, the model was less accurate at predicting the status of each side channel under various flow scenarios (**Table 8** and **Table 9**).

The model was more inconsistent near the river's edge where mapped side channel habitat polygons had to be clipped, even though original modelled cell sizes within these locations were 5 m compared to other areas (10 m; F. Yusuf, Specialist Engineer, BC Hydrotechnical Department, personal communication, 9 March 2017). The largest difference was for 7.6R, where the model predicted 89% of the actual mapped area compared to >93% for the other side channels (**Table** 7). Side channel 7.6R was also predicted as OFF and no habitats available until >150 m^3/s (**Table** 8). However, 7.6R has been observed BW at 75 m^3/s and ON at 100 m^3/s (**Table 9** and **Appendix C**).

Table 7: Maximum Kokanee spawning/incubation habitat (m^2) physically mapped (DDMMON-4) versus the maximum modelled habitat (m^2) in LDR critical side channels

Side Channel	Maximum Habitat Mapped (m^2)	Maximum Habitat Predicted with Model (m^2)	% Area Predicted
3.5R	2,190	2,160	98.6
6.9R	581	540	93.1
7.6R	900	801	89.1
8.2L	3,072	2,942	95.8
Total	**6,742**	**6,445**	**95.6**

Although the model predicted 93% of the maximum habitat area mapped for 6.9R, the model also predicted that habitat areas were not present at the flows examined (**Table** 5 and **Appendix C**) and that it was FW/BW at approximately 300 m^3/s (**Table** 8). Kokanee spawning areas were mapped in 6.9R between 200-250 m^3/s (24-25 September 2008, 26 September 2011, and 26 September 2012) and this side channel has been observed ON at flows of 125 m^3/s (30 September 2010)[4] and OFF at flows of 100 m^3/s (29 September 2016).

The model was not able to predict side channel status with a high level of accuracy. Direct observations of side channel status recorded during ground truthing surveys in 2010 and 2016 suggested the model only correctly predicted the status 55% of the time (**Table 9**).

3.3.1.1 Spawning Success

The BC Hydrotech model underestimated Kokanee spawning success (i.e., dewatering of spawning/incubation habitat area) in critical side channel areas. For example, the model predicted that approximately 95% of spawning/incubation habitats would be dewatered at 75 m^3/s and approximately 71% of these habitats would dewater at 100 m^3/s (**Table 6**). Spawn mapping conducted under DDMMON-4 observed that up to 33% of the spawning/incubation areas became dewatered at 73-75 m^3/s (AMEC 2012, ONA et al. 2017). In 2016, flows were held higher at 100 m^3/s and approximately 3% of spawning/incubation habitats became dewatered (ONA et al. 2017).

[4] Substantial morphological changes took place in the river during very high flows in July 2012 (NHC 2013). This side channel was originally predicted as OFF (NHC 2010) prior to updated hydrological surveys (NHC 2013) and was predicted as OFF after updating the model.

Table 8: Side channel status (ON, OFF, BW, FW) in the Lower Duncan River at DRL flows from 75 m^3/s to 400 m^3/s based on updated BC Hydrotech model.

Side Channel	DRL Gauge Flow (m^3/s)													
	75	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**	**325**	**350**	**375**	**400**
1.1R	BW	BW	BW	BW	BW	BW	BW	BW	ON	ON	ON	ON	ON	ON
2.7L	BW	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
3.5R	**BW**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**
4.1R	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
4.4R	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
6.9R	**OFF**	**OFF**	**OFF**	**OFF**	**OFF**	**OFF**	**BW**	**BW**	**BW**	**FW/BW**	**FW/BW**	**FW/BW**	**ON**	**ON**
7.6R	**OFF**	**OFF**	**OFF**	**OFF**	**FW**	**FW**	**FW**	**FW**	**FW**	**ON**	**ON**	**ON**	**ON**	**ON**
8.2L	**BW**	**BW**	**BW**	**BW**	**BW**	**BW**	**BW**	**FW/BW**	**ON**	**ON**	**ON**	**ON**	**ON**	**ON**
8.8L	OFF	OFF	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON

Notes: Bolded side channels are critical areas where Kokanee redds have been observed to dewater. Definitions for ON, OFF, BW from NHC (2010). FW = water entering from upstream end to half way down channel, but does not reach downstream end of channel; FW/BW = side channel is both FW and BW, but water is separated by dewatered area and not connected.

Table 9: Side channel status (ON, OFF, BW, FW) in the Lower Duncan River at DRL flows from 75 m³/s to 400 m³/s based on actual ground observations. Comparisons are made to modelled predictions from Table 8.

Side Channel	DRL Gauge Flow (m^3/s)													
	75	100	125	150	175	200	225	250	275	300	325	350	375	400
1.1R	ON	-	ON	-	-	ON	-	-	-	-	-	-	-	-
2.7L	ON	-	ON	-	-	ON	-	-	-	-	-	-	-	-
3.5R	BW	BW	ON	-	-	ON	-	-	-	-	-	-	-	-
4.1R	ON	-	ON	-	-	ON	-	-	-	-	-	-	-	-
4.4R	ON	-	ON	-	-	ON	-	-	-	-	-	-	-	-
6.9R	OFF	OFF	ON	-	-	ON	-	-	-	-	-	-	-	-
7.6R	BW	ON	ON	-	-	ON	-	-	-	-	-	-	-	-
8.2L	BW	BW	ON	-	-	ON	-	-	-	-	-	-	-	-
8.8L	ON	-	ON	-	-	ON	-	-	-	-	-	-	-	-
% Correct	56%	50%	56%	-	-	56%	-	-	-	-	-	-	-	-

Notes: Red = model incorrect; Green = model correct. Definitions for ON, OFF, BW from NHC 2010. FW = water entering from upstream end to half way down channel, but does not reach downstream end of channel; FW/BW = side channel is both FW and BW, but water is separated by dewatered area and not connected. (-) denotes that no information is available.

4.0 DISCUSSION

The following discussion is based on key biological criteria, habitat flow modelling, and the field flow trial conducted during the Kokanee spawning/incubation period.

4.1 Spawning, Incubation & Fry Emergence Timing

Peak of Kokanee spawning has been observed between 24 September and 11 October. During years with higher Kokanee spawner abundance, spawning typically begins in side channel habitats, but by peak spawning Kokanee are in side channel and mainstem habitats with approximately equal frequency (AMEC 2008-2012). In more recent years where lower abundances of Kokanee have been observed, spawning in side channels was less frequent compared to mainstem areas during peak spawning (ONA et al. 2016b, 2017). Spawning usually tapers off by late October, but Kokanee have been observed spawning into early November (AMEC 2012). Spawning protection flows occur from 1 to 21 October and do not cover the early portion of the peak spawning period. However, these targets were set prior to initiation of DDMMON-4 spawning monitoring studies.

Commencement of Kokanee fry emergence was estimated to be approximately 2-4 months earlier (January/February) in the LDR (depending on water year) than that estimated for the Lardeau River (late April) and directly measured by MFLNRO in Meadow Creek (mid-late May) (AMEC 2012, AMEC and Poisson 2012). For example, LDR water temperatures from October 2010 through January 2011 were approximately 5°C higher than those measured in the Lardeau River during this time period (AMEC and Poisson 2012). This would explain earlier fry emergence timing estimated for the LDR, since warmer water temperatures would promote faster egg development, earlier hatch times, more rapid alevin development and yolk sac absorption, which would lead to earlier emergence of fry.

It has been observed that water temperatures at the DRL gauge can vary compared to those observed downstream in the LDR depending on the time of year and the relative contribution to total discharge from both DDM and the Lardeau River (AMEC and Poisson 2012). However, these water temperature differences were not observed during the Kokanee spawning and emergence period (AMEC and Poisson 2012). Also, calculated ATUs from DRL water temperatures were similar to early life stages observed during incubation studies conducted in the LDR (AMEC 2010). For example, AMEC (2010) observed eyed Kokanee eggs on November 17, 2009 (413 ATUs) and yolked alevins on January 27, 2010 (692 ATUs) in both side channel (8.2L) and mainstem (2.4R) sites. The ATUs reported in AMEC (2010) were calculated based on site specific temperature loggers.

Kokanee emerge from the gravel as free swimming fry and migrate downstream to Kootenay Lake with water currents. This downstream migration occurs at night with the peak migration between dusk and midnight; fry are negatively phototactic (McPhail 2007). If the migration takes more than one night, they shelter during the day under rocks and organic debris (McPhail 2007). It is unknown at this time how long fry remain in the LDR after emergence, but based on their life history it is likely that they migrate downstream to Kootenay Lake shortly afterward. The only information available on LDR Kokanee fry outmigration is from Envirocon (1985) where Kokanee fry were sampled below all tributary inputs at the Argenta Bridge at approximately Rkm 7.

Although there were technical difficulties in sampling Kokanee fry from the LDR mainstem, Envirocon (1985) observed that fry migrated downstream at night in higher velocity areas near midstream rather than in the lower velocity river margins. Captures of peak fry numbers occurred in two pulses; one in late April and the other in mid-May. These pulses likely corresponded to timing in the Lardeau River (late April) and Meadow Creek (mid-May), but sampling was not conducted in March. AMEC (2003) reported the presence of alevins in a dewatered redd on 16 February 2003 in the main channel of the LDR approximately 1.1 km downstream of DDM. Golder (2017) observed a higher risk of stranding Kokanee fry in mid-April while conducting LDR stranding assessments; this may have corresponded to Lardeau River outmigration timing. Stranding surveys conducted during the early March period observed very few stranded Kokanee fry (Golder 2017). Kokanee fry outmigrate through the LDR to Kootenay Lake during the February/March period for LDR spawned Kokanee and during the April/May period for Meadow Creek/Lardeau River spawned fish (AMEC 2012).

4.2 Modelled Risk Analysis & Kokanee Flow Protection

Flow scenarios derived from the BC Hydrotech model may be useful to evaluate different Kokanee spawning protection flows at a high level if total habitat area for all side channels is used as the model was able to predict 95% of the maximum amount of spawning/incubation habitat that were mapped during DDMMON-4. Modelled flow scenarios demonstrated incremental gains in overall spawning/incubation habitat area when protection flows increased above 75 m^3/s (base case) as measured at DRL. Increasing flows above the base case to 100 m^3/s corresponded to a 24% reduction of dewatered spawning/incubation habitat area, whereas flows of 125 m^3/s corresponded to a 28% reduction, only 4% better than 100 m^3/s. Although flows >150 m^3/s demonstrated over a 40% reduction in overall dewatered spawning/incubation habitat area, there would be a trade-off to holding flows too high and potentially precluding spawning in some areas because depths and velocities may no longer be suitable. Kokanee spawning preferences include depths between 0.2 and 0.4 m and velocities between 0.2 and 0.6 m/s (Ecofish 2009 as cited in NHC 2013). Modelling of Kokanee spawning Weighted Useable Area (WUA) in the LDR under DDMMON-3 demonstrated an asymptotic increase from 50 to 250 m^3/s; suitability slightly declined at flows >250 m^3/s, but flows were not modelled beyond 325 m^3/s (NHC 2013). Eggs deposited in redds would likely not be affected at these higher operated flows as they are buried under layers of gravel substrates. For example, AMEC (2010) observed that Kokanee redd egg pocket depths ranged from 0.24 to 0.51 m during incubation studies on the LDR. However, these higher flows may inhibit spawning adults from moving into higher velocity habitat areas.

The model was less accurate at distinguishing habitat available within specific side channels for each flow scenario. For example, the model predicted that no habitat was available in 6.9R until approximately 300 m^3/s, but actual observations indicated that this side channel was ON at 125 m^3/s and OFF at 100 m^3/s. Similarly 7.6R had no habitat available until approximately 150 m^3/s, whereas ground observations indicated that it is ON at 100 m^3/s. Therefore, the risk analysis of how different protection flows will affect Kokanee spawning success underestimated the amount of habitat area available for the modelled flows when compared to actual ground observations. Improving the BC Hydrotech model for side channel 6.9R and 7.6R by incorporating actual observations from DDMMON-4 or further hydrometric surveying through DDMMON-3 may improve the accuracy.

4.3 Field Flow Trials & Kokanee Flow Protection

Based on biological rationale, DDM operational constraints, and discussions with the regulatory agencies, the Kokanee protection flow field trial was initiated on 25 September 2016 and included maintaining flows at 100 m^3/s through November when flows were increased (COFAC meeting 13 September 2016, ONA et al. 2017). Spawning protection flows were initiated 5 days earlier and held 25 m^3/s higher in 2016 compared to previous years (AMEC 2012, ONA et al. 2017). Peak spawning was estimated to occur between 28 September and 7 October 2016 with an estimated total spawner abundance of 4,341 Kokanee, which is substantially lower than observed over the first five years of this program (ONA et al. 2017). It was estimated that approximately 3% of spawning/incubation areas within critical side channels were dewatered in 2016 compared to previous years that observed up to 33% of these habitats dewatered when protection flows were initiated on 1 October and dropped to 75 m^3/s (AMEC 2012, ONA et al. 2017).

Lower dewatering rates have also been observed in 2014 (~1%) and 2015 (0%) when protection flows were held at 75 m^3/s and initiated on 1 October, during the low Kokanee abundance period (ONA et al. 2017). Kokanee abundance estimates were similar in 2009, 2013[5] and 2014 with 8,000-9,000 spawners present and it was observed that approximately 33%, 13% and 1% of spawning/incubation areas were dewatered after protection flows were held at 75 m^3/s (AMEC 2012, ONA et al. 2017). During 2010, 2011 and 2012, years when spawner abundance was >11,000 fish, it was observed that approximately 6%, 14% and 16% of the spawning/incubation areas became dewatered for protection flows of 75 m^3/s (AMEC 2012).

4.4 Conclusions

Based on past field observations and the high level modelling assessment, increasing protection flows from 75 to 100 m^3/s could be beneficial to Kokanee by reducing the amount of side channel spawning/incubation area dewatered. An additional monitoring year with 100 m^3/s variation, if operationally feasible, is required to monitor the success of the alternative scenario. In addition to increasing the protection flow level, flow timing and duration is also a consideration based on biological observations. Currently, spawning protection flows occur from October 1-21, however, peak spawning was observed to occur between 24 September and 11 October. To avoid impact to spawners and newly spawned eggs and incorporate information from DDMMON-4, spawning protection flows should be initiated in late September with steady or increasing discharge until Kokanee fry emergence is complete as was conducted in 2016. Monitoring ATUs during the incubation period would help determine fry emergence timing and may be a useful tool for planning spring flow reductions. Day-time flow fluctuations should also be minimized during the Kokanee fry outmigration period to reduce the occurrence of stranding.

[5] ONA et al. (2017) indicated that pre-spawn mapping was based on back calculating areas from observed watered and dewatered side channel redds on 2 Oct 2013.

5.0 RECOMMENDATIONS

1. Conduct an additional monitoring year with 100 m^3/s variation, if operationally feasible, to monitor the success of the alternative scenario.
2. Improve utility of the BC Hydrotech model for predicting habitat area in side channel 6.9R and 7.6R by including actual observations from monitoring studies (i.e., DDMMON-4) or by conducting additional hydrometric sampling within these side channels (i.e., DDMMON-3).
3. Collect observations of side channel status during DDMMON-4 field surveys to verify the BC Hydrotech model at various flow levels. The procedure to complete this task should include filling out Table 9 and taking photos of the inlet and outlet of each side channel.
4. Consider using 1:500 scale base maps during DDMMON-4 field surveys to be consistent with 2009-2012 field sampling established for the program (AMEC 2012). This scale provides a higher level of accuracy during helicopter mapping because locations and spawning areas could be better represented compared to the larger scale maps used for spawning enumeration (AMEC 2012). Spawn mapping in 2009-2012 was also conducted as a separate survey from spawner enumeration to focus on the mapping task objective. This separate spawn mapping flight will be imperative during periods of higher Kokanee abundance.
5. Minimize day-time flow fluctuations during the Kokanee fry outmigration period (February/March for LDR; April/May for Lardeau River and Meadow Creek) to reduce the occurrence of stranding.

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Appendix A

Kokanee Spawning/Incubation Mapped Habitat Use Areas

Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Spawning Area
- Spawning Area - Dewatered
- Spawning Area - Dewatered – Approximated Area

0 50 100 200
Meters
1:5,000

Reference:
BC Hydro
2015 Imagery

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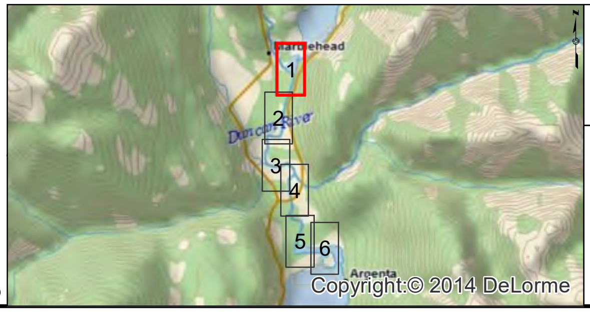

CLIENT:

Prepared for BC Hydro

PROJECT:

DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:

LDR Kokanee Spawning Areas 2008 - 2012 1 of 6

DATE:	ANALYST:	QA/QC:	
November, 2016	MY	CL	Figure 1

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JOB No: VE52598

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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Legend

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- Named Sidechannel
- Spawning Area
- Spawning Area - Dewatered
- Spawning Area - Dewatered – Approximated Area

0 50 100 200
Meters
1:5,000

Reference:
BC Hydro
2015 Imagery

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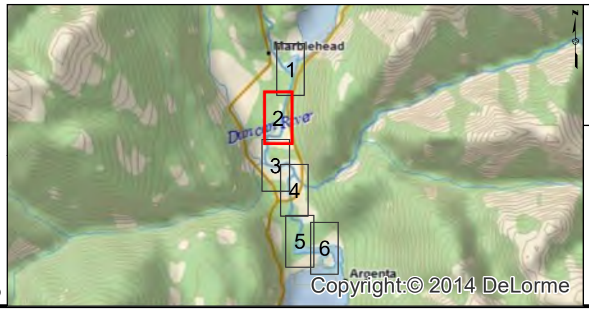

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Prepared for BC Hydro

PROJECT:

DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:

LDR Kokanee Spawning Areas
2008 - 2012
2 of 6

DATE:	ANALYST:	QA/QC:	
November, 2016	MY	CL	Figure 1

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02-01-003_5k_Overview

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COORDINATE SYSTEM:
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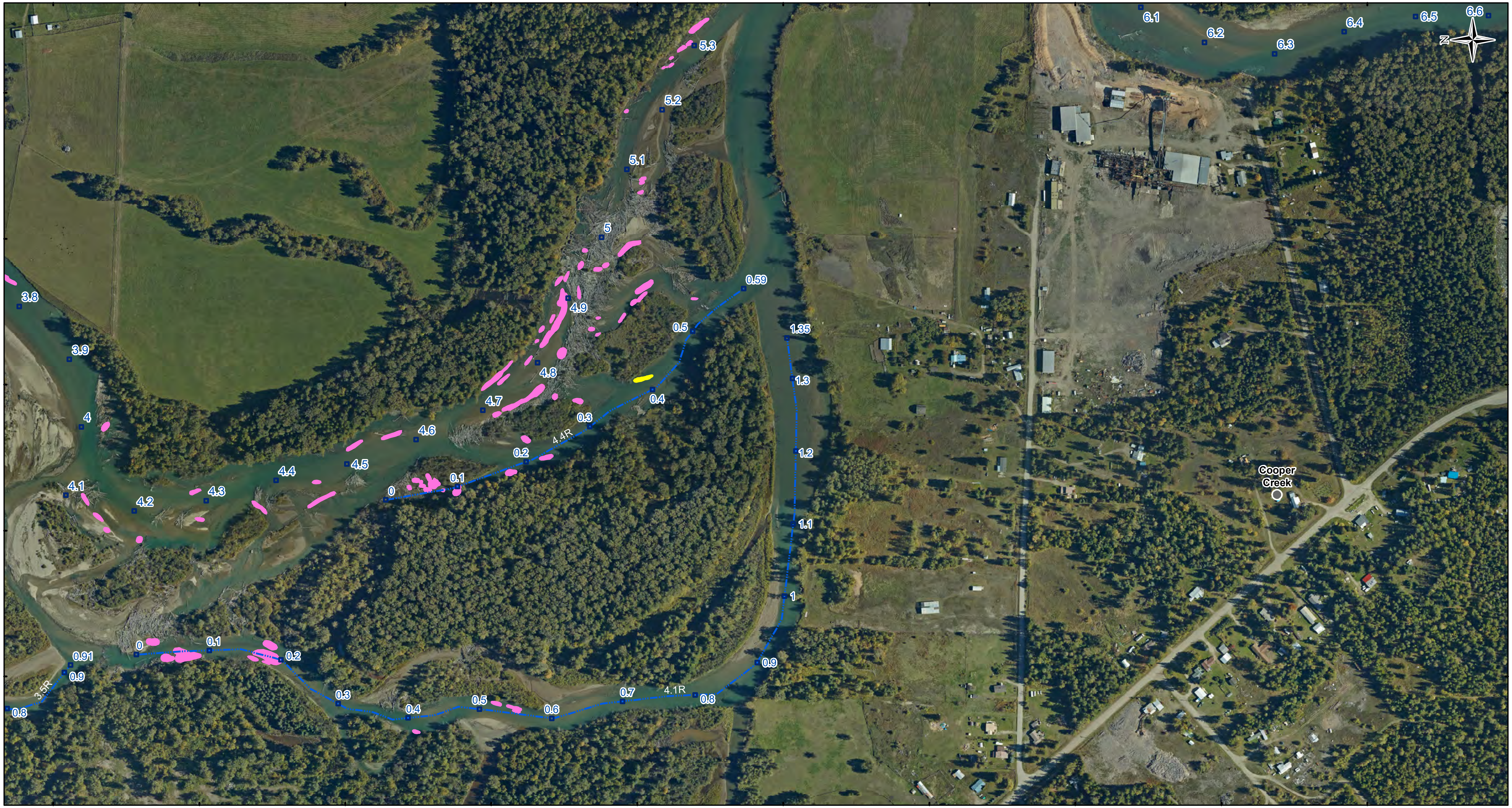

Legend

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- Named Sidechannel
- Spawning Area
- Spawning Area - Dewatered
- Spawning Area - Dewatered – Approximated Area

0 50 100 200
Meters
1:5,000

Reference:
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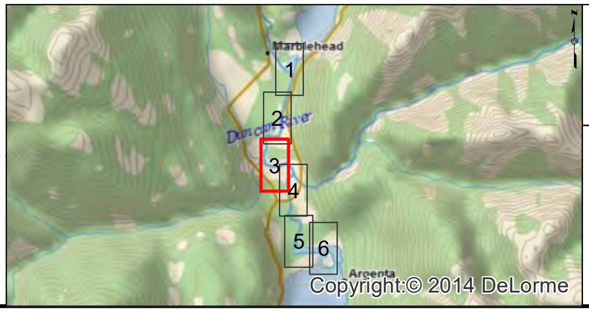

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TITLE: LDR Kokanee Spawning Areas 2008 - 2012 3 of 6	DATE: November, 2016 · ANALYST: MY · QA/QC: CL · Figure 1
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	COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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0 50 100 200
Meters
1:5,000

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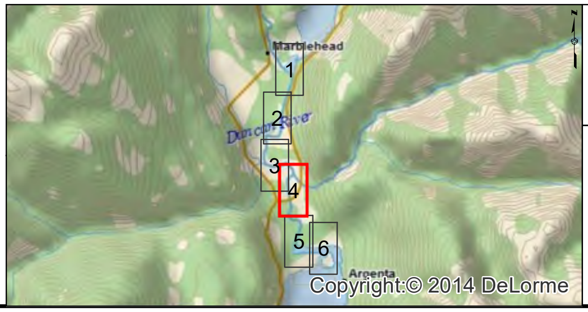

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PROJECT:
DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:
LDR Kokanee Spawning Areas
2008 - 2012
4 of 6

DATE:	ANALYST:	QA/QC:	
November, 2016	MY	CL	Figure 1

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BC Hydro
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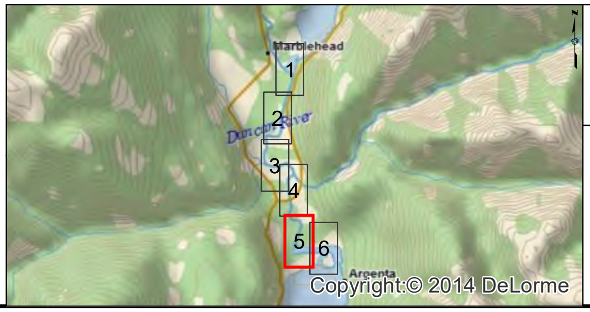

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PROJECT:
DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:
LDR Kokanee Spawning Areas 2008 - 2012
5 of 6

DATE:	ANALYST:	QA/QC:	
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COORDINATE SYSTEM:
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0 50 100 200
Meters
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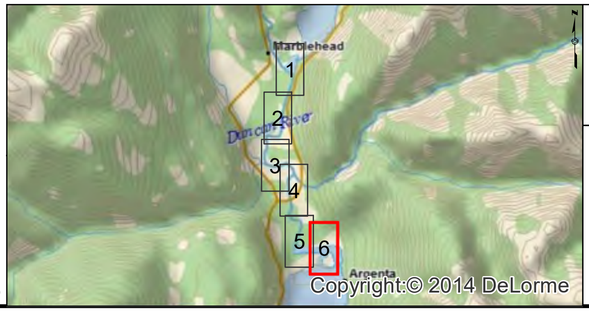

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PROJECT:
DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:
LDR Kokanee Spawning Areas
2008 - 2012
6 of 6

DATE:	ANALYST:	QA/QC:	
November, 2016	MY	CL	Figure 1

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COORDINATE SYSTEM:
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Appendix B

BC Hydrotechnical Department Model Memo

BC hydro
FOR GENERATIONS

Inter-office memo

To:	Philip Bradshaw	Date:	24 April 2015
From:	Faheem Sadeque	File:	DDM15MIS GR0020 D095 R018
CC:	Alf Leake		
Subject:	Duncan Dam Water Use Plan – Updated Hydraulic Modelling of Lower Duncan River		

1. Introduction

As part of the Duncan Dam Water Use Plan (DDM WUP), a two-dimensional (2D) hydrodynamic model was developed for a long-term environmental monitoring program in the Lower Duncan River (NHC 2013). Figure 1 shows a location map of the study area. The hydraulic model includes main channels, side channels and overbank areas adjacent to the Lower Duncan River between Duncan Dam and Kootenay Lake.

A 2D model was initially developed by Northwest Hydraulic Consultants (NHC) in 2010 based on topographic DEM (Digital Elevation Model) data collected by BC Hydro in 2008 and some topographic and bathymetric data collected by NHC in 2008 (NHC 2010). ADCP (Acoustic Doppler Current Profiler) data collected in August 2010 were used for model calibration. Additional bathymetric data were collected in September 2012 after a major flood event in the study area. Substantial morphological changes took place in the river during very high flows that occurred in July 2012. In order to represent the latest bottom geometry of the river channels, the 2D model was updated by NHC with the September 2012 bathymetric data (NHC 2013). Water levels were measured at six locations in the Lower Duncan River Valley during a flow ramping event at Duncan Dam from September 25 to October 2, 2012. These water level time series were compared with model results to check the model calibration. NHC's reports issued in 2010 and 2013 provide detailed description of the model development and calibration.

LiDAR topographic data and orthophotos were collected in the study area on July 4 and July 21, 2012. For reference, the flows were 312 m^3/s and 544 m^3/s on July 4 and July 21, respectively, at the Water Survey of Canada (WSC) gauge below the confluence of the Duncan and Lardeau Rivers (WSC 08NH118). The higher accuracy LiDAR data can provide better geometric representation of current side channel alignments and shallow areas for improved environmental flow modelling compared to the 2008 topographic data used for previous Duncan Water Use Plan assessments. Therefore, the BC Hydro Environmental Risk Management Team requested Hydrotechnical Engineering to update the 2D hydraulic model developed by NHC with 2012 LiDAR data. In addition, hydraulic model simulation results for Lower Duncan River steady discharges of 25 m^3/s to 400 m^3/s at 25 m^3/s increments were also requested for use in further environmental analysis.

This memo provides documentation of the requested model updates and results of hydraulic simulations for steady discharge scenarios.

2. Model Update

NHC provided the 2D hydraulic model of the Lower Duncan River which was developed in Telemac2D version 6.1, and associated model calibration files, as described in their 2013 report. The model extents are shown on Figure 1.

2.1 DEM Update with LiDAR Data

DEM updates were performed only for areas covered by 2012 LiDAR data. No updates were made in the river channels for areas covered by bathymetric data. Figure 2 shows the updated bottom elevations for the study area. Only the elevations of the 2D model mesh developed by NHC (2013) were modified. The x and y coordinates of the mesh vertices were not changed.

Figure 3 shows comparisons of the topographic DEM and 2D model geometry for a selected complex channel area, as an example, between NHC (2013) and the current updates based on 2012 LiDAR data. The river channel bottom elevations were revised by NHC after the major flood of 2012. The updated model preserved the channel bottom elevations from NHC (2013). As shown in Figure 3, LiDAR data coverage provides improved geometric representation of the side channels and shallow areas.

2.2 Model Calibration

NHC calibrated the 2D model using water levels measured at multiple locations along the main channel (see Fig. 1) of the Lower Duncan River during flow ramping at Duncan Dam in 2012. Daily average flows at WSC 08NH118 ranged from 232 m^3/s to 72 m^3/s during the flow ramping event. As a check, the updated model was run in Telemac2D version 6.1 for this scenario and simulated water levels were compared with measured data and NHC (2013) results (see Figure 4). The updated model results are within 0.05 m to 0.1 m of NHC (2013). The agreement between measured data and updated model results are either similar or better than NHC (2013), except at station LL506 downstream of the confluence with Lardeau River. Updated model results are generally within 0.05 m of the measured data. The difference at station LL506 is about 0.2 m to 0.25 m.

Figure 5 shows the available topography and bathymetry data near Duncan Dam. The limited bathymetric data collected after the major flood event in July 2012 that substantially changed the river morphology could be a possible reason for the model discrepancy at station LL506.

The model results are plotted in Figure 6(a-e) against Duncan River discharges (total discharges from Duncan Dam LLO and Lardeau River) at five hydrometric stations with corresponding water levels measured during the flow ramping test in Fall 2012. Updated model results have better agreement with measured data than NHC (2013) model results at Lower Duncan River stations LL111, LL513 and LL510.

Water level assessment in the complex channel area beside Meadow Creek could be critical for environmental monitoring purposes. Figure 7 shows that limited bathymetry data were collected in this area after the major flood in 2012. Hydrometric data in this area were also not available for model calibration. Therefore, the accuracy of model results in this complex channel area cannot be quantitatively assessed. Figure 8 shows modelled water levels at two selected stations in the main channel and in the side channel for the Fall 2012 flow ramping test period. Updated model results are 0.1 m to 0.2 m higher than NHC's (2013) results which seems reasonable as the channels are narrower in the updated model due to 2012 LiDAR data (see Figure 3).

Comparison of the updated model results with 2010 ADCP velocity measurements was not performed as the river bathymetry changed substantially in 2012. NHC used the ADCP data to calibrate their initial 2D model, developed using 2008 bathymetry data.

3. Model Simulation for Steady Flow Scenarios

3.1 Model Setup

The updated hydraulic model was run in Telemac2D version 6.1 for Lower Duncan River steady flows from 25 m^3/s to 400 m^3/s at 25 m^3/s increments. Lardeau River and Meadow Creek flows were assumed to be constant at 20 m^3/s and 5 m^3/s, respectively, for Duncan River below Lardeau River discharges from 50 m^3/s to 400 m^3/s. The remaining flows were assumed to be Duncan Dam releases. For the lowest flow scenario of 25 m^3/s, Duncan Dam, Lardeau River and Meadow Creek flows were assumed to be 10 m^3/s, 10 m^3/s and 5 m^3/s, respectively. As per NHC (2013) and NHC (2010), Hamill and Cooper Creek discharges were assumed to be negligible for all scenarios and a constant water level of El. 531.62 m at Kootenay Lake was assumed as the model downstream boundary condition for all flow scenarios.

The model simulations were carried out for a duration of 24 hours for each discharge scenario to establish steady state conditions in the entire study area. Similar initial conditions with very low flow, approximately 0.2 m water depth in the main channel, were used for each scenario. This approach allowed gradually increasing inundation of the side channels and shallow areas with each flow increment. The modelled steady discharge scenarios do not show any cut-off channels or ponding in low spots on the floodplain. Therefore, additional areas could be wet for these discharge scenarios with much higher initial flows. If estimation of water depths in isolated wet areas is necessary for environmental assessment, modelling of flow ramp down scenarios would be required.

3.2 Model Results

3.2.1 Inundation Extent

The modelled inundation extents for each flow scenario are provided as electronic attachments in ArcView GIS shapefile format. Inundation extents for selected flow scenarios are shown in Figure 9.

For Lower Duncan River discharge scenarios of 375 m^3/s and 400 m^3/s, the inundation extents along a short reach of Meadow Creek were slightly outside the model mesh developed by NHC. This area was backwatered by high flow releases from Duncan Dam which required the inundation extents for the 375 m^3/s and 400 m^3/s discharge scenarios to be locally adjusted based on the updated DEM.

Some manual refinements of the shapefiles were performed in GIS in some areas to provide smoother inundation extents, particularly where the relatively coarse mesh resolution of the 2D model led to locally irregular water surface extents.

3.2.2 Water Depth and Elevation

A 2D hydraulic model computes results at each node (vertices of each triangle) of the model mesh. Steady state water depths and water surface elevations for each flow scenario are provided as electronic attachments in ArcView GIS shapefile format. Location coordinates (UTM zone 11) and bottom elevations at each node are also provided in these shapefiles.

Water depths and water surface elevations inside the shapefile polygons are considered reliable. It is recommended to disregard model results outside the polygon shapefiles.

4. Conclusions and Recommendations

The 2D hydraulic model for the Lower Duncan River has been updated with 2012 LiDAR data which provides improved representation of side channel alignments and shallow areas adjacent to the main channel.

This model has been run for Lower Duncan River steady flow scenarios up to 400 m^3/s and results are provided for further environmental analysis. The inundation extents obtained from the modelled steady discharge scenarios correspond to flow conditions ramping up. They do not show any cut-off channels or ponding in low spots. If estimation of water depths in isolated wet areas is necessary for environmental assessment, modelling of flow ramp down scenarios would be required.

Additional hydrometric (water level) and bathymetric data in key areas such as the side channels near Meadow Creek should be collected to enable further hydraulic model updates.

5. References

NHC (2010): Duncan Dam Water Use Plan, Lower Duncan River Hydraulic Model – Year 2 Reporting, Northwest Hydraulic Consultants Ltd., September 2010.

NHC (2013): Duncan Dam Water Use Plan, Lower Duncan River Hydraulic Model – Year 5 Reporting, Northwest Hydraulic Consultants Ltd., October 2013.

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — Dr. M. A. F. SADEQUE — 34358

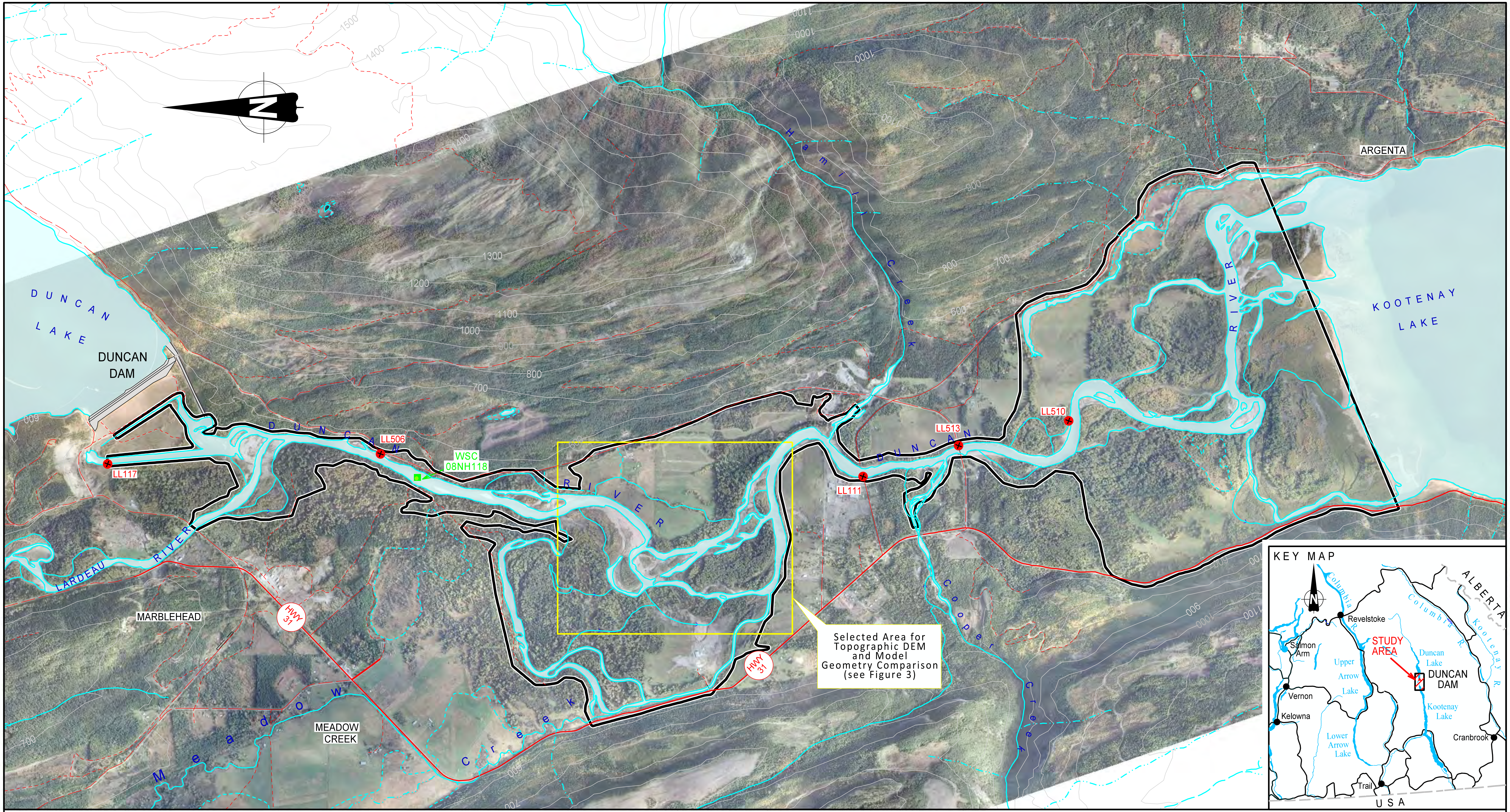
Prepared by: ______________________

Faheem Sadeque, P.Eng.

Reviewed by: ______________________

Faizal Yusuf, P.Eng.

FIGURES



Normal Water Level

Shore Line / River / Creek

Highway / Main Roads

Secondary / Forestry Roads

Water Survey of Canada Hydrometric Station

Water Level Measurement Locations During Fall 2012 Flow Ramping

Hydraulic Model Extent

1000 0 1000 2000m

PRODUCED BY PHOTOGRAMMETRY SERVICES, BC HYDRO

UTM ZONE 11, NAD83
BCGS REFERENCE: 92G

BASE MAP DERIVED FROM TRIM 1:20 000
IMAGE IS DIGITAL ORTHOPHOTO
BC HYDRO DUNCAN DAM 2008,
(1:20000 Aerial Photography flown on Oct. 20, 2008)

TRIM CONTOURS - CONTOUR INTERVAL IS 100m

SCALE AS SHOWN

BC hydro ENGINEERING

DUNCAN DAM
to
KOOTENAY LAKE

STUDY AREA

DATE	DISTR #	DWG NO / CAD		SIZE	R
Mar. 31, 2015			Figure 1	B	0

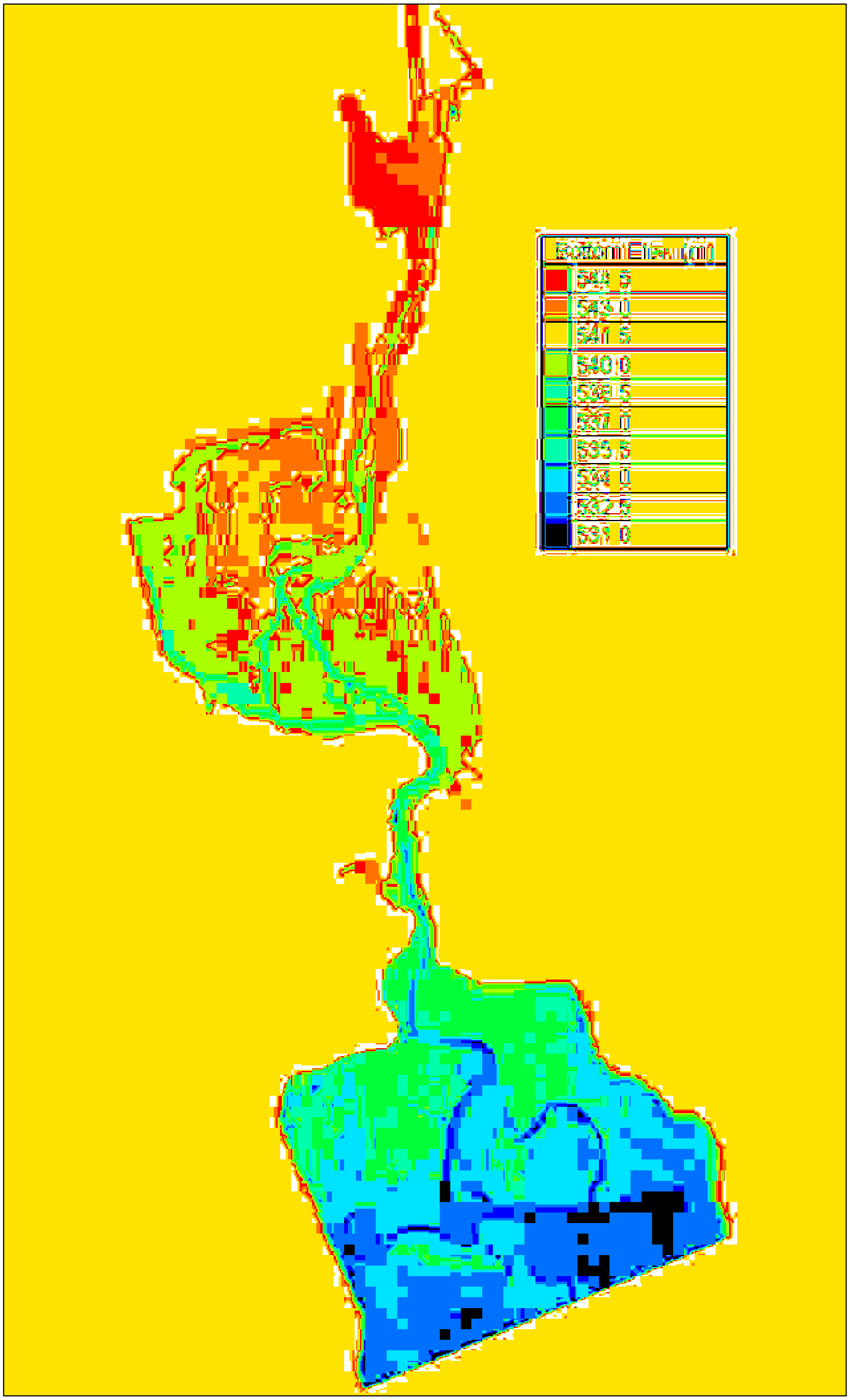


Figure 2: Updated Telemac2D Model Bottom Elevations with 2012 LiDAR Data

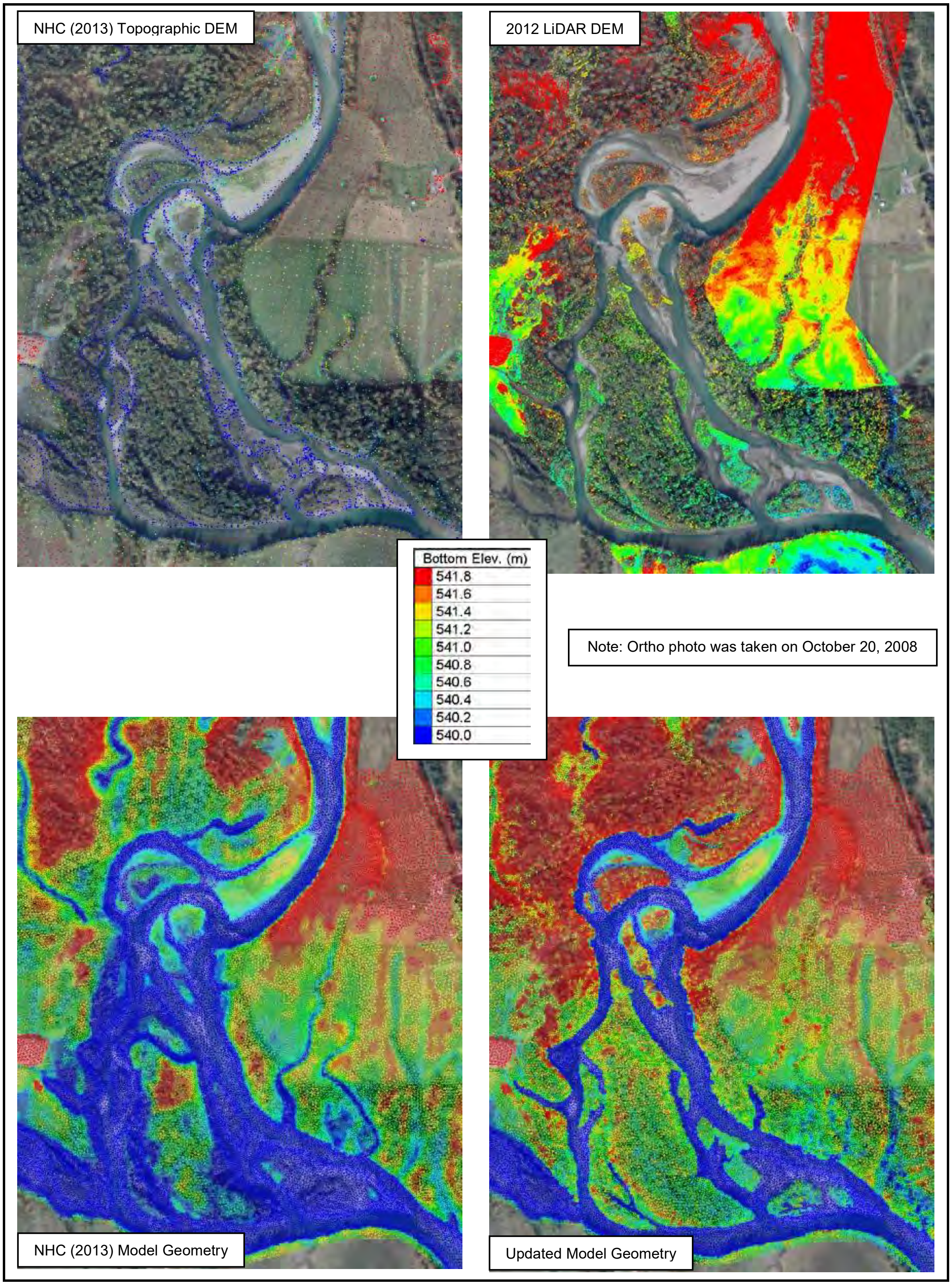


Figure 3: Comparison of Topographic DEM and Model Geometry for a Selected Area between NHC (2013) and Updated Model Using 2012 LiDAR Data

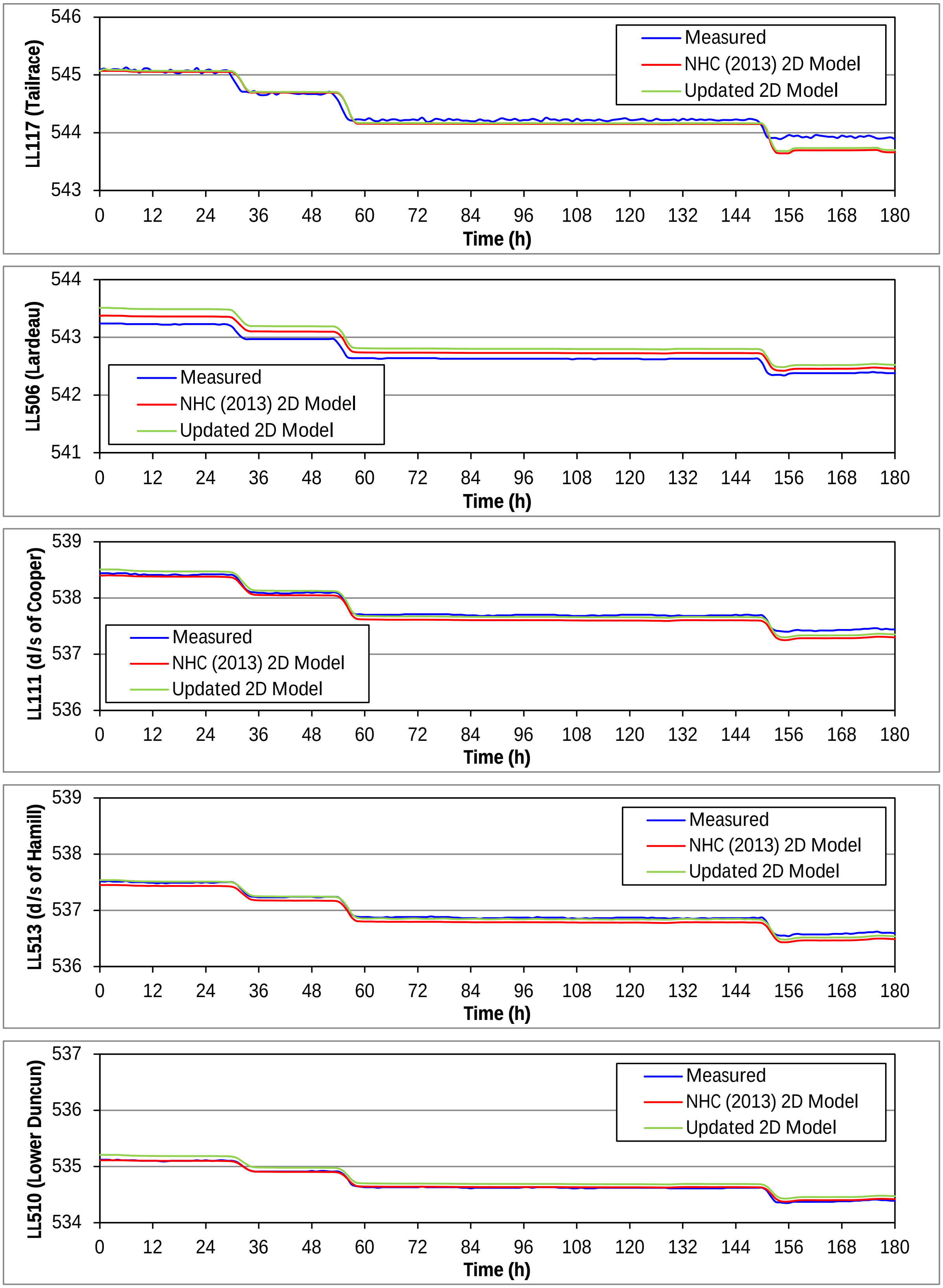


Figure 4: Comparison of Updated Modelled Water Levels with Measured Data and NHC (2013) 2D Model Results for the Fall 2012 Flow Ramping Scenario

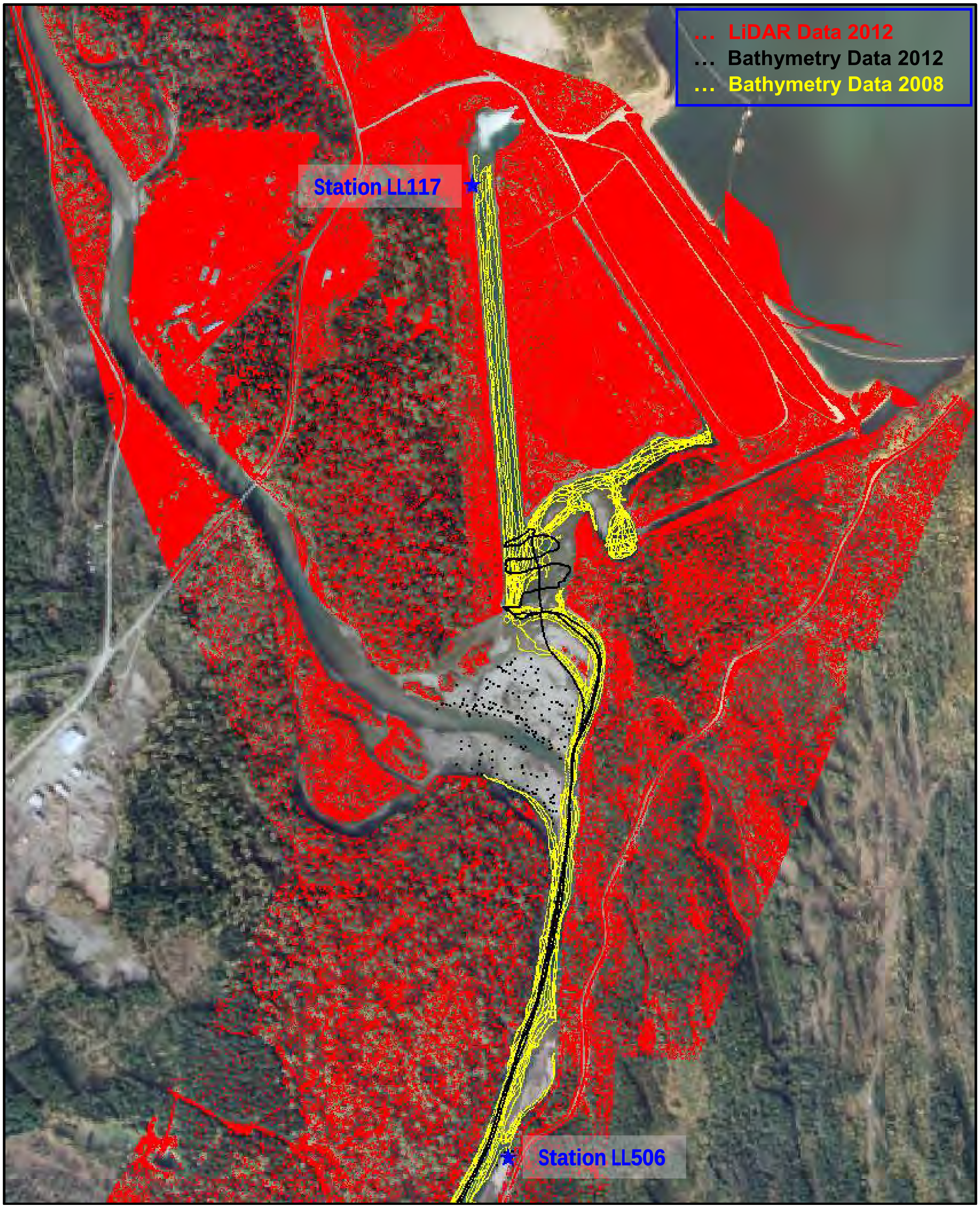


Figure 5: Topography and Bathymetry Data Coverage Near Duncan Dam

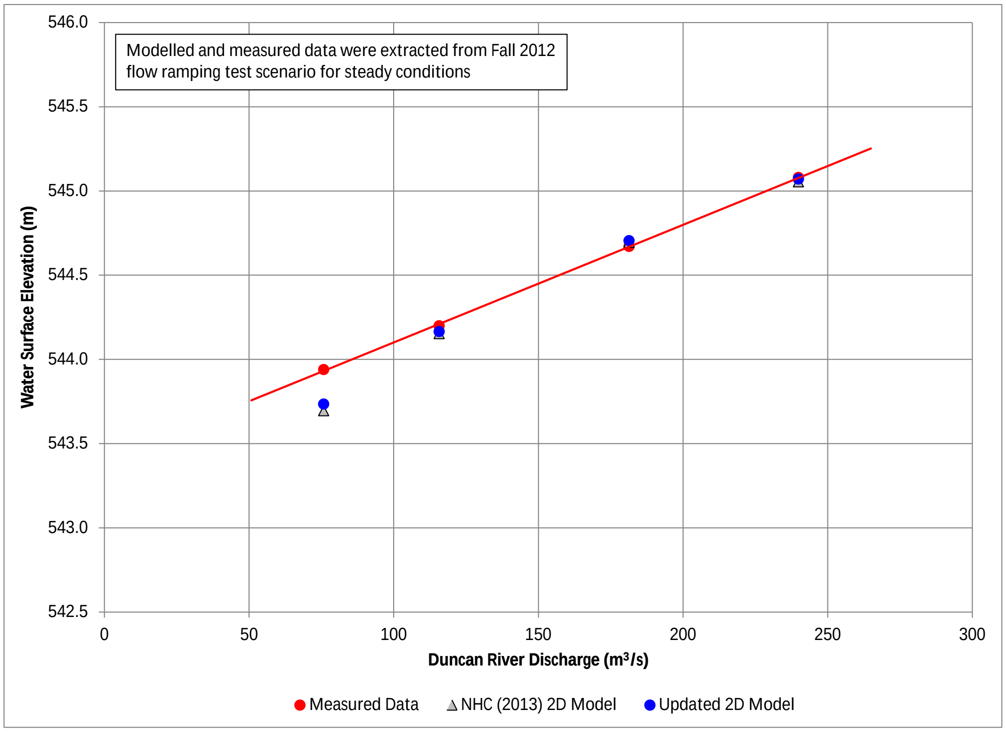


Figure 6(a): Water Surface Elevation and Duncan River Discharge (Total Discharges from Duncan Dam and Lardeau River) Relationship at Tailrace Station LL117

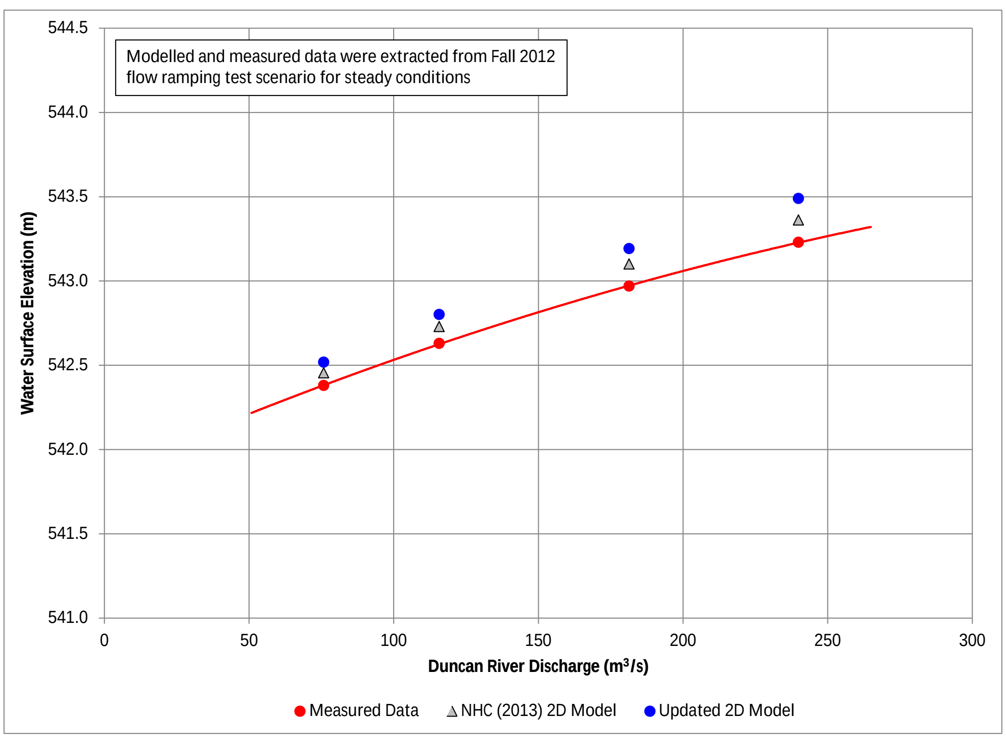


Figure 6(b): Water Surface Elevation and Duncan River Discharge (Total Discharges from Duncan Dam and Lardeau River) Relationship at Station LL506 Downstream of Lardeau River

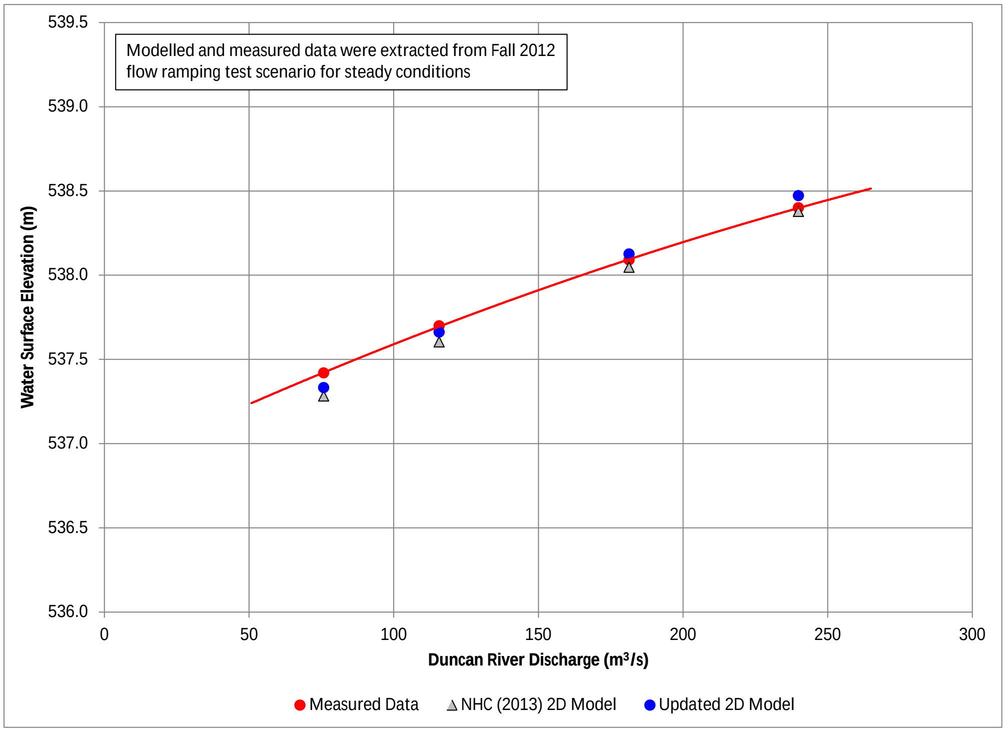


Figure 6(c): Water Surface Elevation and Duncan River Discharge (Total Discharges from Duncan Dam and Lardeau River) Relationship at Station LL111 Downstream of Cooper Creek

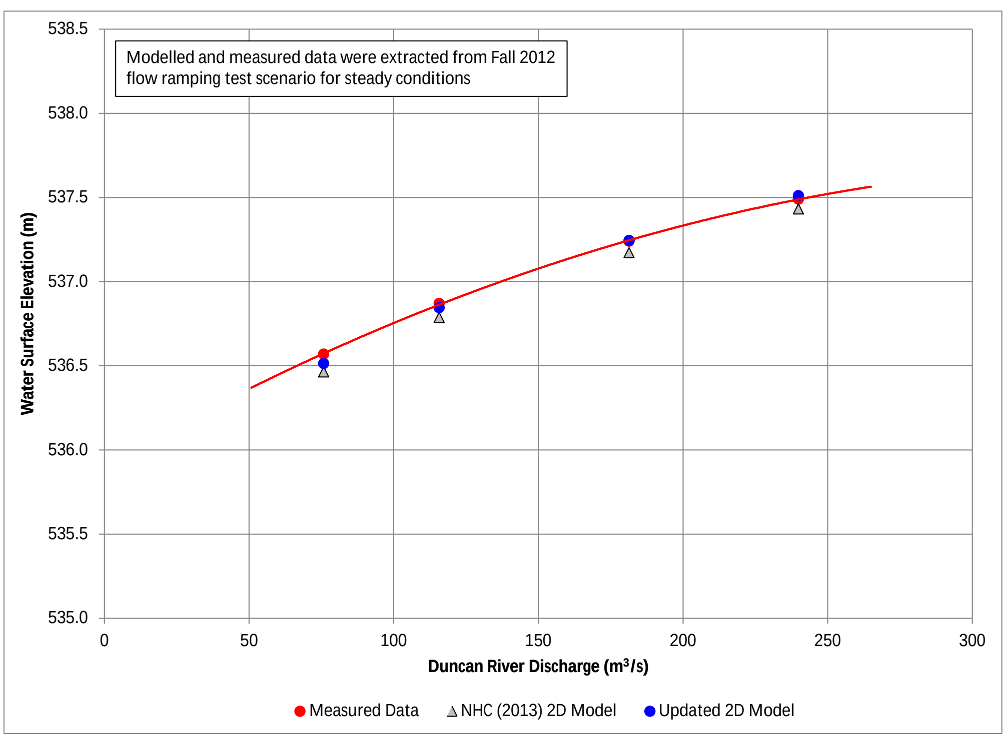


Figure 6(d): Water Surface Elevation and Duncan River Discharge (Total Discharges from Duncan Dam and Lardeau River) Relationship at Station LL513 Downstream of Hamill Creek

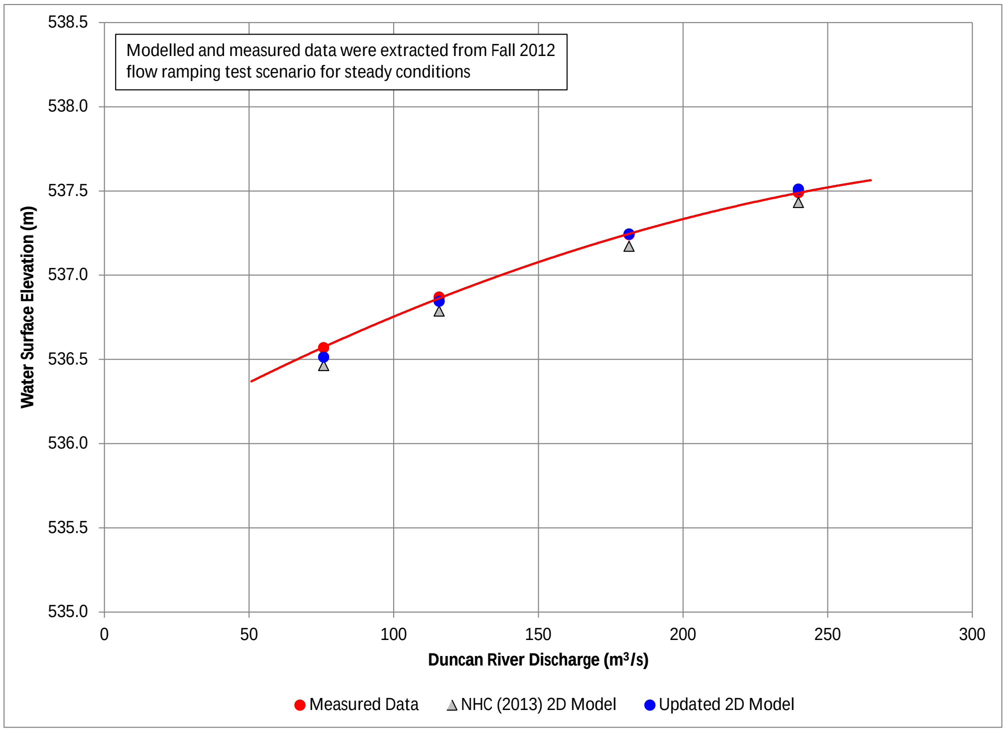


Figure 6(e): Water Surface Elevation and Duncan River Discharge (Total Discharges from Duncan Dam and Lardeau River) Relationship at Lower Duncan River Station LL510

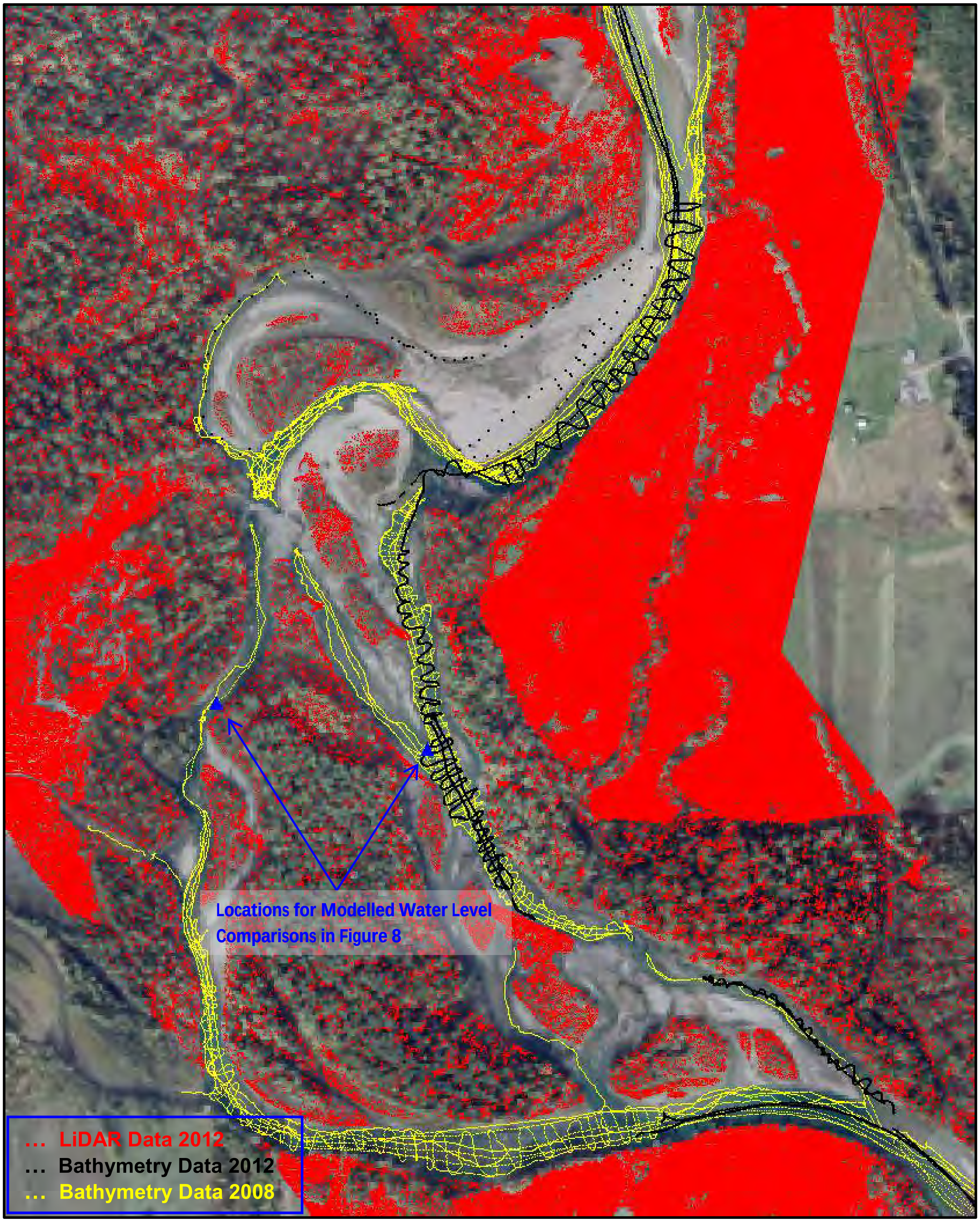


Figure 7: Topography and Bathymetry Data Coverage in Duncan River and Side Channels near Meadow Creek

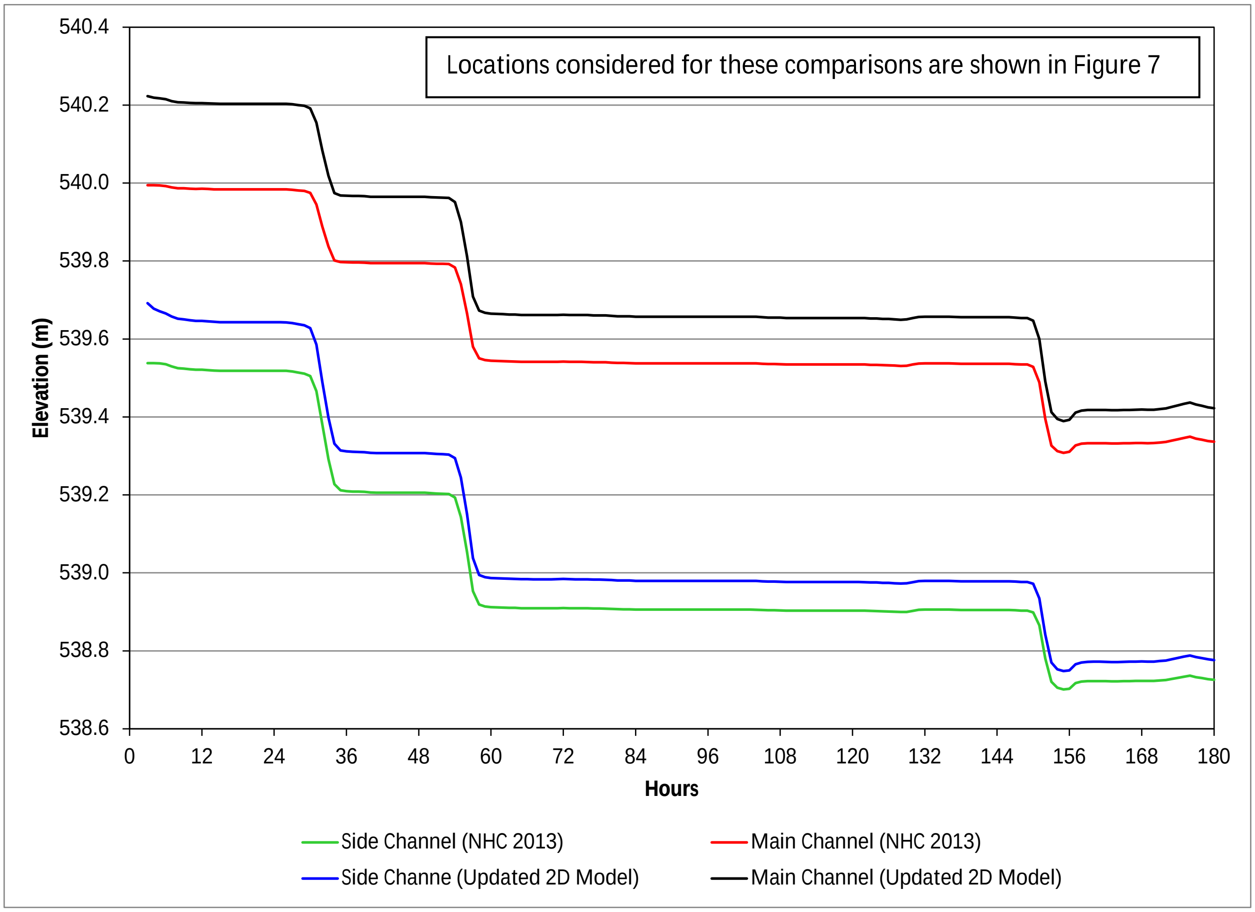
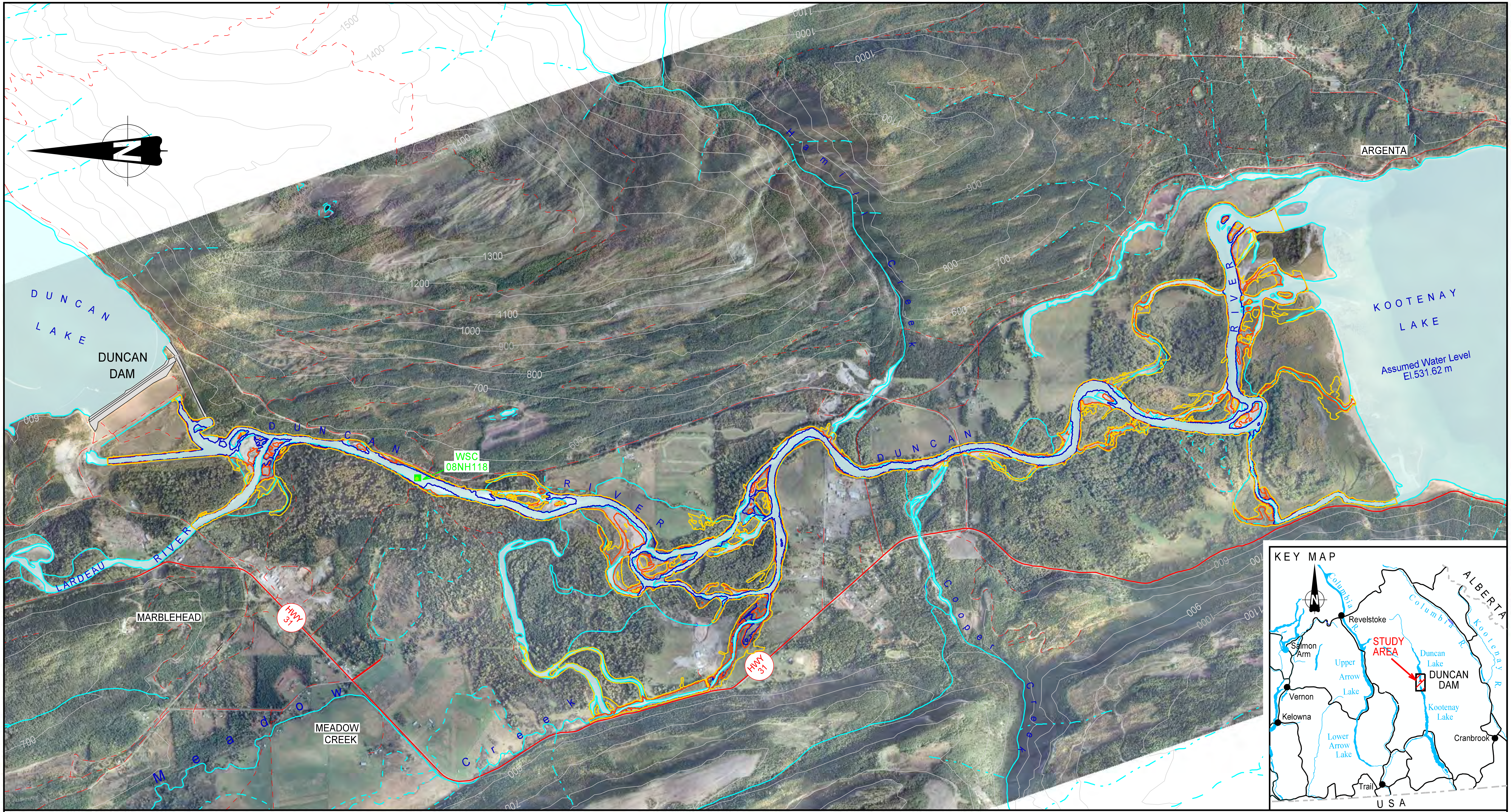


Figure 8: Comparison of Updated Modelled Water Levels with NHC (2013) 2D Model Results for the Fall 2012 Flow Ramping Scenario at Selected Area Upstream of Meadow Creek Confluence



Normal Water Level

Shore Line / River / Creek

Highway / Main Roads

Secondary / Forestry Roads

Water Survey of Canada Hydrometric Station

Modelled Inundation for Selected Discharge Scenarios

400 m^3/s

200 m^3/s

25 m^3/s

1000 0 1000 2000m

PRODUCED BY PHOTOGRAMMETRY SERVICES, BC HYDRO

UTM ZONE 11, NAD83
BCGS REFERENCE: 92G

BASE MAP DERIVED FROM TRIM 1:20 000
IMAGE IS DIGITAL ORTHOPHOTO
BC HYDRO DUNCAN DAM 2008,
(1:20000 Aerial Photography flown on Oct. 20, 2008)
TRIM CONTOURS - CONTOUR INTERVAL IS 100m

SCALE AS SHOWN

BC hydro ENGINEERING

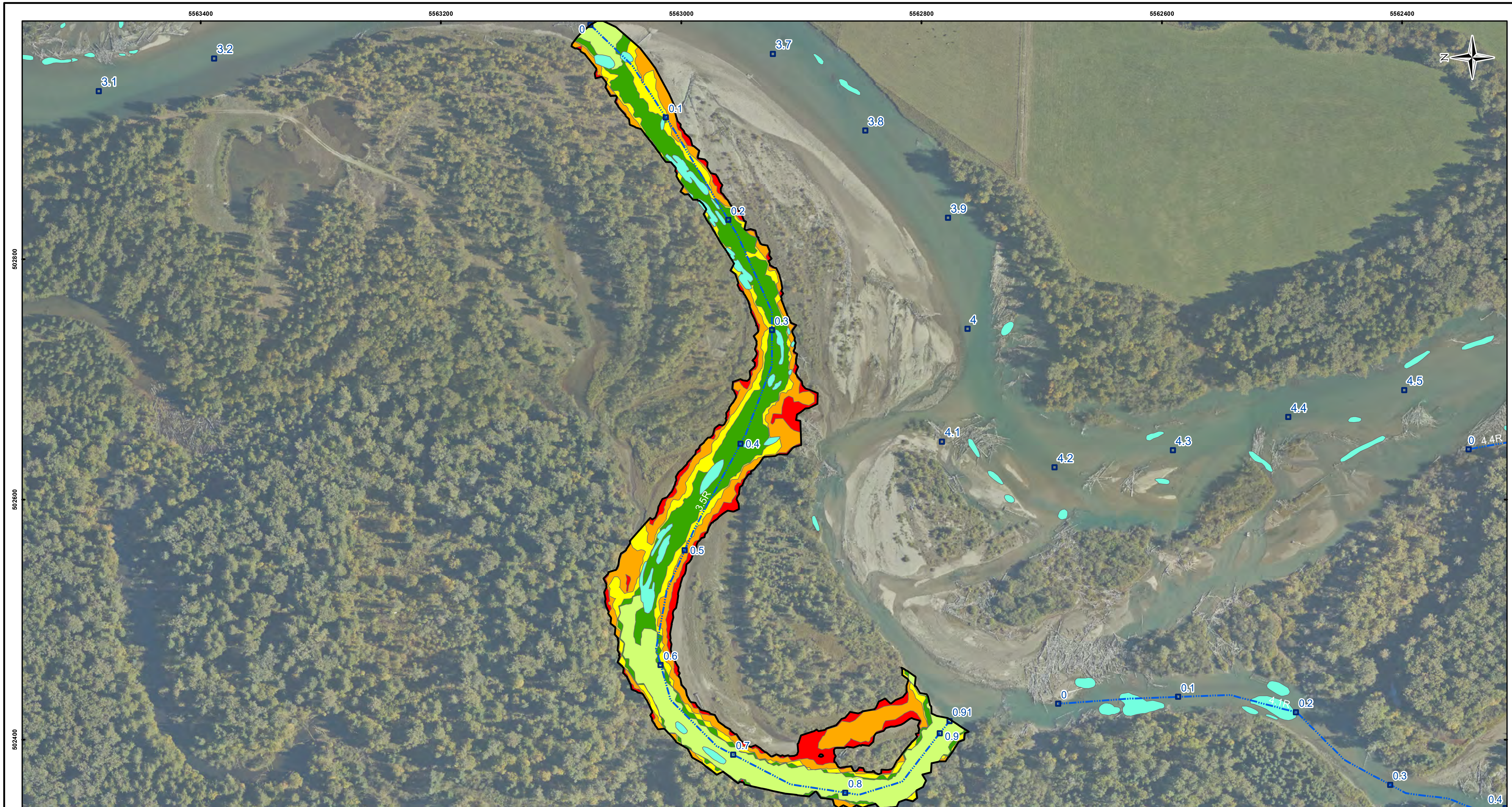
DUNCAN DAM to KOOTENAY LAKE

MODELLED INUNDATION
FOR SELECTED DISCHARGE SCENARIOS

DATE	DISTR.	DWG NO / CAD	SIZE	R
Apr. 16, 2015		Figure 9	B	0

Appendix C

LDR Critical Side Channels and Modelled Flow Scenarios



Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Kokanee Spawning
- Side Channel Extent

CMS Flow

- 75
- 100
- 125
- 175
- 200

0 50 100
Meters
1:3,000

Reference:
BC Hydro
2015 Imagery

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CLIENT:
Prepared for BC Hydro

PROJECT:
DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:
LDR Kokanee Spawning Areas
Side Channel 3.5R

DATE:	ANALYST:	QA/QC:	
November, 2016	MY	LP	Figure 1

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COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

amec foster wheeler

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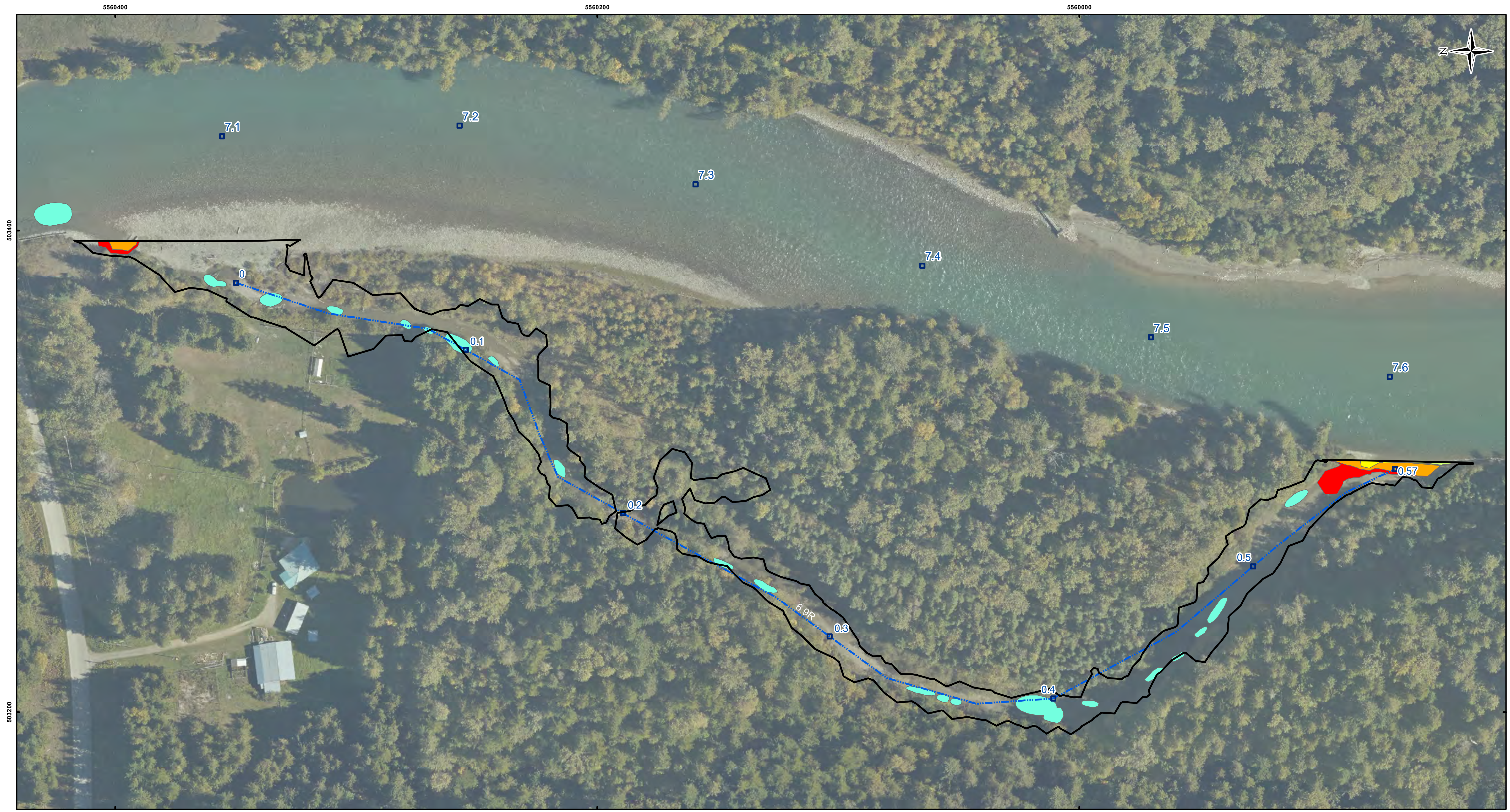

Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Kokanee Spawning
- Side Channel Extent

CMS Flow

- 75
- 100
- 125
- 175
- 200

0 25 50
Meters
1:1,500

Reference:
BC Hydro
2015 Imagery

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CLIENT:
Prepared for BC Hydro

PROJECT:
DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:
LDR Kokanee Spawning Areas Side Channel 6.9R

DATE:	ANALYST:	QA/QC:	
November, 2016	MY	LP	Figure 2

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COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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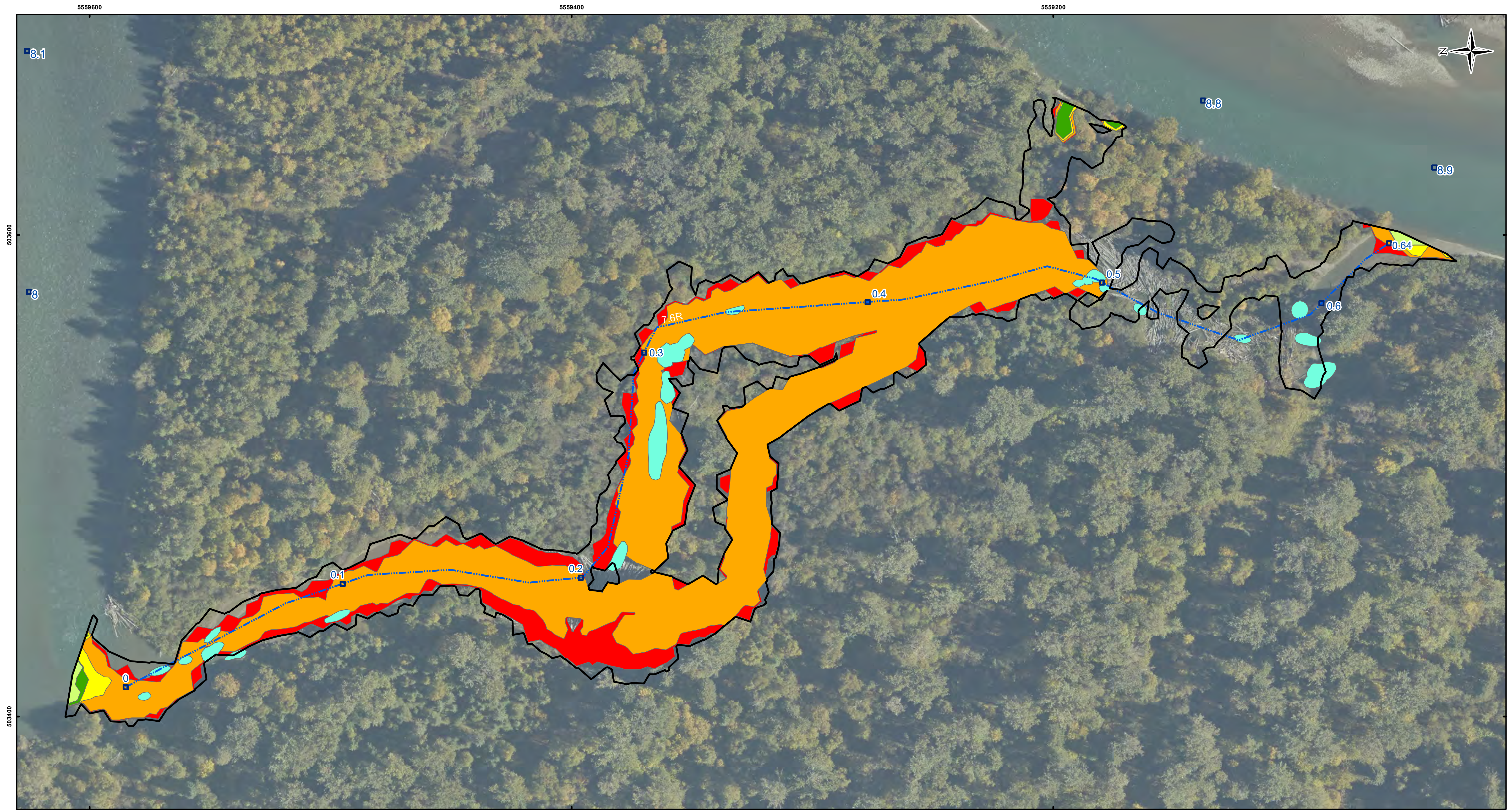

Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Kokanee Spawning
- Side Channel Extent

CMS Flow

- 75
- 100
- 125
- 175
- 200

0 25 50
Meters
1:1,500

Reference:
BC Hydro
2015 Imagery

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PROJECT:
DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:
LDR Kokanee Spawning Areas
Side Channel 7.6R

DATE:	ANALYST:	QA/QC:	
November, 2016	MY	LP	Figure 3

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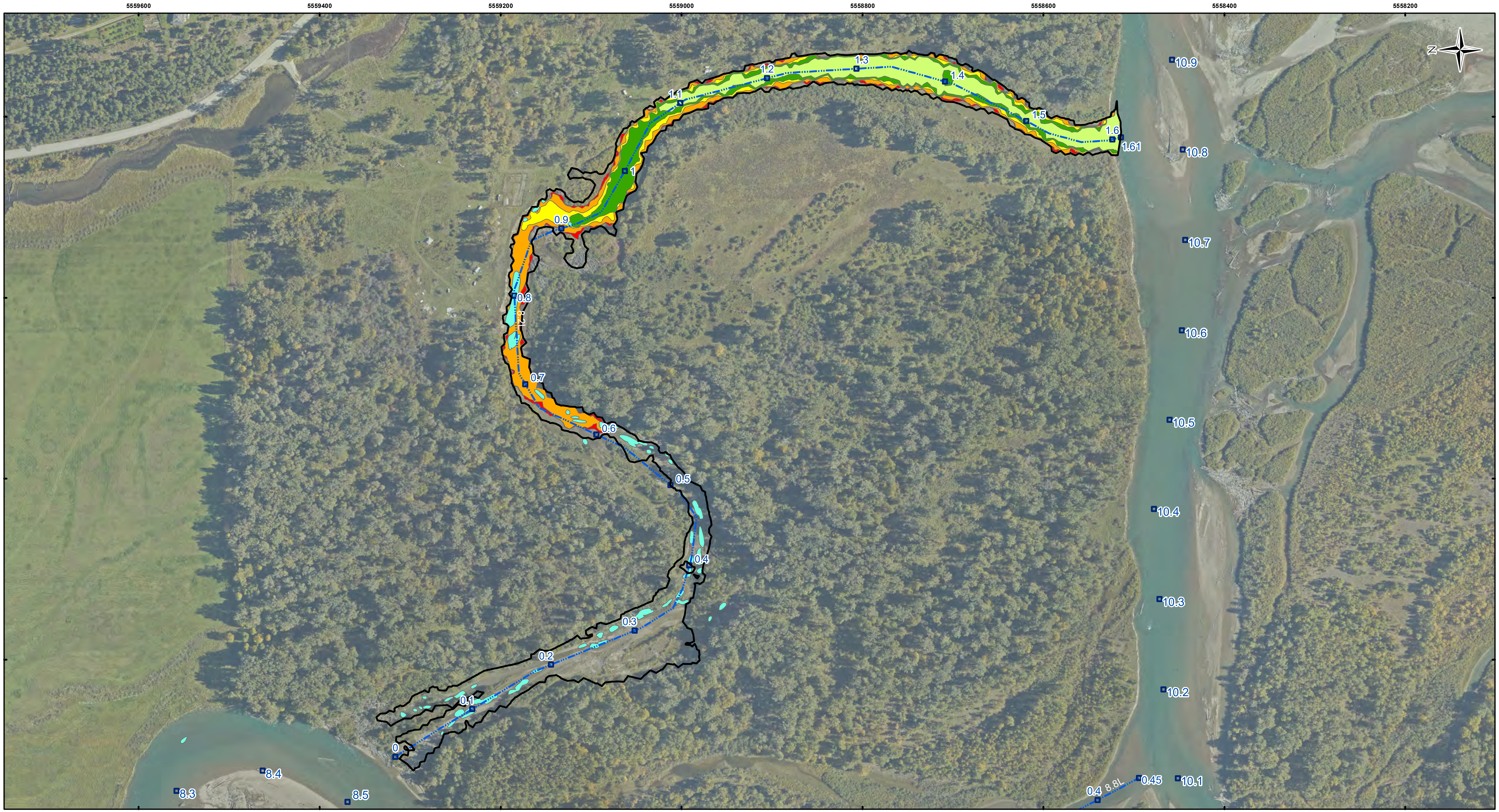

Legend

- River km (AMEC, 2009)
- Named Sidechannel
- Kokanee Spawning
- Side Channel Extent

CMS Flow

- 75
- 100
- 125
- 175
- 200

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Meters
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Reference:
BC Hydro
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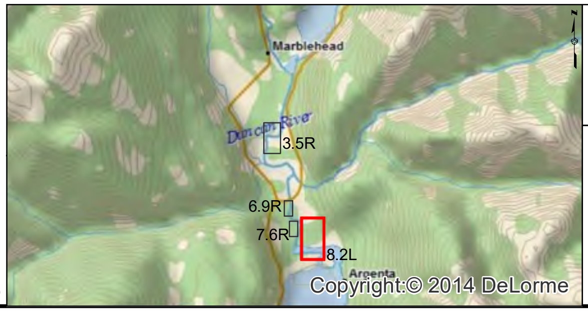

CLIENT:
Prepared for BC Hydro

PROJECT:
DDMMON-4 Lower Duncan River Kokanee Spawning Monitoring

TITLE:
LDR Kokanee Spawning Areas Side Channel 8.2L

DATE:	ANALYST:	QA/QC:	
November, 2016	MY	LP	Figure 4

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COORDINATE SYSTEM:
NAD 1983 UTM Zone 11N

amec foster wheeler

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