Columbia River Project Water Use Plan

Kinbasket and Arrow Reservoirs Revegetation Management Plan

Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works

Implementation Year 5

Reference: CLBMON-11b4

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Study Period: 2016

Okanagan Nation Alliance, Westbank, BC
and
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CLBMON-11B (modules 1 and 4) Monitoring Wetland and Riparian Habitat in Arrow Lakes Reservoir in Response to Wildlife Physical Works

   

Final Report
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Cover photos:

From left to right: Cartier Bay, water-milfoil (*Myriophyllum* sp.) in Cartier Bay, Four-spotted Skimmer (*Libellula quadrimaculata*), Airport Marsh. Photos © Virgil C. Hawkes 2010.

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1.0 INTRODUCTION

The Columbia River Water Use Plan (WUP) was developed as a result of a multi-stakeholder consultative process to determine how to best operate BC Hydro's Mica, Revelstoke, and Keenleyside facilities to balance environmental values, recreation, power generation, cultural/heritage values, navigation, and flood control. The WUP process followed the guidelines established by the Government of British Columbia (BC Hydro 2000; Government of British Columbia 1998) and involved a number of interest groups, First Nations, government agencies and other stakeholders, collectively referred to as the Consultative Committee (CC). Initiated in 2000, the WUP was completed in 2004 (BC Hydro 2005) and was approved by the Comptroller of Water Rights in January of 2007 (Comptroller of Water Rights 2007).

During the WUP planning process, a number of reservoir operating alternatives were explored to balance environmental and social values in the Columbia system. While several of these alternatives included changes to the operating regime of the Arrow Lakes Reservoir (specifically maintaining lower, more stable reservoir levels during the spring, summer and fall), the CC recognized that physical works in lieu of operational changes may be a more cost-effective means of achieving environmental and social benefits given the value of the lost power generation associated with these alternatives. Consequently, the CC supported the implementation of physical works (revegetation and habitat enhancement) in the mid-Columbia River rather than changes to reservoir operations to help mitigate the impact of Arrow Lakes Reservoir operations on wildlife and wildlife habitat.

Coupled with habitat enhancements, the CC also recommended monitoring to assess the effectiveness of these physical works at enhancing habitat for wildlife. In particular, nest mortality and impacts to bird populations, along with impacts to reptile and amphibian species and their habitats, were identified as important wildlife concerns in Revelstoke Reach. As a result, 42 potential wildlife physical works projects were identified by the WUP wildlife technical subcommittee (BC Hydro 2005), and the feasibility of completing these wildlife physical works projects in the drawdown zone of Revelstoke Reach was investigated by Golder (2009). Out of this assessment, five potential projects were prioritized and identified for development based on their engineering feasibility and ecological merit. Site plans for these five projects were developed (Golder 2009), which incorporated environmental, engineering, and archaeological considerations; two of these were undertaken by BC Hydro (Site 6 and Site 15A in Revelstoke Reach).

The wildlife physical works implemented in Revelstoke Reach (Site 6A and 15A) were initially intended to increase shallow wetland habitat and, as such, there was an expectation that wetland productivity would improve in these areas over time. Nevertheless, the possibility that the proposed projects would have the undesired consequence of lowering productivity in some of the existing shallow productive habitats was also considered. Following an ecological impact assessment of the proposed project at Site 15A on Cartier Bay (Hawkes et al., 2015), BC Hydro elected to implement a project that would retain the current conditions of Cartier Bay. The proposed project at Site 6A was implemented in 2013 as originally designed.

Several physical parameters and biological response variables were considered when evaluating wetland productivity including: 1) changes to the aquatic macrophyte community; 2) changes to aquatic plant biomass and volume; 3) changes to the areal extent of the target habitat type (i.e., shallow wetland habitat); 4) changes to the aquatic macroinvertebrate assemblage associated with each shallow wetland; and 5) changes to the physical parameters (e.g., water depth, spatial extent, water temperature and chemistry) of affected wetlands. To properly assess the efficacy of a given wildlife physical works at enhancing wetland productivity, data related to the aforementioned physical parameters and biological response variables were collected before and after the implementation of the proposed physical works.

In 2016 the physical works project implemented at Site 6A in Revelstoke Reach was assessed relative to the performance measures for that project (see Miller and Hawkes 2014). We also started collecting data at the proposed physical works locations in mid-Arrow Lakes Reservoir (i.e., Burton Creek, Lower Inonoaklin Road, and Edgewood South as per Hawkes and Howard 2012). Although the scope of CLBMON-11B4 was initially focussed on Revelstoke Reach, the geographic scope was expanded in 2016 to accommodate baseline data collection of certain wildlife resources at the proposed physical works locations in mid-Arrow Lakes Reservoir.

2.0 MANAGEMENT QUESTIONS AND HYPOTHESES

2.1 Monitoring Program Objectives

The overall objectives of this study are to:

1. monitor the appropriate physical parameters and biological response variables to assess the effectiveness of the wildlife physical works programs at enhancing wildlife habitat in Revelstoke Reach;
2. assess the effectiveness of wildlife physical works projects at enhancing wetland and associated riparian habitat at both the site and landscape level; and
3. provide recommendations based on the results of the monitoring program to improve wetland enhancement techniques.

2.2 Management Questions

This monitoring program is designed to assess the effectiveness of revegetation programs and wildlife physical works at enhancing wildlife habitat in the drawdown zone of Arrow Lakes Reservoir. The monitoring program will assess the response of several wildlife taxa and habitat elements to wildlife habitat enhancements. The primary management questions to be addressed by the monitoring program are:

1. Are the wildlife physical works projects effective at enhancing wildlife habitat in the drawdown zone?

If so,

2. To what extent do the wildlife physical works projects increase the productivity of habitat in the drawdown zone for wildlife?
3. Are some methods or techniques more effective than others at enhancing wildlife habitat in the drawdown zone?

2.3 Management Hypotheses

The hypotheses to be tested under the proposed monitoring program relate to the effectiveness of the revegetation program and wildlife physical works projects at improving wildlife habitat within the reservoir drawdown zone. Specifically, these hypotheses test the quality and quantity of aquatic vegetation and aquatic macroinvertebrates that become established within the habitats created through the physical works projects. These parameters can then be used to assess the quality of the habitat for other wildlife.

The management hypotheses of CLBMON-11B that specifically relate to this project (CLBMON-11B4) are as follows:

$HA_{2:}$ Wildlife physical works do not change wildlife use of the drawdown zone.

HA_{2A}: Wildlife physical works projects do not change the area (m^2) or increase the suitability of wildlife habitat in the drawdown zone.

HA_{2D}: Wildlife physical works projects do not change the abundance (e.g., biomass) and species diversity in the drawdown zone of invertebrates, which are prey for amphibians and reptiles, birds, and mammals.

HA_3: The methods and techniques employed do not result in changes to wildlife habitats in the Arrow Lakes Reservoir drawdown zone.

HA_{3B}: The methods used for wildlife physical works do not result in changes to wildlife habitat in the Arrow Lakes Reservoir drawdown zone as measured by indices of habitat suitability, site productivity (e.g., arthropod biomass), and forage production.

The workplan developed for CLBMON-11B4 in 2016 included three specific tasks:

Task 1: Site 6A Physical Works Monitoring.

Task 2: Bat Surveys. Data to be collected under CLBMON-11B4 but reported under CLBMON-11B1, Bat surveys to occur at the physical works locations identified for mid-Arrow Lakes Reservoir in CLBWORSK-29B (Burton Flats, Lower Inonoaklin Road, and Edgewood South Hawkes and Howard 2012).

Task 3: Assessment of Wetland Primary Productivity.

3.0 STUDY AREA

Site 6A is located in Revelstoke reach north of Machete Island (Figure 1). Wetland productivity assessments occurred at Edgewood South (south of Eagle Creek), and bat data were collected from 14 locations in and adjacent to the drawdown zone of mid- and lower Arrow Lakes (see maps in Appendix A).

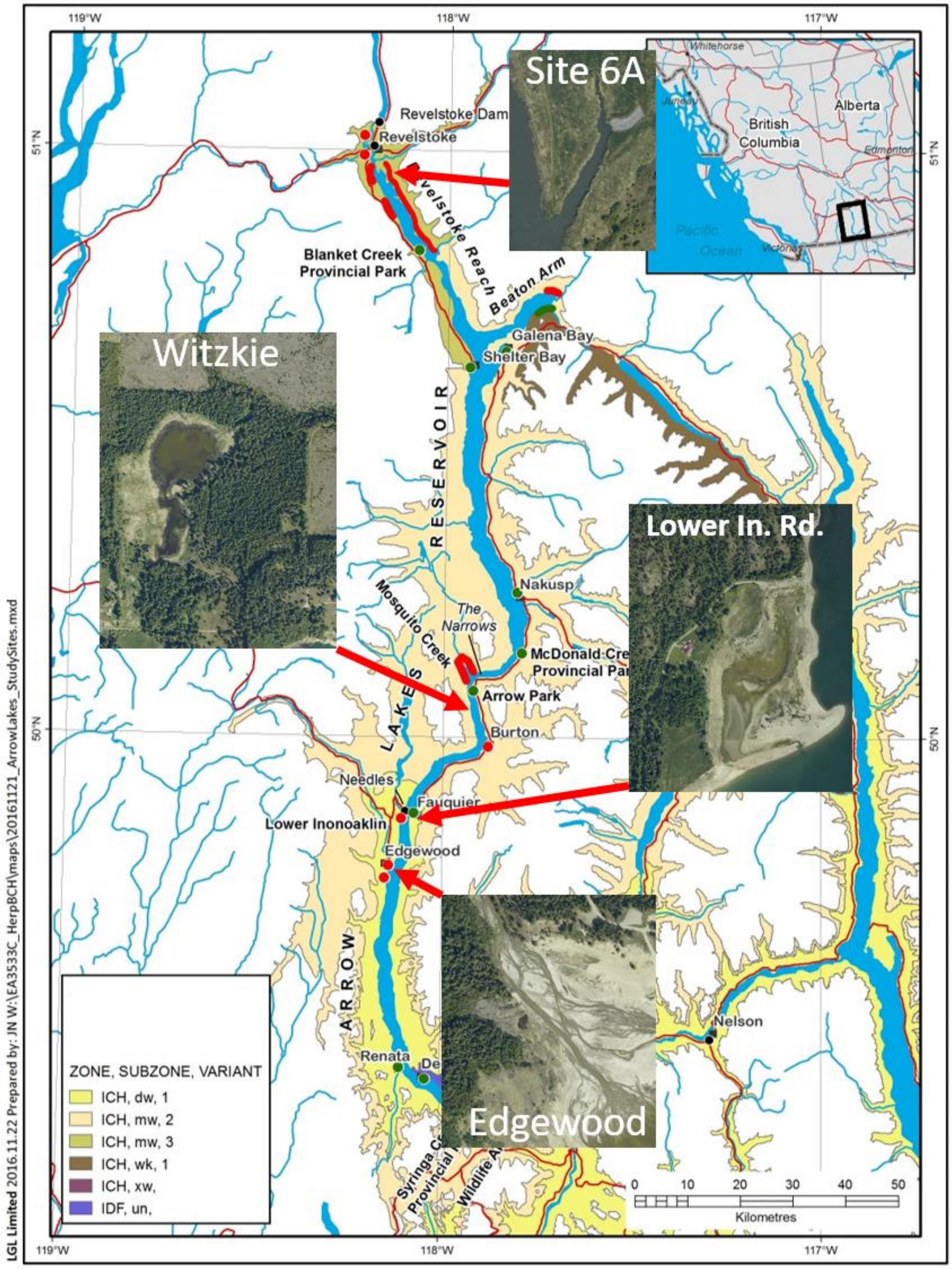

Figure 1. Arrow Lakes Reservoir and sites studied under CLBMON-11B4 in 2016. The wetland on the Witzkie property functioned as a non-drawdown zone reference site.

4.0 METHODS

4.1 Task 1: Site 6A Physical Works Monitoring

Site 6A is a small erosion channel (120 m in length) that has developed in the floodplain of the Arrow Reservoir north of Machete Island (Figure 2). The channel begins at the northwest edge of Machete Island and runs northeast towards the Old Arrowhead Highway Roadbed before splitting into two side channels (east and west) forming a “Y” like configuration. Erosion occurs in the spring during run-off and in the summer or fall when the reservoir recedes from elevations above 438 m ASL.

Figure 2: Aerial image of the Site6A “Y shaped” erosion channel. Scale 1:500. Image date May 2016.

In 2009, the Site 6A project was proposed to maintain wildlife values in the footprint of the Arrow Lakes Reservoir near Revelstoke, BC (Golder Associates 2009). The goal of the project was to stop erosion along the east arm by infilling the channel with riprap. The west arm of the channel was not infilled to assess how effective the infilling of the east channel by comparing rates of erosion between the two side channels.

Project Site 6A was implemented in the fall of 2013 by Landmark Solutions Ltd under BC Hydro’s supervision. Aside from environmental monitoring during construction, no further monitoring was conducted to assess the project's effectiveness. Golder provided recommendations for monitoring Site 6A (Golder Associates 2015) in 2014 and in 2016, LGL Limited was requested to assess Site 6A and establishing an erosion monitoring program.

A site visit was conducted on May 6, 2016 to assess whether any physical changes to the site have occurred since the completion of construction. During the site visit, we documented the following:

- Assessment of erosion at the northwest leg of the main erosion channel (slumping, deepening, widening);
- Assessment of areas of exposed mineral soil at the physical works locations;
- Assessment of the development of new erosion channels;
- Assessment of weedy plant ingrowth;
- Assessment of disturbance and erosion where the erosion mats were laid;

- Assessment of any changes to the main channel;
- Assessment of erosion on the Old Arrow highway, adjacent to the site; and
- Assessment of erosion in the West fork of erosion ditch.

Photographs of the site were taken, and a brief post-construction monitoring report was completed. References pins were established along the perimeter of the east and west channels for future assessment. GPS coordinates (in UTM) were obtained for each reference pin, and a stake was established 1 m behind the pin to aid in relocation. Images of the channel bank/floodplain interface were obtained at each pin. Visual surveys of the east, west, and main channels were conducted to inspect signs erosion, slumping, site disturbance, and the presence of weeds.

4.2 Task 2: Bat Surveys

To study bat presence and distribution over and adjacent to the drawdown zone, Wildlife Acoustics SM2BAT+ autonomous recording units were deployed from early June to late September. Each unit was programmed with a schedule to document bats during two periods: i) half an hour before sunset for 5.5 hours; and ii) an hour before sunrise for 1.5 hours, for a total of 7 hours per 24 hour period. A total of fourteen bat detectors were deployed along the Arrow Lakes Reservoir. The location of each detector is provided in Appendix A. Four detectors were deployed in upland areas (>440.1 m ASL) to serve non-reservoir reference sites. These included: Armstrong Lake (n=1), Box Lake (n=1), and a natural wetland located at West Arrow (n=2). Within the drawdown zone, three detectors were deployed in each site at: Burton Creek, Edgewood South, and Lower Inonoaklin, with an additional detector deployed at Mosquito Creek (n=1). The results of the bat surveys are reported in the 2016 CLBMON-11B1 report (Hawkes et al. 2018).

4.3 Task 3: Wetland Primary Production

To assess whether physical works improve habitat suitability it is desirable to understand the baseline conditions present prior to construction. One of the primary goals of the physical works is to improve habitat conditions for wildlife and because wildlife physical works are proposed for enhancement of wetlands, it was recommended that metrics of daily primary production at each site be determined before construction begins (Hawkes et al. 2011). To do so, wetland primary productivity was assessed through the collection and analysis of water physicochemical data at two drawdown zone locations: Edgewood South and Lower Inonoaklin Road; and one upland wetland on the west side of Arrow Lakes Reservoir on private property (Witzkie; Figure 1).

The physicochemical parameters measured were dissolved oxygen in mg/L, conductivity in µs, temperature in °C, and pH. Increased temperatures elevate the biological oxygen demand, which in conjunction with reduced oxygen solubility, can impact many wetland-associated species, including amphibians. pH is the measurement of the hydrogen-ion concentration in the water. High pH values tend to facilitate the solubilisation of ammonia, heavy metals, and salts. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9.5. Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. It affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems. Low levels of dissolved oxygen facilitate the release of nutrients from the sediments and certain taxa (e.g., amphibians) have variable tolerance to hypoxia (Bickler and Buck 2007). Lastly, specific conductivity is the measurement of the ability of water to conduct an electric current - the greater the content of ions in the water, the more current the water can carry. Specific conductivity may be used to estimate the total ion concentration of the water and is often used as an alternative measure of dissolved solids. Exposure to altered conductivity can negatively impact many freshwater system inhabitants, including bacteria, plants, invertebrates, and vertebrates. Increased conductivity can be a powerful stressor for amphibians, affecting their behaviour and ecology (Snodgrass et al. 2008, Chambers 2011).

Monitoring wetland physicochemistry is essential for assessing changes in wetland integrity and provides valuable information for interpreting biological data, verifying wetland classification, and diagnosing potential stressors (Finlayson and Davidson 1999; Mitsch and Gosselink 2007; US EPA 2008). At each station, point samples of water temperature (°C), dissolved oxygen (mg/L), conductivity (µs), and pH were recorded at a depth 30 cm below the surface of the water using multi-metric meters (YSI Model 85 and Oakton 35423-10 EcoTestr pH2). Conductivity (Onset HOBO U24-001) and dissolved oxygen (PME MiniDOT) data loggers were installed to collect continuous data for monitoring changes in water physicochemistry and aquatic metabolism. Data loggers were installed in each wetland between June and July and October 2016 and were affixed to ¾" rebar or wooden stake using a pipe clamp in the middle of the water column at approximately 50 cm depth. In addition to measuring conductivity and dissolved oxygen, each data logger recorded water temperature (°C). Data loggers were installed between May and September 2016. The DO data loggers were programmed to record data every 10 minutes and calibrated by the manufacturer prior to installation. Conductivity loggers were programmed to record data every one hour. Data were downloaded using the manufacture's software (Onset Hoboware and PME miniDOT software).

Onset weather stations (n=3; one per location) were deployed to collect wind speed (kph), barometric pressure (kPa), air temperature (°C), and photosynthetic active radiation (PAR). These data are required to estimate atmosphere diffusion of dissolved oxygen to calculate pond metabolism (Staehr et al. 2010). Weather stations took samples every minute, which were averaged and recorded at ten-minute intervals.

Daily (diel) changes in dissolved oxygen (DO) concentrations were used to determine daily primary production in aquatic ecosystems (Odum 1956; Staehr et al. 2010; Staehr et al. 2012). With recent advances in sonde technology, reliable metabolic rates including net ecosystem production (NEP), gross primary production (GPP), and ecosystem respiration (ER or simply, R), can be determined from high frequency sampling of DO.

The following definitions are provided for clarity:

Gross Primary Production (GPP) – Gross primary production is the amount of chemical energy as biomass that primary producers create in a given length of time. (GPP is sometimes confused with Gross Primary productivity, which is the rate at which photosynthesis or chemosynthesis occurs). GPP is calculated in units of mg of Oxygen (O_2) per litre per day (mgO_2/L/d).

Net Ecosystem Production (NEP) – the total metabolic balance of an ecosystem; the difference between gross primary production and respiration. NEP is calculated in units of mg of Oxygen (O_2) per litre per day (mgO_2/L/d).

Respiration (R) or Ecosystem Respiration (ER) – is the sum of all cellular respiration occurring by the living organisms in a specific ecosystem. R is calculated in units of mg O_2 per litre per day (mgO_2/L/d). By convention, this value is negative.

Aquatic Metabolism– represents how energy is created (primary production) and used (ecosystem respiration) in an aquatic wetland.

This approach assumes that changes in oxygen concentration reflect the balance between daily photosynthesis and respiration. The production of DO occurs only during daylight hours via photosynthesis, whereas respiration is the only metabolic process occurring at night. Thus, NEP, R, GPP can be calculated by measuring temporal changes in DO throughout a 24 hour period from the equations:

$$\Delta O_2/\Delta t = GPP - R + D$$

$$NEP = GPP - R$$

where $\Delta O_2/\Delta t$ is the change in oxygen concentration over time, and D is the exchange of oxygen with the atmosphere via diffusion (Odum 1956; Hoellein et al. 2013). NEP, R, and GPP are expressed in O_2 m^{-3} day^{-1}, which is equivalent to mg O_2 l^{-1} day^{-1}.

Prior to calculating metabolic activity, DO were corrected for altitude (rather than barometric pressure), and data from sondes were reviewed to identify anomalous data.

Values (daily totals) for NEP, GPP, and R from 2016 were estimated with the *metab.kalman* Model using the LakeMetabolizer package in R (Winslow et al. 2016). The *metab.kalman* Model implements observation and process error dynamic linear regression models to estimate metabolism by finding the parameter set that corresponds to the maximum likelihood of the model given the data. LakeMetabolizer implements five different metabolism models with diverse statistical underpinnings: bookkeeping, ordinary least squares, maximum likelihood, Kalman filter, and Bayesian. Each of these five metabolism models can be combined with one of seven models for computing the coefficient of gas exchange across the air–water interface (*k*). The model also employs a Kalman filter that smoothes the DO time series. The statistical explanations and documentation associated with the LakeMetabolizer package are too technical for this report, and interested readers are directed to Winslow et al. (2016). (Winslow et al. 2016). Equations for calculating NEP, GPP, and R are provided in Staehr et al. (2010).

As defined, negative GPP and positive R are ecologically impossible, but unfortunately, unconstrained metabolism estimates using free-water oxygen often return negative GPP, and positive R. These impossible results are often from days when physical processes (e.g., wind mixing) dominate the DO signal and overwhelm the biological signal by other sources of DO variability (Rose et al. 2014). To constrain the model, all values estimated with negative GPP and positive R were removed from the data set prior to further analyses. Plots of NEP, R, and NEP were produced to provide visual comparisons of each parameter between ponds.

Prior to field work, three locations were selected to determine wetland productivity: the wetland at Edgewood South, the wetland at Lower Inonoaklin Road, and an upland wetland on the west side of Arrow Lakes Reservoir on private property (Witzkie). The wetland at Lower Inonoaklin Road was too low to deploy data loggers and access to the Witkie property did not occur until later in the season. As a result, we were only able to deploy data loggers and a weather station at the Edgewood South location. The data obtained from the data loggers and weather stations were used to calculate GPP, NEP, and R.

5.0 RESULTS

5.1 Task 1: Site 6A Physical Works Monitoring

An assessment of Site 6A was conducted on May 6, 2016. A monitoring report is provided in Appendix B detailing the observations made during the site visit. UTM coordinators are provided in Table 1 in Appendix C.

No residual signs of site disturbance from previous construction activity were observed at Site 6A (Appendix B). *Phalaris arundinacea* (Reed canary grass) has re-established on previously exposed mineral soil, and there was no evidence of other noxious weeds. A perimeter survey of the east channel did not reveal any major signs of erosion between the interface of the floodplain and riprap. In fact, the riprap appeared to be integrating nicely into the floodplain with moss and *P. arundinacea* (Appendix B) establishing along the margin of the riprap. Slumping was observed in the main channel at the southwest terminus of the riprap (Appendix B); however, there was no evidence that the riprap in the east channel has contributed to this.

During the perimeter survey, a common garter snake (*Thamnophis sirtalis*) was observed in the margin of the riprap of the east channel.

Extensive slumping was observed in both the west and main channels (Appendix B). Crank formations and exposed mineral soil were observed at the crest of the bank along the west channel. Recent slumping and active erosion were observed at the mouth of the main channel.

5.2 Task 3: Wetland Primary Production

Conductivity (µS/cm) values averaged 93.1 (min: 61.9; max: 109.8), which is indicative of a freshwater wetland (i.e., conductivity < 500 µS/cm; Figure 3). Dissolved oxygen averaged 9.14 mg/l (min: 6.4; max: 11.8) and water temperature varied from a low of 12.4 °C to a high of 21.4 (mean: 16.9), indicating the wetland provides suitable habitat for aquatic life for the time of year sampled (i.e., May through September). The elevation of the wetland at Edgewood South averages 436.36 m ASL and it would have been inundated by Arrow Lakes Reservoir for 18 days between 5 and 22 June in 2016. Arrow Lakes Reservoir reached a maximum elevation of 437.24 m ASL on 10 June 2016, adding 88 cm of water into the wetland at Edgewood South. Although conductivity, dissolved oxygen, and temperature varied over time, conductivity and temperature appeared to decrease following inundation while the apparent decline in dissolved oxygen ceased with inundation (Figure 3). All three parameters increased slightly thought July and August as the reservoir receded (Figure 3).

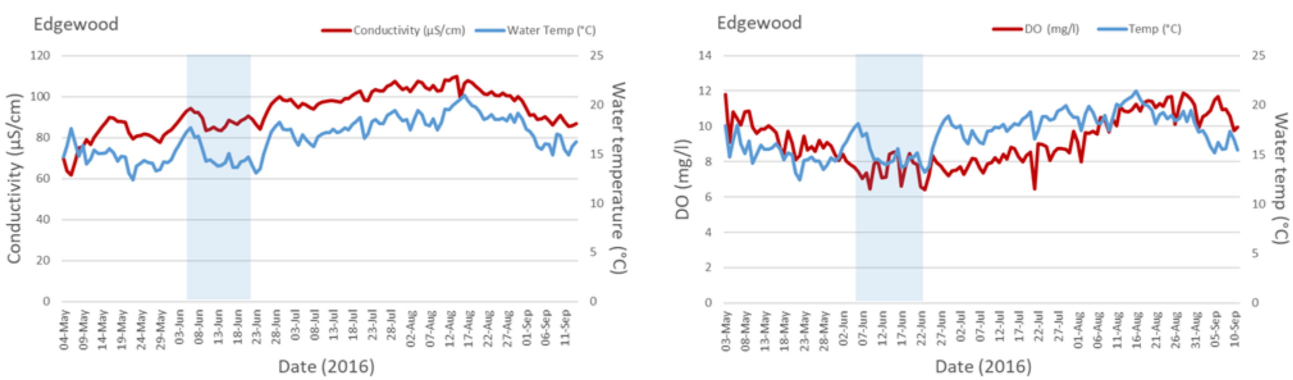

Figure 3. Variation in conductivity (µS/cm) water temperature (°C), and dissolved oxygen (mg/l) in the wetland at Edgewood South between May 4 and September 15, 2016. Inundation by Arrow Lakes Reservoir occurred between June 5 and 22 (shaded rectangle).

Metabolic activity (as seen in the mean daily GPP values) appears to have been suppressed during the period of inundation (Figure 4), which may be related to the influx of cooler water from the reservoir (Figure 3). An increase in GPP followed immediately after the period of inundation ended on June 22, 2016. As expected, GPP increased with warmer temperatures through to mid-August, after which cooler ambient temperatures likely contributed to a reduction in metabolic activity. NEP increased over the study period, particularly through August and September (Figure 4), likely as a result of increasing nutrient level accumulation following inundation and increased metabolic activity associated with an increase in water temperature observed in July and August.

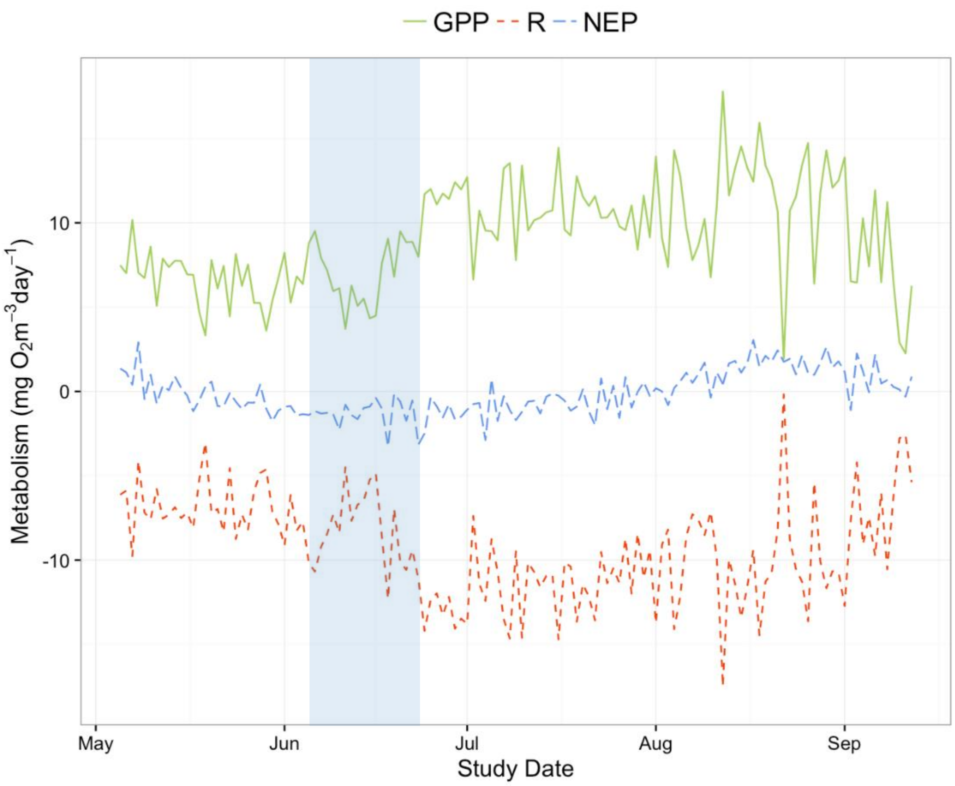

Figure 4. **Variation in wetland metabolism (GPP, R, and NEP; mg $O_2m^{-3}day^{-1}$) calculated for the wetland at Edge wood South, Arrow Lakes Reservoir.** This wetland was inundated for 18 days between June 5 and 22, 2016 (shaded area).

6.0 DISCUSSION

6.1 Site 6A

The installation of riprap in the east channel at Site 6A appears to have arrested erosion in this channel. There were no signs of erosion or slumping along the perimeter of the riprap, although slumping was observed at the southwest terminus of the riprap in the main channel. However, considering the degree of slumping occurring in the main channel, there is no indication that the riprap in the east channel is contributing to this erosion. Extensive slumping and active erosion continue to occur in the west and main channels. Given the effectiveness of the riprap in arresting erosion in the east channel, consideration should be given to applying a similar treatment to the west and main channel to prevent further erosion.

6.2 Wetland Primary Productivity

Metabolic metrics are considered to be good indicators of ecosystem integrity (Allan and Castillo 2007; Mitsch and Gosselink 2007; van der Valk 2012). Temperature is also an important driver of variation in ecosystem metabolism across terrestrial and aquatic ecosystems (Staehr et al. 2012; Hoellein et al. 2013). In shallow aquatic systems, GPP is provided by phytoplankton, periphyton, and submerged macrophytes and their relative contribution according to nutrient and light availability, and water temperature (e.g. Vadeboncoeur et al. 2001). The deposition of fine sediments following inundation (by the reservoir) may also contribute to increased metabolic activity and macrophyte abundance in DDZ ponds (Adama 2017). Nutrient availability in natural systems can be limiting for aquatic phytoplankton and macrophytes and sedimentation provides an important means of nutrient renewal to the littoral zone. Following short periods of inundation, the growth of submersed macrophytes may be stimulated by the import of fine-textured inorganic materials such as clays and silts (Barko et al. 1991). However, water coming into Arrow Lakes is known to be nutrient poor due to nutrient depletion and trapping behind the Mica and Revelstoke Dams (Bray 2018). Thus, it is unlikely that inundation contributed a significant source of sediment or nutrients into the wetland. Instead, higher temperatures along with light interception likely attributed to the observed variation in aquatic metabolism observed in the Edgewood south wetland.

Additional sampling in 2017 at Lower Inonoaklin Road (if wetland depth permits) and on the Witzkie property (if access is granted) would enable a comparison of wetland productivity between drawdown and non-drawdown zone wetlands.

7.0 RECOMMENDATIONS

7.1 Site 6A

Based on the efficacy of the riprap installation to mitigate erosion and slumping, the following recommendations are made:

- Reassess the channels again in the spring of 2018 to assess the medium-term efficacy of the riprap to arrest erosion and to document whether further erosion or slumping has occurred in the main and west channels.
- In future visits, the perimeter of the riprap should be reassessed and photographs should be taken of the riprap-floodplain interface from the established control points (Appendix C). Attention should be paid to the southwest terminus where active slumping continues. If the erosion at this location accelerates displacement of riprap in the east channel may occur, requiring mitigation. Photographs should be taken from the same points as those taken in 2016 to provide side-by-side comparisons.
- Erosion of the west and main channel should also be reassessed. A perimeter survey of the west channel should be repeated, and photographs taken of the channel bank from the established control points (Appendix B). The banks and mouth of the main channel should also be assessed for active slumping and erosion. Photographs should be taken from the same points as those taken in 2016 to provide side-by-side comparisons.
- Conduct surveys for snakes at Site 6A to determine if the riprap is providing denning habitat. It is possible that the riprap may provide a suitable hibernaculum for *Thamnophis sirtalis*.

7.2 Wetland Primary Productivity

- If the wetland at Lower Inonoaklin Road is deep enough, deploy DO and conductivity data loggers in each of the two compartments to assess GPP, NEP, and R for those wetlands. This will provide useful pre-physical works data for this location.
- If access to the Witkie property is provided again in 2017, consider deploying data loggers and a weather stations for the calculation of GPP, NEP, and R for a non-drawdown zone wetland.

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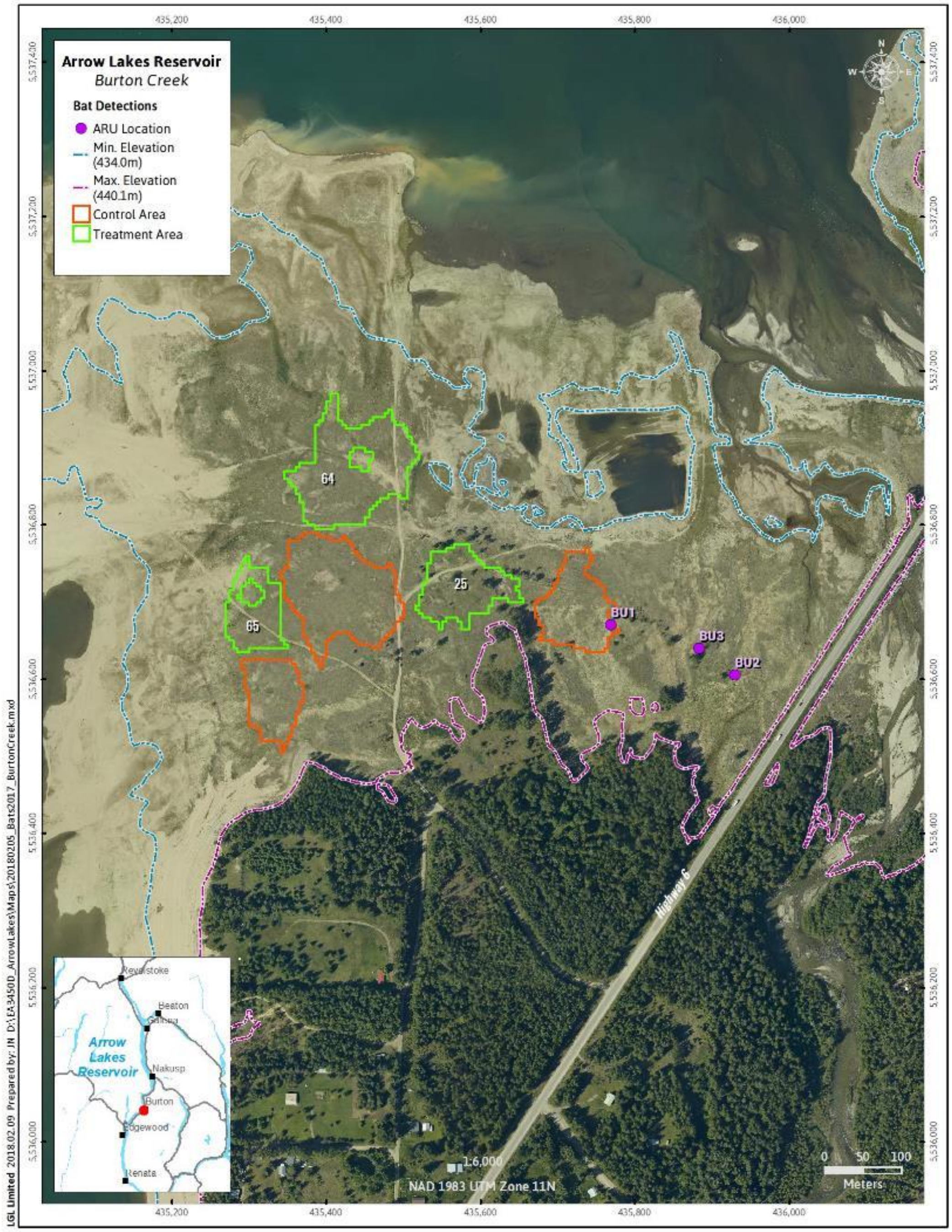
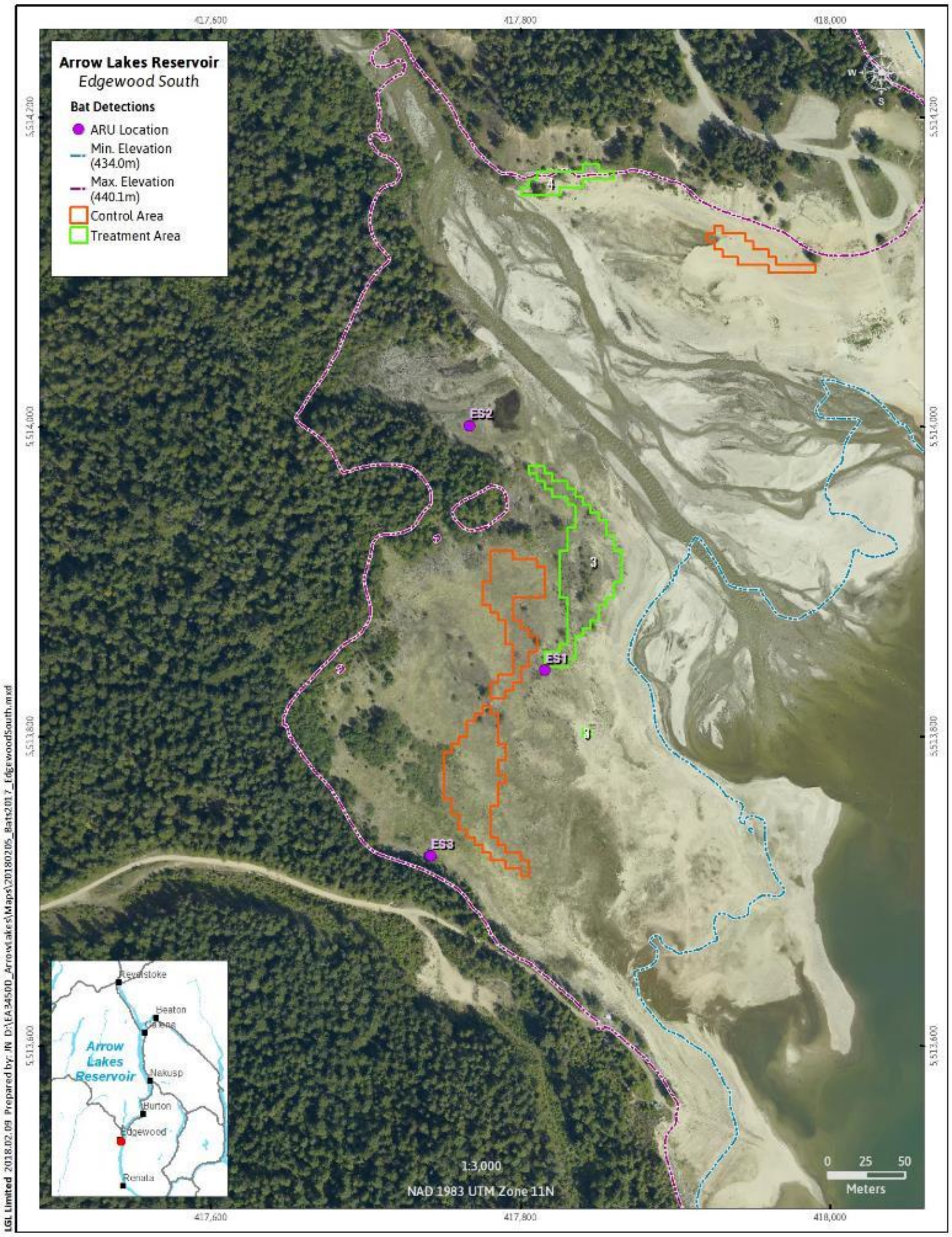
9.0 APPENDICES

Appendix A. Location of Autonomous Recording Units (ARUs) deployed in and adjacent to the drawdown zone of Arrow Lakes Reservoir. See also Hawkes et al. (2018) for more details.

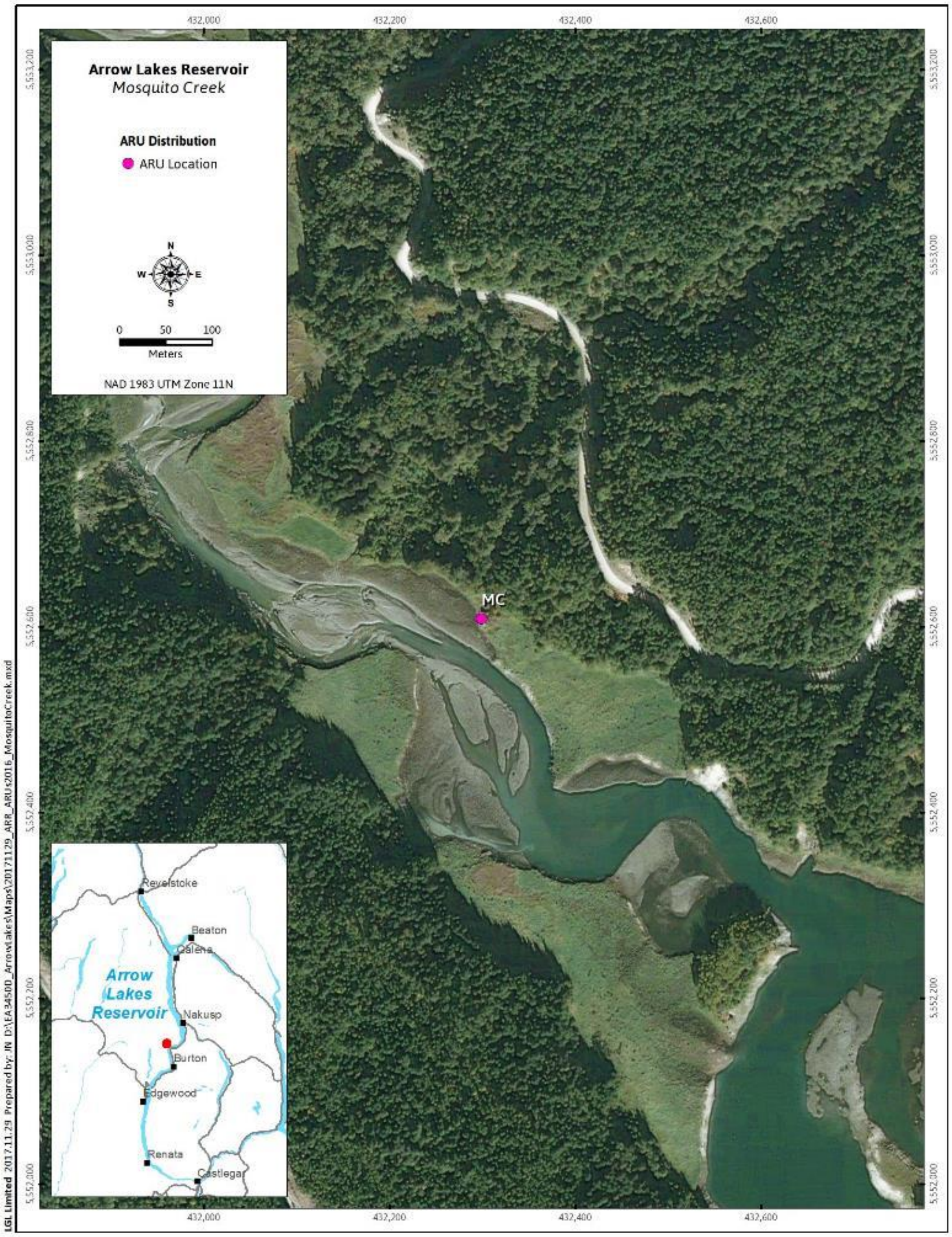


Map 1: Location of bat detector units installed at Burton Creek

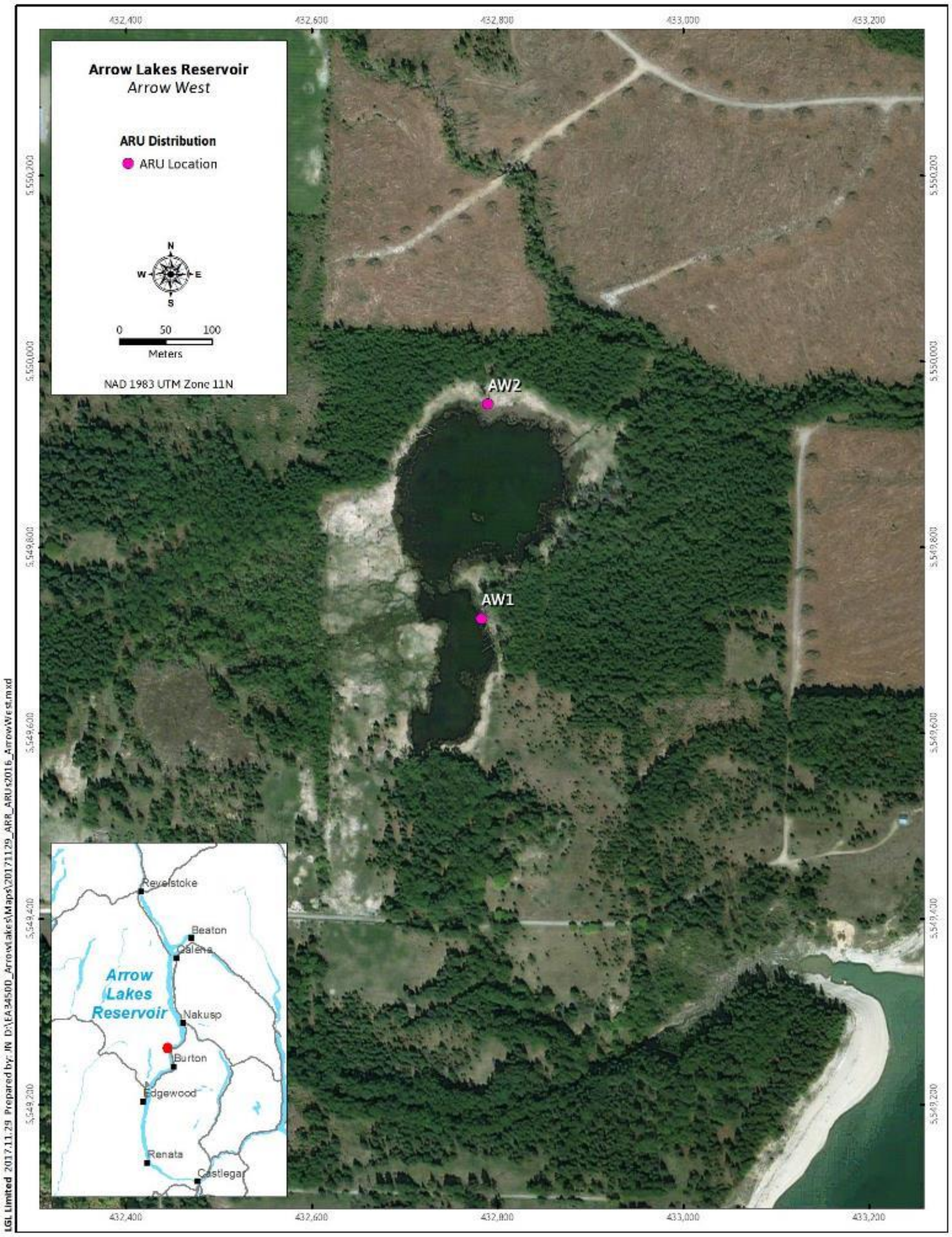


Map 2: Location of bat detector units installed at Edgewood South

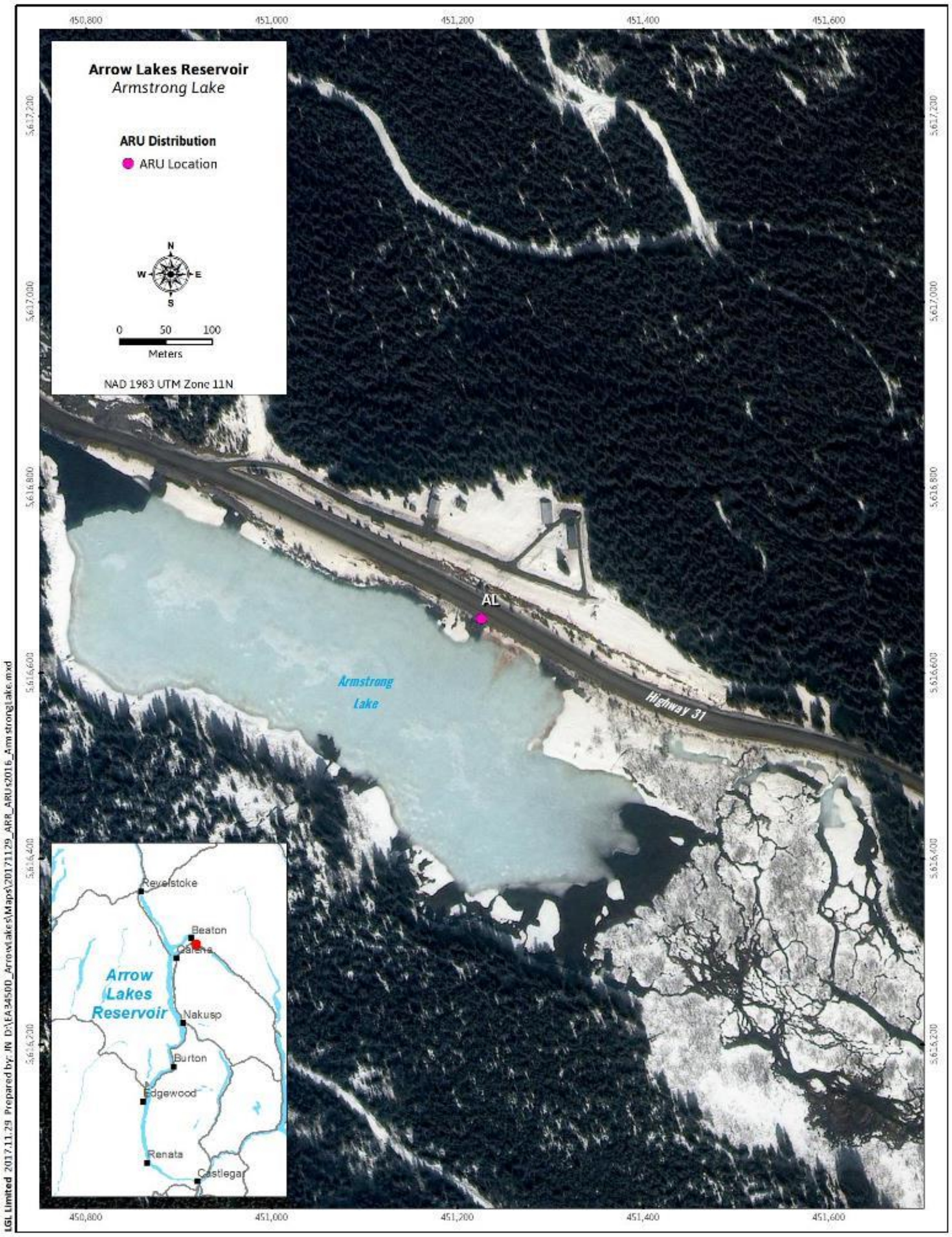
Map 3: Location of bat detector units installed at Lower Inonoaklin



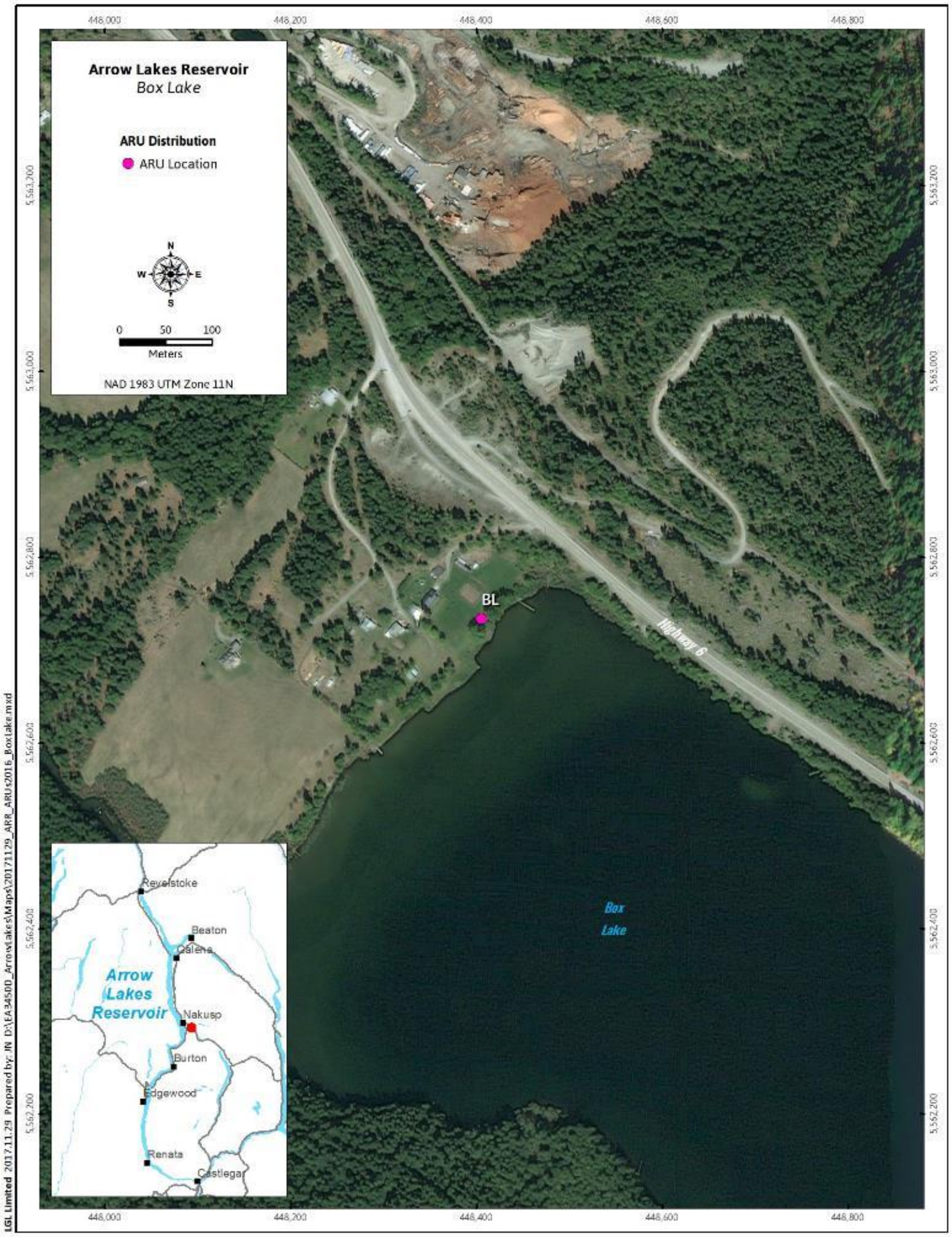
Map 4: Location of the bat detector unit installed at Mosquito Creek



Map 5: Location of the bat detector units installed at Arrow West (non-reservoir site)



Map 6: Location of the bat detector unit installed at Armstrong Lake (non-reservoir site)



Map 7: Location of the bat detector unit installed at Box Lake (non-reservoir site)

Appendix B. Monitoring Report for Site 6A, 2016

A. Primary Purpose of Review	**Date:** May 6, 2016 **Weather:** Sunny, Clear **Photos Taken:** Yes
Post-Construction Assessment of Site 6A channel	**In Attendance, or In-Person Discussion:** Doug Adama, LGL Limited Keegan Meyers, UVIC Karle Zelmer, ONA

B. Description of Activities

1. Assess the Access route for weeds, exposed soil, and persistent signs of disturbance
2. Assess the east fork of the erosion channel for signs of erosion, weeds, or persistent signs of site disturbance
3. Assess the west fork of erosion channel for signs of erosion
4. Assess the main channel for signs of erosion
5. Establish erosion monitoring control points along the east and west channels

C. Observations

Ref No.	Location	Observations, Comments & Recommendations (For tracking of outstanding items from this and previous FRR's, please refer to D below)	Photos See Section E	Action Required By:
C.1	Access route	**Observations:** Vigorous reed canary grass (RC) growth. No visual signs of site disturbance. **Recommendations:** None		**None**
C.2	Erosion channel and Riprap placement	**Observations:** Vigorous RC growth where soil was previously exposed (**1601A**). Signs of moss on riprap and RC growing in the riprap along the perimeter of riprap (**1601B**) Minor sign of exposed soil at the east tip of the channel. This is a low spot where enter the channel. However, still signs of integration of riprap into the channel back. Slumping is occurring on the south west end of the channel (**1601C**) **Comment:** Erosion appears to have been arrested along the perimeter of the channel and the riprap appears to be integrating with the channel bank. However, slumping is occurring on the south west end of the channel slumping **Recommendations:** Reassess in two years. Pay attention signs of erosion at the east end of the east channel and reassess the south west edge for slumping.	1601A 1601B 1601C	BCH
C.3	East Channel Riprap	**Observations:** *Thamnophis sirtalis* (THSI) observed at the edge of the riprap. THSI likely using the riprap for warmth and foraging. Possibly hibernaculum site.	-	BCH LGL/ONA
C.4	West Channel	**Observations:** Cracks and slumping along the east and west banks along the West Channel.	1601D	BCH LGL/ONA
C.5	Main Channel	**Observations:** Fresh signs of slumping at the mouth of the main channel. Slumping along the north and south channel banks.	1601E	BCH LGL/ONA

D. Outstanding Follow-up Items *(from this and previous reports)*

Ref. No.	Observations and Comments	Follow-up Action	Action Required by:	Resolved
D.1	Consider applying the same riprap treatment to the west and main channel to stop further slumping and erosion.	Yes	BCH	
D.2	Reassess the site in two years	Yes	BCH	
D.3	Monitor the riprap for use by garter snakes.	Yes	BCH	

E. Photo Reference

Photo No.	Description

1601A	Vigorous reed canary grass growth along the perimeter of the east channel.
1601B	Integration of fines and vegetation in the riprap.
1601C	Slumping at the southwest corner of the channel.
1601D	Slumping in the west channel.
1601E	Slumping and active erosion at the mouth of the main channel

Photo 1601A. Vigorous reed canary grass growth along the perimeter of the east channel.

Photo 1601B. Integration of fines and vegetation in the riprap.

Photo 1601C. Slumping at the southwest corner of the channel.

Photo 1601D. Slumping in the west channel.

Photo 1601E. Slumping and active erosion at the mouth of the main channel

Photo 1601F. Slumping in the main channel.

Appendix C. UTM Locations of erosion monitoring pins at Site 6A

Table 1: UTM locations of erosion monitoring pins at Site6A

Pin Number	UTM_E	UTM_N
P1	415518	5647553
P2	415525	5647553
P3	415533	5647557
P4	415541	5647565
P5	415516	5647560
P6	415501	5647608
P7	415501	5647560
P8	415502	5647563
P9	415503	5647573
P10	415503	5647581
P11	415500	5647596
P12	415503	5647596
P13	415508	5647582
P14	415511	5647572
P15	415510	5647563
P16	415524	5647561
P17	415529	5647562
P18	415535	5647567
P19	415541	5647571