Duncan Dam Project Water Use Plan

Duncan Reservoir Burbot Monitoring

Habitat Mapping, Modelling & Optimization

Implementation Year 5

Reference: DDMMON-11

Duncan Reservoir Burbot Monitoring

Final Habitat Mapping, Modelling & Optimization Report

Study Period: January 2015 to August 2016

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August 5, 2016

DDMMON-11 Duncan Reservoir Burbot Monitoring – Habitat Mapping, Modelling & Optimization

FINAL REPORT

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5 August 2016

VE52477-2014-005

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Suggested Citation: Amec Foster Wheeler. 2016. DDMMON-11 Duncan Reservoir Burbot Habitat Mapping, Modelling & Optimization. Final Report Prepared for BC Hydro Burnaby. Prepared by Amec Foster Wheeler Nelson. 22 pp. + 4 App.

ACKNOWLEDGEMENTS

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

BC Hydro

Phil Bradshaw, Burnaby
Alf Leake, Burnaby
James Baxter, Castlegar
Len Wiens, Meadow Creek
Kris Wiens, Meadow Creek
Ron Greenlaw, Meadow Creek

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EXECUTIVE SUMMARY

Duncan Dam (DDM) was built in 1967 as a storage facility under the Columbia River Treaty (CRT). The reservoir that formed behind DDM (herein referred to as Duncan Reservoir) back flooded Duncan Lake and a portion of the Upper Duncan River. A number of flow management issues (e.g., CRT, fisheries, and recreational users) impose significant challenges for the operation of DDM. The Duncan Dam WUP was developed to address flow management issues with respect to impacts on competing resources in the area (BC Hydro 2007).

Burbot (*Lota lota*) were identified by the DDM WUP Consultative Committee (CC) as potentially impacted by large reservoir fluctuations during their suspected spawning period. The fluctuations may result in reduced spawning success and egg survival in sites along the shoreline and in lower sections of tributaries (BC Hydro 2008). Baseline studies were undertaken to better understand Burbot life history and habitat use (BC Hydro 2014). However, after three years of limited success in monitoring adult spawning behaviour through radio telemetry and no success in capturing juveniles, it was recommended that a physical monitoring approach be used to address the study objectives. The first phase of the physical monitoring approach included conducting a literature review and professional judgement solicitation to identify key habitat attributes that will be used to evaluate reservoir operations impacts and quantify the spawning habitats available under different operating scenarios (AMEC 2014). During the literature review it was identified that the following conditions were required for optimal Burbot spawning: depths >0-10 m; velocity 0-0.25 m/s; substrates include silt, sand, gravel, cobble, boulder and bedrock; stable water levels; water temperatures 1-5°C; and relatively ‘clear’ water. In addition, it was recommended that water temperature monitoring be conducted to fill in data gaps.

This report represents the second phase of the physical monitoring approach to physically map and quantify spawning habitats and water temperature thresholds identified during the literature review in order to optimize Burbot spawning success. Burbot spawning habitat areas were mapped in March 2014 at an elevation of 550 m and were used to model habitat changes during typical reservoir operations during the spawning and incubation period. Based on water temperature monitoring conducted during this study, the estimated Burbot spawning/incubation period for Duncan Reservoir is early January to mid-March. During typical operational years, Duncan Reservoir is around 564 m in early January and declines to approximately 552 m by mid-March when eggs may be incubating in the substrates. Modelled habitat area is estimated at 1111 ha and 979 ha for the 564 m and 552 m elevation scenarios, respectively. Therefore, it is estimated that approximately 130 ha of habitat may be dewatered during the incubation period indicated above. Based on habitat area and the assumption that optimal habitat criteria remained throughout reservoir drawdown, Burbot spawning success in 2015 may have been estimated at 88% because 12% of the total spawning/incubation area was dewatered for the predicted hatch/swim up period (assuming a higher amount of habitat equates to higher spawning success).

Water temperature is a key performance measure to optimize Burbot spawning success in Duncan Reservoir based on information collected at this time. This represents the completion of the development of the Burbot spawning performance measure for the DDMMON-11 monitoring program. According to the WUP review process, this performance measure will be used to evaluate alternative options if the current operating scenario requires review. To further improve the measure, BC Hydro may wish to continue monitoring water temperatures in the Duncan Reservoir to confirm our assessment of most suitable Burbot spawn and incubation timing.

1.0 INTRODUCTION

Duncan Dam (DDM) was built in 1967 as a storage facility under the Columbia River Treaty (CRT). The reservoir that formed behind DDM (herein referred to as Duncan Reservoir) back flooded Duncan Lake and a portion of the Upper Duncan River (UDR; Figure 1-1). The Duncan Reservoir provides water storage for flow management and flood control below DDM that is dictated by the DDM Water Use Plan (WUP) operating requirements, seasonal operating targets set by the CRT, water level requirements for Kootenay Lake set by the International Joint Commission (BC Hydro 2007) and the Columbia River Project WUP for the Columbia River below Hugh L. Keenleyside Dam (HLK). Duncan Reservoir has a surface area of 7,350 ha at full pool and declines to 2,190 ha at low pool, which exposes the reservoir bottom at drawdown (BC Hydro 2007). The reservoir is targeted to reach full pool (elevation 576.68 m) at the end of July and drawdown begins sometime in August targeting 569.0 m elevation on 31 December and low pool elevation on 28 February (elevations between 551.0 m to 564.4 m depending on projected snowpack; minimum elevation at drawdown 546.87 m).

A number of flow management issues (e.g., CRT, fisheries, and recreational users) impose significant challenges for the operation of DDM. The Duncan Dam WUP was developed to address flow management issues with respect to impacts on competing resources in the area (BC Hydro 2007). Burbot (*Lota lota*) were identified by the DDM WUP Consultative Committee (CC) as potentially impacted by large reservoir fluctuations during their suspected spawning period. The fluctuations may result in reduced spawning success and egg survival in sites along the shoreline and in lower sections of tributaries (BC Hydro 2008). Baseline studies were undertaken to better understand Burbot life history and habitat use (BC Hydro 2014). However, after three years of limited success in monitoring adult spawning behaviour through radio telemetry and no success in capturing juveniles, it was recommended that a physical monitoring approach be used to address the study objectives (Section 1.1). The first phase of the physical monitoring approach included conducting a literature review and professional judgement solicitation to identify key habitat attributes that will be used to evaluate reservoir operations impacts and quantify the spawning habitats available under different operating scenarios (AMEC 2014). The second phase of the physical monitoring approach was to physically map and quantify spawning habitats identified during the literature review in order to optimize Burbot spawning success. Results of habitat mapping and optimization for this second phase are provided herein.

1.1 Objectives and Management Questions

The Key **Management Questions** outlined in the original TOR for DDMMON-11 include (BC Hydro 2008):

1. What are some basic biological characteristics of Burbot populations in Duncan Reservoir (e.g., distribution, abundance, growth, and age structure)?
2. Does winter drawdown of Duncan Reservoir dewater Burbot spawning habitat and affect spawning success?
3. Can modifications be made to the operation regime and rule curves of Duncan Reservoir to protect or enhance spawning success of this Burbot population?

The main objective of the present study is to determine the most likely habitat conditions that are required to optimize Burbot spawning success in terms of variations in water levels, while determining potential adverse conditions on spawning success stemming from reservoir operations (BC Hydro 2014). In addition, adult migration, incubation and juvenile rearing habitat conditions are reviewed to provide further context on potential operational influences on Burbot recruitment (BC Hydro 2014).

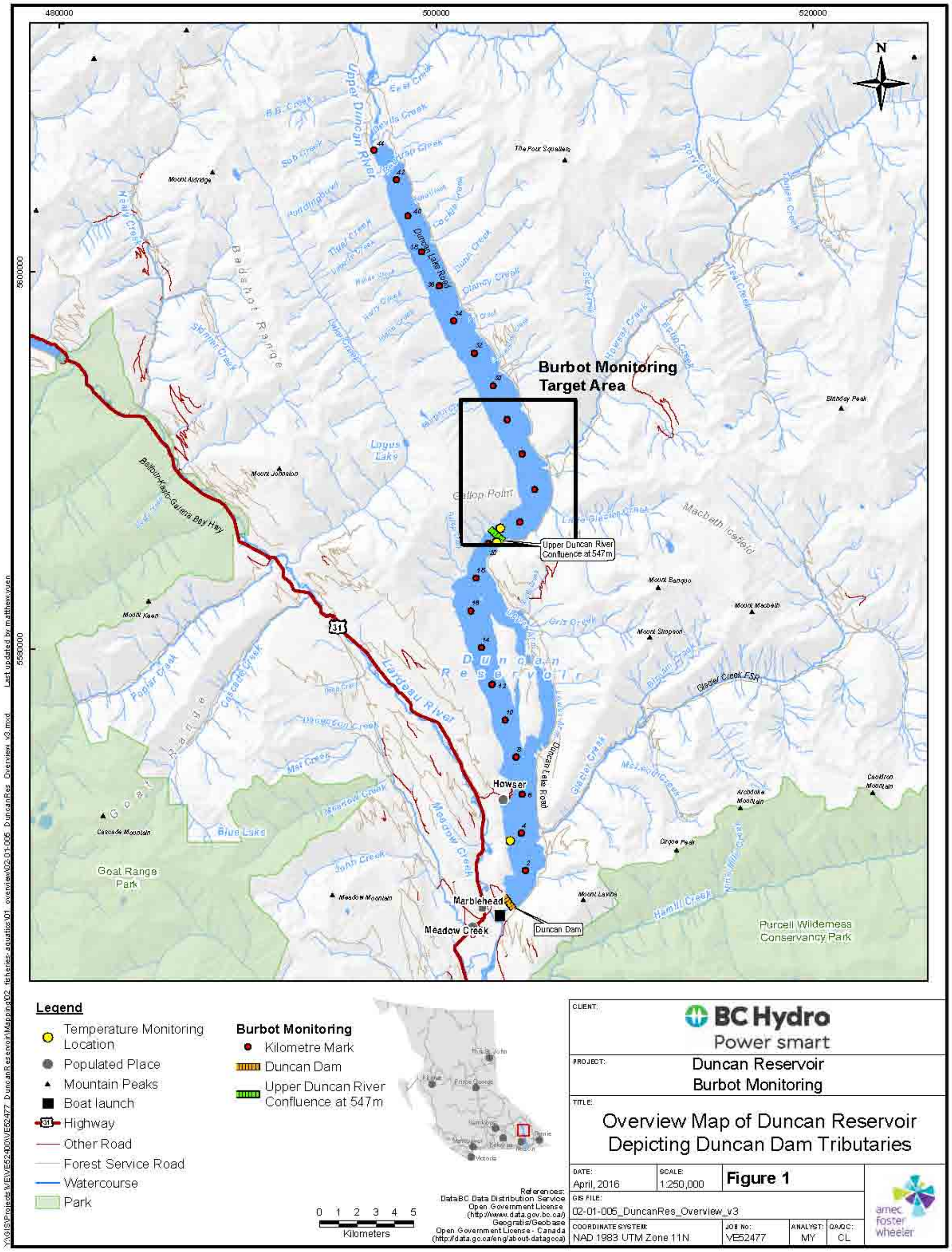


Figure 1-1: Overview of Duncan Reservoir Depicting Duncan Dam, Tributaries and the Burbot Monitoring Target Area

2.0 STUDY AREA

2.1 Physical Characteristics

The study area is located in the Purcell trench of southeastern British Columbia. The headwaters of the Duncan River system originate at Mount Dawson, near Glacier National Park where it flows south easterly for 55 km to Duncan Lake Reservoir (herein called Duncan Reservoir) (BC Hydro 2007). Prior to the construction of Duncan Dam in 1967, Duncan Lake divided the upper and lower Duncan rivers. Duncan Dam was built on the Lower Duncan River, approximately 5 km downstream from the original Duncan Lake outlet (Westslope 2011) and 8 km upstream of Kootenay Lake (BC Hydro 2007). The reservoir formed by the dam is approximately 45 km long, 1 – 2.5 km wide with a mean depth of 52 m and maximum depth of 117 m (BC Hydro 2007, de Zwart et al. 2013). Mean annual inflow is approximately 126 m^3/s, which is mostly from heavy snow pack that builds throughout the winter (BC Hydro 2007). Duncan Reservoir has a surface area of 7,150 ha at full pool, which declines to 2,190 ha at low pool and results in 5,160 ha of reservoir bottom exposed during drawdown (de Zwart et al. 2013).

At minimum elevations, the reservoir approximates historic Duncan Lake elevations and exposes the original channel of the Upper Duncan River (UDR) (Vonk 2001 as cited by Westslope 2011). This portion of the UDR floodplain is unforested and infilled with glacial till that is prone to erosion and channel braiding. The remainder of the reservoir is steeper and more confined, with the exception of the confluence of larger tributaries such as Glacier Creek.

2.2 Reservoir Operations

There are no power generation facilities at Duncan Dam and the reservoir is used to provide storage and downstream flood control as dictated by the Columbia River Treaty (BC Hydro 2007). Duncan Reservoir has a usable storage volume of 1,727,000,000 m^3 with a normal operating range between 546.87 m (1794.2 ft) and 576.68 m (1892.0 ft) (BC Hydro 2007; Figure 2-1). Duncan Reservoir mainly operates based on releases from Duncan Dam and three elevation based constraints on operations that include: i) maximum reservoir elevation at full pool (576.68 m) on July 31; ii) elevation target (<569.8 m) on December 31; and, iii) targets to reach low pool on February 28 (<551.0 m high snow year; <564.4 m low snow year) (de Zwart et al. 2013; Figure 2-1). There is also a minimum elevation at draw down of 546.87 m (Figure 2-1). The reservoir may be drawn down at different rates yearly, but by the end of March reservoir elevations reach a similar level as it is drawn down to low pool in preparation of freshet each year (de Zwart et al. 2013). Water elevational changes in Duncan Reservoir result in annual water surface elevation variation of 29.6 m between a full pool elevation of 576.5 m and a minimum pool elevation of 546.9 m (Westslope 2011).

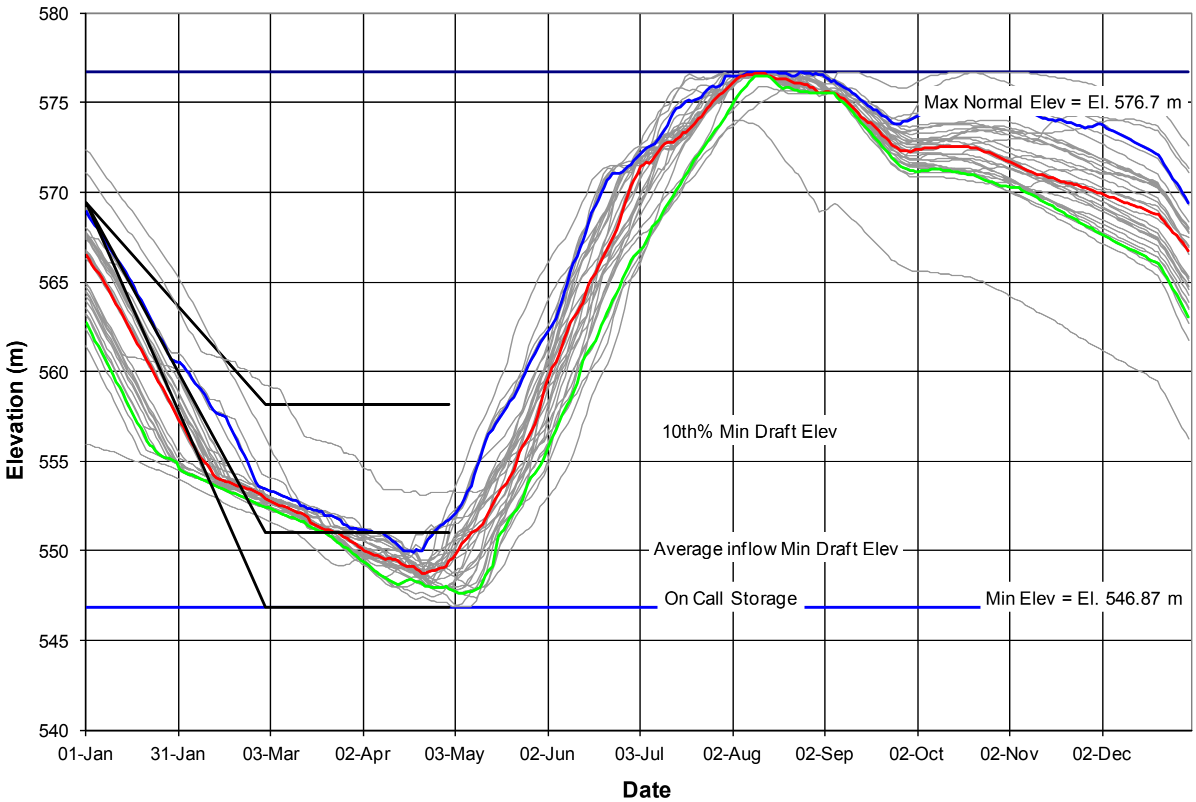


Figure 2-1: Duncan Reservoir elevations (Source: BC Hydro 2014)

3.0 METHODS

3.1 Site Selection

As recommended from the literature review (AMEC 2014), the lowermost 7.4 km of the seasonally inundated UDR between Rkm 28.0 (upstream limit) and Rkm 20.6 (downstream limit represented by the historic UDR confluence) was targeted for habitat mapping. This section of river represents the suspected spawning and egg incubation area for Burbot in the Duncan Reservoir (Neufeld and Spence 2004, Westslope 2011). Although, direct evidence of spawning within the UDR was not confirmed during these studies, evidence of migration and spawning behaviour for some tagged Burbot was most consistent within this area (Spence and Neufeld 2002, Westslope 2011). Telemetry studies conducted during this program from 2009-2011 indicated that 32% of tagged Burbot were suspected to use the UDR for spawning (Westslope 2011). The remaining tagged Burbot used deeper areas of the reservoir at this time (Westslope 2011) and these areas are less likely to be affected by reservoir drawdown. Since Burbot are potentially spawning in the UDR-confluence zone (Rkm 28.0-20.6) and this area is subject to significant change during reservoir drawdown it is important to ground truth potential habitat areas that are available during the Burbot spawning/incubation period.

3.2 Sample Timing

Surveys were conducted from 23 to 26 March 2015 at an average elevation of 550.5 m (BC Hydro unpublished) during the period when the Duncan Reservoir was being drafted to reach low pool, and the 7.4 km section of the Upper Duncan River was ice free and accessible. The timing of the field surveys corresponded with the estimated spawning period for Burbot (January – March) in Duncan Reservoir based on background information (AMEC 2014).

3.3 Water Temperature Monitoring

It was identified that limited continuous water temperature monitoring data was available for the Duncan Reservoir and that this parameter was a key performance measure for Burbot spawning/incubation success (AMEC 2014). Therefore, temperature monitoring stations were installed within the study area for the anticipated Burbot spawning period during the 2015 and 2016 study years. Temperature monitoring station placement was limited to areas that were accessible by boat at all reservoir elevations and included the historical outlet of the Upper Duncan River (n=2) as well as near the Glacier Creek outlet (n=1; Figure 1-1). Location information for continuous water temperature monitoring in Duncan Reservoir is provided in Table 3-1.

Temperature monitoring stations consisted of a weight, rope and surface float with Onset Tidbit v2 temperature loggers (±0.2°C accuracy). Loggers were attached to the rope by cable ties approximately 1 m from the bottom of the reservoir. Reservoir elevation at deployment was used to ensure stations were placed in areas that would remain wetted following draw down (Table 3-1). A small float was placed on the rope near each logger to keep them buoyant above the reservoir floor. In 2016, an additional temperature logger was added to the rope approximately 2 m from the surface float to collect surface water temperatures in case bottom loggers became snagged on debris upon retrieval as occurred in 2015.

Tidbit temperature loggers were set to measure water temperature every 30 minutes. Two Tidbits were deployed at each temperature monitoring station to provide back-up in case of mechanical failure. Data were downloaded using the HOBOware Pro Version 2.x for Windows software and exported to Excel spreadsheets. In 2015, stations were deployed in early February, downloaded once during the monitoring period (March 24, 2015) and retrieved in early May. In 2016, stations were deployed in late October 2015 and retrieved in early May 2016 to collect data over the entire Burbot spawning period (Table 3-1).

Table 3-1: Duncan Reservoir Continuous Water Temperature Monitoring Locations, 2015-2016

Year	Location	Description	UTM	Deployment Date	Deployment Depth (m)	Reservoir Elevation at Deployment (m)	Retrieval Date	Notes
2015	Rkm 21.0	Upper Duncan River at low pool	11U 503412 5586403	Feb. 6, 2015	12	559	May 8, 2015	
	Rkm 20.3	Historic Duncan Lake downstream of Upper Duncan River outlet	11U 503207 5585654	Feb. 6, 2015	30	559	March 24, 2015	Snagged on submerged debris and unable to retrieve in May; data available Feb to March only.
	Rkm 4.0	Historic Duncan Lake downstream of Glacier Creek outlet	11U 503640 5570514	Feb. 6, 2015	12	559	May 8, 2015	
2016	Rkm 21.0	Upper Duncan River at low pool	11U 503412 5586403	Oct. 28, 2015	24	571	-	Station not relocated; likely snagged on debris generated during early freshet.
	Rkm 20.3	Historic Duncan Lake downstream of Upper Duncan River outlet	11U 503207 5585654	Oct. 28, 2015	45	571	May 4, 2015	
	Rkm 4.0	Historic Duncan Lake downstream of Glacier Creek outlet	11U 503640 5570514	Oct. 28, 2015	22	571	May 4, 2015	

3.3.1 Estimated Time for Burbot Eggs to Hatch in Duncan Reservoir

The influence of incubation temperature on minimum time for Burbot eggs to hatch was predicted by the fitted regression line:

$$1/Y=0.0134+0.00474*X$$

where X is the average incubation temperature (°C) within the first two weeks of incubation and Y is time to start hatching (days) (Taylor and McPhail 2000). Data collected between October 2015 and May 2016 was used for analysis of time to hatch. Average temperature within the first two weeks of spawning was calculated between Day 7 and 14 after the estimated onset of spawning (i.e., when water temperatures were consistently 4°C).

3.4 Habitat Mapping/Ground Truthing

Field surveys were conducted by boat, daily from March 23rd to 26th, 2015. Habitat mapping focused on the 7.4 km Burbot spawning area (Rkm 20.6 to 28.0) to verify/ground truth actual field conditions likely required to optimize Burbot spawning success, AMEC (2014) identified the following conditions for optimal Burbot spawning:

- depths >0-10 m;
- velocity 0-0.25 m/s;
- substrates include silt, sand, gravel, cobble, boulder and bedrock;
- stable water levels;
- water temperatures 1-5°C; and
- relatively ‘clear’ water.

Prior to each field day, the crew consulted with BC Hydro Duncan Dam operators to determine the ‘real-time’ reservoir elevation and for safety check-in/out procedures.

The water’s edge was mapped for the study area via boat using a Garmin (62 sc) GPS track log (accuracy ±5-10 m). The offset distance was also estimated for production of habitat maps (Section 3.5.2). As mentioned, habitat area polygons were delineated based on Burbot spawning criteria outlined for this program (AMEC 2014). Polygon identification was facilitated by the use of prepared 1:5,000 orthophotos that were converted to PDF Maps App for mobile devices (Avenza Systems). This created a geospatial PDF that allowed direct interaction with spatially referenced maps to view real-time locations and track movements with GPS as well as enabled plotting placemarks, collecting georeferenced photos and entering attribute data and notes. Physical maps (1:5,000 orthophotos) were also used to hand draw polygon areas that could be identified and where boat access/wading was not possible.

Habitat attributes for each habitat area/polygon were also measured by taking a sub-set of representative habitat points. A UTM was taken at each point in addition to the following habitat measurements. All suitable habitat areas were identified by dominant hydraulic type (riffle, run, pool) and cover (type and qualitative amount). Substrates were identified directly in the field using BC standard substrate sizes (RIC 2001): fines (<2 mm), fine to medium gravel (2 to 16 mm), coarse gravel (16 to 64 mm), small cobbles (64 to 128 mm), large cobbles (128 to 256 mm) and boulders (>256 mm). Where it was not possible to determine substrates, they were inferred from previous substrate mapping that was incorporated into the 1:5,000 orthophotos (AMEC 2014). A hand held Swoffer velocity meter (Swoffer 2100; within 1% accuracy) was used to take average depth/velocity, but in deeper areas (>1.5 m), depths were measured with the boat sounder and velocity was estimated by experienced observers. Average velocity was collected as opposed to bottom velocity to be consistent with previous assessments of Burbot spawning habitat in Duncan Reservoir (Spence and Neufeld 2002). Water temperature and secchi depth (water clarity) were also taken. Turbidity was measured using a Hatch 2100P Turbidimeter on the last field sampling day at representative habitat sites within each delineated polygon throughout the study area. This unit has an accuracy rating of ± 2% of reading plus stray light from 0 - 1000 NTU. The unit was recalibrated using StablCal Stabilized Formazin primary standards on March 22, 2015. A very low concentration standard (0.1 μs) was used to confirm calibration prior to taking any readings. Three samples were collected in standard glass vials provided in the unit and readings taken as specified by the manufacturer.

All field measurements were recorded digitally (GPS units and PDF Maps), on field forms and on maps developed specifically for this program (AMEC 2014). All GPS settings followed BCH Hydro GPS Data Capture Standards.

3.5 Bathymetric Surveys

As outlined during the literature review, the spatial resolution of the digital elevational data available for the Burbot monitoring target area were very coarse and it was not possible to generate contours at the resolution required to map water levels at target elevations for this program (AMEC 2014). In order to fill this data gap, a multi-beam sonar hydrographic survey (1 m x 1 m grid) was conducted by CRA Canada Surveys Inc. in Duncan Reservoir (Rkm 20-28) from August 16 to 21, 2015. Water elevation at the start of the survey was 574.25 m and the water level dropped by approximately 0.40 m during the survey period. Further details on survey equipment, geodetics, coordinate data and limitations are presented in Appendix A.

3.6 GIS Mapping

3.6.1 Habitat Maps

Base maps developed during the literature review for Duncan Reservoir (AMEC 2014) were updated with the 2015 bathymetric survey data (Section 3.5) using the mass point elevational data provided by CRA Canada Surveys Inc. Field maps (Section 3.4) were digitized and UTM and track logs added to the base maps. Habitat polygons were generated to represent site conditions measured during the field surveys and were clipped to the 550 m bathymetric line work to match the water's edge since it was not possible for the boat to accurately map the water's edge (i.e., too shallow) during the March 2015 surveys. A set of maps were plotted to visually display habitat polygons representing the Burbot spawning area with overlays for the following operational targets for Duncan Reservoir:

- 547 m – minimum reservoir elevation at drawdown;
- 551 m – low pool (high snow year) on 28 February;
- 552 – drafting elevation;
- 564 m – low pool (low snow year) on 28 February; and,
- 569 m – target reservoir elevation on 31 December.

Habitat areas were calculated for the habitat polygons mapped at 550 m and differences in areas were calculated for the operational targets listed above.

3.7 Optimizing Burbot Spawning Success

Parameters within the mapped habitat polygons were evaluated against “successful” Burbot spawning/incubation criteria and areas (ha) calculated to represent a base case scenario. This base case scenario, captured at 550 m water elevation within the reservoir during the suspected spawning period, provides a ‘snapshot’ of Burbot spawning/incubation habitats that are potentially available within the area of interest. Habitat area was then calculated for operational targets that fall within the spawning/incubation period to provide a comparison with the base case. Those scenarios that provide adequate Burbot spawning/incubation habitat and water temperatures will be equated to spawning/incubation “success.” Scenarios that maximize Burbot spawning/ incubation area are assumed to equate to higher levels of success.

4.0 RESULTS

4.1 Water Temperature Monitoring

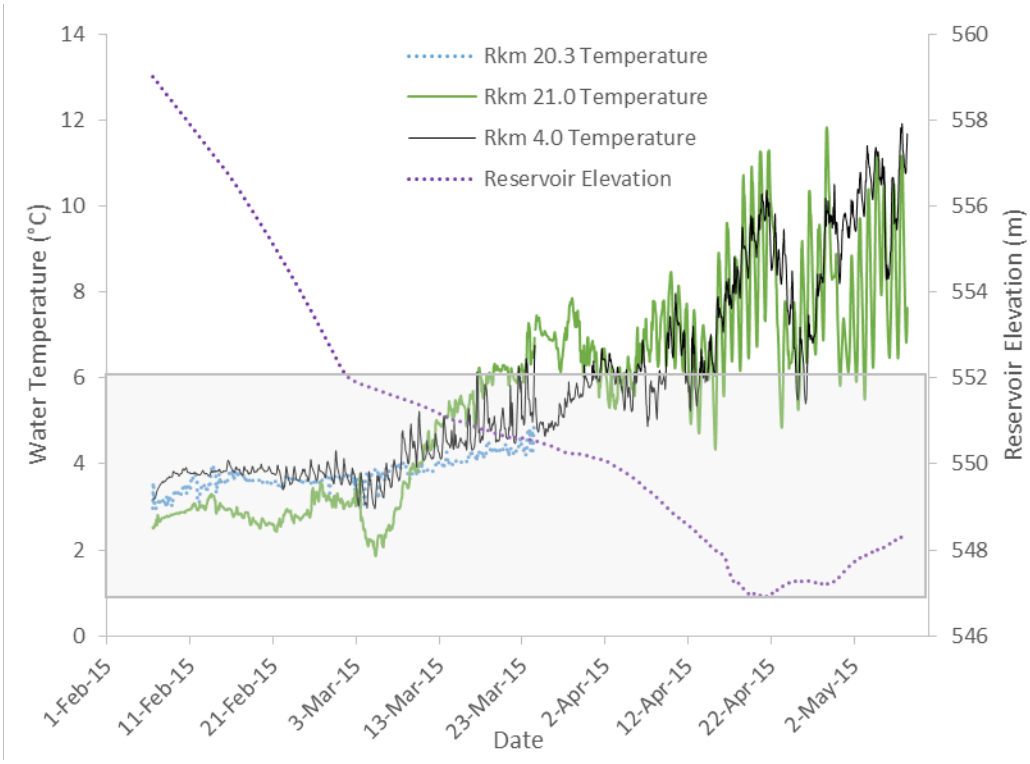
4.1.1 February to May 2015

Water temperatures ranged from 1.9 to 11.2°C between 6 February and 8 May 2015 in the Burbot monitoring target area (Figure 4-1). Ice cover was not observed on Duncan Reservoir during the winter of 2014/2015.

Water temperatures within the historic Upper Duncan River (Rkm 21.0) ranged between 2 and 6°C until mid-March, at which time it went from being the coolest of the three sites to the warmest, with maximum temperature up to 8°C, until the end of March. During the period of reservoir drawdown, daily fluctuations in water temperature of up to 4°C were recorded and temperature was between 4.5 and 11°C from late March until May. Reservoir habitat was observed at this site from early February through late March and by May riverine conditions were present.

Water temperature in the historic Duncan Lake basin (Rkm 20.3) remained stable between 3 and 4°C from February 6 to March 24, 2015; the station was snagged on submerged debris and was not retrievable in May.

Water temperature near the Glacier Creek mouth (Rkm 4.0) remained between 2 and 5°C until the end of March and remained between 5 and 12°C until May, the remainder of the 2015 monitoring period.



Note: The shaded box represents the preferred temperature range for Burbot migration through incubation.

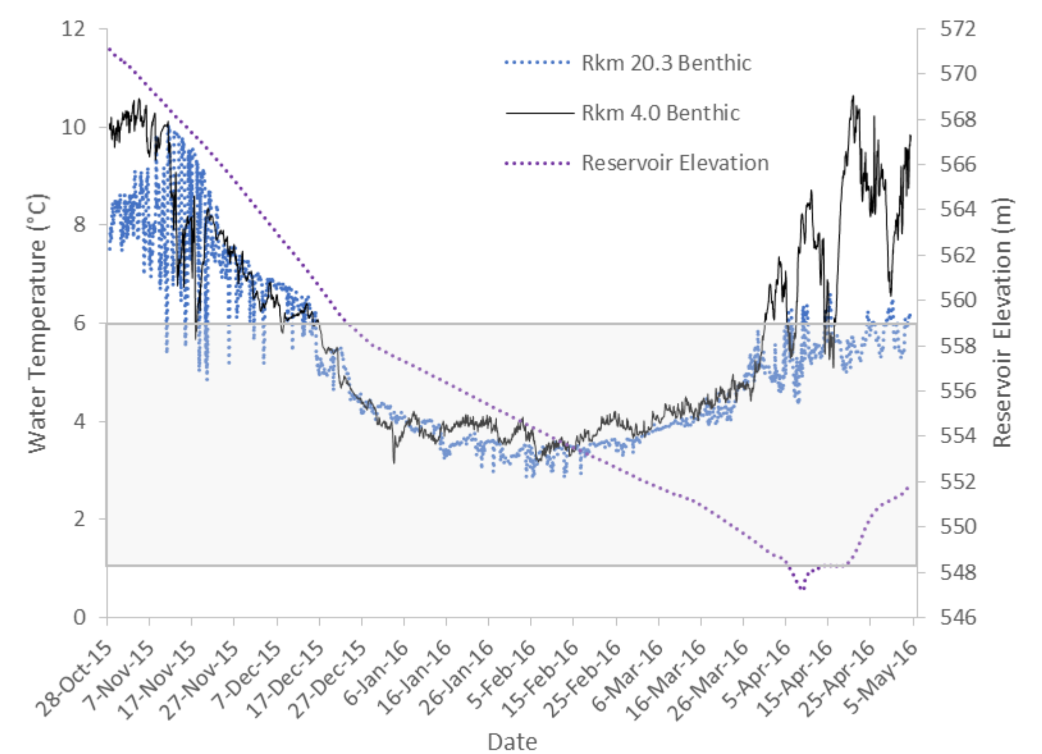
Figure 4-1: Hourly Elevation and Benthic Water Temperature in Duncan Reservoir near the Glacier Creek Outlet (Rkm 4.0), Historic Duncan Lake Downstream of the Upper Duncan River (Rkm 20.3), and the Upper Duncan River at Low Pool (Rkm 21.0), 2015

4.1.2 October 2015 – May 2016

Water temperatures ranged from 2.8 to 10.6°C between 28 October 2015 and 4 May 2016 in the Burbot monitoring target area (Figure 4-2).

Water temperatures in the historic Duncan Lake basin (Rkm 20.3) ranged from 2.8 to 6.6°C between 1 January and 4 May 2016 (Figure 4-2). Water temperatures increased above 6°C briefly in early April to a maximum of 6.6°C (Figure 4-2).

Water temperatures near the Glacier Creek mouth (Rkm 4.0) ranged between 3.1 and 10.6°C from 1 January to 4 May 2016 (Figure 4-2). Water temperatures remained below 6°C until early April at the Glacier Creek mouth in 2016 after which time they were primarily above 6°C (Figure 4-2).



Note: The shaded box represents the preferred temperature range for Burbot migration through incubation.

Figure 4-2: Hourly Elevation and Benthic Water Temperature in Duncan Reservoir near the Glacier Creek Outlet (Rkm 4.0) and the Historic Duncan Lake Downstream of the Upper Duncan River (Rkm 20.3), 2016.

4.2 Estimated Spawning/Incubation Periods in Duncan Reservoir

The estimated spawning and incubation periods for Duncan Reservoir Burbot based on cited literature and water temperatures observed during the 2015/2016 spawning period is summarized in Table 4-1.

Table 4-1: Estimated Spawning and Incubation Periods for Duncan Reservoir Burbot Based on Water Temperature Monitoring, 28 October 2015 to 4 May 2016.

Stage	Timing & Requirements[a]	Estimated Period for Duncan Reservoir[b]
Spawning	Onset is 3-7 days after water drops to 4°C	2 January - onset
	2-3 week period	23 January end spawning
Incubation	30-70 day period; dependent on water temperatures	
	Optimal between 1-5°C	
	Peak survival 3-4°C	
	All eggs/embryos die if water is >6°C in first 2 weeks of incubation (Taylor and McPhail 2000).	2-15 January; Average water temperatures 3.9°C; Maximum water temperature 4.2°C
	Up to 9°C tolerated after week 3 of development (Kainz and Gollman 1996 as cited in Taylor and McPhail 2000)	15-22 January; Average water temperatures ~3.6°C; Maximum water temperature 4.2°C
Hatch	Time to Hatch: Predicted by 1/Y=0.0134+0.00474*X (Taylor and McPhail 2000; Section 3.3.1)	32 days: spawning between 2 and 22 January = hatching between 3 and 23 February
	Spend 1-3 weeks in substrate; 17 days at 4°C filled swim bladder	Late February to early March; estimated 11 March out of substrate.
Larvae	Passibly drift in water column	mid-March to end May
	Early summer shift to benthic shoreline habitat	June

Notes:
[a]Based on references cited from literature review conducted by AMEC (2014) unless otherwise stated.
[b]Based on water temperatures collected from Rkm 20.3, 28 October 2015 to 4 May 2016.

4.3 Habitat Mapping & Conditions

The majority of mapped areas that remained wetted in the Burbot monitoring target area (Rkm 20.6 and 28) during the March 2015 survey had similar attributes including shallow pool habitat with fine/silt substrates and little to no velocity (Areas 1, 2, 3, 4, 5 and 7 in Table 4-2, Appendix B, Map C (Figure 1), Appendix D – Photo Plates). The Upper Duncan River (Area 6) became a defined channel near the Howser Creek confluence and was navigable upstream to the extent of the Burbot monitoring target area (Rkm 28) and beyond. Conditions in the Upper Duncan River outflow channel were similar to other reservoir areas sampled in that it was shallow with fine substrates but differed in that it was run habitat with average velocity near 0.5 m/s (Table 4-2). Spot water temperatures were also cooler in the river channel (approximately 5°C) than other wetted areas that were outside of this defined channel (>7°C; Table 4-2).

Water clarity was low (secchi depth <1 m) in all regions of the reservoir between Rkm 20.6 and 28.0 (Table 4-2). Measured turbidity was highest in the Upper Duncan River channel (Area 6, Photo Plate 6-1). Turbid water conditions were observed throughout the surveyed area and the sediment plume extended downstream beyond Rkm 20.6 into the reservoir to approximately Rkm 18. Turbidity in reservoir areas where sediment was observed ranged from 8.06 to 32.3 NTU (Rkm 18 to 31.2). Conditions downstream within the historic Duncan Lake/Reservoir at RKm 15.0 were clear (<1 NTU).

Table 4-2: Habitat Conditions Within Wetted Areas of the Burbot Monitoring Area in Duncan Reservoir, March 23-26 2015

Polygon Name*	Approximate Area (ha)	Habitat Type (Riffle, Run, Pool)	Substrate		Depth (m)	Mean Column Velocity (m/s)	Water Temperature (°C)	Turbidity (NTU)	Secchi Depth (m)	Photo Plate	Comments
			Dominant	Subdominant							
Area 1	537.1	Pool	Fines	Gravel	2.65	0.06	6.8	9.97	1.1	1-1; 1-2	
Area 2	19.3	Pool	Fines	None	1	0	-	-	-	-	Inaccessible; estimated values.
Area 3	74.7	Pool	Fines	None	0.9	0.01	7.5	-	0.9	3-1	
Area 4	17.6	Pool	Fines	None	1	0	-	-	-	4-1	Inaccessible; estimated values.
Area 5	3.0	Pool	Fines	None	1	0	-	-	-	5-1	Inaccessible; estimated values.
Area 6	8.8	Run	Fines	None	1.3	0.44	4.93	26.31	0.4	6-1	
Area 7	108.2	Pool	Fines	None	<1	0	8.4	-	-	7-1	Inaccessible; estimated values except temperature

Notes: *Polygon areas are illustrated in Appendix C, Figure 1.

4.4 Habitat Area & Reservoir Operations

Mapped habitat areas representing potential Burbot spawning/incubation areas covered approximately 774 ha when the reservoir elevation was approximately 550 m during field surveys conducted in late March 2015 (Table 4-2; Appendix B, Appendix C - Figure 1). Habitat availability for Duncan Reservoir operational targets (i.e., elevational constraints) as compared to the baseline scenario mapped at 550 m is presented in Table 4-2; visual representations for each scenario are provided in Appendix C (Figures 2 to 6). Note that all areas mapped under the 550 m baseline scenario are based on suitable spawning areas for Burbot, with the exception of water temperature and turbidity as indicated in Table 4-1. Habitat availability for the modeled operational scenarios in Table 4-2 is based on area alone and not on optimal Burbot spawning conditions (Section 3.4), with the exception of substrates that would remain the same under various water elevations.

For the scenarios listed below, habitat is maximized, by approximately 40%, at an elevation of 564 m and does not substantially increase at 569 m (Table 4-2; Appendix C - Figure 5 and 6). Habitat is minimized at an elevation of 547 m and habitat availability is approximately 80% less than that estimated at 550 m (Table 4-2; Appendix C - Figure 2). Reservoir elevations of 551 m and 552 m may increase the available habitat by approximately 20% to 27% (Table 4-2; Appendix C – Figures 3 and 4).

Table 4-3: Habitat Availability in Duncan Reservoir within the Burbot Monitoring Area (Rkm 20-28) for listed operational targets.

Duncan Reservoir Elevation (m)	Total Habitat Area Available (ha)	Change in Habitat Area from Field Survey Elevation (%)
550 (field survey elevation)	774.0	0
547 (minimum reservoir elevation at drawdown)	160.8	-79.2
551 (low pool during high snow year on 28 February)	925.2	19.5
552 (drafting elevation)	979.2	26.5
564 (low pool during low snow year on 28 February)	1111.2	43.6
569 (target reservoir elevation on 31 December)*	1122.8	45.1

Notes: *This operational target is within the suspected Burbot migration period prior to spawning/incubation.

5.0 DISCUSSION

The Duncan Reservoir supports a small population of Burbot that are genetically similar to populations in Kootenay Lake (Baxter et al. 2002, Neufeld 2006, Powell et al. 2008). Spawning in Duncan Reservoir has never been directly observed, but based on limited age data (n=2) post-impoundment spawning has occurred (Westslope 2011) although its frequency and success is unknown at this time. Multi-year telemetry studies have indicated that tagged adult Burbot displayed spawning movements during the suspected spawning period for the Duncan Reservoir between January and March (Spence and Neufeld 2002, Neufeld 2006, Westslope 2009, 2010, 2011). Studies conducted from 2009-2011 indicated that approximately 32% of tagged Burbot were suspected to use the Burbot monitoring target area (Rkm 20.6 to 28.0) for spawning, whereas the majority of tagged Burbot used deeper areas of the reservoir at this time (Westslope 2011); deeper areas are less likely to be affected by reservoir drawdown.

5.1 Duncan Reservoir Burbot Spawn Timing & Incubation Based on Water Temperature

Current water temperature monitoring suggests the Duncan Reservoir Burbot spawning and incubation period occurs from January to March, which is within the range that radio tagged Burbot were suspected to be spawning in Duncan Reservoir and within the range indicated for the species in nearby watersheds. The onset of Burbot spawning is between 3-7 days after exposure to 4°C water temperatures (Vught et al. 2007, Zarski et al. 2010 as cited by Cott et al. 2013a), therefore it was estimated that spawning may have occurred in the Duncan Reservoir in early January 2016. The spawning period is highly synchronous and short, typically lasting 2 to 3 weeks in the wild (McPhail 1997, Cott et al. 2013a) and as long as 4 weeks under laboratory conditions (Vught et al. 2007). Therefore, spawning may have occurred throughout the whole month of January 2016 in Duncan Reservoir. Optimal water temperatures during egg incubation are between 1°C and 5°C (McPhail and Paragamian 2000). Burbot egg survival peaks at 3°C to 4°C, but embryos die if exposed to temperatures above 6°C during the first two weeks of incubation (Taylor and McPhail 2000, Vught et al. 2007). Temperatures as high as 9°C can be tolerated after the third week of incubation (Kainz and Gollman 1996 as cited in Taylor and McPhail 2000). In the Duncan Reservoir in 2016, water temperature ranged between 2.8 and 4.3°C during January and the first two weeks of February, the time period that would include spawning and early egg incubation, suggesting the thermal regime during this time was optimal for these life history stages. The thermal regime remained optimal throughout the remainder of the egg incubation period in 2016 (3-4°C).

Burbot egg incubation lasts between 30 and 70 days (McPhail and Paragamian 2000, references cited in Jude et al. 2013). Estimated time to hatch for Duncan Reservoir Burbot was 32 days (based on Taylor and McPhail 2000) and may have occurred between early and late February 2016. Larvae spend approximately 1-3 weeks in the substrate before they eventually fill their swim bladders and become neutrally buoyant (McPhail 2007, Vught et al. 2007). Under laboratory conditions, larvae filled their swim bladders around 17 days at 4°C (Vught et al. 2007). At first the larvae are planktonic and inhabit the pelagic zone (Jude et al. 2013) by passively drifting in the water column (McPhail and Paragamian 2000) and become more mobile as they grow (McPhail 2007). Larvae become more mobile and shift to benthic shoreline habitat in early summer (McPhail and Paragamian 2000, Taylor and McPhail 2000, Jude et al. 2013). In Duncan Reservoir, planktonic larvae may be present in the water column from early March to the end of May and potentially shift to benthic shoreline habitat in June.

5.2 Habitat Characteristics of the Burbot Monitoring Target Area

According to best available information regarding habitat preferences and temperature cues, the present study's physical habitat monitoring component likely occurred during the end of the estimated spawning period for Duncan Reservoir Burbot. Habitat conditions within the Burbot monitoring target area during 2015 physical habitat monitoring, with the exception of water temperature (Section 5.1), are compared to habitat requirements for optimal spawning/incubation below.

5.2.1 Water Depth & Velocity

Water depths in the Burbot monitoring target area were optimal for Burbot spawning. Burbot spawning has been observed in depths between >0 and 10 m (AMEC 2014). Average water depth in all areas surveyed in late March 2015 were between <1 and 2.7 m and the maximum depth observed was approximately 5 m.

Water velocity (measured as average column velocity) in the Burbot monitoring target area was mostly within the parameters for Burbot spawning. Burbot spawning has been observed in water velocities 0-0.25 m/s (AMEC 2014). The majority of the Burbot monitoring target area was described as pool habitat and there was no or very low flow observed in most areas. The exception to this was within the defined Upper Duncan River channel upstream of Rkm 26.5 where average velocity was nearly 0.5 m/s. Spence and Neufeld (2002) indicated that radio tagged Burbot abandoned areas within the Upper Duncan River portion of the target monitoring area due to changing habitat conditions with reservoir drawdown as depths decreased to 0.51 m and velocities increased to 0.5 m/s. However, Westslope (2010) located suspected spawners in this area of the Upper Duncan River with maximum velocities reaching 1.17 m/s. Westslope (2010) indicated that there was an abundance of large woody debris and gravel bars, braiding and side channel habitats to provide velocity refuge.

5.2.2 Substrate

All substrates that were observable in 2015 were suitable for Burbot spawning and possibly for rearing. Burbot spawning has been observed in areas with silt, sand, gravel, cobble, and possibly boulder and bedrock (references cited in AMEC 2014). Burbot rearing habitats include cobble, boulder and possibly silt substrates (references cited in AMEC 2014). The majority of habitat observed in the Burbot monitoring target area was silt with some small gravel areas, however, water clarity was low and it was difficult to conclusively describe the substrate in some areas. Burbot are broadcast spawners and eggs may initially drift but eventually settle into substrate interstices (McPhail and Paragamian 2008).

5.2.3 Water Clarity and Turbidity

Optimal conditions for water clarity and turbidity specific to Burbot spawning, incubation and rearing have not been defined in the literature. Previous studies have suggested the highly turbid water observed in the Upper Duncan River during drawdown may impact incubating eggs and larva (Spence and Neufeld 2002, Westslope 2011). In late March 2015, turbidity was notable within the Burbot monitoring target area and ranged from 8 to 32 NTU, whereas conditions in the historic Duncan Lake (Rkm 15) were clear (<1 NTU). Drawdown exposes and cuts through lake sediments in the Upper Duncan River area as the riverine channel continually moves southward resulting in fine sediment transport and turbidity (Westslope 2011).

5.2.4 Cover

The type of cover observed in the Duncan Burbot monitoring area is likely suitable for Burbot spawning and rearing. According to available literature, ice, braided channels, gravel bars and sidechannels are considered cover for spawning Burbot. For rearing Burbot, cover includes large woody debris, weeds, rocks, cutbanks, interstitial spaces and shoreline littoral areas. Ice was not observed in the Burbot monitoring target area in 2015 but braided channels and sidechannels were observed upstream of Rkm 26.5 in the Upper Duncan River channel bed. Ice has been observed covering the Burbot monitoring target area during previous studies (e.g., Spence and Neufeld 2002, Westslope 2011). Large woody debris, primarily stumps and rootwads, is abundant throughout the Burbot monitoring target area but limited in the Upper Duncan River channel. Interstitial spaces and cutbanks were observed along steeper walls of the reservoir edge near the historic Upper Duncan River outlet as well as along the eroding banks of the river itself.

5.3 Burbot Spawning Success

Spawning success is the ability of an individual or group of individuals to carry out spawning activities, release fertilized gametes and for those gametes to incubate and develop into larval stages (and beyond). In the Lower Duncan River below DDM, Kokanee spawning success was measured by directly enumerating spawners to estimate potential egg deposition which was then used to determine whether there were any egg losses due to flow reductions (AMEC 2012). However, for Duncan Reservoir Burbot, estimation of spawning success cannot be based on spawning observations, since Burbot spawning has not been directly observed. Therefore, an alternative method for estimating Burbot spawning success in the Duncan Reservoir included water temperature monitoring, physical habitat mapping in the field, estimating suitable spawning/incubation habitat (ha) based on criteria from the literature (i.e., depth, velocity, substrate, turbidity, cover) and linking physical habitat availability with reservoir operations. Based on best available information, river km 20.6-28.0 represents the most likely spawning/egg incubation area that could be impacted by reservoir operations for a portion of the Burbot spawning population in the Duncan Reservoir.

Burbot spawning habitat evaluation within this section of the reservoir in 2015 suggested that depth, velocity, substrate and cover parameters fell within the Burbot spawning habitat suitability criteria. Water temperatures also did not exceed 6°C during the potential egg incubation period, however water temperature monitoring did not cover the entire spawning/incubation period during winter 2014/2015. Water temperatures during the Burbot spawning period the following year, the winter of 2015/2016, were within optimal thermal criteria throughout the spawning and incubation period (early January to mid-March).

Based on current water temperature monitoring, the estimated Burbot spawning/incubation period for Duncan Reservoir is early January to mid-March. During typical operational years, Duncan Reservoir is around 564 m in early January and declines to approximately 552 m by mid-March when eggs may be incubating in the substrates (Figure 2-1). Modelled habitat area is estimated at 1111 ha and 979 ha for the 564 m and 552 m elevation scenarios, respectively (Table 4-2; Appendix C). Therefore, it is estimated that approximately 130 ha of habitat may be dewatered during the incubation period indicated above. Based on habitat area and the assumption that optimal habitat criteria remained throughout reservoir drawdown, Burbot spawning success may have been estimated at 88% because 12% of the total spawning/incubation area was dewatered for the predicted hatch/swim up period (assuming a higher amount of habitat equates to higher spawning success).

6.0 RECOMMENDATIONS FOR BURBOT SPAWNING SUCCESS PERFORMANCE MEASURE

6.1 Water Temperature

Water temperature is a key performance measure to optimize Burbot spawning success in Duncan Reservoir based on information collected at this time. Water temperature targets for Kootenai River Burbot conservation efforts include temperatures <5°C by the first week of November and temperatures are maintained between 1°C and 4°C from December through February, which includes the migration and spawning season in that system (Staphanian et al. 2010, Hardy and Paragamian 2013). These authors also reported that water temperatures of 6°C are necessary for migration and cooler temps between 1°C and 4°C are required for spawning.

Maintaining optimal spawning and egg incubation temperatures during the suspected Burbot spawning and egg incubation period in the Duncan Reservoir Burbot target area may help optimize Burbot spawning success. Critical temperature thresholds include:

- Spawning – 1-5°C; onset 3-7 days after exposure to 4°C; target early January.
- Incubation – Peak survival between 3-4°C; must not exceed 6°C during first 2 weeks of incubation; after week 3 up to 9°C may be tolerated; target early January to end February.

6.2 Habitat Area

Maintaining a stable habitat area during the incubation period within the target area may also help optimize Burbot spawning success. After hatch Burbot spend approximately 1-3 weeks in the substrate and then fill their swim bladder and passively drift in the pelagic zone until early summer, likely June in the reservoir, when they become more mobile and start benthic feeding along the shoreline (Taylor and McPhail 2000, McPhail 2007, Vught et al. 2007, Jude et al. 2013). A target of minimizing reservoir drawdown from early January to mid-March may prevent dewatering of eggs and hatched larvae that are not yet neutrally buoyant (i.e., cannot drift with water currents). Based on water temperature and estimated hatch, larvae should be out of the substrate by mid-March; this assumes that passive drift follows water currents downstream to areas that are more reservoir-like and dewatering is avoided.

6.3 Next Steps to Finalize Performance Measures

This represents the completion of the development of the Burbot spawning performance measure for the DDMMON-11 monitoring program. According to the WUP review process, this performance measure will be used to evaluate alternative options if the current operating scenario requires review. To further improve the measure, BC Hydro may wish to continue monitoring water temperatures in the Duncan Reservoir to confirm our assessment of most suitable Burbot spawn and incubation timing.

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Appendix A: Duncan Reservoir Bathymetric Survey Metadata

Canada-Surveys Inc.

October 6, 2015

Multi-beam sonar Hydrographic Survey by CRA Canada Surveys Inc.

Duncan Reservoir- BC KM 20- KM28

Field Survey performed: August 16-21st, 2015

Equipment used:

Horizontal Positioning and Vertical positioning:
Trimble GNSS R8 RTK GPS ROVER.
CRA GNSS R7 GPS base station

Sonar system equipment:
Reson 7125 swath bathymetry system 280 beams , 140-degree width
TSS DSM-05 Heave, Pitch, Roll, Motion Sensor
Hemisphere's VS 110 heading and Position sensor
AML Minos-x , Velocimeter capable of 500m
HYPACK/ Hysweep software
Duo core data collection/processing computers with multiple com-ports

FINAL DATA PRESENTED:

- Multi-beam sonar 1.0M XYZ Data File,
  (Duncan res Combined.xyz)
- Sunlit Image drawing showing coverage and detail
  (Duncan Reservoir survey 082015(PDF and Autocad))
- Autocad DEM file with 1m point density(C3D2012 DEM File)
  (Duncan reservoir.dem)
- Survey boundary Polygon In poly-line form
  (Duncan Reservoir Survey Boundary)

XYZ data and Geodetics

Horizontal data (Meters) collected and presented in UTM, Zone 11, NAD83

Vertical data (meters) CVD 28 Tied to water survey of Canada BM #12 at the Duncan Dam site   Elevation - 580.660 meters

Multi-beam sonar Co-ordinate Data

XYZ Data file format: DATA BIN SIZE 1.0 X 1.0m
Space delimited
x,y, elevation

Notes:

1. Multi- beam sonar coverage was limited to areas where water depth and conditions were suitable for equipment and crew safety.

2. Overall sonar return conditions were excellent however we did have trouble tracking the lake bed in KM 20 area where the water was quite deep. We believe The bottom type, water conditions (turbidity) and depth were the causes of the trouble, these Issues disappeared when we weren't work in the area near the 20 km mark.

3. Water elevation at start of survey was 574.25m or the period of the survey the water level dropped by approximately 0.40m

Any questions about the data provided please contact:

Alex Howden, CRA Canada Surveys Inc.

Ph. 604-824-9609 or 604-845-0174

Appendix B: Habitat Characteristics and Areas

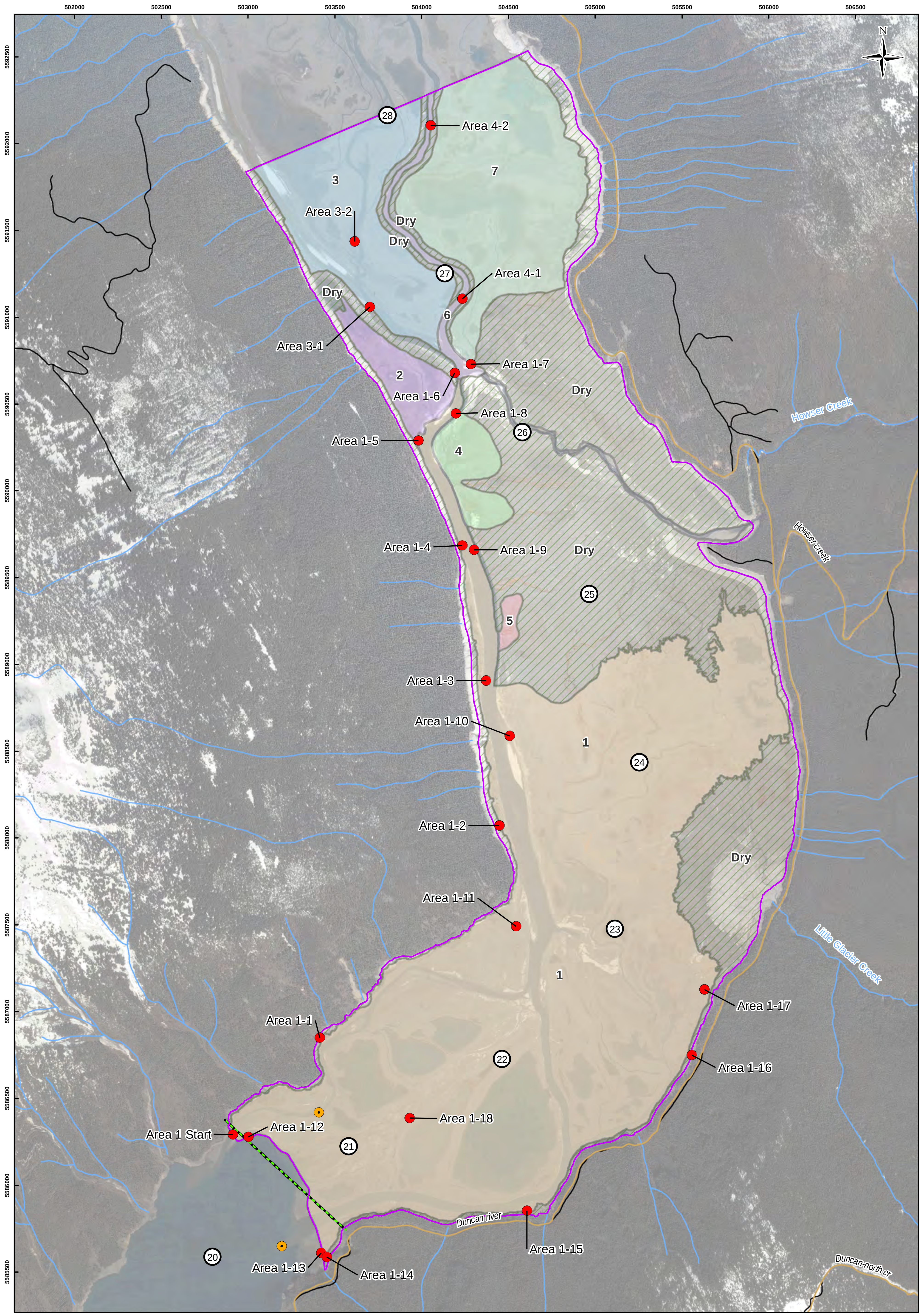
Appendix B. All habitat data collected in the Burbot monitoring target area of Duncan Reservoir, March 23 - 26, 2015.

Sample Area	Habitat Point Name	River Km	Date	Photos	Turbidity Readings (NTU)			Average Turbidity (NTU)	Water Temperature (°C)	Habitat Type (Riffle, Run, Pool)	Average Depth (m)	Mean Column Velocity (m/s)	Substrate[1]		Secchi Depth (m)	Comments
													Dominant	Sub-dominant		
1	1-1	21.4	24-Mar-15	1-1	9.21	9.38	8.73	9.11	7.2	Pool	1	0	Bedrock	Boulder	1.1	
1	1-2	23.1	26-Mar-15	1-2	9.65	9.71	9.77	9.71	6.7	Pool	-	-	-	-	-	Additional tubidity and habitat point.
1	1-3	24.5	24-Mar-15		-	-	-	-	-	Pool	3.1	0.09	Gravel	Fines	1	Velocity observed.
1	1-4	25.5	24-Mar-15	1-4	11.90	12.40	11.70	12.00	5.6	Pool	4.6	0.13	Boulder	Cobble	1.2	
1	1-5	26.3	24-Mar-15	1-5, 1-5b	-	-	-	-	7.8	Pool	1.6	0	Fines	Gravel	1.1	
1	1-6	26.5	24-Mar-15	1-6	-	-	-	-	7.5	Pool	3.9	0.36	Fines	-	1.2	
1	1-7	26.5	24-Mar-15	1-7, 1-7(2)	9.6	13.3	13.2	12.03	7.1	Pool	0.9	0.03	Fines	-	0.4	
1	1-8	26.3	24-Mar-15	1-8, 1-8b	-	-	-	-	5.5	Pool	2.7	0.1	Fines	-	0.9	Howser confluence (coolest point).
1	1-9	25.5	24-Mar-15	1-9	-	-	-	-	6.3	Pool	2.9	0.18	Fines	-	1.2	
1	1-10	24.2	24-Mar-15	1-10	-	-	-	-	-	Pool	0.9	0.05	Fines	-	1	
1	1-11	22.8	24-Mar-15	1-11, 1-11(2)	-	-	-	-	-	Pool	0.8	0.07	Fines	-	1	
1	1-12	20.3	24-Mar-15	1-12	8.98	9.29	9.57	9.28	7.4	Pool	10	0	Bedrock	Cobble	1.3	5 m contour west side.
1	1-13	20.5	24-Mar-15	1-13, 1-13(2)	-	-	-	-	-	Pool	4.3	0	Bedrock	Cobble	1.3	5 m contour east side.
1	1-14	20.6	25-Mar-15	1-14	-	-	-	-	-	Pool	3	0	Gravel	Boulder	1.2	
1	1-15	21.5	25-Mar-15	1-15	9.28	8.51	8.16	8.65	6.8	Pool	1.45	0	Cobble	Gravel	1.2	
1	1-16	22.8	25-Mar-15	1-16	-	-	-	-	-	Pool	1.45	0	Cobble	Gravel	1.1	
1	1-17	23	25-Mar-15	1-17	-	-	-	-	-	Pool	1	0	Cobble	Gravel	1.2	
1	1-18	21.4	25-Mar-15	1-18	8.8	9.1	9.04	8.98	6.9	Pool	1.4	0	Fines	-	1.2	
2	2-1	26.3	24-Mar-15	-	-	-	-	-	-	Pool	1	0	Fines	-	1	Too shallow to survey via boat.
3	3-1	27	24-Mar-15	3-1	-	-	-	-	-	Pool	1	0	Fines	-	1	Tracked lower area but became too shallow to navigate and not the main UDR channel. Flooded to points past km 28.
3	3-2	27.4	24-Mar-15	3-2	-	-	-	-	-	Pool	0.8	0.02	Fines	-	0.8	
4	-	26	24-Mar-15	-	-	-	-	-	-	Pool	1	0	Fines	-	-	Too shallow to survey via boat.
5	-	25	24-Mar-15	-	-	-	-	-	-	Pool	1	0	Fines	-	-	Too shallow to survey via boat.
6	4-1	26.9	26-Mar-15	4-1	30	19.3	19.3	22.87	4.9	Run	2.4	0.38	Fines	-	0.5	Following mid-channel of Upper Duncan River. Reservoir is wetted on either side of channel with ~10 m wide exposed silt each side of channel.
6	4-2	27.8	26-Mar-15	4-2, 4-2(2)	33.4	31.5	32.3	32.40	4.9	Run	1.5	0.19	Fines	-	0.3	
6	4-3	29.8	26-Mar-15	4-3	24.8	19	22.1	21.97	4.9	Run	0.5	0.5	Fines	-	0.5	
6	4-4	31.2	26-Mar-15	4-4	26.4	32.1	25.5	28.00	5	Run	0.8	0.7	Fines	-	0.3	
7	7-1	27.8	26-Mar-15	-	-	-	-	-	8.4	Pool	<1	0	Fines	-	-	Backflooded area upstream of Howser to Km 28; parallel to Upper Duncan River. Too shallow to survey. Water temp 4°C warmer than in UDR 10 m to the west.
-	Background	15	26-Mar-15	Km 15 Turbidity	0.5	0.44	0.85	0.60	5.2	Pool	-	0	-	-	-	Mid reservoir surface turbidity reading.
-	Temp Logger	20.3	26-Mar-15	Temp Logger 20.3	8.06	8.74	8.53	8.44	7.1	Pool	-	0	-	-	-	Turbidity and temperature collected at logger float.

[1] : Substrate classes: F=fines (<2 mm), FG= fine to medium gravel (2 to 16 mm), CG=coarse gravel (16 to 64 mm), SC=small cobble (64 to 128 mm), LC=large cobble (128 to 256 mm) and B=boulder (>256 mm

"-": No data available

Appendix C: Habitat Areas and Elevation Maps



Legend

- Kilometer Marker
- Temperature Logger
- Waypoint
- Stream
- Forest Service Road
- Existing Road
- Upper Duncan River Confluence at 547m
- Bathymetry Boundary (574m)

Habitat: 1, 2, 3, 4, 5, 6, 7; Dry; Substrate

0 125 250 500
Meters
Scale:1:20,000

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

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

CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Habitat Overview (550m)

DATE:	ANALYST:	QA/QC:	
November, 2015	MY	LP	Figure 1

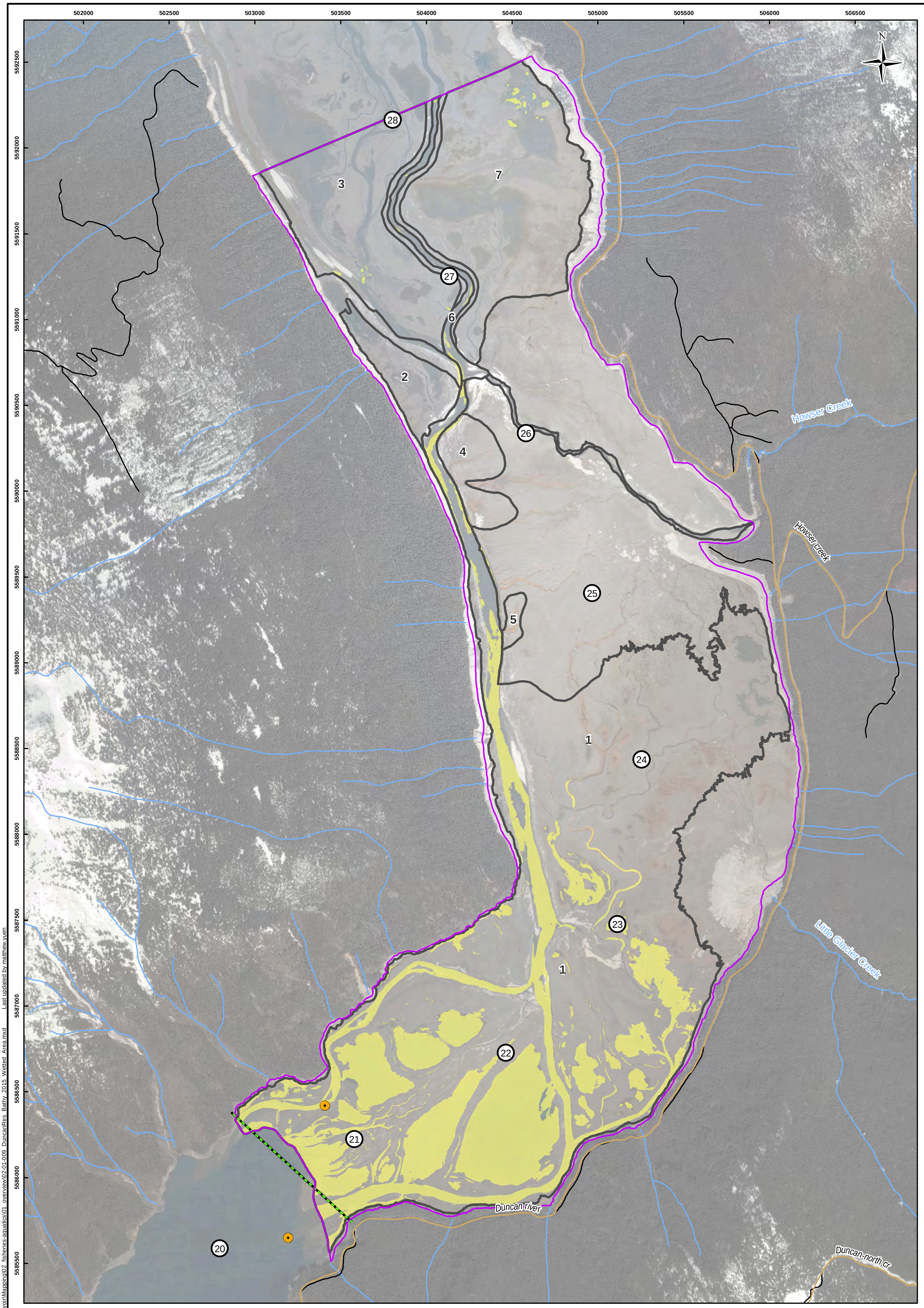
GIS FILE: 02-01-010_DuncanRes_Bathy_2015_Habitat

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

amec foster wheeler

Y:\GIS\Projects\VE\VE52400\VE52477_DuncanReservoir\Mapping\02_fisheries-aquatics\01_overview\02-01-010_DuncanRes_Bathy_2015_Habitat.mxd
Last updated by matthew.yuen



Legend

- Temperature Logger
- Kilometer Marker
- Stream
- Forest Service Road
- Existing Road
- Upper Duncan River Confluence at 547m
- Bathymetry Boundary (574m)
- Wetted Area Available
- Habitat

0 125 250 500
Meters
Scale:1:20,000

Reference:
DataBC Data Distribution Service
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CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir
Burbot Monitoring

TITLE:

Wetted Area Available
at Elevation 547

DATE: November, 2015
ANALYST: MY
QA/QC: LP
Figure 2

GIS FILE: 02-01-009_DuncanRes_Bathy_2015_Wetted_Area

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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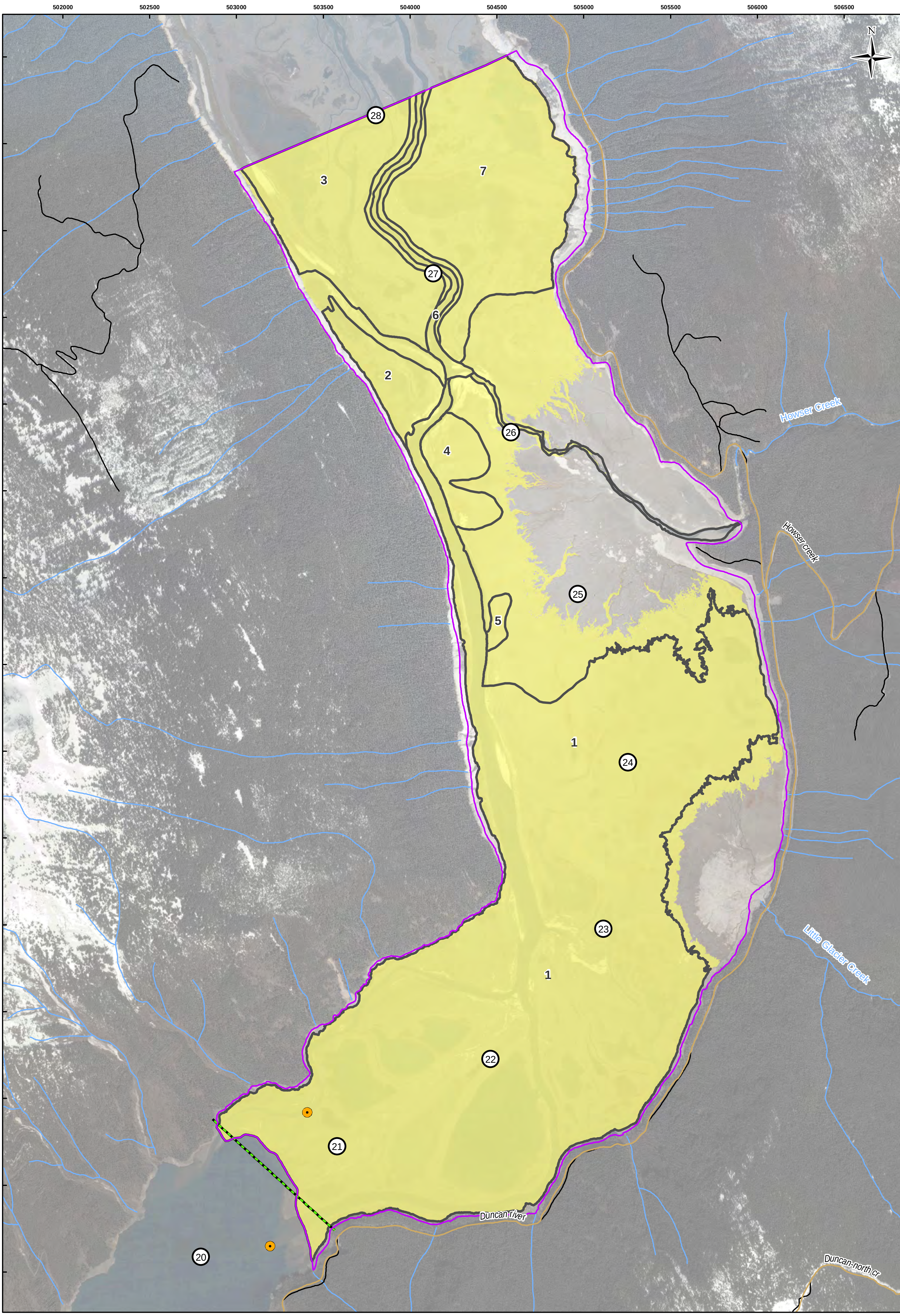
V:\GIS\Projects\VE\VE52400\VE52477_DuncanReservoirMapping\02_fisheries-aquatics\01_overview\02-01-009_DuncanRes_Bathy_2015_Wetted_Area.mxd
Last updated by matthew.yuen



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Legend

- Temperature Logger
- Kilometer Marker
- Stream
- Forest Service Road
- Existing Road
- Upper Duncan River Confluence at 547m
- Bathymetry Boundary (574m)
- Wetted Area Available
- Habitat

0 125 250 500
Meters
Scale:1:20,000

Reference:
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CLIENT:
BC hydro

PROJECT:
DDMMON-11 Duncan Reservoir
Burbot Monitoring

TITLE:
Wetted Area Available
at Elevation 551

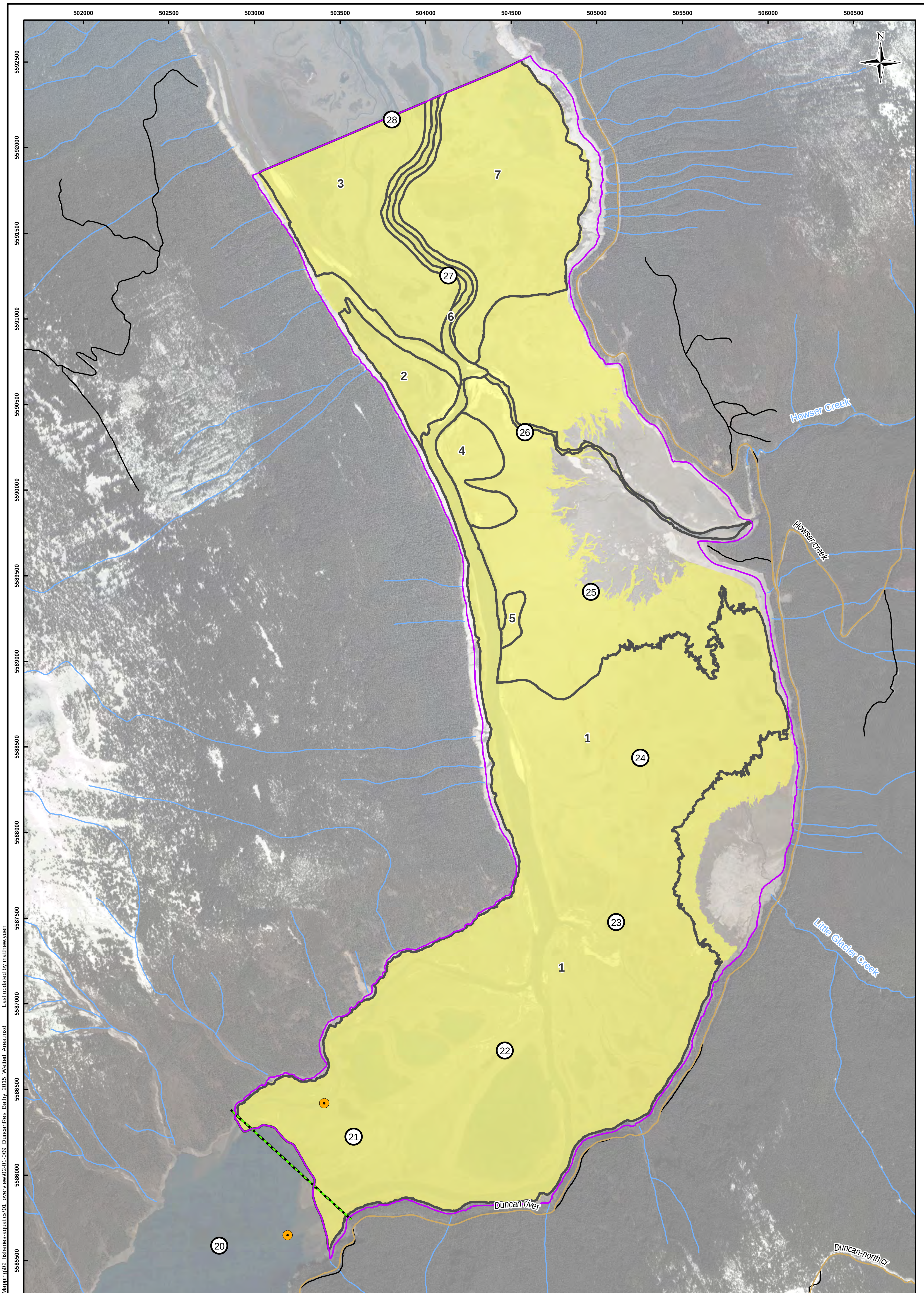
DATE:	ANALYST:	QA/QC:	
November, 2015	MY	LP	Figure 3

GIS FILE:
02-01-009_DuncanRes_Bathy_2015_Wetted_Area

JOB No:
VE52477

COORDINATE SYSTEM:
NAD 1983 UTM Zone 11N

amec foster wheeler



Legend

- Temperature Logger
- Kilometer Marker
- Stream
- Forest Service Road
- Existing Road
- Upper Duncan River Confluence at 547m
- Bathymetry Boundary (574m)
- Wetted Area Available
- Habitat

0 125 250 500
Meters
Scale:1:20,000

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CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Wetted Area Available at Elevation 552

DATE:	ANALYST:	QA/QC:	
November, 2015	MY	LP	Figure 4

GIS FILE: 02-01-009_DuncanRes_Bathy_2015_Wetted_Area

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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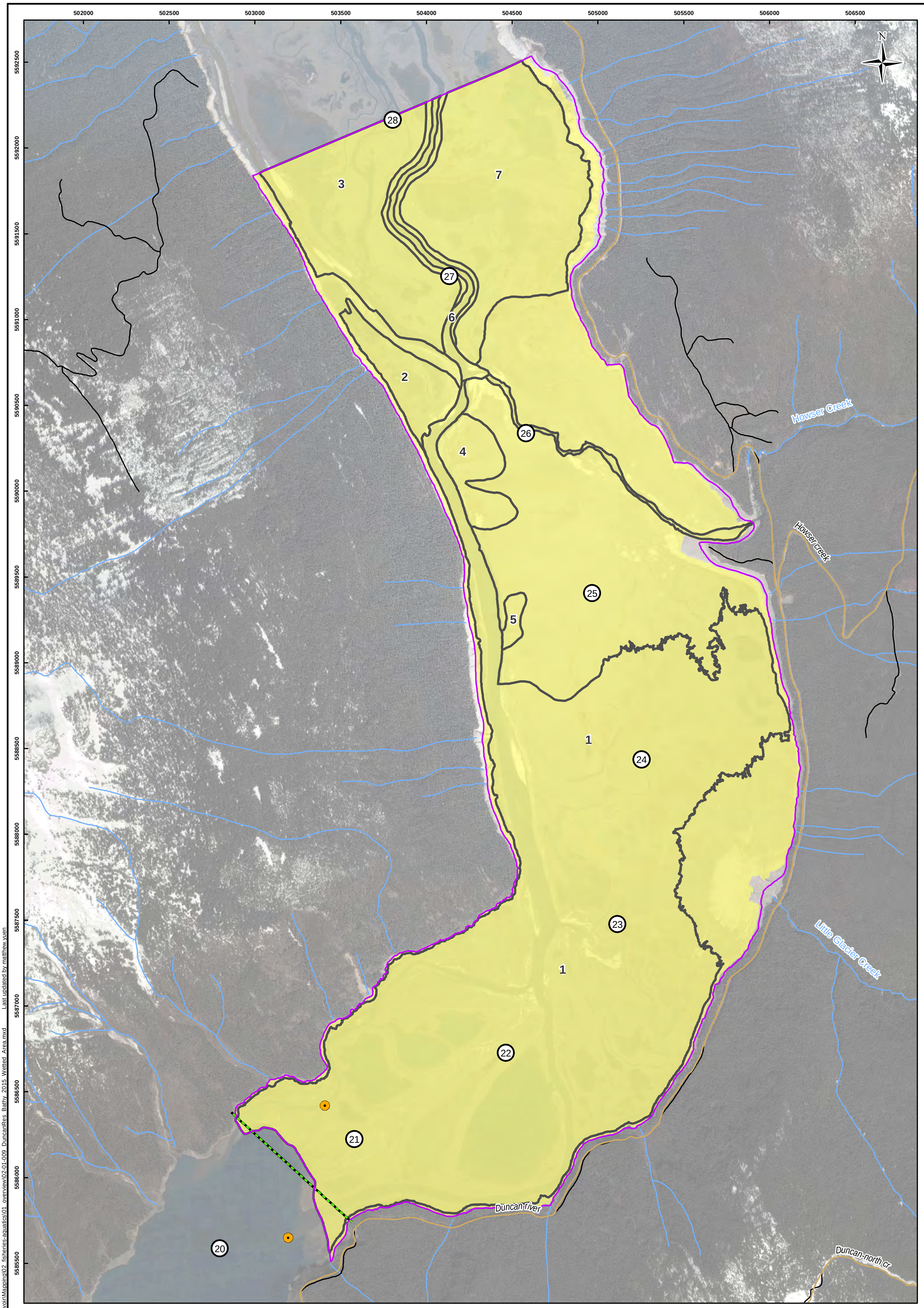

Legend

- Temperature Logger
- Kilometer Marker
- Stream
- Forest Service Road
- Existing Road
- Upper Duncan River Confluence at 547m
- Bathymetry Boundary (574m)
- Wetted Area Available
- Habitat

0 125 250 500
Meters
Scale:1:20,000

Reference:

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CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Wetted Area Available at Elevation 564

DATE:	ANALYST:	QA/QC:	
November, 2015	MY	LP	Figure 5

GIS FILE: 02-01-009_DuncanRes_Bathy_2015_Wetted_Area

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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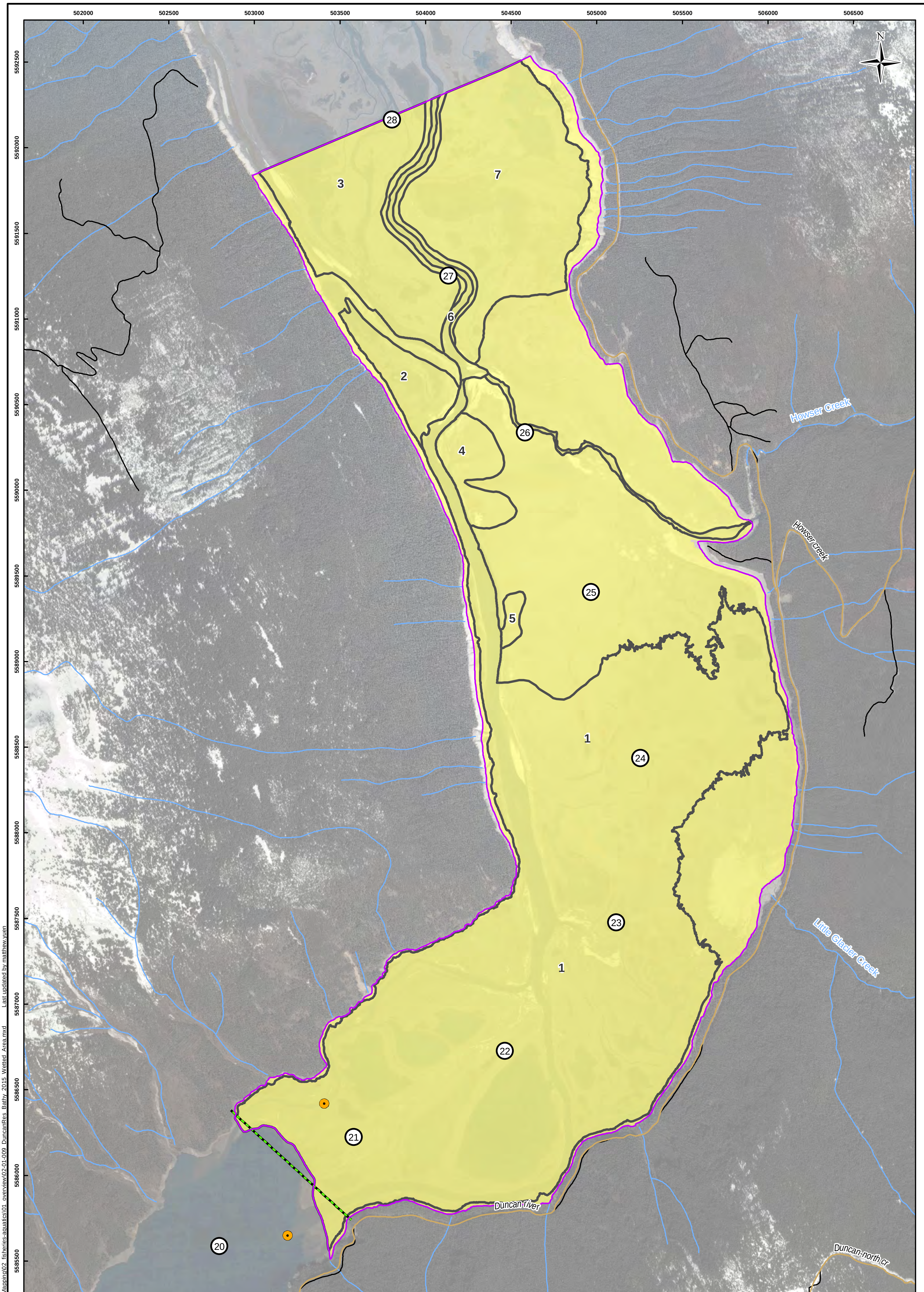

Legend

- Temperature Logger
- Kilometer Marker
- Stream
- Forest Service Road
- Existing Road
- Upper Duncan River Confluence at 547m
- Bathymetry Boundary (574m)
- Wetted Area Available
- Habitat

0 125 250 500
Meters
Scale:1:20,000

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CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Wetted Area Available at Elevation 569

DATE: November, 2015
ANALYST: MY
QA/QC: LP
Figure 6

GIS FILE: 02-01-009_DuncanRes_Bathy_2015_Wetted_Area

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

amec foster wheeler

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Appendix D: Photo Plates


Photo Plate 1-1: Representative photo of Area 1.


Photo Plate 1-2: Representative photo of Area 1 nearshore habitat.


Photo Plate 3-1: Representative photo of Area 3.

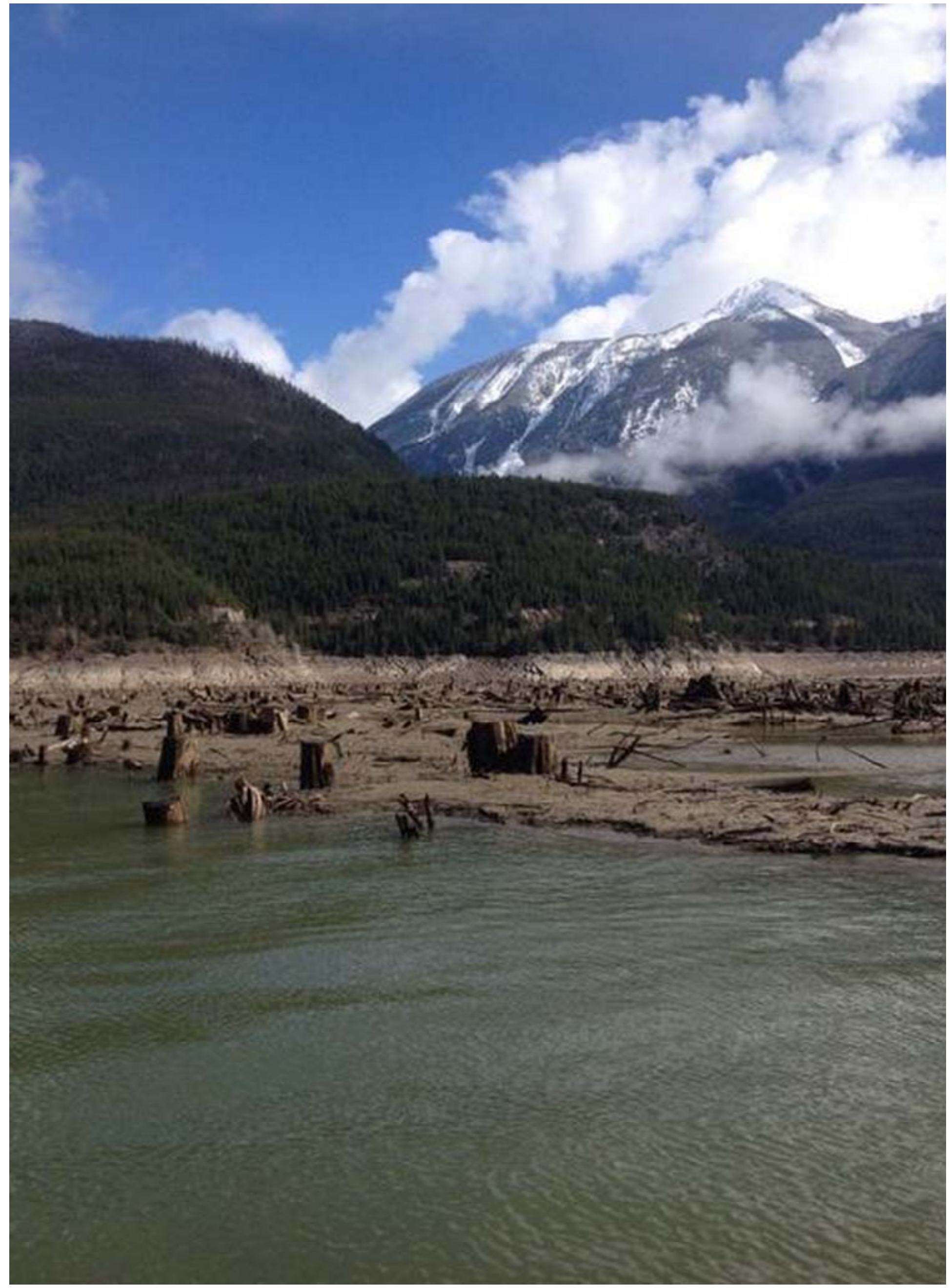
Photo Plate 4-1: Representative photo of Area 4 as viewed from Area 1.


Photo Plate 5-1: Representative photo of Area 5.


Photo Plate 6-1: Representative photo of Area 6.

Photo Plate 7-1: Representative photo of Area 7 which is on the right of the exposed bar (Area 6 is on the left).

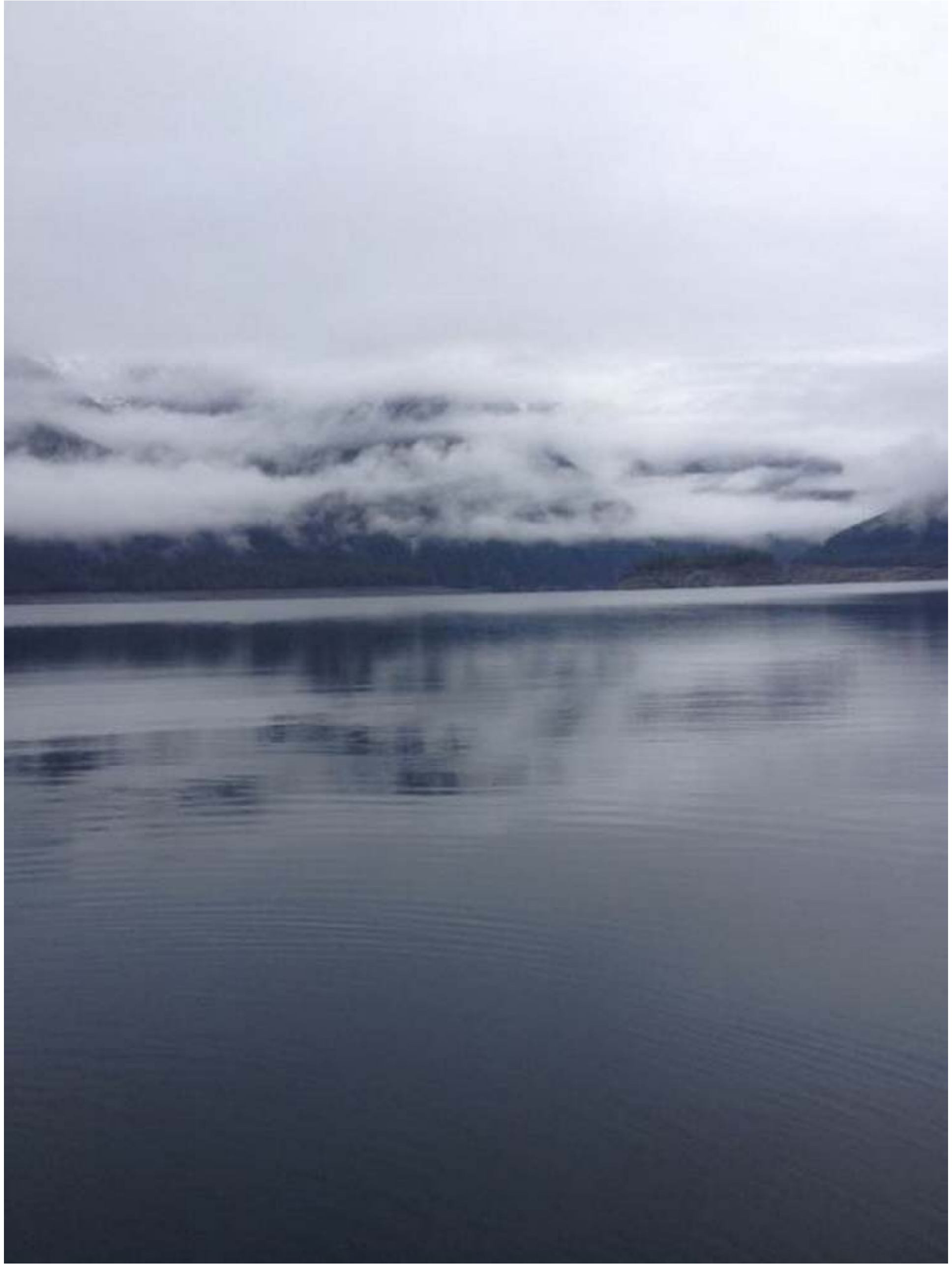

Photo Plate 8-1: Duncan Reservoir at Rkm 15 where background turbidity readings were taken.

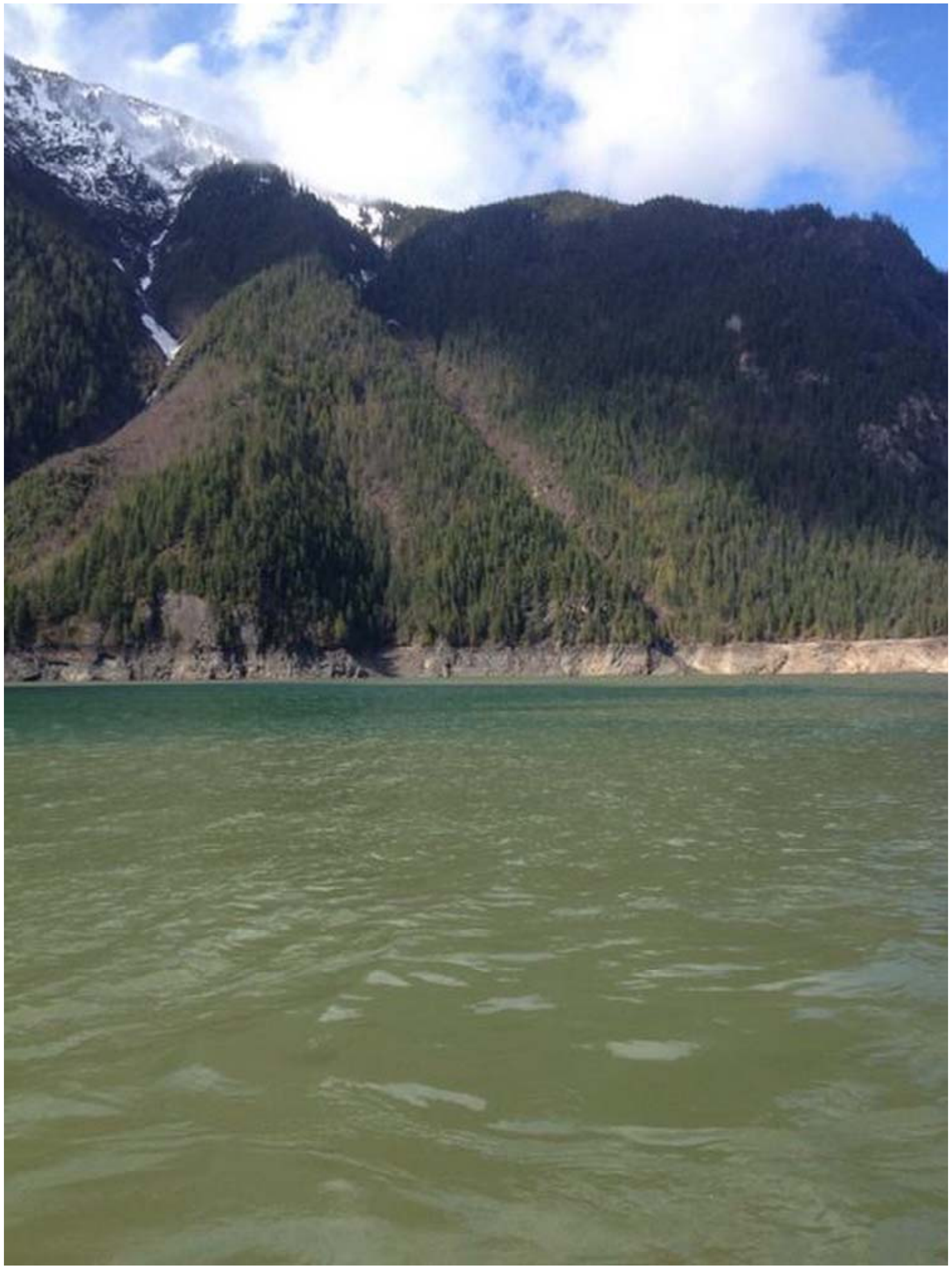

Photo Plate 8-2: Edge of sediment plume at Rkm 18 that extended from the Burbot monitoring target area.