Columbia River Project Water Use Plan

Monitoring Program Terms of Reference

Kinbasket Reservoir Fish & Wildlife Information Plan and Mica 5 and 6 Project Commitments

- **CLBMON-62: Impacts of Mica Units 5 and 6 on Synchronous Condense Operations and Aquatic Life (Addendum #2 to CLBMON-1 Mica Dam Total Gas Pressure Monitoring and Abatement Program)**

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1.0 MONITORING PROGRAM RATIONALE

1.1 Background

Mica Generating Station (Mica Dam) currently has four generating units, with Units 1, 2, and 3 discharging into Tailrace 1, and Unit 4 into Tailrace 2. Originally, Units 1 and 2 were the only units historically capable of synchronous condense (S/C) operation, which is used to provide voltage support and quick unit return to service. More recently, Units 3 and 4 were upgraded to provide S/C capacity. In April 2010, BC Hydro secured approval to install two additional generating units (Units 5 and 6) at the Mica Dam which, by their in-service dates of 2014 and 2015 respectively, will have S/C capacity as well. S/C operations can result in higher localized total dissolved gas pressure (TGP) levels below Mica Dam due to surface water being exposed to pressurized air which is injected at 16 psi into the draft tube to force water below the runner and hence allow the runner to spin in air. Water surface turbulence from the spinning runner combined with the increased air pressure forces additional gas into the water column, creating supersaturation. Because the water in the immediate vicinity of the unit is stagnant during synchronous condense operation, supersaturation increases (volume of water supersaturated and level of supersaturation) over time. Cooling water and dam leakage in the draft tube then carries supersaturated water near the units down the draft tube and into the tailrace after 3-4 hours of synchronous condense operation.

Units are operating in synchronous condense mode to some extent every month, although this operation occurs primarily during spring (March to May) and fall (October and November). Fish are able to move up into the draft tubes when units are operating in synchronous condense mode due to the limited discharge from the units, resulting in particular concern by BC Hydro staff and the fisheries regulatory agencies regarding fish mortalities in September and October when kokanee congregate at the base of the dam. It is anticipated that due to the higher efficiency of the new units, Units 5 and 6 will be operated in S/C mode preferentially to the other four older units (Byron Mackenzie, pers. comm.).

Fish mortalities in the Mica Dam tailrace were formally investigated by BC Hydro in 1995 (Millar et. al. 1995). Potential causes of these mortalities included: entrainment from Kinbasket Reservoir; fish moving into the draft tube and potentially becoming injured during unit start up; fish dying at the completion of their life cycle (kokanee); and gas supersaturation. From 1996 to 1998, total dissolved gas (TDG) data were collected at Mica Dam during a variety of unit operations. These data showed that TDG levels can reach levels of 200% TGP in the draft tube when both Units 1 and 2 were operated in synchronous condense mode; however, there was no conclusive relationship between TDG levels and time spent operating in synchronous condense mode. BC Hydro implemented a TDG best management practice (BMP) in 1996, which was developed in consultation with fisheries regulatory agencies (BC Hydro 2013). The current operating criteria stipulate a 15 minute flushing operation (300 MW or 5000 cfs) for each generating unit for a cumulative 12 hours of synchronous condense (known as the "fish flush").

Since 1998, periodic dissolved gas supersaturation (DGS) data collection and analysis have been conducted (Klohn Crippen Berger 2014, Golder 2011, Golder 2014). Due to the limited available information on synchronous condense operational impacts, the Water Use Plan (WUP) Consultative Committee (CC) Fish Technical Sub-Committee recommended further study should be undertaken to determine the downstream extent of TGP impacts, and to assess whether the BMP are most effective in maintaining local TGP levels below acceptable thresholds. In 2005, BC Hydro undertook a comprehensive review of all previously collected DGS data and conducted monitoring to confirm TDG levels (Fidler et al. 2005). This study, which characterized TDG levels and downstream extent for the two units with existing synchronous condense capability, showed that elevated DGS still exist in the draft tubes and tailrace, extending as far downstream as the Mica Blue Bridge. In 2012, TDG at the Mica Blue Bridge site approached 125% TGP following an extended period of synchronous condense operations where periodic flushes were the only source of diluting waters (i.e., there was no generation) (Klohn Crippen Berger 2014). The question of downstream extent posed by the WUP CC was therefore addressed for existing synchronous condense operations; however, it is still uncertain whether there are benefits or additional impacts associated with installation of synchronous condense into Units 3 - 6. One of the goals of this monitoring program is to evaluate DGS levels and extent for synchronous condense operations of Units 3 and 4, when operated either separately or in conjunction with Units 1 and 2.

In the Mica Unit 5 and Unit 6 Environmental Assessment Certificates, BC Hydro committed to monitoring changes in synchronous condense operations and the relative potential for downstream TGP impacts resulting from the addition of Unit 5 and 6 to the Mica Dam (Commitment 10, Unit 5 and 6, EAC 2010)[1]. The CLBMON-1 Study Team was asked to review the potential implications of adding Units 5 and 6 on the monitoring program and to recommend changes in study design that can address any impacts to study objectives. The addition of another 2 units operating in synchronous condense mode could incrementally increase the magnitude of DGS so that it exceeds threshold levels considered safe for fish, as well as possibly increase the areal extent of high TDG waters. It was decided that the monitoring required to assess the TDG impacts of operating Units 5 and 6 in synchronous condense mode (CLBMON-62) should be folded into the CLBMON-1 study design and treated as an Addendum.

1.2 Management Questions

The key management questions to be addressed through the monitoring program are:

1. What is the impact of synchronous condense operations in Mica Units 1-6 on dissolved gas supersaturation?

    a. Is there a difference in dissolved gas supersaturation depending on which of the six units at Mica Generation Station are operated in synchronous

[1] The Unit 5 and 6 EAC commitment states: "BC Hydro will undertake a new Columbia River TGP study of the Mica Plant operating record at three years post in-service date to identify any changes in synchronous condense operation. If the Synchronous condense operation is significantly greater than historic, then BC Hydro will undertake a TGP monitoring program to confirm that the current Best Management Practices are still applicable."

condense mode (can all units be treated the same in term of generating high TDG)?

b. For a given combination of units in synchronous condense mode and normal operations, what are the impacts on downstream TGP including magnitude, areal extent, and duration of exposure for a given period of use (hours vs. days vs. weeks)?

c. Does the TGP plume generated by synchronous condense operations readily dissipate or mix with the water column, or does it remain as a cohesive plume traveling through Revelstoke reservoir. If as a plume, what is the rate of travel and hence potential exposure to resident fish?

2. With the installation of Mica Units 5 and 6, are there significant changes in the use of synchronous condense operations at the Mica Project and if so, does this represent a significant increase in TDG exposure for downstream aquatic environments?

3. Given what is known of Revelstoke reservoir fish ecology, what is the potential biologic impact of a given high TGP event?

4. Where biological impacts warrant response (i.e. population level impacts), are there any opportunities to mitigate impacts to critical fisheries while meeting intended operational flexibility?

1.3 Management Hypothesis

The primary hypotheses associated with these management questions are:

$H_0$1a: There is no difference in TGP generation between units during S/C operations. (*Accepting this null hypothesis would suggest that all units can be treated the same in terms of TGP generation. Rejecting this hypothesis would indicate that some units are more "TGP friendly" than others, and could lead to a priority sequence of unit use if TGP was exposure was sufficient to cause downstream harm.*)

$H_0$1b: Downstream TGP (% Saturation) does not increase incrementally as the number of units operating in synchronous condense mode increases from 1 to 6. *(Accepting of $H_0$1b, would suggest that all units contribute equally to downstream TGP and that rate of dispersal or dilution remains proportional to the volume of high TGP water being generated. Rejection of $H_0$1b would suggest that dissipation/dilution is a fixed quantity and that as more units are in S/C mode, it plays less of a role mitigating overall tailwater TGP.)*

$H_0 1c_1$: Downstream TGP (% Saturation) does not increase over time as the duration of S/C operations increases.
(*Accepting $H_0 1c_1$ would suggest that the high TGP waters generated during S/C operations is rapidly dissipated or diluted by other tailwater water sources. Alternatively, rejecting $H_0 1c_1$ suggests that the high TGP waters generated during S/C operations is accumulating in the tailwaters of the powerhouse, thus creating a plume*).

H_01c_2: The areal extent of a TGP plume downstream of Mica Dam does not increase with the number of units and during of S/C operations.
(*If this hypothesis is rejected, the follow-up question would be: what is the rate of plume growth for a given number of units, and hence what is the size of the plume for a given duration of S/C operations. Also, does the average TGP of the plume increase with the number of units, and/or with the duration of S/C operations*?)

H_02: There is no significant change in the duration, frequency or intensity of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use.
(*Accepting H_03 would indicate that the installation of units 5 and 6 have no significant impact on the amount that S/C is used at Mica. However, rejecting the hypothesis would trigger further monitoring and necessitate addressing H_04)*

H_03: Given what is known of Revelstoke fish ecology and the level of saturation, areal extent and persistence of the plume for a given duration and combination of units in S/C operation, there is no expected population impact.
(*Accepting H_04 would indicate that the duration and combination of units in questions has no impact downstream and can occur without restriction. Alternatively, rejecting H_04 would require that restrictions be put in place, or that alternative mitigative actions be considered. If restriction or mitigation are not feasible, then a fisheries act authorization would have to be sought*).

H_04: Given system requirements for synchronous condense operations and potential mechanisms for fisheries impacts, there are no mitigation options that would be applicable for Mica Generating Units.
Previous studies have concluded that the "fish flush" is unlikely to be an effective mitigation for high TDG concentrations in the Mica Generating Station tailrace to the Revelstoke Reservoir confluence (Klohn Crippen Berger 2014). Studies proposed to evaluate alternative mitigations have not yet been implemented and should otherwise be conducted under these terms of reference.

It should be noted that test of H_04 is consistent with implementation of BC Hydro's TDG management strategy (BC Hydro *in draft*).

1.4 Key Water Use and Mica 5/6 Project Decisions Affected

The key Mica 5/6 Project decision affected by this study is whether the expansion of synchronous condense capacity at the Mica Generating Station will lead to significantly increased use of S/C operations and impacts. The key water use decision affected by the results of the monitoring program is whether the existing best management practice (dissolved gas supersaturation flush operation) is sufficient to minimize risks to fish health potentially caused by S/C operations. If not, it is expected that sufficient data will have been collected to explore alternative mitigative strategies and if none are feasible, BC Hydro will seek authorization of impacts caused by S/C operations under the federal Fisheries Act (as per BC Hydro's TDG management strategy)

2.0 MONITORING PROGRAM PROPOSAL

2.1 Objective and Scope

The terms of reference for study CLBMON-62 have been revised from the scope of study CLBMON-1 originally recommended by the WUP CC. Study CLBMON-1 was implemented from December 2010 to May 2011 under its original Terms of Reference; however, insufficient data was obtained during this period to characterize both synchronous condense operations and their physical effects on downstream TDG. This amendment takes into account the 2005 study data (Fidler et al. 2005), the commitments made through the TDG Strategy (BC Hydro *in draft*), and commitment 10 of the Mica Unit 5 and Unit 6 Environmental Assessment Certificates (EAC, 2010). The scope of this amended monitoring program has been revised to focus on assessing the impacts of synchronous condense operations from all units, both prior to and for at least three years following in-service dates of Mica Units 5 and 6 Project. The primary objectives of the monitoring program are to determine the relationship between dissolved gas supersaturation and synchronous condense operation of Units 1-4 (augmenting existing information for Units 1 and 2) and to compare the use of pre- Unit 5 and 6 commissioning S/C operation with post Units 5 and 6 commissioning S/C operation. Should a risk to downstream fisheries populations be found, the study results will be used to assess potential mitigation options.

Though it is preferable to schedule specific S/C operations and to minimize the duration of the monitoring periods, it is recognized that this may not be feasible given prevailing power demand and hydrological conditions at the time of study. It is also recognized that the greater the number of units that are in S/C operation, the greater number of unit combinations that must be assessed. The original recommendation of the WUP CC included monitoring to determine the timing and duration of S/C operation to reduce costs of implementing the BMP, however a subsequent study (Fidler et al. 2005) found that DGS levels were elevated despite implementation of the BMPs. Therefore, CLBMON-62a will assess the potential for S/C operations to impact downstream fisheries and propose alternative mitigation strategies as warranted. .

2.2 Approach

Monitoring will focus on DGS levels measured during operation of Units 3 through 6 in synchronous condense mode, either alone or in various combination with Units 1 and 2. The monitoring approach will replicate monitoring activities undertaken in 2005 with respect to locations and duration (Fidler et al. 2005), using a combination of spot and continuous dissolved gas supersaturation measurements under a variety of operating scenarios defined by BC Hydro. To determine persistence of any plume that is generated, the monitor should include TGP measurement at the forebay of Revelstoke Dam.

Annual spring and fall monitoring will occur during two of the first eight years of the Columbia River Water Use Plan implementation, as described in Section 2.3.3 and focus on Units 3 and 4. The dissolved gas supersaturation monitoring will occur during periods of extended synchronous condense operation (two or more units on synchronous condense operation with no other units generating). As such, a protocol between the BC Hydro Generation Resource Management planning engineer, the Mica Generating Station and the field crew will need to be established for: (1) communication; (2) operation scheduling; and (3) safety. Assessment of Units 5 and 6 in combination with the other units will take place in the three years following commissioning of these two units.

2.3 Tasks

2.3.1 Task 1: Project Coordination

Project coordination will involve the general administrative and technical oversight of the program. This coordination will include, but will not be limited to: 1) budget management; 2) study team management; 3) logistic coordination – in particular, the identification, and, where possible, the coordination of S/C operations monitoring opportunities; 4) technical oversight for field and analysis components; and 5) facilitation of data transfer among related investigations.

A safety plan must be developed and submitted to the BC Hydro contact, for all aspects of the study involving field work, in accordance with BC Hydro procedures and guidelines. Specific safety training may be required.

2.3.2 Task 2: Development of Study Plan

In consultation with BC Hydro Environment staff and Operations Planners, a study plan to monitor dissolved gas supersaturation will be developed, using up to four monitoring stations that would include

- two sites between the Mica Generating Station tailrace and confluence with Revelstoke Reservoir (“Blue Bridge LDB” per Golder (2014) and “LON5 Water Gauge TGP Site” per Fidler (2005));
- one site in the Mica Dam forebay (“MCA Forebay LDB” per Golder (2014));
- one site at the Revelstoke Dam forebay.

The study plan will optimize the deployment of units for time periods thought to best capture synchronous condense use. Based on historic use data, this period is likely to be late March to mid-May (see assessment below). These TOR assume that one month of monitoring will be selected based on historic frequencies.

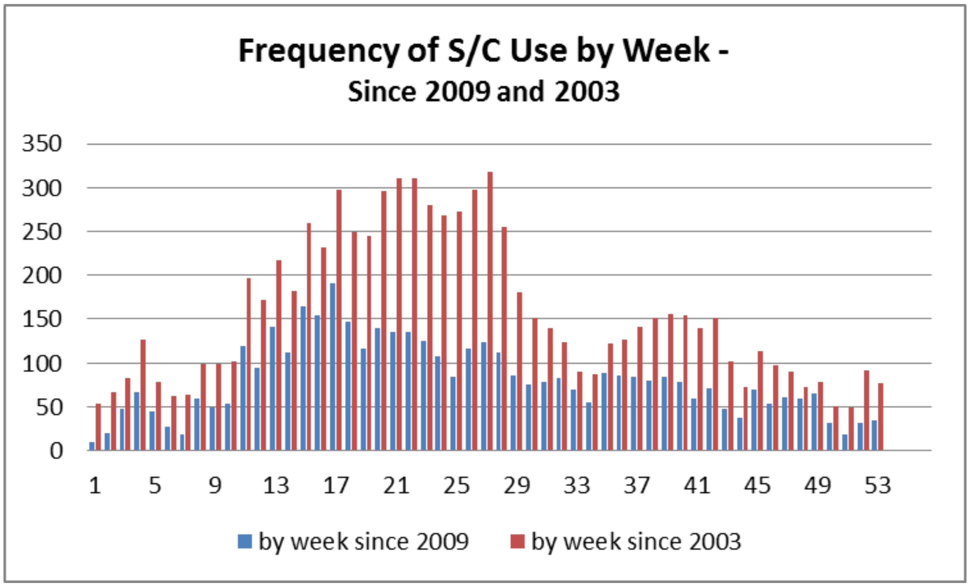

Figure 1: Frequency of Synchronous Condense (S/C) use by week number since 2009 and since 2003 (CRO 2014).

Additional operating scenarios to those already monitored will be tested. The following methods are suggested as possibilities and have been used as the basis for establishing the budget. Alternative methods may be proposed during the contracting process.

2.3.3 Task 3: Data Collection, Model Development and Analysis

Up to five annual sessions (each comprising 1 month of continuous monitoring at the four sites identified in the study plan) are anticipated to address the study program's management questions; three years of monitoring sessions will be conducted following the commissioning and full operation of Unit 6. Total dissolved gas meters, provided by BC Hydro, will be serviced and calibrated by their manufacturer prior to each deployment (servicing, installation and calibration expenses to be covered under this study budget). The "Blue Bridge LDB" site will be equipped with a back-up monitoring unit, and field re-calibration will be provided as required. All data obtained from the recording instruments will be downloaded to a computer in the field and backup copies of the computer files will be produced. Units will be checked once per week during each 4-week deployment (installation and de-installation plus two additional checks).

A conceptual model will be developed to define the data requirements to address the management questions. Previous data collected (Fidler 2005; unpublished data 2010-2011) will be used to augment in this study. If annual assessments are found to not to be answering the management questions, the proponent will propose alternative study designs to meet the management questions within the proposed time and budget of the study program. Any recommended change in approach would need to be implemented well in advance of the end of the study program.

All field data collection shall follow the detailed methods used for monitoring described in Golder (2014). BC Hydro will maintain records of unit operation and air injection into the units, and provide this information for presentation with the data report.

A MS Excel database will be developed to enter all collected data, and QA/QC of all data will be undertaken against spot measurements and unit operation.

2.3.4 Task 4: Fisheries Use Assessment and Synchronous Condense Review

While direct biological monitoring is not within the scope of this project, the proponent will be responsible for using existing fisheries use data from the Mica tailrace and Revelstoke Reservoir to interpret risk to fish populations relative to each habitat on a local and watershed scale (e.g., Plate 2014 and Irvine et al 2013). Fish species of focus will include Bull trout, Kokanee, Mountain whitefish and species of concern. Criteria for risk assessments may include species life history habitat use proximal to supersaturation zones, relative distribution of the population to those zones, species specific dose-response information, and characterization of operations risk (frequency of S/C use, timing, duration, intensity – Unit #, etc.). The criteria will be developed and assessments provided that will inform both the hypotheses and management questions above.

A review of historical operation of Unit 1-4 will be conducted to identify synchronous condense operations requirements and physical processes that cause dissolved gas supersaturation. A similar review of anticipated Unit 5 and Unit 6 operations will be conducted. An assessment of the typical use patterns (time of year, market/system conditions which require S/C use, and projected scenarios that will dictate S/C use) will be done to inform the fisheries risk assessments above. A review of strategies used in other utilities to manage TDG during S/C operations will be conducted to ensure best management practices are pursued.

2.3.5 Task 5: Reporting - Final Risk Assessment and Alternatives Review

A brief technical report of the findings of the program will be prepared annually. The annual reports will document the progress on the tasks above and identifying opportunities to improve the resolution of management questions.

Upon completion of the monitoring program, a comprehensive final synthesis report will be prepared which will include:

a) an executive summary documenting the status of hypotheses and management questions;

b) a description of the methods employed with sample sites mapped and site configurations

c) a data summary of dissolved gas supersaturation information collected (spot and continuous measurements) in MS Excel format by site for all years; data will also be summarized to highlight the effects of different unit S/C and normal operations configurations to illustrate any potential for mitigation or lack thereof;

d) Professional judgment will be supplied by a specialist in total dissolved gas impact assessment as to the potential local and watershed-level fish population impacts of both observed and extrapolated unit operations, and specifically comparing the impacts of Unit 1-4 and Unit 1-6 S/C capacities and use.

e) Where impacts are predicted to persist due to current/anticipated operations, the effectiveness of “fish flush” operations as evaluated in Fidler (2005) will be re-evaluated by a specialist in total dissolved gas impact assessment where opportunity is provided. The specialist will provide a recommendation for a mitigation strategy based on comparison of TDG management alternatives defined by key metrics (approximate costs, effectiveness (biologic, physical), and feasibility (historic success, operational compatibility, dam safety concerns)). Alternatives will include the current operation, optimized Unit use (unit/draft tube #, intensity of use, frequency of use, timing with respect to fisheries use and environmental variables such as temperature), other best practices identified in this review or other physical mitigation measures.

Reports will follow the standard format that is being developed for WUP monitoring programs. All reports will be provided in hard copy and as Microsoft Word and Adobe Acrobat (*.pdf) format, and all maps and figures will be provided either as embedded objects in the Word file or as separate files.

2.4 Interpretation of Monitoring Program Results

Dissolved gas supersaturation data collected during various combinations of synchronous condense operation at the Mica Generating Station will be compared to BC Hydro's total dissolved gas management thresholds established in consultation with DFO and MOE - to determine the effects of synchronous condense operation of Units 1 through 6 in relation to historic operations of Units 1 through 4, and on overall TDG levels. Results from the various operational scenarios will be examined in conjunction with the evaluations of S/C operating requirements and project use to evaluate options to reduce TDG levels, either through operations or other means. All analyses will be linked to the management questions and related impact hypotheses, leading to a risk assessment as prescribed in BC Hydro's TDG management strategy.

2.5 Schedule

It is proposed that this program be conducted during two sessions prior to the commissioning of Unit 6 and 3 sessions following the confirmed addition of the new units to synchronous condense operating capacity at the dam. Commissioning of Unit 6 is proposed for 2016. Year 1 monitoring of the "Addendum Phase" of this monitoring program will be initiated in spring 2015 where 2016 operations will likely see limited Unit 6 use.

2.6 Budget

Total Revised Program Cost for CLBMON-1 **$111,099**.

Total Program Cost for CLBMON-62 **$174,250**.

3.0 REFERENCES

BC Hydro 2013 (working copy). Mica Project Generation Operating Order. Prepared for BC Hydro Generation Resource Management, Burnaby, BC.

Commercial Resource Optimization (CRO) 2014. Summary of unit operations (filtered for synchronous condense operations) 2003-2014. BC Hydro uncorrected data.

Environmental Assessment Certificate Application 2010. Certification for Mica Generating Station Unit 5 Project. Prepared for BC Hydro by the BCEAA Office, Victoria, BC.

Fidler, L.E., et al. 2005. Dissolved Gas Supersaturation at the Mica Dam, 2005. Draft report prepared by Aspen Applied Sciences Ltd. for BC Hydro. 74 pp.

Fidler, L.E., and Miller, S.B. 1997. British Columbia Water Quality Criteria for Dissolved Gas Supersaturation - Technical Report. Contract report to the B.C. Ministry of Environment, Department of Fisheries and Oceans, and Environment Canada. Aspen Applied Sciences Ltd., Cranbrook, B.C., Canada.

Fidler, L.E. 2004. Addendum to the "British Columbia Water Quality Guidelines for the Protection of Aquatic Biota from Dissolved Gas Supersaturation (DGS)" and Protocols for Development of Site-specific Guidelines for DGS. Contract report to Fisheries and Oceans Canada, Habitat and Enhancement Branch, Pacific Region, Vancouver, B.C., Canada by Aspen applied Sciences Ltd., Kimberley, B.C., Canada.

Golder, 2011. MICA Outlet Works Operating Gates TGP Assessment. Prepared for BC Hydro, Castlegar, BC.

Golder 2014. Memo – Mica Dam total gas pressure (TGP) monitoring in 2013. Memo from Chris King to Leanne Todd for BC Hydro GIS Project, Burnaby, BC.

Irvine, R.L., Thorley, J.L. and J. Bisset, 2013. Mica tailrace fish indexing study – interim report (year 1). Report prepared for BC Hydro, Vancouver, BC by the Canadian Columbia River Inter-tribal Fisheries Commission and Poisson Consulting Ltd. 34pp + 7 appendices.

Klohn Crippen Berger, 2014. Mica Generating Station GIS (Gas Insulated Switchgear) 2012 Outage Impact and Mitigation Summary Report and Lessons Learned. Prepared for BC Hydro Project Delivery, Burnaby BC.

Millar, Scott, G. Ash, C. Powell, 1996. Seasonal and operational survey of total gas pressure production in the Columbia River Basin (1995). Prepared for BC Hydro Strategic Fisheries, Burnaby, BC.

Personal communication with Byron MacKenzie (2013) regarding the use of Mica Units 5 and 6 for synchronous condense operations.

Plate, E.M., 2014. Mica Dam, Revelstoke Reservoir 2013 – A literature review and field work to assess fish residency and total gas pressure supersaturation risk in the Upper Revelstoke Reservior. Prepared for BC Hydro by LGL Ltd.