# Duncan Dam Project Water Use Plan

## Duncan Reservoir Burbot Monitoring

## Implementation Year 4

## Reference: DDMMON-11

***Final Literature Review and Site Selection Report***

**Study Period: September 2014 to January 2015**

**AMEC Environment & Infrastructure**
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**January 21, 2015**

# DDMMON-11 Duncan Reservoir Burbot Monitoring – Literature Review & Site Selection

**FINAL REPORT**

**Version 2.0**
**January 21, 2015**

Submitted to:

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# 1 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**). The Duncan Reservoir provides water storage for flow management and flood control below DDM that is largely dictated by seasonal operating targets set by the CRT and, to a lesser degree, water level requirements for Kootenay Lake set by the International Joint Commission (BC Hydro 2007) and BC Hydro's Water Use Plan 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 low pool elevation at the end of February (elevations between 551.0 m to 564.4 m depending on projected snowpack; de Zwart et al. 2013).

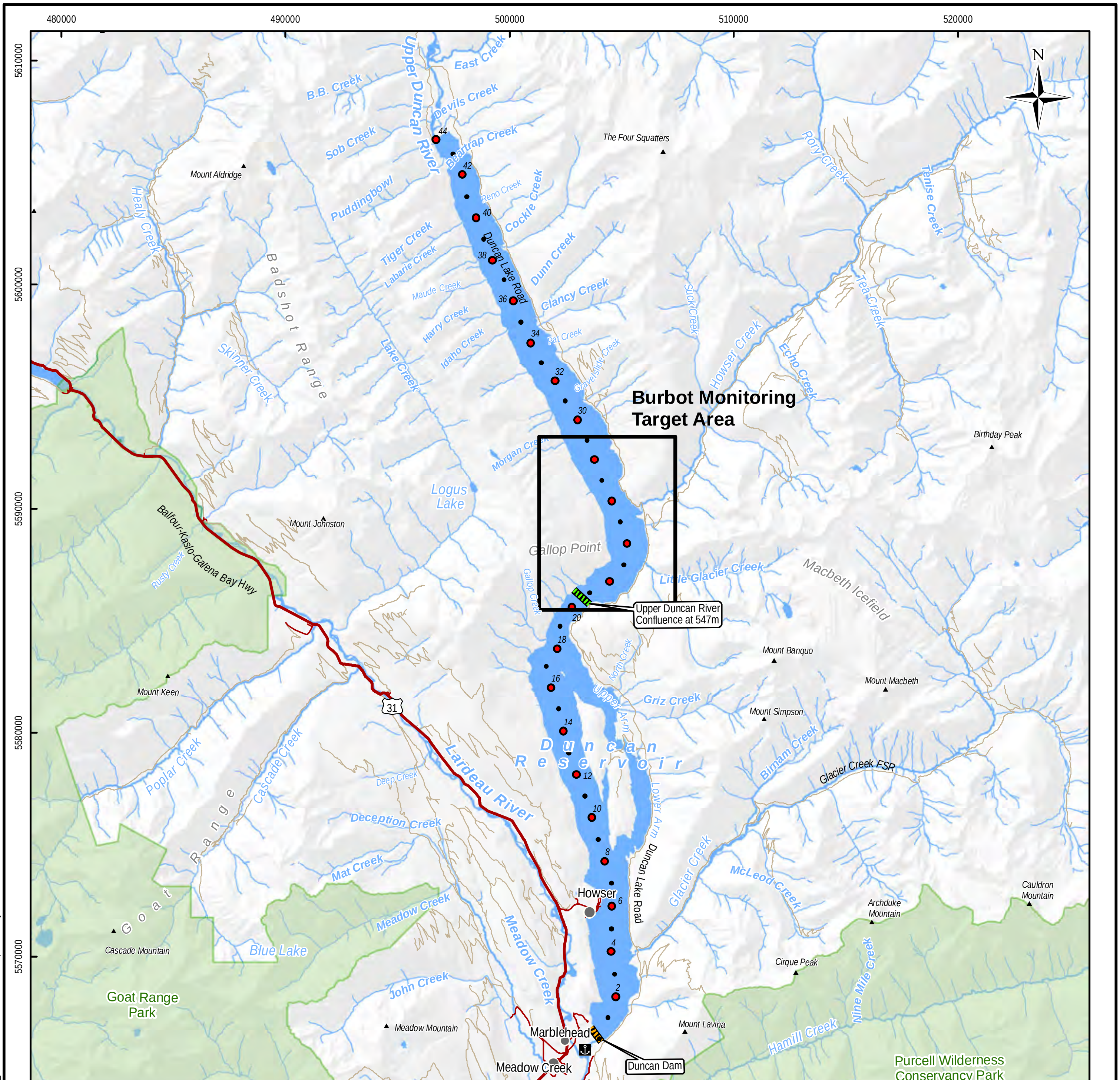
A number of flow management issues (e.g., CRT, fisheries, and recreational users) impose significant challenges for the operation of DDM. The Duncan Dam Water Use Planning (WUP) project was initiated to address flow management issues with respect to impacts on competing resources in the area (BC Hydro 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 monitoring adults 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 this physical monitoring approach is to conduct 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 (BC Hydro 2014). These key habitat attributes will also inform selection of field habitats for further study. Results of the literature review and preliminary habitat site selection is provided herein.

## 1.1 Objectives

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).




Y:\GIS\Projects\VE\VE52400\VE52477_DuncanReservoir\Mapping\02-01-005_DuncanRes_Overview.mxd Last updated by kristin.aldous

## Legend

- Populated Place
- Mountain Peaks
- Boat launch
- Highway
- Other Road
- Forest Service Road

Stream Order

- =>5th
- 3rd and 4th
- 2nd
- Waterbody
- Park

Burbot Monitoring

- Kilometre Mark
- Duncan Dam
- Upper Duncan River Confluence at 547m


**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)

Scale: 1:250,000
0 2.5 5 10
Kilometers

CLIENT: BC hydro

PROJECT: Duncan Reservoir Burbot Monitoring

TITLE: Overview Map of Duncan Reservoir Depicting Duncan Dam Tributaries

| DATE: | ANALYST: | QA/QC: | |
|---|---|---|---|
| October, 2014 | WR/KA | MY | **Figure 1** |

GIS FILE: 02-01-005_DuncanRes_Overview

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

amec

# 2 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).

Perhaps the most dramatic change that occurs with drawdown to low pool is the dewatering of approximately 5,160 ha (or 72% by area) of habitat mostly along the northern half of the reservoir (**Figure 1**; Westslope 2011). At minimum elevations, the reservoir approximates elevations that the historic Duncan Lake would have experienced and exposes the original channel of the UDR (Vonk 2001 as cited by Westslope 2011). However, the seasonal re-emergence of the UDR post-impoundment exposes a deforested valley bottom with high loads of fine glacial sediments that erode along its banks as water levels decline (Spence and Neufeld 2002, Westslope 2011). Therefore, this area has been described as a barren mud flat that is biologically non-productive (Vonk 2001 as cited in Westslope 2011). 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**). 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**). There is also a minimum elevation at draw down of 546.87 m (**Figure 2**). 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). The largest variation in reservoir operations occurs from the end of October to the end of February.

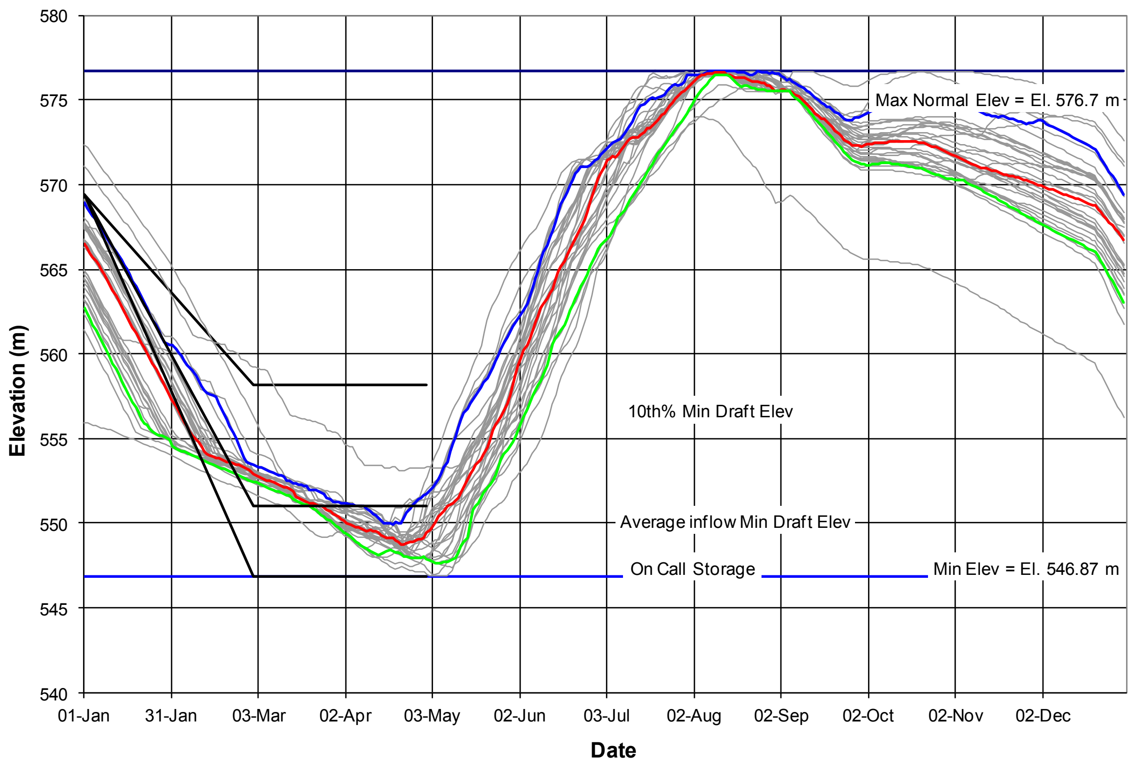



***Figure 2: Duncan Reservoir elevations (Source: BC Hydro 2014)***

## 2.3 Historic Water Temperatures

Limited continuous historic water temperature data is available for Duncan Reservoir; the majority of data consists of spot measurements. Continuous water temperature monitoring data has been limited to DDM Forebay (2002, 2010/2011), with limited data available for the main reservoir in 2011 at Km 6 (near Howser boat launch) and at the upper Duncan River confluence (Km 20.5; Table 1). Westslope (2011) plotted available data for the expected Burbot spawning and rearing period and noted that water temperatures ranged between 1.5°C and 4.7°C.

***Table 1: Summary of Temperature Monitoring in Duncan Reservoir and tributaries, 2002 to 2011.***

| Source | DDMMON Project | Waterbody | Location | Logging Interval (minutes) | Start Date | End Date | Notes |
|---|---|---|---|---|---|---|---|
| BC Hydro | - | Duncan Reservoir | DDM Forebay (Bottom) | 30 | 12-Jun-02 | 12-Jul-02 | |
| BC Hydro | - | Duncan Reservoir | DDM Forebay (Bottom) | 30 | 17-Sep-02 | 2-Jul-03 | |
| BC Hydro | - | Duncan Reservoir | DDM Forebay (Surface) | 30 | 12-Jun-02 | 12-Jul-02 | |
| BC Hydro | - | Duncan Reservoir | DDM Forebay (Surface) | 30 | 17-Sep-02 | 8-Oct-03 | |
| BC Hydro | DDMMON-11 | Duncan Reservoir | Duncan Reservoir at Km 20.5 (Upper Duncan River confluence) | unknown | January 2011 | April 2011 | Deployed at depth (63 m) and surface (1m) |
| BC Hydro | DDMMON-7 | Duncan Reservoir | Duncan Reservoir at Km 6 (near Howser) | 30 | May 2010 | May 2011 | Deployed at 1 m and 13 m from bottom |
| BC Hydro | DDMMON-7 | Duncan Reservoir | DDM Forebay (various depths) | 30 | May 2010 | May 2012 | Deployed 1, 5, 10, 15, 20 and 25 m depths. |

# 3 METHODS

## 3.1 Literature Review

A literature review was conducted to obtain Burbot spawning and juvenile rearing habitat use requirements for the Burbot population in Duncan Reservoir (BC Hydro 2014). In addition, information was compiled to determine the most likely habitat conditions 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). Pertinent information was also incorporated from a previous literature review for Duncan-Kootenay Burbot populations (AMEC 2009). Sources reviewed included:

- EcoCat – Ministry of Environment (MOE) Ecological Catalogue search tool, which also provides pdf versions of the reports;
- FishBase – University of British Columbia website that allows access to a large database on the general life history characteristics of several fish species (including Burbot) from a vast array of references;

- American Fisheries Society (AFS) – Searches were conducted on all AFS journals for pertinent publications;
- Idaho Department of Fish and Game – Dr. Vaughn Paragamian (Principle Fisheries Research Biologist) has conducted several studies on Burbot in the Kootenai River and has published studies and a text entitled Burbot: Ecology, Management, and Culture that were currently reviewed;
- BC Hydro – Internal reports were provided by BC Hydro contract authorities under the Duncan Water Use/Licensing Requirements Program;
- Personal Communications – Discussions with Burbot experts from the regulatory agencies, First Nations and independent biologists/technicians were also conducted as outlined in AMEC (2009); and

Other – Additional reports/publications were also gathered from interview recommendations.

### 3.2 GIS Mapping

Base maps were developed for Duncan Reservoir and included existing substrate mapping, digital elevation models (DEM), provincial linework, and orthophotography (Appendix A). River kilometer (Rkm) markings were added to base maps and started at Duncan Dam (Rkm 0.0) to the upstream extent of the reservoir at full pool, which is the seasonally inundated UDR (Rkm 44.0); this method is consistent with other studies including previous DDMMON-11 mapping (e.g., Westslope 2011). Substrate and DEM files were provided by BC Hydro and Northwest Hydraulic Consultants (NHC) Ltd.

Substrate mapping was limited and provided coverage of four tributaries including Glacier Creek, Little Glacier Creek, Howser Creek and a portion of the UDR (Rkm 37.5 to past Rkm 44.0 to the Duncan River FSR Bridge; **Appendix A**).

Data supplied by BC Hydro included DEM mass point elevation data and break lines for the target portions of Duncan Reservoir (approximately Rkm 20 to 28). Additional mass point elevation data collected by NHC was also supplied (S. North, GIS Analyst, NHC, pers. comm., 2014), however data was only available for a small portion of the target area (to Rkm 23) and as the spatial resolution of the data was very coarse (points collected in linear transects spaced at 200 m) it was not possible to use to generate contours at the resolution required to map water levels at target elevations (**Appendix A**).

As described in the text file supplied by NHC (**Appendix B**), the BC Hydro mass point and breakline data was collected from aerial photography taken May 3, 1993 and has vertical/horizontal accuracy of 0.3 m. Point data is evenly spaced at approximately 20 m grid. Although this data does cover the entire reservoir, data was only collected between 548 m and 630 m elevation, as was likely the dry land areas at the time of data collection (L. Giles, Manager Photogrammetry Services, BC Hydro, pers. comm., 2014).

There are several anomalies in the data that will result in inaccuracies in generating contours at the resolution required. For example, mass point data elevations appear to have 'ridgeline' pattern where a row of points is at higher or lower elevations (~0.5 m difference) than surrounding rows of points, or 'point' anomaly where a single point is at higher or lower elevations (~1.5 m difference) than surrounding points, as well as large discrepancy between elevations that have been collected in ridgeline data compared with elevations collected in point data (**Appendix**

**B**). To smooth these discrepancies when generating contours, Inverse Distance Weighting (IDW) interpolation of points was used in ArcGIS (parameters set to power of 1 and search distance of 100 m), using a hard break line set at the BC Hydro data breakline of 582 m. These contours should be used as an estimate and visual reference only, as they are not likely to be accurate with known data anomalies. Thus, preliminary Burbot spawning areas could not be calculated because seasonal operational reservoir elevation levels and operational target elevations were not available to add to base maps at this time (Appendix C).

# 4 DUNCAN RESERVOIR BURBOT

Burbot (*Lota lota*) are widely distributed around the globe and in North America (McPhail 1997). In British Columbia, Burbot most likely colonized the province from separate unglaciated areas including the Columbia (Columbia-Kootenay Burbot population) and Great Plains refugiums (Liard-Peace Burbot population; McPhail 1997). In the Columbia River Basin, Burbot are at the most southern limit of their western North American distribution (Taylor and Arndt 2013) and populations are found mostly in lakes such as Kootenay, Duncan, Trout, Arrow, Columbia, Moyie, and Windermere. Burbot in Kootenay, Duncan and Trout lakes likely originated from the same stock, since they share the same haplotype distributions and frequencies (Powell et al. 2008).

Historical information on Burbot populations in the Columbia River Basin is limited, but it was noted that the Burbot fishery on Kootenay Lake and Kootenai River (Idaho, USA) may have been the most robust in North America (Paragamian and Hoyle 2005 as cited in Hardy and Paragamian 2013). It was estimated that there was an annual harvest of up to 26,000 Burbot from the West Arm of Kootenay Lake (Martin 1976). However, after the construction of Libby Dam (US Army Corps of Engineers - 1972), the Burbot fishery collapsed in Idaho and fishing was closed in 1992. This was followed by a similar collapse in Kootenay Lake, B.C., with fishing closures in 1997. The collapse of the Kootenay Lake/Kootenai River Burbot population likely resulted from unsustainable harvest rates, spawning stream habitat degradation, a reduction in juvenile Burbot food due to introduction of mysids (*Mysid relica*), and impoundment of the Kootenai and Duncan rivers by Libby and Duncan dams, respectively (Spence 1999, Ahrens and Korman 2002, Hardy and Paragamian 2013). The Burbot population in Kootenay Lake, B.C. is currently red listed as extirpated, endangered or threatened (B.C. Conservation Data Centre 2014).

As for most Burbot populations in B.C., historical information for populations in Duncan Lake and Duncan River are largely unknown. Peterson and Withler (1965) indicated that potential fisheries for Burbot existed in the Duncan Lake and river system, but the species was only lightly exploited prior to construction of Duncan Dam. With the construction of Duncan Dam (BC Hydro - 1967), Burbot in Duncan Lake were subsequently isolated from the rest of the population in Kootenay and Trout lakes. It is unknown whether Burbot in Duncan Reservoir were originally adfluvial Burbot from Kootenay Lake that were impounded by Duncan Dam or if the current stock originates from the Duncan system (Westslope 2011). Some gene flow may have occurred between Duncan and Kootenay lakes, since Burbot are genetically similar between these populations (Baxter et al. 2002, Neufeld 2006). However, migration to Duncan Reservoir may not be a regular occurrence or may not be a life history requirement for Burbot in the Kootenay-Duncan-Trout lake system (AMEC 2009). Although some entrainment through Duncan Dam has been documented, upstream passage at the dam is blocked (Vonk 2001, Spence and Neufeld 2002, Westslope 2009). Currently, it is estimated that approximately 3,429 adult Burbot reside in Duncan Reservoir (Westslope 2011). Spawning behaviour, as denoted by observations of migration to shallow areas at time of spawn, and of the presence of radio tagged Burbot in tributary confluence regions has been observed in the lower 7.4 m section of the historic UDR at the northern end of Duncan Reservoir (Spence and Neufeld 2002, Neufeld and Spence 2004, Westslope 2011) and potentially at the confluence of Glacier Creek (Spence and Neufeld 2002). However, direct spawning has not been observed nor have juveniles been captured in Duncan Reservoir despite targeted sampling (Westslope 2009, 2010, 2011).

## 4.1 Adult Size, Age & Growth

Adult Burbot can attain lengths up to 1 m and can weigh up to 8 kg, but most are between 300 to 600 mm with weights of 1 to 3 kg (Fisher et al. 1996, McPhail and Paragamian 2008). Size differences between males and females have not been reliable to determine sex (Jensen et al. 2007). Adult Burbot captured within the Kootenay Lake and Duncan River/Reservoir systems are reported as being heavier than averages reported for the species overall (e.g., Fisher et al. 1996, McPhail and Paragamian 2008). In Duncan Reservoir, Burbot have ranged from 540 to 1010 mm in length and between 0.95 to 5 kg in weight (Baxter et al. 2002, Spence and Neufeld 2002, Westslope 2009, 2010, 2011).

Adult Burbot typically live between 7 and 12 years, but they have also been aged between 20 to 22 years in northern populations (McPhail and Paragamian 2008). Age at maturity for males is 3 to 4 years and for females it is 4 to 5 years (McPhail and Paragamian 2000). Laboratory studies have shown that males can mature as early as 1 year old, while females mature at 2 years (Vught et al. 2007).

Historical age data is limited for Burbot within Duncan Reservoir and more recent studies have had restricted ability to collect otoliths for age determination due to population status concerns (Westslope 2009, 2010, 2011). Only two otolith samples were taken from Duncan Reservoir Burbot that were aged at 6 (570 mm TL) and 24 (620 mm TL) years old (Westslope 2011). Age structure analysis for Burbot populations in southern BC (e.g., Moyie and Trout lakes, Kinbasket and Arrow reservoirs) have shown that length does not vary by age, since there is high variability in growth rates (Neufeld et al. 2011, Westslope 2011). Thus, a usable link between length and age may not be possible, even when stratified by sex (Neufeld et al. 2011). Growth rates measured for the two Burbot in Duncan Reservoir were found to be similar to those in Trout Lake and Kinbasket Reservoir, which were classified as slower with an older mean age compared to other regional populations (Westslope 2011). These slower growth rates are expected because of the low productivity rates that are observed in Duncan Reservoir due to its oligotrophic status, which is a consequence of the cold, glaciated, low nutrient nature of the watershed and the short residence time of water within the reservoir (de Zwart et al. 2013).

## 4.2 Spawning Behaviour, Timing & Habitats

### 4.2.1 General

Burbot spawning migrations occur during winter usually between November and March when discharge is low and water temperatures are declining (McPhail and Paragamian 2008, Paragamian and Wakkinen 2008). Water level and temperatures have been reported to influence both upstream and downstream Burbot migrations (e.g., Dillen et al. 2007, Paragamian and Wakkinen 2008). Spawning takes place in lakes, rivers and streams usually during winter or early spring at water temperatures between 1 to 4ºC and at night, but this may vary by region (McPhail 1997, McPhail and Paragamian 2008). There is some disagreement about the time of day Burbot spawn: most accounts are at night, but some researchers have observed "writhing balls" of Burbot during the day (McPhail 2007). Burbot populations in the Great Lakes have been observed to have different spawning strategies from spawning in shallow water shoals and tributaries in winter to deep-water spawning later in spring/summer (e.g., Jude et al. 2013).

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). Spawn timing among hatchery-raised Burbot has been shown to be highly correlated with water temperatures and Burbot exposed to 4°C spawned as early as 3 days afterwards, but most were after 7 days (Vught et al. 2007, Zarski et al. 2010 as cited by Cott et al. 2013a). Recent studies have also indicated that the onset of spawning may result from under ice communication (Cott et al. 2014). Mature Burbot use a series of calls from slow knocks to fast buzzing, similar to that used by other Gadoid species during the spawning period (Cott et al. 2014). Burbot calling may be an important part of the spawning period because under ice spawning and light limitations would reduce the effectiveness of visual cues (Cott et al. 2014).

Although winter spawning may seem inhospitable, spawning conditions under ice in unregulated lakes are relatively stable (Cott et al. 2013a) and spawning may occur at the same location each time (McPhail and Paragamian 2008). Burbot are iteroparous (spawn several times over their lifetime), but individuals may not spawn every year. Skipping spawning enables Burbot to replenish energy required for reproduction and growth and endure adverse conditions (Cott et al. 2013a). Depending on environmental conditions, Burbot may keep up their energy stores by feeding during the spawning season (Cott et al. 2013b). Burbot populations employ a periodic life history strategy meaning that the population spawns seasonally, spawners are larger in size and females have large clutches of small eggs (Cott et al. 2013a) compared to non-periodic spawners.

Aggregations of spawners have been observed with one or two females at the center surrounded by many males (Arndt and Hutchinson 2000, Evenson 2000 as cited in Paragamian et al. 2005, Neufeld and Spence 2009). Eggs and sperm are released as this ball writhes around in the water column (McPhail and Paragamian 2008). Laboratory studies indicate that Burbot may not require direct physical contact to promote volitional spawning and that possibly chemical or pheromone communication may occur to synchronize events (Jensen et al. 2007).

Female Burbot are highly fecund and have between 300,000 to 1 million eggs/kg bodyweight (Vught et al. 2007 and references therein). Eggs are transparent, yellowish and have a lipid droplet (Vught et al. 2007). Males are often observed to be ripe well before, during and after spawning females are available (Vught et al. 2007). In addition, ripe males seem to be more available and easier to capture in the wild during the spawning season (e.g., Neufeld 2010, Westslope 2009, 2010, 2011).

Burbot broadcast eggs and sperm over an unprepared site in shallow water (0 to 10 m) over a variety of substrates from silt and sand to coarse gravel and cobble (McPhail and Paragamian 2008, Cott et al. 2013a), with little overhead cover (McPhail 2007). Semi-buoyant eggs (1.2 to 1.8 mm diameter) may initially drift, but eventually settle into substrate interstices (McPhail and Paragamian 2008). Incubation lasts between 30 and 70 days, depending on water temperatures with optima between 1°C and 5°C (McPhail and Paragamian 2000, references cited in Jude et al. 2013). Burbot egg survival peaks at 3°C to 4°C, but embryos die at temperatures above 6°C (Taylor and McPhail 2000, Vught et al. 2007). Taylor and McPhail (2000) indicated that time to hatch at 4°C was 32 days. Jude et al. (2013) reported that a 4 to 9 mm Burbot larva collected in

July and August in the Great Lakes would be from 1 to 29 days old, while a 10 to 15 mm larva would be 30 to 39 days old. Vught et al. (2007) reported that age-1 Burbot reared in the lab averaged 10 cm with a range of 5.5 to 19.8 cm in length and 7 grams with a range of 1.0 to 4.8 grams in weight.

Newly hatched larvae are very small (3 to 9 mm total length) and “wriggle” to the surface and sink to the bottom for over a week (under laboratory conditions) before they eventually fill their swim bladders and become neutrally buoyant (McPhail 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). Under laboratory conditions, larvae filled their swim bladders around 17 days at 4°C (Vught et al. 2007). Larvae become more mobile around 17 to 21 mm in length and shift to benthic shoreline habitat in early summer (McPhail and Paragamian 2000, Taylor and McPhail 2000, Jude et al. 2013).

In lakes, spawning takes place in near-shore shallows (1.0 to 10 m deep) or over shallow offshore reefs and shoals with substrates of sand, gravel or cobbles that are relatively free of silt (McPhail 2007, McPhail and Paragamian 2008). Spawning over mid-lake reefs and deep offshore sites has been observed in the Great Lakes (Jude et al. 2013). At the north end of Kootenay Lake, Burbot have been observed spawning near Davis Creek at depths between 1.5 to 2.0 m, over cobble and boulder substrates and water temperatures near 4ºC (Spence 1999). Spawning concentrations of Burbot were observed under ice in Moyie Lake near steep sided banks typically localized over cobble and gravel substrates with the depth of most spawning locations at 3 m; water temperatures were between 1°C to 3°C (Neufeld and Spence 2009, Neufeld et al. 2011). In Arrow Lakes Reservoir (ALR) on the Columbia River upstream of Hugh L. Keenleyside Dam, ripe Burbot were observed via underwater video during the spawning season (late February/early March) either alone or in groups of two or more near the bottom (Robichaud et al. 2013). Although spawning was not directly observed, based on a 5 year telemetry study, it was concluded that Burbot in ALR use the Beaton Arm/Flats area for spawning at depth (>20 m); these areas have bottom substrate materials such as sand, gravel, cobbles and bedrock (Robichaud et al. 2013). Optimal incubation temperatures for Columbia Lake Burbot were reported between 1.0°C and 6.0°C, peaking at 3°C (Taylor and McPhail 2000, Taylor 2001 as cited in Westslope 2011).

In rivers, Burbot spawn in low velocity areas in main and side channels behind deposition bars (McPhail 1997, McPhail and Paragamian 2008) with preferred substrates appearing to be fine gravel, sand, or even silt (McPhail 2007). In Alaska, Burbot spawning appeared to take place in the main channels of glacial rivers, which became clear from December through March (Breeser et al. 1988). At the south end of Kootenay Lake, Burbot have been observed in suspected spawning habitats in the lower Goat River (Creston, B.C.) in mid-February when water temperatures were between 1.5°C to 2.0ºC; habitats were not described, but residence time was between 1 to 8 days for a small number of fish (Bisset and Cope 2002). Tagged Burbot moved into the Goat River in January and February when water temperatures were between 3°C and 5°C and a few of these fish came back multiple years, but spawning was not directly observed (Paragamian and Wakkinen 2008). Burbot spawning in an unnamed tributary of Columbia Lake were observed at depths <1 m and over cobble substrates (Arndt and Hutchinson 2000).

### 4.2.2 Duncan Reservoir

In the Duncan Reservoir, spawning may occur from January to April when water temperatures are between 1°C and 5°C and when reservoir elevations are declining to annual minimums. Spawning in Duncan Reservoir has never been directly observed, but has been inferred based on telemetry observations of tagged mature Burbot during the suspected spawning period (Spence and Neufeld 2002, Westslope 2009, 2010, 2011). In addition, ripe and spent male Burbot have been collected in the Duncan Reservoir from mid-March to late April; ripe/spent females have not been observed (Neufeld 2006, Westslope 2009, 2010, 2011). The incubation period is estimated to occur from February through May (Westslope 2011).

Spence and Neufeld (2002) observed small aggregations of radio tagged Burbot in February/March 1999 at the confluence of the UDR and at the mouth of Glacier Creek. Direct spawning was not observed, but these Burbot were suspected to have spawned based on their behaviour. Two radio tagged Burbot were tracked to the upper end of the reservoir and into the UDR on February 18, 2000, where they remained until March 21, 2000. It was suspected that these fish were spawning under ice due to the timing of their migration (Spence and Neufeld 2002). The authors indicated that ‘preferred’ stream habitat conditions for Burbot in the UDR during this period included mean depth of 62.3 cm with an average velocity of 0.132 m/s (Spence and Neufeld 2002). They concluded that once the reservoir began declining and water levels receded from the UDR, Burbot abandoned the sites due to changing habitat conditions (i.e., depths decreased to 51 cm and velocities increased to 0.5 m/s). River conditions went from completely covered in ice in February to partial ice coverage in March and they reported that as the reservoir declined exposed bank sediments began to fall away into the old river channel, thus creating high turbidity that would likely impact Burbot egg and larval survival (Spence and Neufeld 2002).

Three radio tagged Burbot were located at the mouth of Glacier Creek from late January to early March 2000 (Spence and Neufeld 2002). Night spotlight surveys were conducted in late February to confirm whether these fish were spawning, but declining reservoir levels near minimum levels exposed mud flats at the outlet of Glacier Creek and viewing conditions were poor due to high turbidity and wind conditions, so no fish were observed. Suspected spawning sites near Glacier Creek was over shallow shoal areas (Spence and Neufeld 2002).

More recent studies conducted by Westslope (2009, 2010, 2011) monitored mature Burbot during the suspected spawning period in Duncan Reservoir, but direct spawning was not observed. They indicated that Burbot moved into suspected spawning areas from February 15 to March 15. In total, 16 of 28 adult Burbot tagged with Combined Acoustic Radio Transmitters (CART) were detected in or adjacent to the historic UDR/Duncan Reservoir confluence area and seasonally inundated UDR from mid-February to mid-March (Westslope 2011). Nine of these 16 tagged Burbot were considered to display spawning behaviour (i.e., movement of mature fish into shallow water <10 m depth in February/March), whereas 7 individuals remained at the ‘drop-off area’ between 10 to 30 m depth. Four of the 9 tagged Burbot suspected to have spawned were observed to return to the UDR confluence area during two of the three spawning periods studied (Westslope 2011). During these studies, a few tagged Burbot were observed in deep water reservoir habitats near areas identified as potential shoal spawning areas (e.g., Griz Creek confluence and small tributaries near Gallop Point) during the spawning period, but these fish did not migrate into shallow water or demonstrate spawning movement behaviour (Westslope 2010, 2011). Only one tagged Burbot moved into the Glacier Creek confluence area in 2010, but was subsequently confirmed as a mortality (Westslope 2010, 2011).

In the UDR (Rkm 30 to Rkm 44), suspected spawners were located in pool habitat adjacent to gravel bars (Westslope 2010). Habitats in this area included deep pools (3 to 4 m depth, 0.26 m/s velocity) with silt and fine sand substrates as well as riffles (0.50 to 1.17 m/s velocity). Westslope (2010) indicated that there was an abundance of large woody debris and gravel bars, braiding and side channel habitats to provide velocity refuge. Water temperatures were between 1.5°C and 4.7°C and based on published estimates of incubation requirements (Taylor and McPhail 2000) these temperatures would result in a 29 to 49 day incubation period for Duncan Reservoir Burbot (Westslope 2011).

Laboratory studies were conducted by Jensen et al. (2007) on mature Burbot collected from Duncan Reservoir. They observed live or developing embryos ranged between 0.7 and 1.1 mm in diameter from captive spawners. The spawning period for captive Burbot was 34 days (February 24 to March 28, 2004) the first year and 14 days (March 9-23, 2005) the second year. Fecundity was not estimated due to the difficulty of removing all eggs from females.

### 4.3 Juvenile Habitats

Information on habitat use for juvenile Burbot is sparse, but in general they have been observed to use shallow littoral areas containing cover such as rocks, weeds, debris and cut banks during the day (McPhail 1997, McPhail and Paragamian 2000). Cover may provide refuge from predators and higher velocities (Dixon and Vokoun 2009). Studies indicate that age-0 Burbot may shelter under stones and debris in shallow bays and along rocky shores of lakes during the day, but they are out foraging at night (McPhail and Paragamian 2000). In rivers and streams, age-0 Burbot also shelter in weed beds, under rocks, debris and cutbanks during the day (McPhail and Paragamian 2000). Tributary habitat for Burbot fingerlings (2 to 4 cm in length) was characterized by a high abundance of vegetation and low or zero flow velocity and were associated with silt substrates (Dillen et al. 2007). In the lab, small Burbot (10 to 20 cm TL) were observed to have a temperature preferendum of 11.4°C (Hofmann and Fischer 2002).

Although specific habitat use was not always measured, Spence (1999) reported that juveniles at the north end and east shore of Kootenay Lake were observed in cobble and boulder substrates, silt substrates with woody debris and at depths of approximately 30 cm. Similarly, Neufeld and Spence (2004) observed juveniles at the north end of Kootenay Lake in cobble/boulder substrates, silt substrates with woody debris, but at depths between 1.5 and 2.0 m. Few juveniles have been observed in the LDR below Duncan Dam in cobble/boulder substrates at 1.8 m depth (AMEC 2005).

Juvenile Burbot have not been observed in the Duncan Reservoir to date. The original terms of reference for this Water License Requirements study program (DDMMON-11) intended to correlate recruitment success with operations by assessing juvenile densities annually. Assessments using a wide variety of techniques such as day and night-time electrofishing, pit-lamping, and trapping at depth using custom juvenile cod traps failed to capture juveniles (Westslope 2009, 2010, 2011). Based on the apparent low densities of juveniles, the terms of reference were refined to focus on adult spawning conditions only.

### 4.4 Effects of Winter Flow Regulation on Burbot

#### 4.4.1 General

Studies on the effects of flow regulation below dams and winter reservoir drawdown on Burbot are limited. In Bull Lake, Wyoming, extreme winter drawdowns of approximately 13 m exposed sand and gravel habitats used by Burbot spawners and was implicated for failed reproduction (Bergersen et al. 1993). Increased winter discharge (and hence increased velocity) below Libby Dam on the Kootenai River caused Burbot migration delays and disrupted spawning (Paragamian 2000, Paragamian et al. 2005, Paragamian and Wakkinen 2008). Paragamian (2000) indicated that disruption to Burbot spawning migrations may reduce spawning fitness, reduce stamina, affect vitellogenin synthesis, or disturb spawning synchrony.

#### 4.4.2 Duncan Reservoir

Winter flow management in Duncan Reservoir is typical of hydroelectric reservoirs with annual drawdowns to evacuate water and obtain minimum elevation levels prior to freshet (**Section 2.2**). Annual drawdown to low pool elevations within Duncan Reservoir coincides with the Burbot migration, spawning, egg incubation and larval drift period estimated to occur between early February and mid-April[1] (Neufeld and Spence 2002, Westslope 2011). Reservoir water levels were observed to decline as much as 20 m during this period (Westslope 2009, 2010, 2011). Drafting of the reservoir was thought to have caused some tagged Burbot located in the UDR to move downstream from previously occupied locations because evacuating water created higher velocities within the river channel (Spence and Neufeld 2002). Burbot migrate in an upstream direction and altered hydraulics from winter drawdown in Duncan Reservoir may create zones of high velocity flow that exceed maximum sustainable swim speeds, depending on drawdown rate and hydraulic characteristics. In addition, the banks along the historic UDR were noted to be highly erodible and composed of fine glacial sediments and dewatering caused high turbidity that was thought to potentially impact Burbot egg/larva survival although spawning was not directly observed (Spence and Neufeld 2002, Westslope 2011). The confluence of Glacier Creek was also observed to be highly turbid during this dewatering period, but investigations were inconclusive as to whether Burbot were using this area for spawning (Spence and Neufeld 2002, Westslope 2011). Staphanian et al. (2010) indicated that lower population densities found in Duncan Reservoir may be associated with its drawdown regime, but further explanation was not provided.

## 5 OPTIMIZING BURBOT SPAWNING SUCCESS IN DUNCAN RESERVOIR

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 includes the evaluation of suitable spawning/incubation habitats and estimation of the area that is available

[1] Migration/Spawning: Early February to mid-March; Incubation/Larval Drift: Early March to mid-April.

during the migration through incubation/larval drift period. Based on the literature review, the following section describes habitat conditions that may be useful to optimize Burbot spawning success (migration through larval drift) in terms of variations in water levels and associated habitats available, while determining potential adverse conditions on spawning success stemming from reservoir operations.

A summary of habitat conditions that support Burbot migration, spawning, incubation and rearing as compiled in **Section** 4 is provided in **Table 2** and conditions relevant to the Duncan Reservoir are discussed below.

## 5.1 Water Levels

As described above, successful spawning for Burbot appears to be optimized with stable water levels during the spawning and incubation period of early February to mid-April. Water levels that optimize the availability of Burbot spawning/incubation habitat will be further investigated during field studies conducted for this program.

## 5.2 Water Temperature

Reported water temperatures during spawning range from 1°C to 5°C and Burbot embryos die at temperatures >6°C (**Table 2**). 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. In the Duncan Reservoir and UDR, water temperatures have been between 1.5°C and 5°C from early January to late April 2011 (Westslope 2011; **Section 2.3**).

## 5.3 Turbidity

Habitat conditions observed in the UDR by researchers conducting Burbot telemetry studies during the spawning period have indicated that eggs/larva may be impacted by highly turbid conditions resulting from the drawdown of Duncan reservoir. Drawdown exposes and cuts through lake sediments in the UDR area as the riverine channel continually moves southward resulting in fine sediment transport and extreme turbidity (Westslope 2011). However, Westslope (2010) also reported that within the Rkm 30-44 in the UDR there is an abundance of suitable, low velocity pool habitat for Burbot to maintain position during this drawdown period. In glacial rivers in Alaska, water was observed to be highly turbid in summer, but then ran clear during the Burbot spawning period (Breeser et al. 1988). The UDR naturally experienced high turbidity due to glacial ‘flour’ during spring and summer, but in winter and early spring it was reported as ‘clear’ (Peterson and Withler 1965).

***Table 2: Summary of Burbot spawning, incubation and rearing habitat characteristics***

| Location | Habitat Use Type | Depth | Velocity | Substrate | Water Temperature | Discharge | Cover | Other | References |
|---|---|---|---|---|---|---|---|---|---|
| General | Migration/Spawning/ Incubation | 0-10 m | low | silt and sand to coarse gravel and cobble | 1-5°C | low | Ice; little overhead cover | embryos die >6°C | Taylor and McPhail 2000, McPhail 2007, McPhail and Paragamian 2008, Cott et al. 2013a |
| General - Lakes | Migration/Spawning/ Incubation | 1.5-10 m | low | sand, gravel, cobbles free of silt | 1-4°C | | | nearshore shallows, shoals | McPhail and Paragamian 2008 |
| Kootenay Lake (north end) | Migration/Spawning/ Incubation | 1.5-2.0 m | none to low | cobble, boulder | 4°C | | | near confluence of Davis Creek | Spence 1999 |
| Moyie Lake | Migration/Spawning/ Incubation | 3 m | none to low | cobble, gravel | 1-3°C | | ice | | Neufeld and Spence 2009 |
| Arrow Lakes Reservoir – Beaton Arm/Flats | Migration/Spawning/ Incubation | >20 m | none to low | sand, gravel, cobble, bedrock | | | | | Robichaud et al. 2013 |
| General - Rivers | Migration/Spawning/ Incubation | 0.29-0.82 m | | fine gravel, sand or silt | 1-4°C | declining/ low | ice | main channel, side channels behind depositional bars. Discharge increases help accessibility to reach spawning grounds. | McPhail 1997, McPhail 2007, McPhail and Paragamian 2008, Dillen et al. 2007 |
| Alaskan Rivers - glacial | Spawning/Incubation | | | | | clear | | | Breeser et al. 1988 |
| Lower Goat River | Spawning/Incubation | | | | 1-2°C | | | | Bisset and Cope 2002 |
| Unnamed Tributary in Columbia Lake | Spawning/Incubation | <1 m | low | cobble | | | | silt that turns to clean cobble substrate after spawning disturbance | Arndt and Hutchinson 2000 |
| Upper Duncan River confluence | Spawning/Incubation | 0.6 m | 0.13 m/s | Unknown due to turbidity | | | | | Spence and Neufeld 2002 |

| Location | Habitat Use Type | Depth | Velocity | Substrate | Water Temperature | Discharge | Cover | Other | References |
|---|---|---|---|---|---|---|---|---|---|
| Upper Duncan River (km 30-44) | Spawning/Incubation | 3-4 m | Pools: 0.26 m/s | silt, fine sand | 1.5-4.7°C | | large woody debris and gravel bars, braiding and side channel | pool holding | Westslope 2010 |
| Upper Duncan River (km 30-44) | Spawning/Incubation | | Riffles: 0.50-1.17 m/s | gravel, cobble | 1.5-4.7°C | | large woody debris and gravel bars, braiding and side channels | riffles | Westslope 2010 |
| General | Rearing | Shore-line habitat | 0.05-0.15 m/s | | 11°C; summer | low | shallow littoral areas containing cover such as rocks, weeds, debris and cut banks | high abundance of vegetation | McPhail and Paragamian 2000, Taylor and McPhail 2000, Jude et al. 2013, Dillen et al. 2007; Dixon and Vokoun 2009, Hofmann and Fischer 2002 |
| North end and East Shore Kootenay Lake | Rearing | 0.3 m, 1.5-2 m | none | cobble, boulder, silt | | | woody debris | | Spence 1999, Neufeld and Spence 2004, AMEC 2005 |
| Columbia Lake | Rearing | <1 m | none | rocky substrates | | | interstitial spaces in rocky substrates | | Taylor and Arndt 2013 |

### 5.4 Depth, Velocity, Substrate, Cover

The following habitat variables have been observed for Burbot migration, spawning, incubation and rearing (**Table 2**):

- Depths between >0 and 10 m;
- Low velocities <0.25 m/s;
- Spawning substrates include silt, sand, gravel, cobble, and possibly boulder and bedrock;
- Rearing substrates include cobble, boulder, and possibly silt;
- Cover and other habitat attributes during spawning includes ice, braided channels, gravel bars and sidechannels; and,
- Cover and other habitat attributes during rearing includes large woody debris, weeds, rocks, cutbanks, interstitial spaces and shoreline littoral areas.

In addition, one study probabilistically quantified that at the microhabitat scale, Burbot (including spawners and juveniles between 1 to 5 years) used channel units with low current velocities, increased depth and large substrate particles with low levels of embeddedness in small tributaries (Dixon and Vokoun 2009).

## 6 SITE SELECTION & STUDY PLANNING

### 6.1 Upper Duncan River

It is recommended that 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) be targeted for further habitat mapping. This section of river represents the suspected spawning and egg incubation area for Burbot in the Duncan Reservoir (Neufeld and Spence 2002, 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 (**Section 4.2.2**; Spence and Neufeld 2002, Westslope 2011). Telemetry studies conducted during this program from 2009-2011 indicated that only 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. Burbot may also be spawning in deeper, lake-type habitats within the reservoir, but this remains unconfirmed and these areas are less likely to be affected by reservoir drawdown. Since Burbot are potentially spawning in the UDR and this area has been observed to dramatically change during reservoir drawdown it is important to ground truth potential habitat areas that are available during the Burbot spawning/incubation period.

### 6.2 Glacier Creek

Although evidence is limited for use of the Glacier Creek mouth as a spawning area by Burbot, it is the only additional site that may be of interest for the current program. Further discussion regarding effort/budget is warranted prior to including this site during field sampling activities.

## 6.3 Field Verification & Habitat Mapping

The following is an updated description of our field verification and habitat mapping methods that were outlined in our proposal (AMEC 2014). Further discussion is required to confirm methods and coordinate timing for sampling target elevations.

### 6.3.1 Sample Timing

Surveys will be completed in mid- to late-March, during the period when the Duncan Reservoir is being drafted to reach low pool (reservoir elevation is anticipated to be between approximately 548.5 and 552.0 m), and the 7.4 km section of the Upper Duncan River is ice free. This corresponds with peak spawn timing for Burbot in Duncan Reservoir based on background information (**Section 4.2.2**). Surveys will be coordinated with BC Hydro Duncan Dam operations in order to map the water's edge during key elevations (see below).

### 6.3.2 Ground Truthing

Sites will be accessed by boat from the Howser boat launch during the main survey period (mid-March). Habitat mapping will focus on the 7.4 km Burbot spawning area (**Section 6.1**) to verify/ground truth actual field conditions and likelihood for Burbot spawning based on previous Burbot experience and conditions likely required to optimize Burbot spawning success (**Section** 5).

It is important that surveys be coordinated with reservoir drawdown over the scheduled three-day field sampling period so that the water's edge can be mapped each day of the survey to provide the "real" conditions observed. Mapping the water's edge will be conducted by boat (and GPS) as much as possible; however ground surveys may need to be deployed in shallow areas. The boat will drive slowly along the water's edge using the boat sounder GPS unit with a calibrated offset to the shoreline (accuracy ±5-10 m). Ground surveys will use hand held Garmin (62sc) GPS track log and point functions. Settings for GPS units will follow BC Hydro GPS Data Capture Standards.

Habitat mapping for Burbot spawning areas will consist of ground truthing habitat areas via boat and ground surveys as per water's edge mapping. However, mapping will focus on delineating area polygons that fall within Burbot spawning criteria (**Section 5**). UTM points will be taken at upstream and downstream locations as well as left/right bank locations for back up points in the event that track logs do not take enough points due to coverage conditions. Length and width will also be measured for each delineated polygon to calculate area as an error check for digital calculations. If GPS coverage is spotty or non-existent due to time of day and satellite position, distance to the nearest UTM point will be measured as well as a compass reading to determine the location of the habitat area. Hand drawn areas may also be used if locations can be verified in the field. Surveys will be conducted by wading within the habitat areas identified as areas most suitable for Burbot spawning. However, field crews will be equipped with one set of snorkel gear in case identified areas are beyond wadeable depths or unsuitable for wading (see below).

Habitat attributes for each habitat area/polygon will be measured in the field. All suitable habitat areas will be identified by dominant hydraulic type (riffle, run, pool) and cover (type and qualitative amount). Substrates will be defined using BC standard substrate sizes (RIC 2001) and those used during previous substrate mapping: 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). Water depth and mean column water velocity will be measured throughout each delineated habitat area to obtain habitat attributes for each polygon (RIC 2001). Average velocity and depth will be 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 (to give indication of turbidity) will also be taken within each habitat area identified. Biological judgment based on the literature review and previous Burbot monitoring experience will also be used to assess Burbot habitat quality. A hand held Swoffer velocity meter (Swoffer 2100; within 1% accuracy) will be used to take depth/velocity, but in deeper areas (>1.5 m), depths will be measured with the boat sounder and velocity will be estimated by experienced observers. Judgement will be used to determine how inundation/drawdown will change depth/velocity in the habitat areas. In addition, where it is too deep or viewing conditions prevent substrate classification, a viewing tube or snorkel gear may be employed if substrates cannot be viewed from the shore or boat due to depth and or water clarity conditions. However, Burbot substrate conditions identified during the literature review are very broad and range from silt through to bedrock, so this parameter does not seem to be as critical to capture during the field program. Snorkelling or a viewing tube may also be used if direct observations of Burbot are made within these habitat sites. A GPS waypoint, habitat use information (depth, velocity, and substrate), photos and notes (number of fish, tags observed, behavior, etc.) will be collected when any direct observations are made. All field measurements will be recorded digitally (GPS units) and on field forms and maps developed specifically for this program (AMEC 2014; **Appendix C**).

# 7 DATA INTEGRATION AND PERFORMANCE MEASURE DEVELOPMENT

Based on the criteria associated with each habitat polygon measured during the proposed field survey, spawning/incubation area can be linked to the observed reservoir elevation and reservoir influences on the suitability of spawning/incubation habitat will be noted. The main performance measures will include spawning/incubation habitat area ($m^2$) and average water temperature for the UDR. These performance measures can be used to investigate different operational scenarios. 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.

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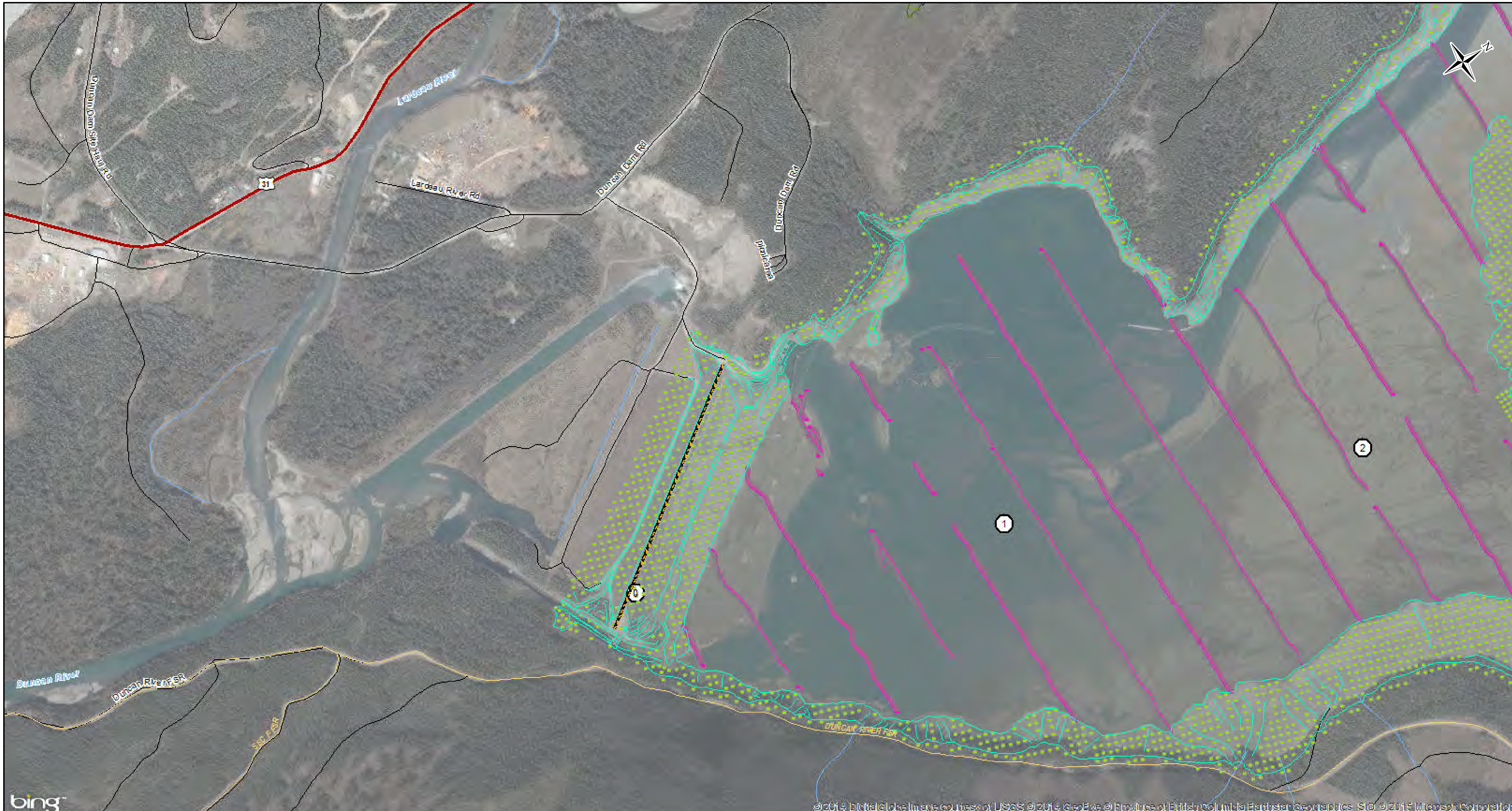
## APPENDIX A

## Duncan Reservoir Base Mapping




- Populated Place
- Kilometer Marker
- Streams
- Highway
- Forest Service Road
- Existing Road
- Wetland
- Duncan Dam
- Upper Duncan River Confluence at 547m

**Substrate**

- Fines (< 2mm)
- Gravel (fine to med) 2-16mm
- Gravel (coarse) 16-64mm
- Cobble (small) 64-128mm
- Cobble (large) 128-256mm
- Boulder (> 256mm)

Substrate data was collected by NHC in 2010.
Data was supplied by BC Hydro.

**Shoreline and Bathymetry Data**

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- BC Hydro Mass Points
- NHC Bathymetric Survey

BC Hydro Mass Point and Breakline data collected from aerial imagery taken May 3, 1993.
NHC Bathymetry Survey Mass Points collected 2009.

0 50 100 200 300
Meters
Scale: 1:10,000

**Reference:**
Geogratis/Geobase
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(http://data.gc.ca/eng/about-datagcca)
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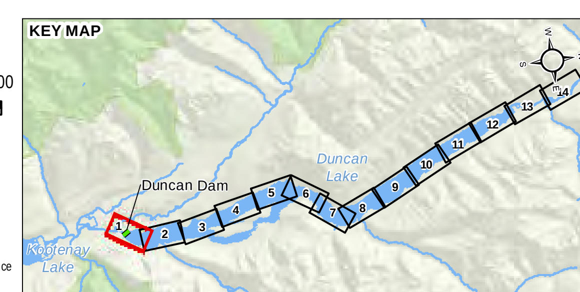
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 1 of 14

| DATE: | ANALYST: | QA/QC: | Figure |
|---|---|---|---|
| January, 2015 | MY | KA | |

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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Last updated by willem.van-riet

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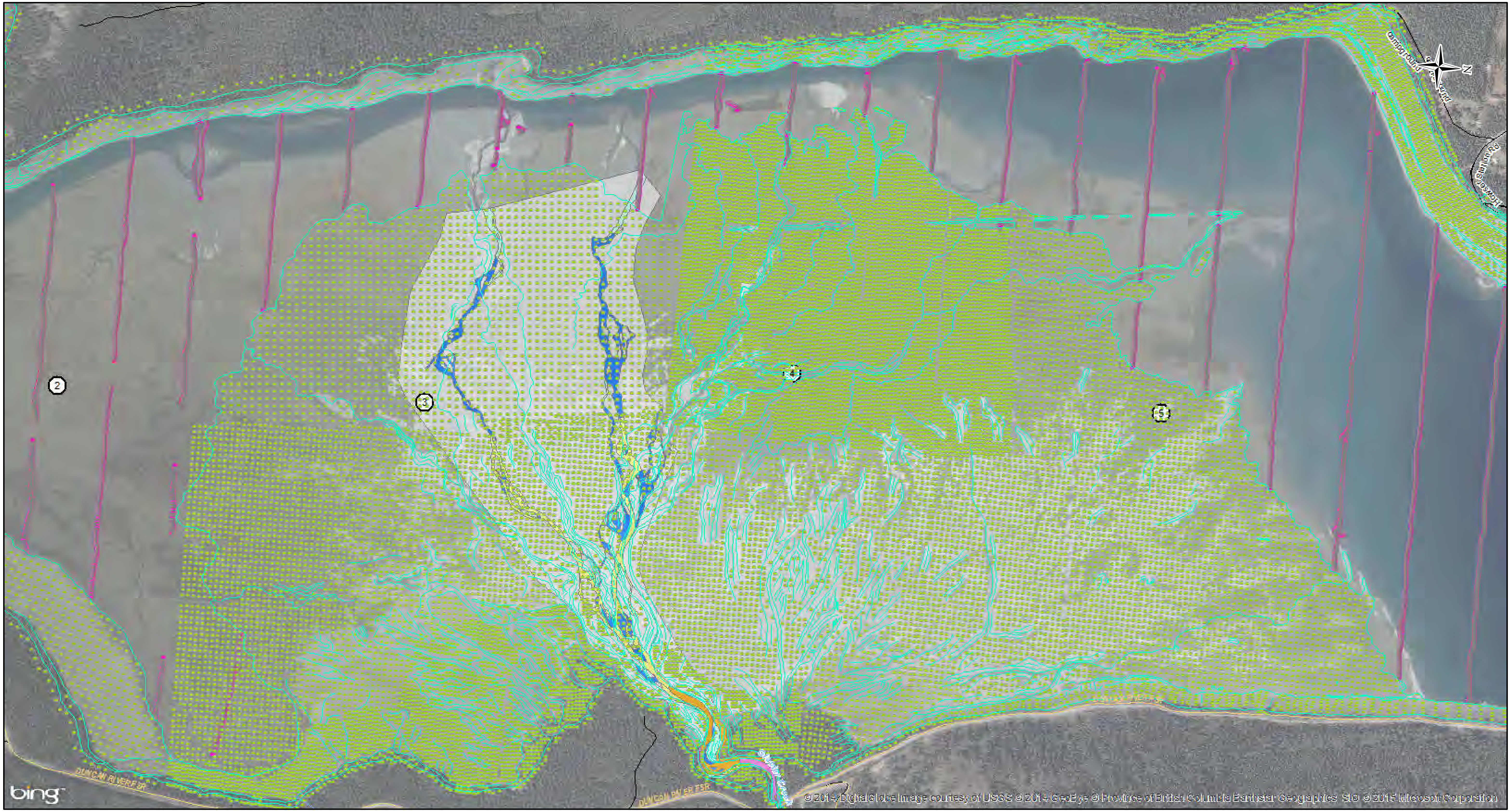


- Populated Place
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- Streams
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Meters
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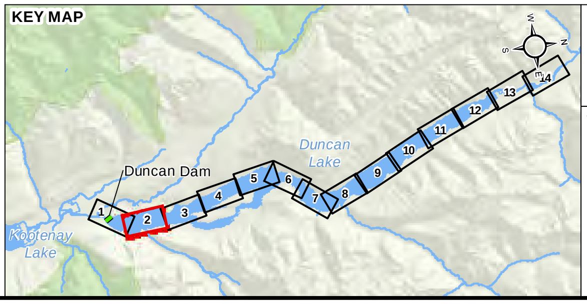


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| | GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4 |
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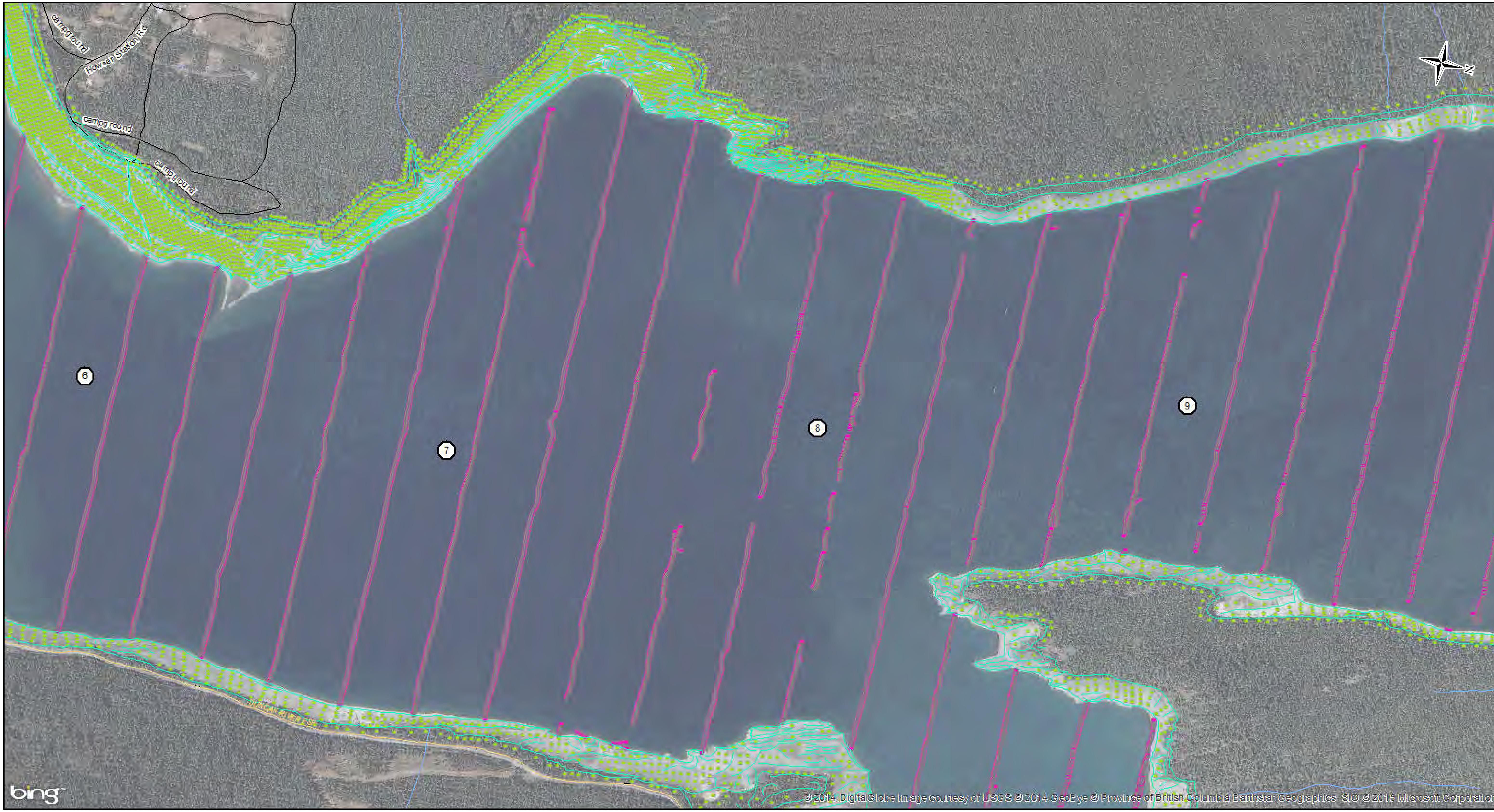


- Populated Place
- Kilometer Marker
- Streams
- Highway
- Forest Service Road
- Existing Road
- Wetland
- Duncan Dam
- Upper Duncan River Confluence at 547m

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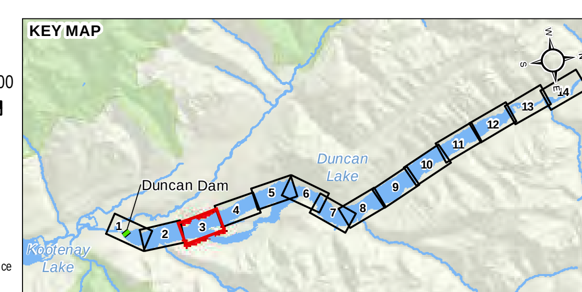
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 3 of 14

| DATE: | ANALYST: | QA/QC: | Figure |
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| January, 2015 | MY | KA | |

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JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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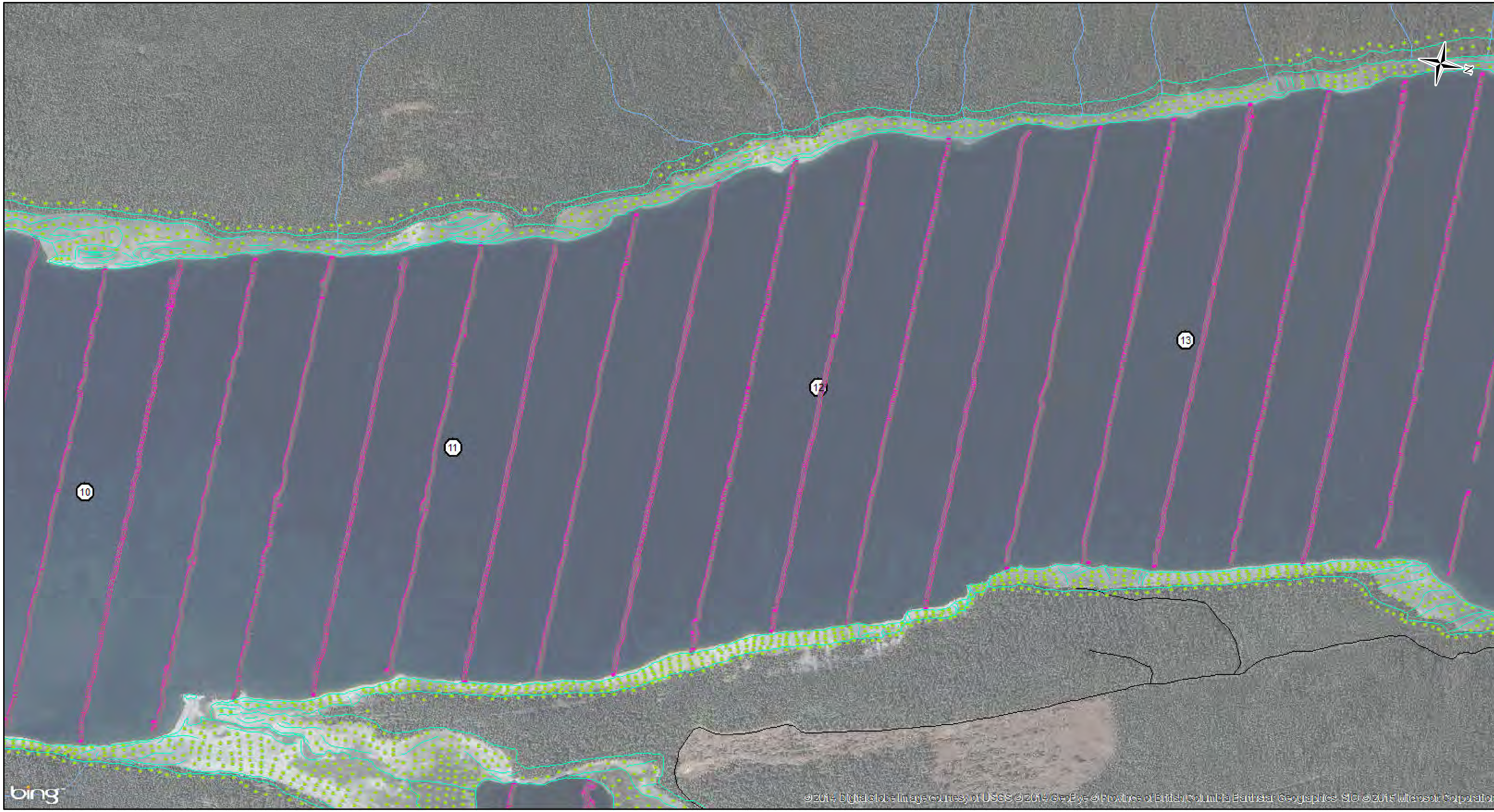


## Legend

- Populated Place
- Kilometer Marker
- Streams
- Highway
- Forest Service Road
- Existing Road
- Wetland
- Duncan Dam
- Upper Duncan River Confluence at 547m

**Substrate**

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Meters
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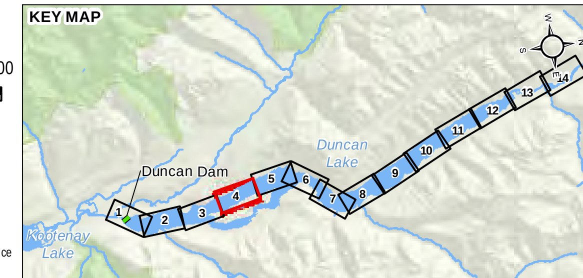
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 4 of 14

| DATE: | ANALYST: | QA/QC: | Figure |
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| January, 2015 | MY | KA | |

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- Populated Place
- Kilometer Marker
- Streams
- Highway
- Forest Service Road
- Existing Road
- Wetland
- Duncan Dam
- Upper Duncan River Confluence at 547m

**Substrate**
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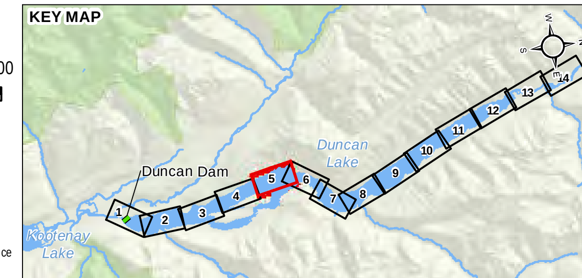
KEY MAP




CLIENT:

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE:
# Duncan Reservoir Base Map
## Map 5 of 14

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COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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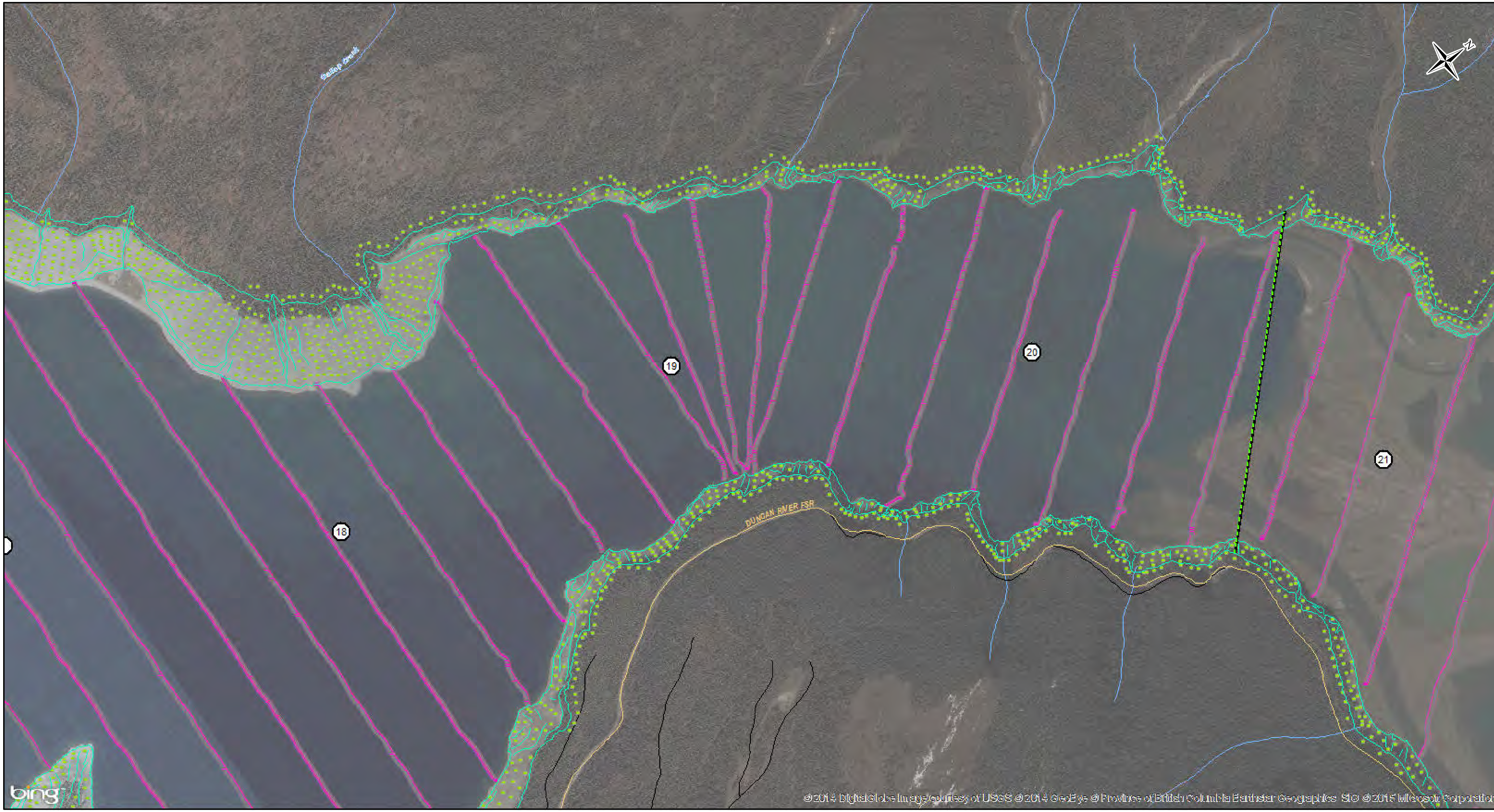


- Populated Place
- Kilometer Marker
- Streams
- Highway
- Forest Service Road
- Existing Road
- Wetland
- Duncan Dam
- Upper Duncan River Confluence at 547m

**Substrate**

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Meters
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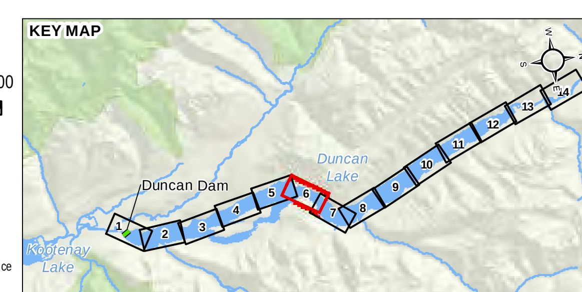
KEY MAP




CLIENT: BC hydro

TITLE: Duncan Reservoir Base Map
Map 6 of 14

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

DATE: January, 2015 | ANALYST: MY | QA/QC: KA | **Figure**

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

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COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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**Populated Place**
- Populated Place
- Kilometer Marker
- Streams
- Highway
- Forest Service Road
- Existing Road
- Wetland
- Duncan Dam
- Upper Duncan River Confluence at 547m

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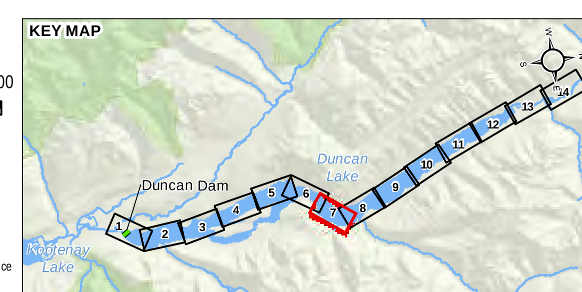
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 7 of 14

| DATE: | ANALYST: | QA/QC: | Figure |
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| January, 2015 | MY | KA | |

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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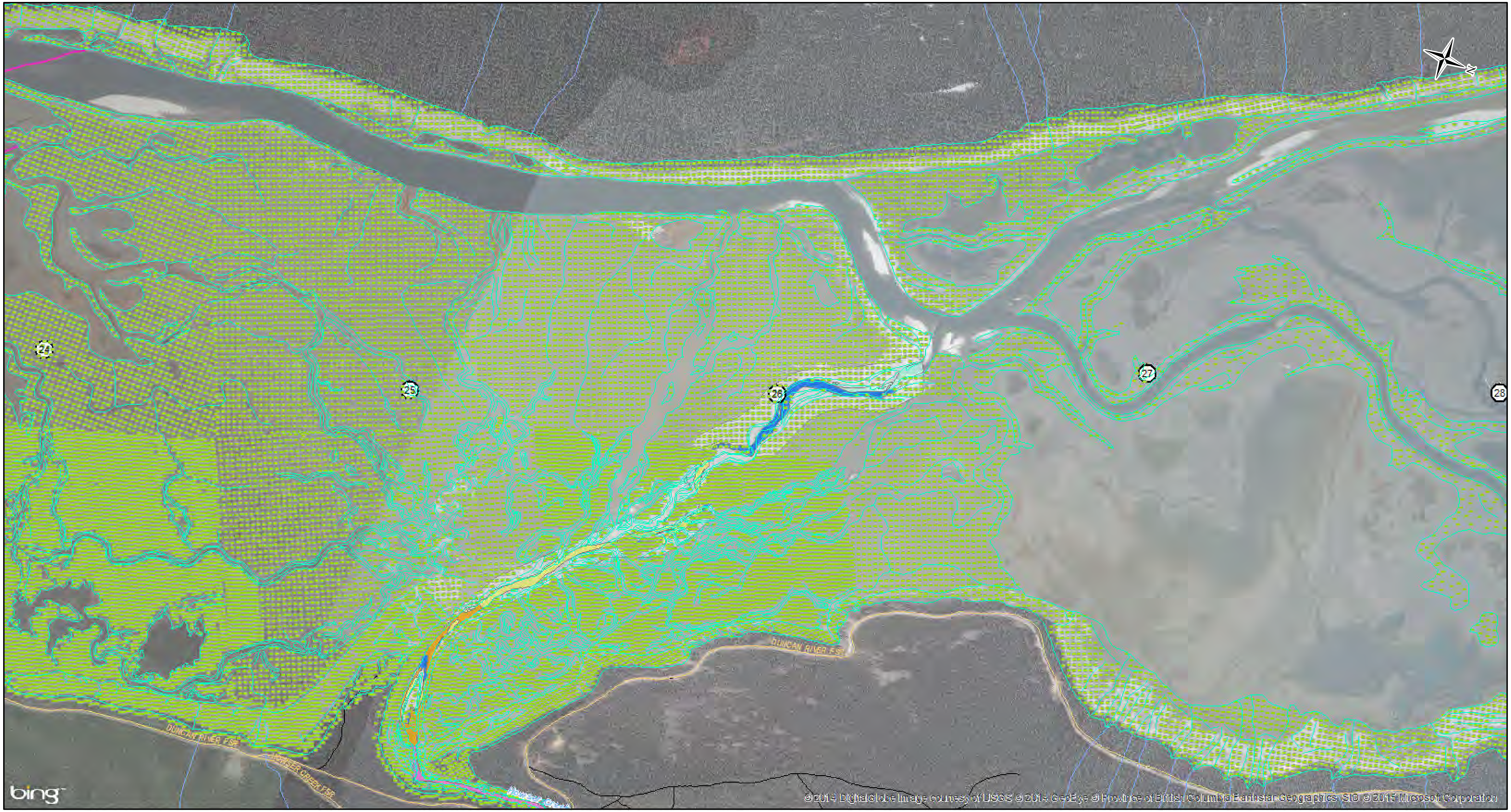


- Populated Place
- Kilometer Marker
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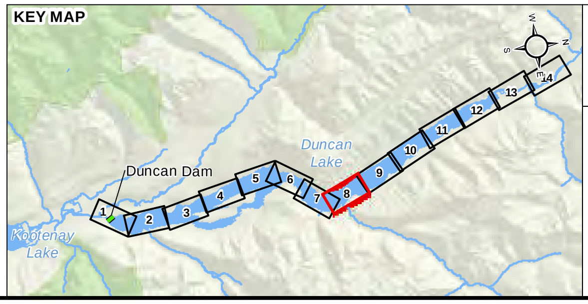
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE:

# Duncan Reservoir Base Map
## Map 8 of 14

| DATE: | ANALYST: | QA/QC: | Figure |
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| January, 2015 | MY | KA | |

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

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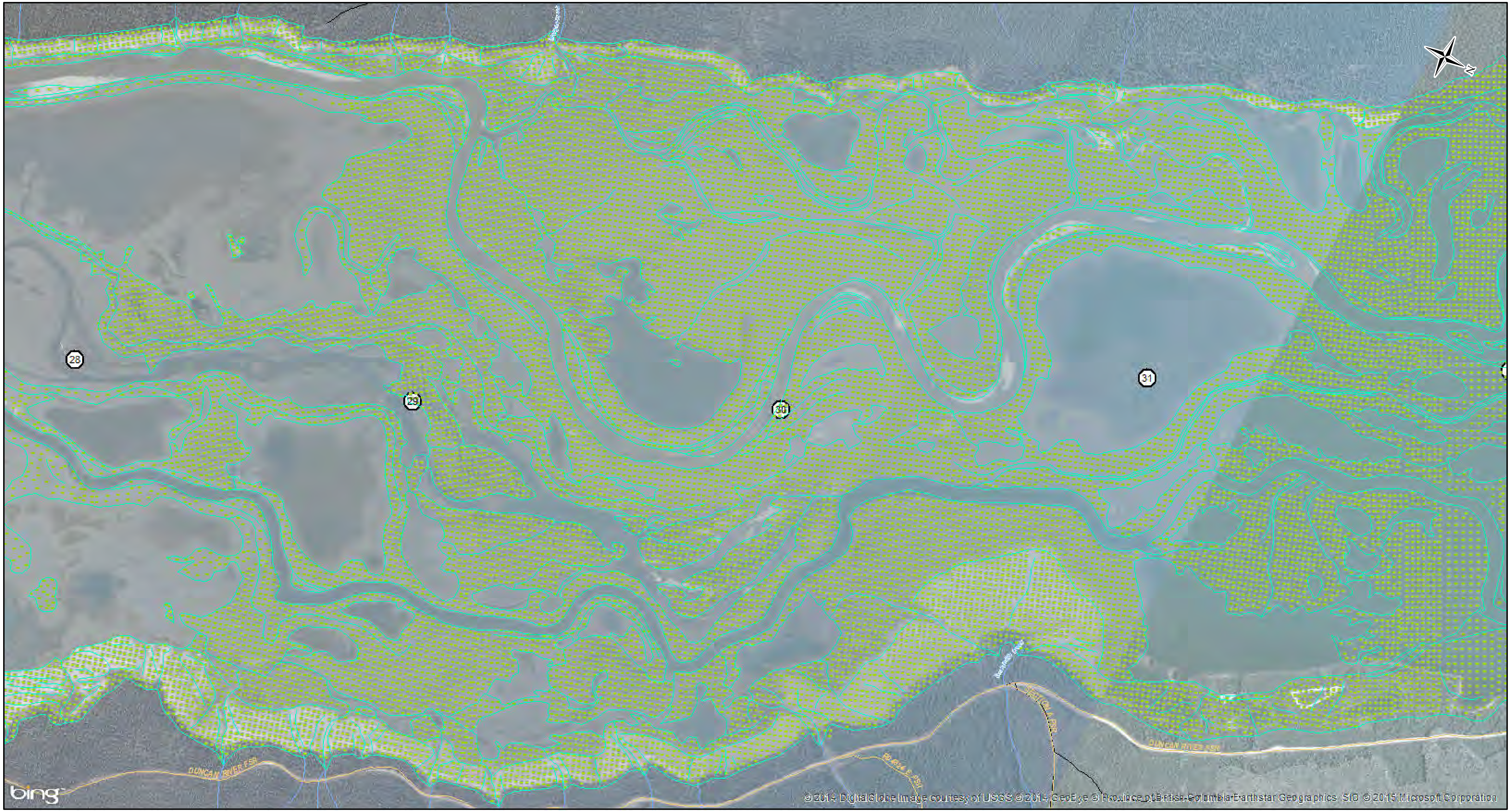


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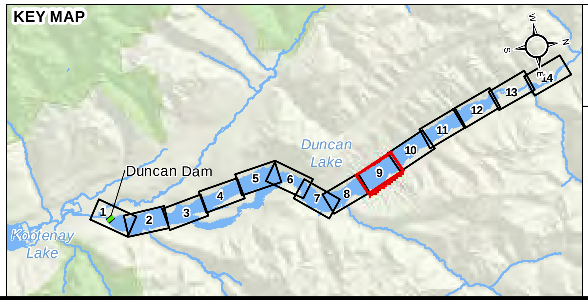
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map Map 9 of 14

| DATE: | ANALYST: | QA/QC: | Figure |
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| January, 2015 | MY | KA | |

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

JOB No: VE52477

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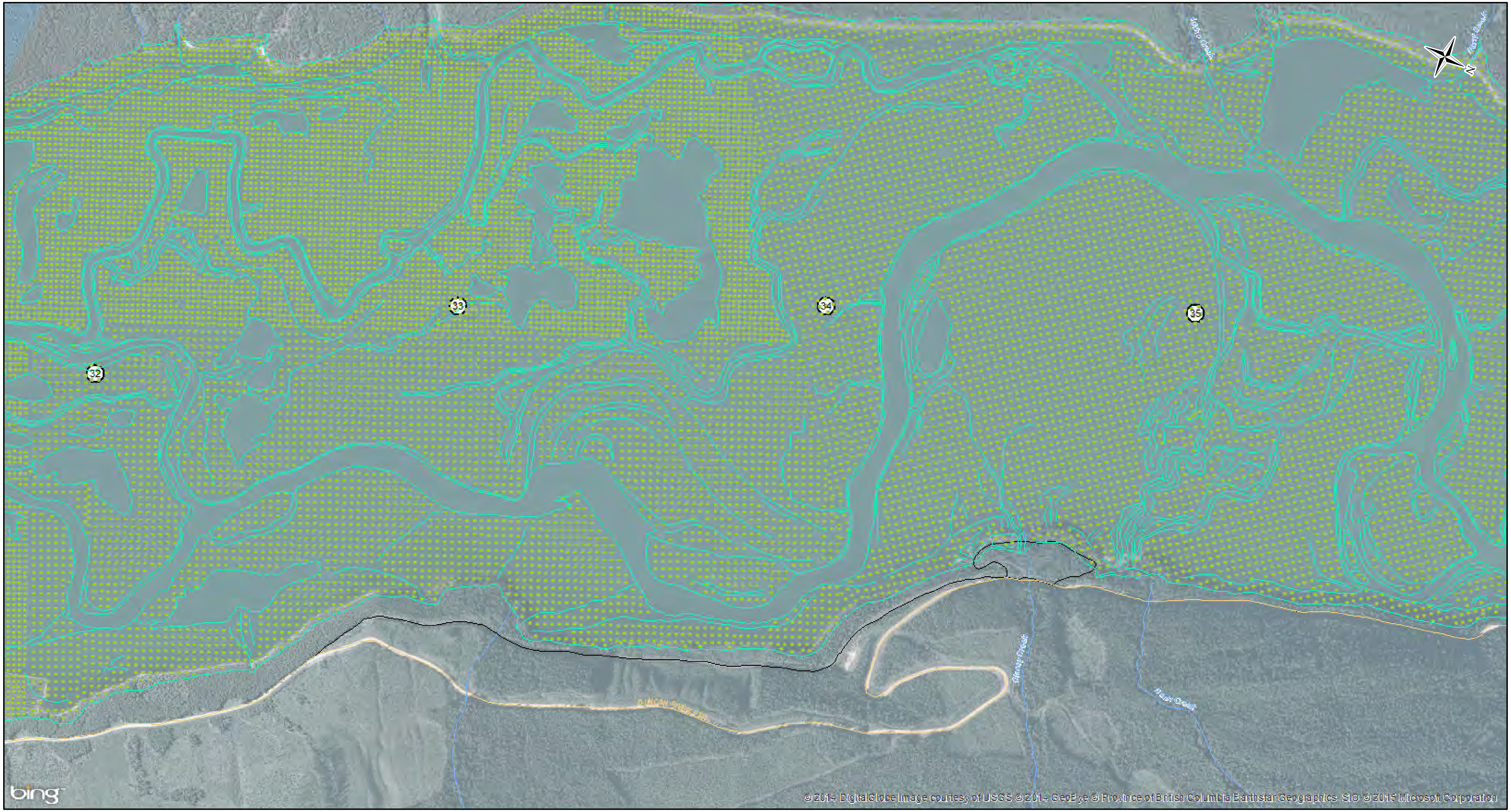


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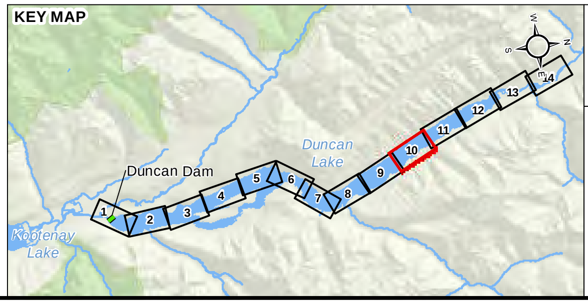
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 10 of 14

| DATE: | ANALYST: | QA/QC: | Figure |
|---|---|---|---|
| January, 2015 | MY | KA | |

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

amec

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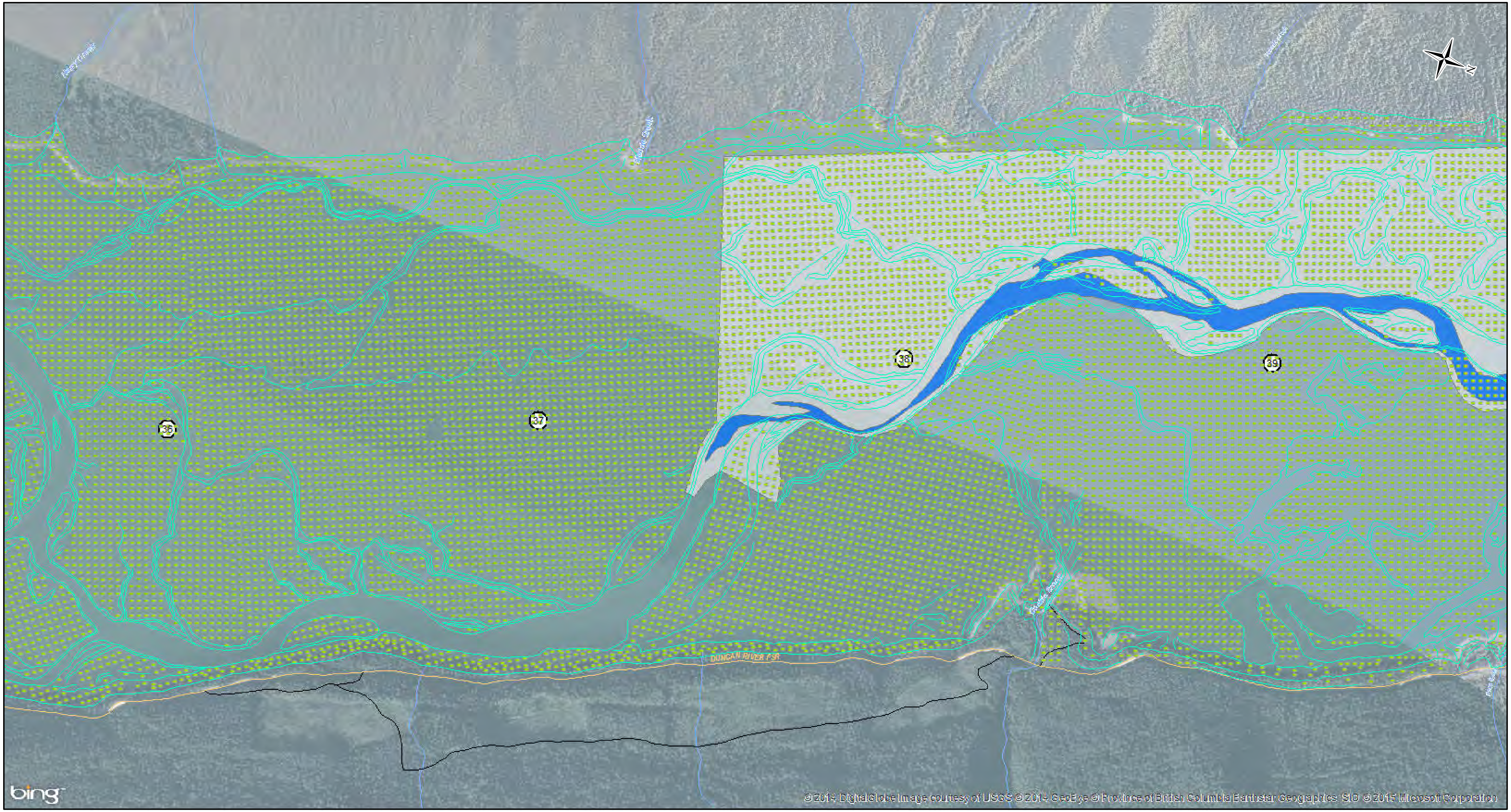
Last updated by willem.van-riet




- Populated Place
- Kilometer Marker
- Streams
- Highway
- Forest Service Road
- Existing Road
- Wetland
- Duncan Dam
- Upper Duncan River Confluence at 547m

**Substrate**

- Fines (< 2mm)
- Gravel (fine to med) 2-16mm
- Gravel (coarse) 16-64mm
- Cobble (small) 64-128mm
- Cobble (large) 128-256mm
- Boulder (> 256mm)

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**Shoreline and Bathymetry Data**

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0 50 100 200 300
Meters
Scale: 1:10,000

**Reference:**

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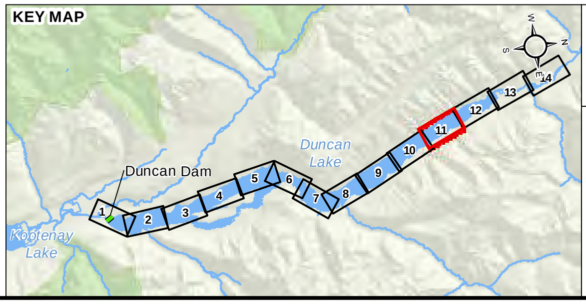
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 11 of 14

DATE: January, 2015
ANALYST: MY
QA/QC: KA
Figure

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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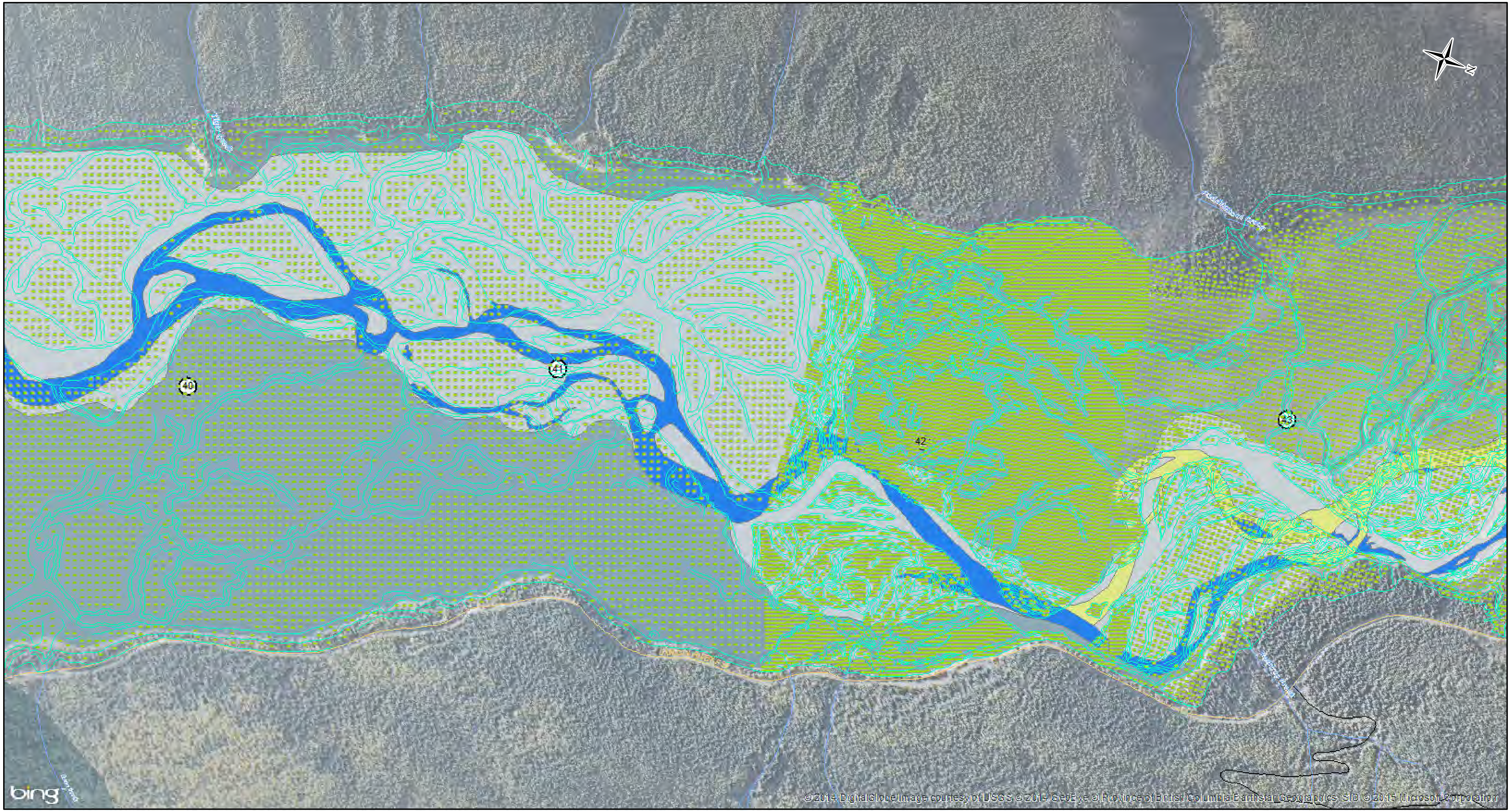


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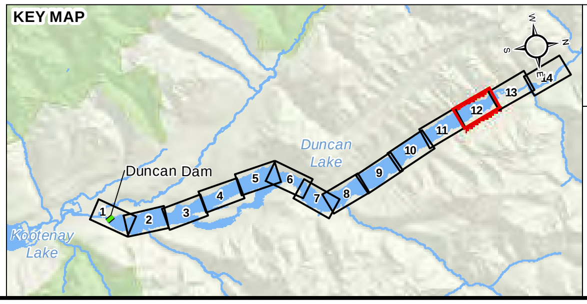


CLIENT: BChydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 12 of 14

DATE: January, 2015 | ANALYST: MY | QA/QC: KA | Figure

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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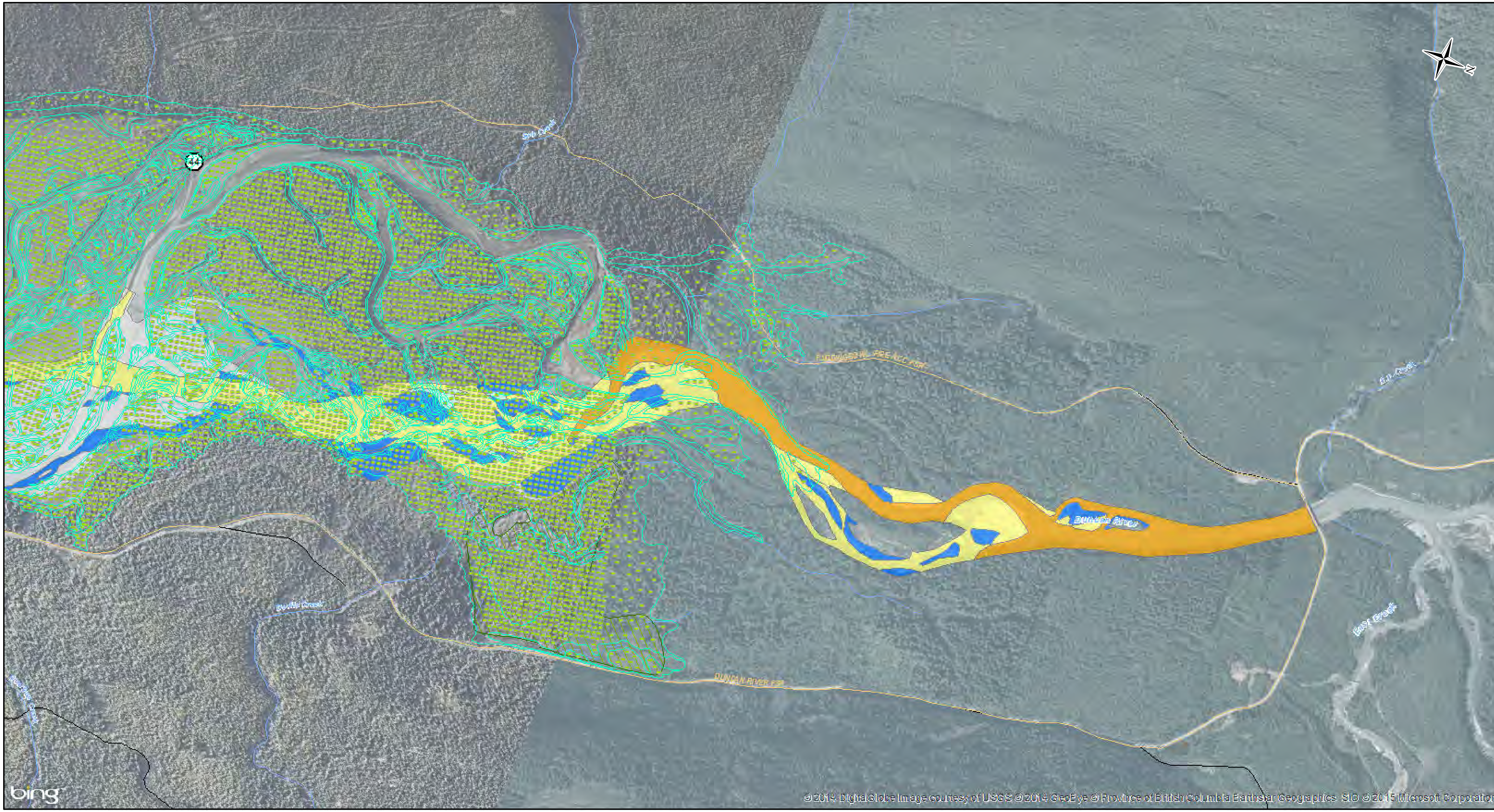


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- Kilometer Marker
- Streams
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0 50 100 200 300
Meters
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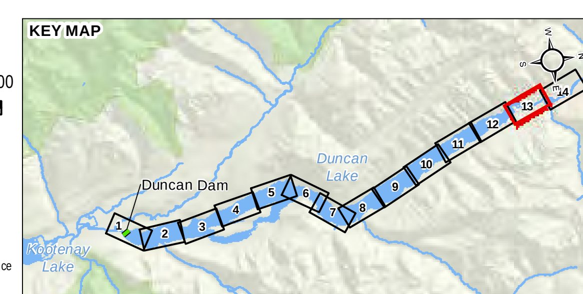


CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 13 of 14

| DATE: | ANALYST: | QA/QC: | |
|---|---|---|---|
| January, 2015 | MY | KA | Figure |

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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0 50 100 200 300
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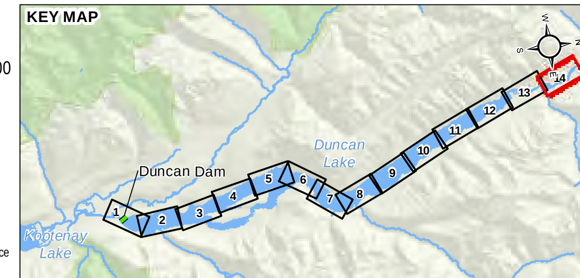
KEY MAP




CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Duncan Reservoir Base Map
Map 14 of 14

DATE: January, 2015
ANALYST: MY
QA/QC: KA
**Figure**

GIS FILE: 02-01-001_DuncanRes_BurbotMonit_mapbook_v4

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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Last updated by willem.van-riet

## APPENDIX B

## DEM Data Description

**Appendix B**

DUNCAN RESERVOIR
DEM Data for Client

Prepared for: BC Hydro
Prepared by: Northwest Hydraulic Consultants
Prepared on: 17-Jun-2010

DESCRIPTION OF DATA:

ArcGIS 9.3.1 SP1 software used for preparation of DEM.

Input Files:

BC Hydro DEM data, extracted from a DGN file supplied by BC Hydro
- bchdem_pts1.shp = points
- bchdem_lns1.shp = breaklines

NHC bathymetric survey
- bathySurvey2.shp = NHC bathymetric survey points imported directly from text files supplied by survey staff
- bathySurvey2_mod1.shp = points from bathySurvey2.shp, with points that overlap BCH data removed
  - manually filtered data in this file to remove as many outliers as possible
- bathySurvey_ctrs2.shp = manually interpreted contours based on visual examination of NHC bathymetric points
  - created this as an aid to building DEM

- dem_extent4.shp = extent polygon used for building DEM

Output File:

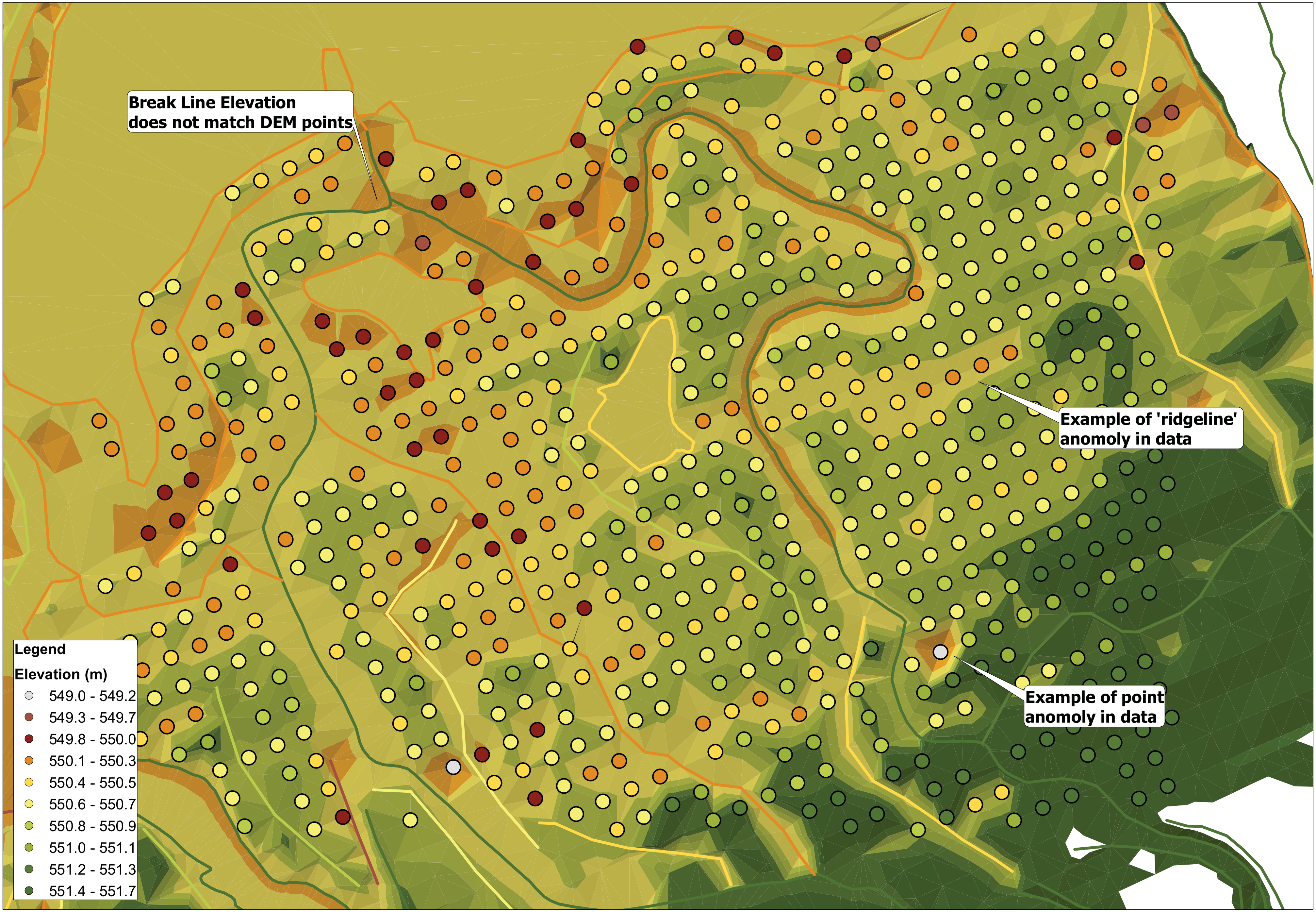
gcomb2c = ESRI Grid file, 200 metre DEM
  - coordinate system: UTM Zone 11 NAD 83 metres
  - vertical datum: CGVD28
  - includes entire reservoir

Overview of methodology used to create this file:
- input: BC Hydro DEM data (mass points and breaklines)
  - Compiled from aerial photography taken May 3, 1993.
  - Approx elevation of reservoir 549 m. Scale of photo 1:10,000.
  - Horizontal and vertical accuracy plus/minus 0.30 metres.
  - Average point spacing approx 20 metres.
  - Covers entire reservoir.
- input: NHC 2009 bathymetric survey (mass points)
  - Data collected August 2009.
  - Vertical datum: CGVD28 (canadian geodetic vertical datum).
  - GPS geoid model: HT2.0 ( Height Transformation version 2.0 (published by Geodetic Survey of Canada))

- Survey transects approx 200 metres spacing.
  - Covers southern portion of reservoir to Howser Creek.
- processing of NHC bathymetric data:
  - removed data that overlaps with BC Hydro data coverage
  - removed obvious outliers
  - manually added "contours"
- built TIN from input data
- built 10 metre Grid from TIN
  - each Grid cell has value of TIN at centre of cell
- built 200 metre Grid from 10 metre Grid
  - each output Grid cell value is mean of input cells (excluding NoData cells)

For more information, please contact:
Sarah North, GISP
GIS Analyst
Northwest Hydraulic Consultants
30 Gostick Place, North Vancouver, BC, V7M 3G3
tel. 604-980-6011 x212
email. snorth@nhc-van.com

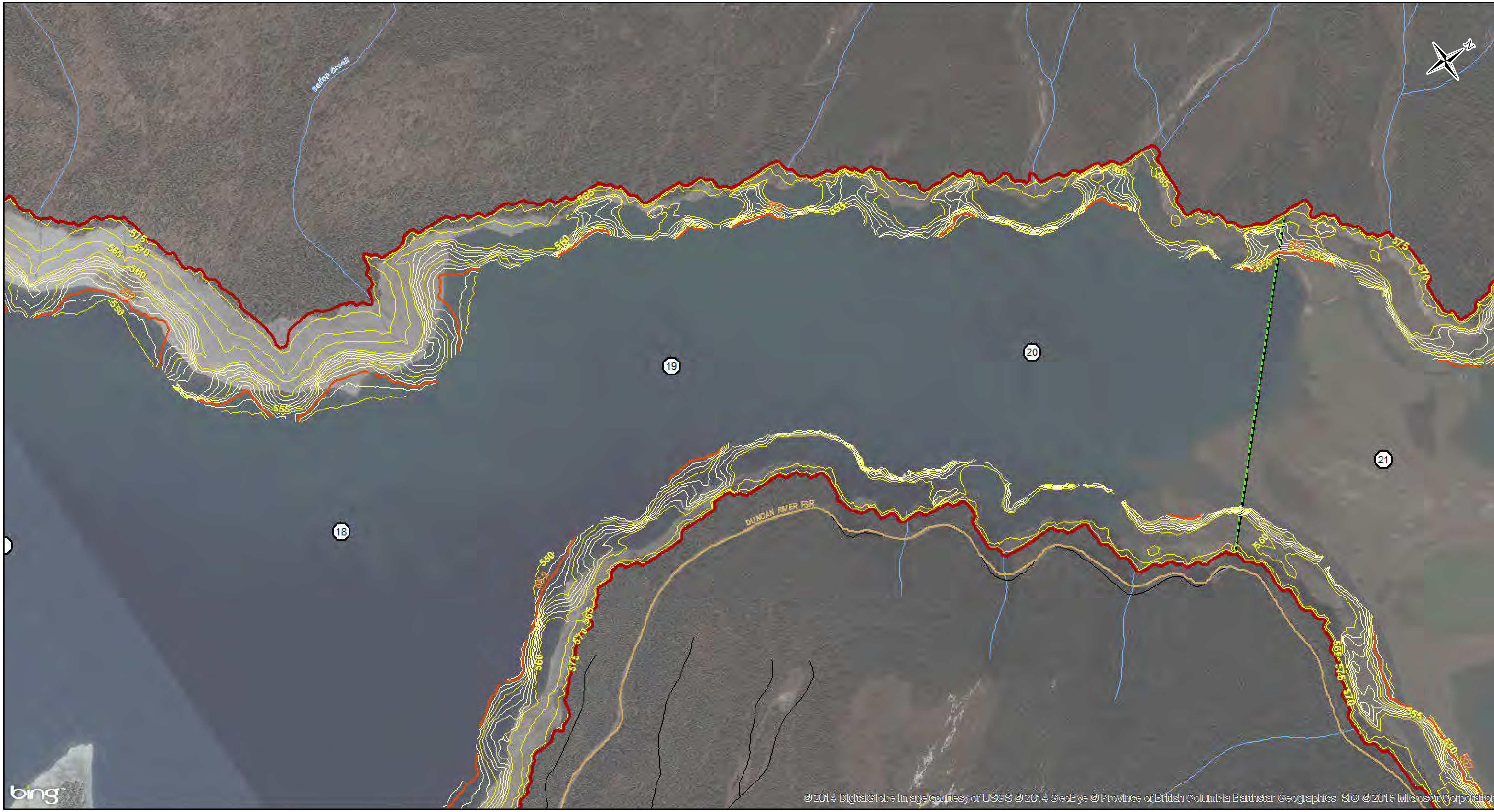
END.



Break Line Elevation
does not match DEM points
Example of 'ridgeline'
anomoly in data
Example of point
anomoly in data
Legend
Elevation (m)
549.0 - 549.2
549.3 - 549.7
549.8 - 550.0
550.1 - 550.3
550.4 - 550.5
550.6 - 550.7
550.8 - 550.9
551.0 - 551.1
551.2 - 551.3
551.4 - 551.7

## APPENDIX C

## Upper Duncan River Area of Interest




**Legend**

- Populated Place
- Kilometer Marker
- Streams
- Forest Service Road
- Existing Road
- Duncan Dam
- Upper Duncan River Confluence at 547m

**Substrate**

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**Bathymetry Contours**

- 1 m Interval
- 5 m Interval
- 552m Elevation
- 576.7m Elevation - Full Pool Extent

0 50 100 200 300
Meters
Scale: 1:10,000

**Reference:**
Geogratis/Geobase
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(http://data.gc.ca/eng/about-datagcca)
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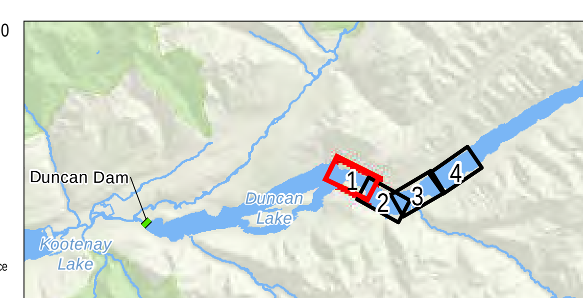


CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Upper Duncan River and Duncan Reservoir Interface Area Map 1 of 4

| DATE: | ANALYST: | QA/QC: | Figure |
|---|---|---|---|
| January, 2015 | MY | KA | |

GIS FILE: 02-01-003_DuncanRes_Bathy_km20to28_v2

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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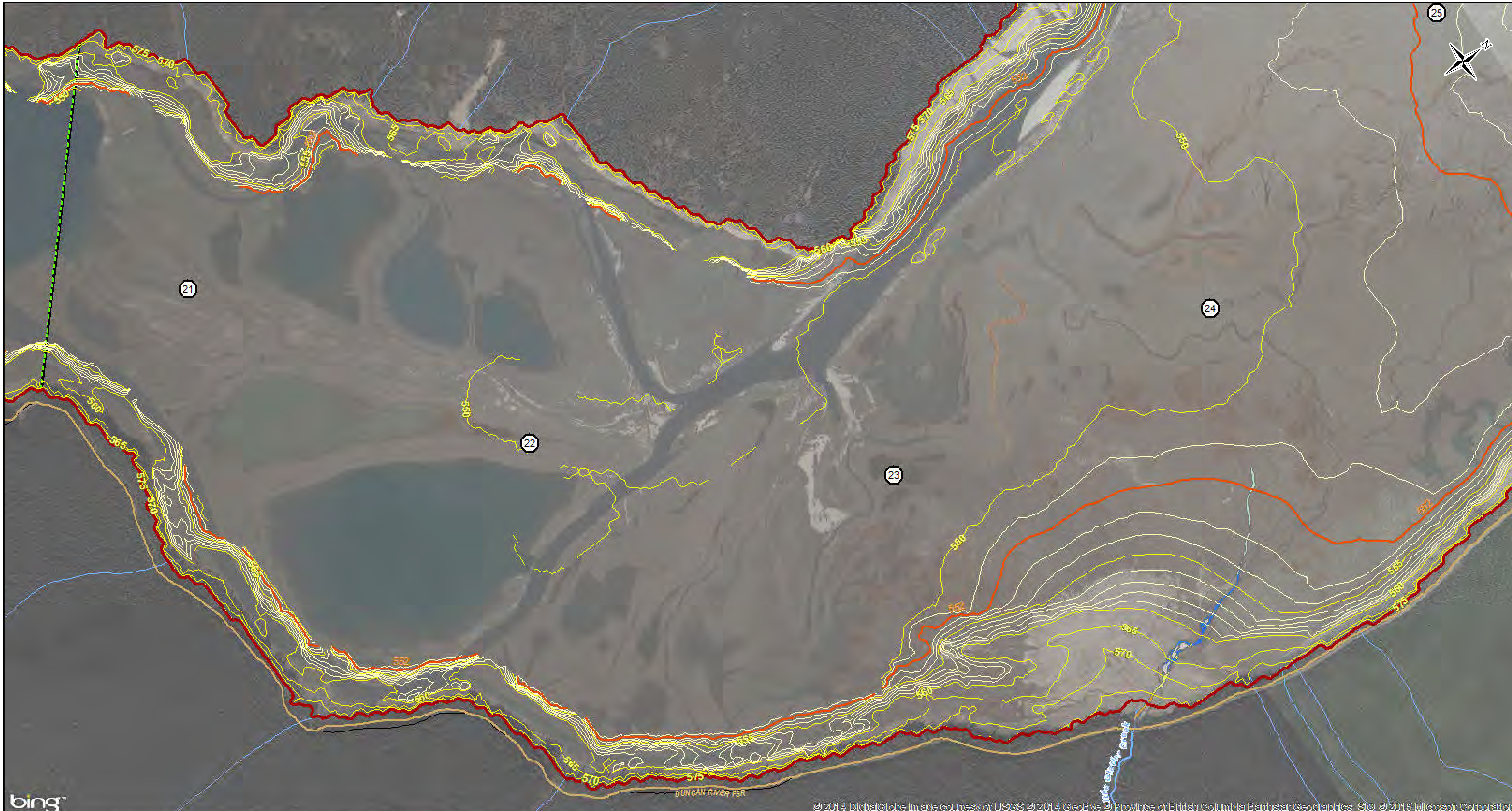


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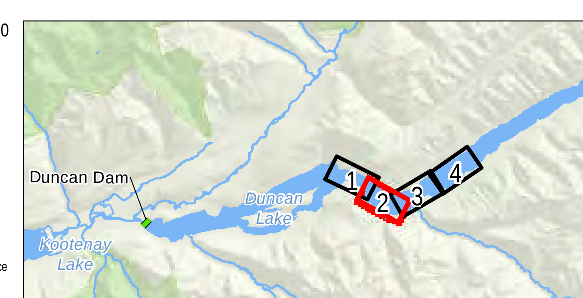


CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Upper Duncan River and Duncan Reservoir Interface Area Map 2 of 4

| DATE: | ANALYST: | QA/QC: | Figure |
|---|---|---|---|
| January, 2015 | MY | KA | |

GIS FILE: 02-01-003_DuncanRes_Bathy_km20to28_v2

JOB No: VE52477

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

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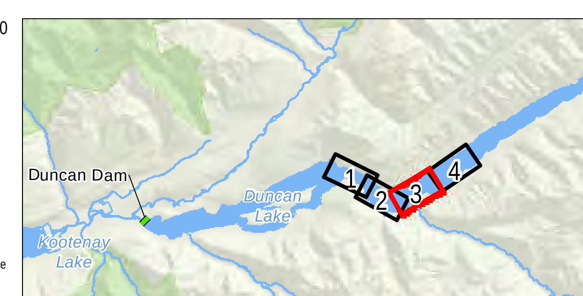


CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Upper Duncan River and Duncan Reservoir Interface Area Map 3 of 4

| DATE: | ANALYST: | QA/QC: | Figure |
|---|---|---|---|
| January, 2015 | MY | KA | |

GIS FILE: 02-01-003_DuncanRes_Bathy_km20to28_v2

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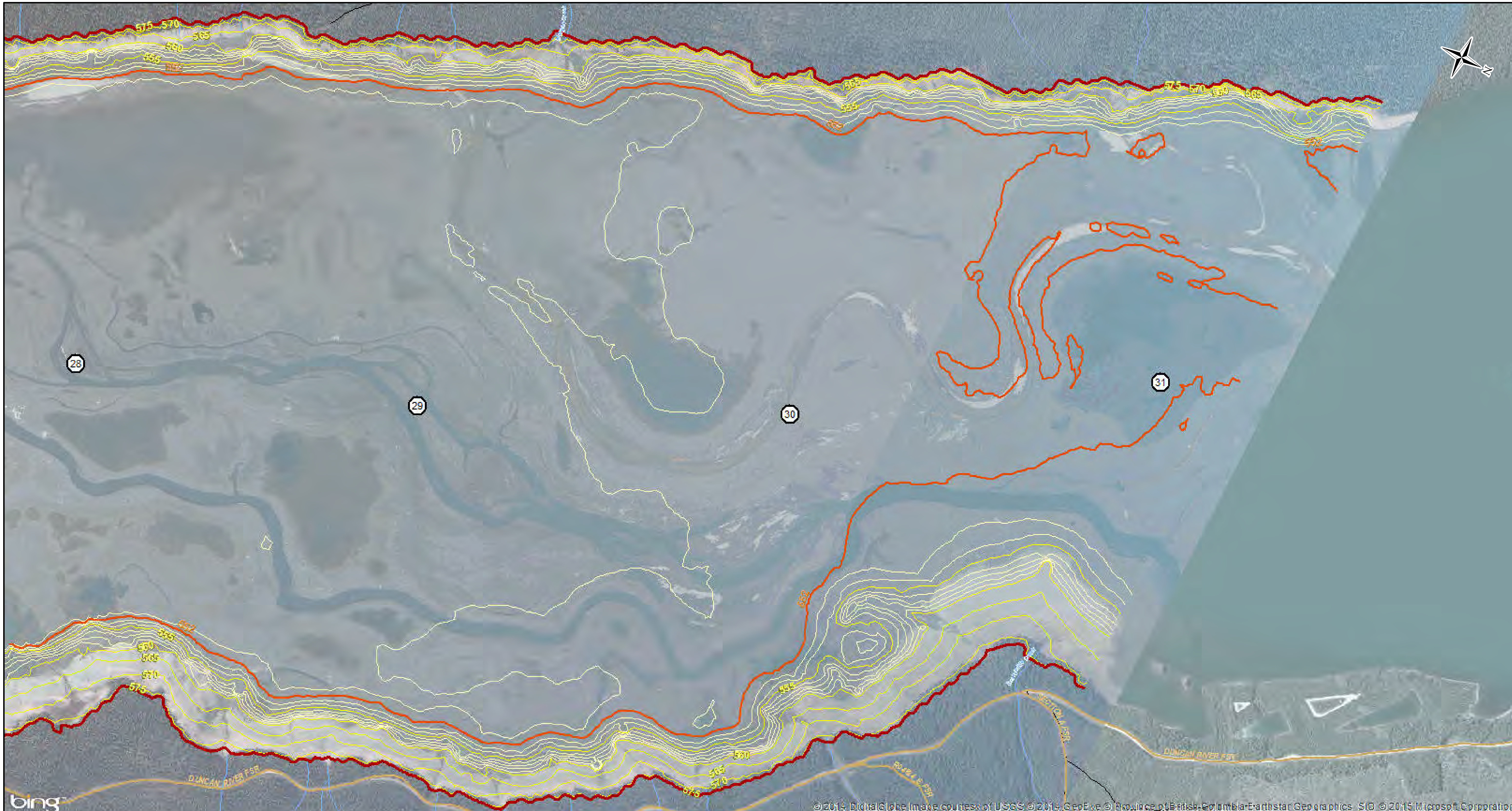


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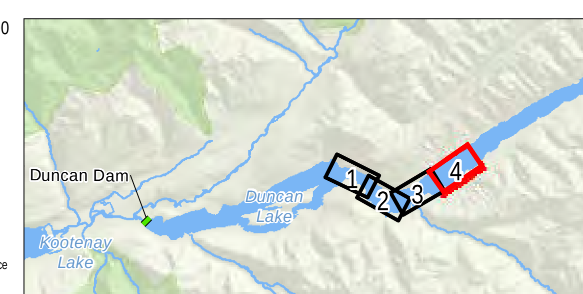


CLIENT: BC hydro

PROJECT: DDMMON-11 Duncan Reservoir Burbot Monitoring

TITLE: Upper Duncan River and Duncan Reservoir Interface Area Map 4 of 4

| DATE: | ANALYST: | QA/QC: | Figure |
|---|---|---|---|
| January, 2015 | MY | KA | |

GIS FILE: 02-01-003_DuncanRes_Bathy_km20to28_v2

JOB No: VE52477

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