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)

Implementation Year 3

Reference: CLBMON 1-62

Study Period: May 2017 to June 2017

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EXECUTIVE SUMMARY

Rainbow Trout (*Oncorhynchus mykiss*), Kokanee (*Oncorhynchus nerka*), Bull Trout (*Salvelinus confluentus*), Mountain Whitefish (*Prosopium williamsoni*) are all occupying Revelstoke Reservoir downstream of Mica Dam. All four species have been shown to hold near the tailrace and are presumed to hold at times right in the outflow of the draft tube since currents at this location are reduced in certain operational modes. These species have varying sensitivity to super saturated (>100%) levels of total dissolved gas pressure (TGP) that diminish with the depth that they are rearing in. All species can also display behavioural changes or gas bubble trauma (GBT) based on long-term (days to weeks) exposure of TGP levels > 110% and the same symptoms based on short-term (hours to days) exposure to TGP levels > 130%. The effects of GBT in fishes can range form behavioural modifications and tissue damage to mortality. Therefore, TGP levels and the operational scenarios that high TGP levels are caused by need to be monitored in the shallow water downstream of Mica Dam as part of CLBMON-1/62 to assess the potential for damage to the resident fish species.

Originally, the Mica Dam consisted of four generating units; two of which were capable of synchronous condense operation. Due to recent upgrades and the installation of a fifth generating unit in 2015 and a sixth generating unit in 2016, all generators at Mica Dam were capable of performing Synchronous Condense (SC) operations in 2017. Generating units are operated in the SC mode to maintain electrical current on distribution systems and thus be flexible to generate and distribute electrical power on short notice. SC operations involve air being injected into the draft tube to lower water levels below the generator blades, in turn allowing the generator blades to be rotated by a motor with less friction in air than in water. The resulting water turbulence and increased air pressure in the draft tube causes supersaturation with gas, increasing levels of TGP in the water. The supersaturated water is then released into the Columbia River through the tailrace.

Total Gas Pressure (TGP) in Revelstoke Reservoir below Mica Dam was monitored from May 9 to June 13, 2017 under combinations of the three operating modes (generating, idling and synchronous condense or SC) for each of the six turbines installed in Mica Dam. During this period, Generators 1 and 2 mainly operated idling with short periods of generation and minimal time in SC. Generators 3 and 4 mostly operated in SC mode with some generation periods and little idling. Newer Generators 5 and 6 were mainly idling with short periods of generation. Only Generator 6 operated in SC during the sampling period for a total of two hours and forty-five minutes.

The highest mean TGP Supersaturation or TGPS was observed when SC occurred without generation (either with one or two generators operation in SC). For these states, the mean TGPS values measured in 2017 were 108% in comparison to 114% in 2016. The highest TGPS peaks were also caused by operating two turbines (mainly Generators 3 and 4) in SC while all the other generators were idling. For this state, peak values of up to 119% - 122% were reached for an average of 4 h 22 min in 2017 in comparison to 128% in 2016. When one or two generators were operated in SC mode while the other generators were idling, all flow through the dam was generated by turbines in the SC mode without any additional flow and dilution from generation. No other combination of operating modes created any peaks higher than 110%, the BC Water Quality Guideline (BCWQG) TGP benchmark for aquatic life. In this context, it should be mentioned that the BCWQG for TGP is independent of the depth that the aquatic life is holding contrary to the fact that physiological TGP effects are counteracted by hydrostatic pressure. This means that for every meter of holding depth the physiological TGP effects are reduced similar to a reduction of TGP by 10%. Therefore, a fish holding in 1m depth will experience the measured TGP of 110% as a physiological TGP of 100%.

TGPS peaks generated by the aforementioned combinations of turbine modes dissipated with increasing distance from the dam to values that rarely exceeded BCWQGs (110%) at a distance of 11 km when peaks of 122% were measured close to the dam.

To investigate potential operational adjustments for the reduction of high TGP values, TGP peaks caused by long-term SC operations were analyzed in detail. Large (>10%) reductions in TGP from TGP supersaturation (>110%) to 100% background values could not be accomplished within periods of SC discontinuation and simultaneous generation shorter than 2 h. In 2017, long periods of SC operation were more often interrupted by short periods of generation and thus the mean and peak TGPS values were lower than in 2016.

Based on TGP and temperature data collected during the spring of 2017, a positive linear relationship between temperature and TGP levels was identified.

As part of the data reporting for this project, we developed a password protected web-based application under the tradename “Shiny App” to allow for real time manipulation of factors. In addition, a click with a cursor exported final graphs as picture files for direct inclusion into this report. All data graphs created in this report are examples of the use of the “Shiny App”. The progress made in 2017 in respect to project management questions are summarized below.

Management Questions (MQs)	**Has MQ been addressed?**	**Current Supporting Results**	**Identified data gaps to address**
1. What is the impact of synchronous condense operations in Mica Units 1 - 6 on dissolved gas supersaturation?	The MQ has been addressed for Mica Units 1-4 and will be addressed for Units 5 and 6 as soon as they can be operated in synchronous condense mode (likely in 2018).	**1.** High levels of TGP appear to be the result of any time one or two of the units are operated in synchronous condense mode for more than 8 h while the other units are operated in idling mode, thus creating no to little discharge to dilute the high TGP water. Once one or more generators are switched to generation mode for longer than 2 h, TGP levels decrease by 12%.	The effect of generators 5 and 6 synchronous condense mode operation on TGP level have not yet been assessed.
a. Is there a difference in dissolved gas supersaturation depending on which of the six units at Mica Generation Station is operated in synchronous condense mode (can all units be treated the same in terms of generation of high TDG)?		a. No, there is no difference between Units 1-4.	
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)?		b. GP levels >120% measured within 300 m of Mica Dam, decrease to levels of 110% at a distance of 11 km at a travel rate of approximately 1 km/h and slightly increased TGP levels can persist throughout the reservoir to Revelstoke Dam.	

Management Questions (MQs)	**Has MQ been addressed?**	**Current Supporting Results**	**Identified data gaps to address**
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 a Plume, what is the rate of travel and hence potential exposure to resident fish?		c. The TGP plume generated by synchronous condense operations appears to remain as a cohesive plume with slightly diminishing TGP levels as it travels down the Revelstoke reservoir at an estimated rate of 1.0 km/h. The plume will expose fish to high TGP levels along its path but will have the highest potential health effects within the first 3.5 km downstream of the dam where all resident fish species can be found.	
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?	No	The effect of generators 5 and 6 synchronous condense mode operation on TGP level have not yet been assessed	TGP needs to be monitored during synchronous condense operation in units 5 and 6 in 2018 and 2019.
3. Given what is known of Revelstoke reservoir fish ecology, what is the potential biological impact of a given high TGP event?	Yes	During the 2016 and 2017 sampling seasons, TGP levels were not high enough for long enough periods of time to suspect negative biological impacts based on indicator species	

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?	Yes	Changing the ratio of SC mode to generation mode to favour slightly shorter periods of SC (< 8 h at a time) and longer periods of generation (> 2 h) should keep TGP levels < 110% based on synchronous condense results for generators 1-4. Such assumptions cannot be made for generators 5 and 6 due to a lack of data.	More monitoring is required to observe trends in data for operating generators 5 and 6 in synchronous condense mode.

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INTRODUCTION

Setting

Mica Dam is located in south east British Columbia, 150 km north of Revelstoke and represents the upstream border of Revelstoke Reservoir. Revelstoke Reservoir is part of the Upper Columbia River located between the Monashee Mountains on its west and the Selkirk Mountains on its east shores. The reservoir has many tributaries and is oriented in a north to south direction (Figure 1). It was formed when Revelstoke Dam was completed in 1984. Revelstoke Dam is located ~6 km upstream of the city of Revelstoke. Revelstoke Reservoir is the second in a series of three hydroelectric reservoirs, located downstream of Kinbasket Reservoir to the north and upstream of Arrow Lake Reservoir to the south. Kinbasket Reservoir was formed by the construction of Mica Dam in 1973 and Arrow Lakes Reservoir was formed by the construction of Hugh Keenleyside Dam in 1968 both as a result of the Columbia River Treaty.

Revelstoke Reservoir is operated as a run-of-the-river storage basin with small water level fluctuations throughout the year (Figure 2). The majority of inflow into the reservoir is created by discharge from Mica Dam for all seasons aside from early summer when the freshet flow of the Revelstoke Reservoir tributaries contribute the majority of the inflow and the discharge from Mica Dam is reduced to maintain a steady reservoir level (Figure 2). The freshet discharge from tributaries is also the biggest contributor of nutrients into Revelstoke Reservoir (Bray et al. 2013).

For the first 3 km below the dam and upstream of the mouth of Nagle Creek the reservoir is narrow (<300 m), shallow (5 – 10 m), slowly flowing and has very clear and nutrient poor water (Plate 2014). With the contribution of nutrients from Nagle Creek, the water in the reservoir becomes more turbid and a small amount of additional nutrients is added. Approximately 3 km downstream of Nagle Creek, the valley and the reservoir also widen to more than 1 km and to full width at Mica Camp, approximately 8 km downstream of Mica Dam. Here the reservoir also becomes deeper (>20 m) along the former river bed of the Columbia River and can be weakly thermally stratified in the summer.

Revelstoke Reservoir has all attributes of an oligotrophic system with low Nitrogen (60 – 160 µg/L of Nitrate) and Phosphorus (4 – 7 µg/L of Total Dissolved Phosphorus) concentrations and a deep photic zone (10 – 20 m) (Bray et al. 2013). Small annual spikes of main nutrients follow freshets that transport nutrients from the tributary watersheds to the reservoir. Accordingly, Chlorophyll concentrations (mean= 0.92 µg/L), as a measure of primary productivity, are also very low (Bray et al. 2013). Despite the low productivity, the phytoplankton community composition of Revelstoke Reservoir appears to offer a grazing base for the zooplankton community that contains several large species of Daphnia and Copepods which in turn represent a good food source for Kokanee (*Oncorhynchus nerka*) (Bray et al. 2013).

The upper 20 km of Revelstoke Reservoir below Mica Dam are characterized by hypolimnetic (taken from below the thermocline) cold water (~ 9 – 11 ^{o}C in the summer) fed into the reservoir through Mica Dam from Kinbasket Reservoir.

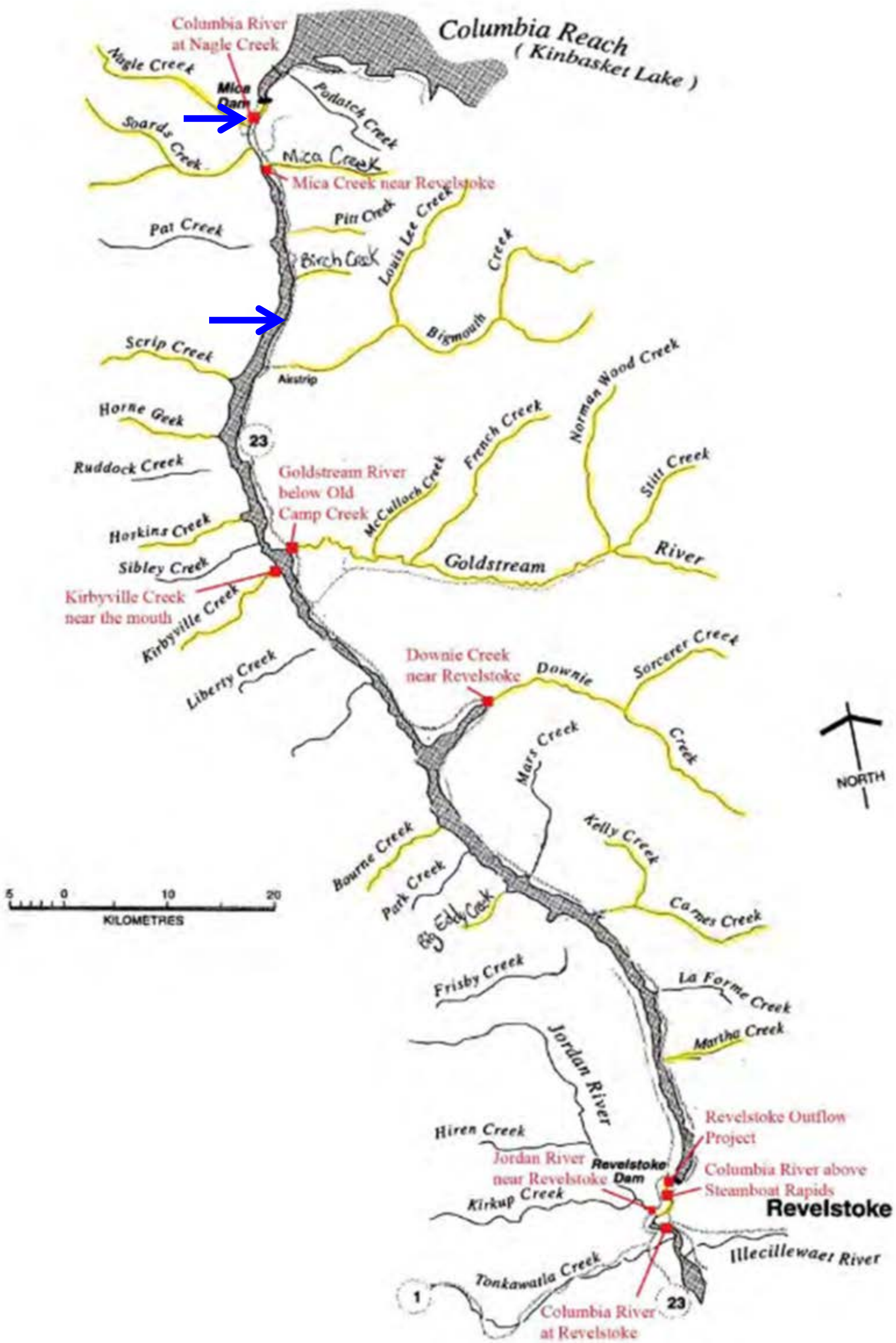

Figure 1 Map of Revelstoke Reservoir and main tributaries. The study area for this project reaches from Mica Dam in the north to the area between the mouth of Birch and Bigmouth Creeks (blue arrows) in the south (from: BC Hydro 2010). Red markers are showing local names for points of interest.

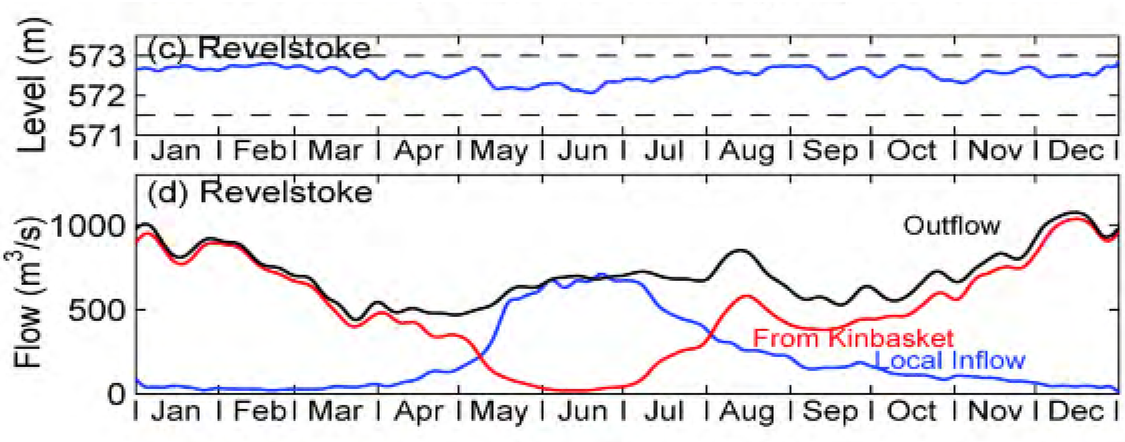

Figure 2 Water level and flow in Revelstoke Reservoir in 2008 typical for other years (unmodified from: Bray et al. 2013, Figure 2 c).

Mica Generating Station Total Gas Pressure and Fish

Rainbow Trout (*Oncorhynchus mykiss*), Kokanee (*Oncorhynchus nerka*), Bull Trout (*Salvelinus confluentus*), Mountain Whitefish (*Prosopium williamsoni*) have all been found directly downstream of Mica Dam (Bisset et al. 2015). Originally, the Mica Dam consisted of four generating units; two of which were capable of synchronous condense operation. Due to recent upgrades and the installation of a fifth generating unit in 2015 and a sixth generating unit in 2016, all generators at Mica Dam were capable of performing Synchronous Condense (SC) operations in 2017. Regardless, aside from 2.5 h, generating Units 5 and 6 were not operated in SC mode in 2017. Generating units are operated in the SC mode to maintain electrical current on distribution systems and thus be flexible to generate and distribute electrical power on short notice. While the SC mode requires energy to drive motors that keep turbines rotating, the flexibility to generate and deliver power immediately in response to power demands makes SC operations economically worthwhile. SC operations involve air being injected into the draft tube to lower water levels below the generator blades, in turn allowing the generator blades to be rotated by a motor with less friction in air than in water. The resulting water turbulence and increased air pressure in the draft tube causes supersaturation with gas, increasing levels of total dissolved gas pressure (TGP) in the water. The supersaturated water is then released into the Columbia River through the tailrace. Bull Trout, Burbot (*Lota lota*), Mountain Whitefish and Rainbow Trout have been shown to hold in the vicinity of the tailrace (Golder Associates Ltd. 2009, Irvine et al. 2013) and are presumed to hold at times right in the outflow of the draft tube since currents at this location are reduced in SC mode. Should Mica Dam generators be operated in SC mode in October and November, extended periods (>24 h) of TGPS at levels >120% could lead to injury or mortality of Kokanee spawning in shallow water (1-3 m) in the vicinity of the Blue Bridge (3 km downstream of Mica dam) in Revelstoke Reservoir as observed by Plate (2014).

In 1995 BC Hydro investigated fish mortalities in the Mica Dam tailrace and identified TGP Supersaturation or TGPS as one of the causes (Millar et al. 1996). Following the study, BC Hydro collected data on total dissolved gas to identify TGP levels during different unit operations and found levels could reach 200% in the draft tube when Units 1 and 2 were operated in SC mode for long periods of time, thus exceeding the 110% no-effects threshold by a wide margin. Based on this knowledge, BC Hydro created total dissolved gas best management practices in 1996 (BC Hydro 2013). Following the establishment of best management practices, periodical sampling of TGP has been conducted in several systems, but due to limited information regarding SC operational impacts, the Water Use Plan Consultative Committee – Fish Technical Sub Committee recommended additional sampling downstream of Mica Dam for TGP impacts. In addition, the recently installed Unit 6 and the previously installed Unit 5 will also be capable of operating in SC mode and their effects on the TGP situation downstream of Mica Dam will need to be investigated. Therefore, BC Hydro initiated the five-year Mica Dam TGP or CLBMON-1/62 monitoring program.

Total Gas Pressure and Fish

The recorded TGP supersaturation in Revelstoke Reservoir and other similar systems is the result of increased partial gas pressure of one or more gases in water. During supersaturation, TGP becomes higher than the barometric pressure and can therefore be reported as a relative percentage of barometric pressure, or directly as the difference in pressure between the barometric and the pressure encountered in the water column expressed as mm Hg. For the ease of use and because the BC Water Quality Guideline TGP value is also expressed as a relative dissolved gas saturation percentage, we will from here on refer only to the TGP percentage relative to the barometric pressure.

The blood of fish exposed to elevated TGP levels will quickly attain TGP equilibrium with their environment via gas exchange at the gills and become supersaturated. In the supersaturated state, dissolved gases in blood have the tendency to come out of solution and form bubbles that can lead to embolism or blockage of blood vessels. Embolism can cause lack of blood circulation to parts of the organism and in severe cases lead to mortalities. In fish, the state of gas bubble formation in the organism is called Gas Bubble Disease (GBD). The same condition is known as "the bends" when human SCUBA divers encounter bubble formation in their body or blood. The symptoms of GBD in fish can be as subtle as small changes in behaviour, such as lethargy or cessation of feeding (Weitkamp and Katz 1980) or as advanced as visible bubble formation under the skin, in the eyes or in fins that can ultimately lead to fish mortality. Typically, TGP saturation levels of less than 110% do not damage fish while TGP levels between 110 – 120% can lead to behavioural changes and reversible damage; long-term exposures to TGPS >120% in a laboratory setting often leads to permanent damage or mortality (Weitkamp 2008; Weitkamp and Katz 1980; Fidler and Miller 1994). Therefore, the British Columbia Water Quality Guidelines and the U.S. Water Quality Standards set 110% TGPS as the upper acceptable limit for the well-being of fish and other aquatic organisms.

TGPS will only lead to GBD in fish if they are in shallow water where gases are not kept in solution by hydrostatic pressure. As a general rule, for every meter of depth gained by a fish it can tolerate 10% more TGP (Weitkamp 2008) while the measured TGP levels could be consistent throughout the full depth range. For example, most fish would die of GBD and embolism at a long-term TGPS of 130% near the surface. At a depth of three meters, the same fish would only experience physiological effects that are similar to a TGP of 100% and therefore not experience GBD and the resulting injury or mortality. TGP levels ranging from 120 – 140%, typically encountered below dams during water release over spill ways will therefore only lead to GBD in fish that are in the top 2 – 3 m of the water column.

TGPS in water can result from different causes but in the context of power generation at dams it is commonly related to three factors:

1. Air bubbles are entrained in falling water released over surface spill ways or sluice ways. The same air bubbles are then entrapped in deep plunge pools by hydrostatic pressure that forces them into solution and supersaturates the water with a gas mixture mainly composed of Nitrogen and Oxygen (Fidler and Miller 1994). The supersaturated water then flows down the river while gases are only exchanged at the surface of the water column where supersaturation is slowly abated. For deeper water without direct gas exchange with the environment and with laminar flow without riffles or rapids, the supersaturated state can persist with minor dissipation downstream for tens of kilometres. This scenario typically leads to TGPS values ranging from 110 – 140% below dams during water release over surface spillways but can lead to TGPS values that are higher than 140% (Clark 1977 in Fidler and Miller 1994; Weitkamp and

Katz 1980; Hildebrand 1991; White et al. 1991). In the case of Revelstoke Reservoir, of 17 TGP measurements carried out between Mica Dam and Revelstoke Dam before 1977, 9 showed values below 110% while 8 measurements showed values between 110 – 120% (Clark 1977 in Fidler and Miller 1994). Twelve (6 < 110% and 6 > 110%) of the 1977 TGP measurements were carried out between Mica Dam and the Blue Bridge (3.5 km below dam), while the other five TGP measurements (3 < 110% and 2 > 110%) were carried out in 35 km downstream of the Blue Bridge in Revelstoke Reservoir. For these TGP values, the Mica Dam operational details are unknown but nevertheless above guideline TGPS values (110%) can occur in Revelstoke Reservoir. In addition, preliminary results from TGP monitoring carried out in 2012 during a prolonged spill over Mica Dam showed TGPS values of 120 – 125% (BC Hydro, unpublished data). At these values, GBD and potentially long-term damage or mortality can occur in fish that do not have access to deeper habitat (e.g., >1.5m depth) or are holding in water <1.5 m depth.

2. Water is mixed with air bubbles in a suction scenario. In this case the air bubbles are entrained into the water in surface vortices at water intakes or through air leaks or intentional air injection occurring at the upstream side of turbines or pumps (Fidler and Miller 1994). When gravity fed turbines are turning they have the tendency to suction in water from the upstream side and increase the hydrostatic pressure at the face of the turbine blades, thus entraining air bubbles on the upstream side and bringing them into solution on turbine blades and releasing supersaturated water on the downstream side (Fidler and Miller 1994). This scenario can occur below dams when generating electricity without spilling especially when the water level at the in-take is low and thus more vortices are created. This scenario is not considered as problematic since it typically leads to TGPS pressures of 102 – 110% (Fidler and Miller 1994), which do not appear to affect the behaviour or the physical well-being of fish (Weitkamp 2008; Weitkamp and Katz 1980). These lower TGPS values also do not surpass neither the British Columbia Water Quality Guidelines nor the U.S. Water Quality Standards that state an upper limit of 110% TGPS for the well-being of fish and other aquatic organisms.

3. The operation of turbines in SC or Synchronous Condense mode as is the case at Mica Dam. The physical details and rationale for using this mode is explained above.

The frequency of TGPS occurrence is dependent on many factors but higher TGPS levels are often connected to SC mode of operation or surface spills as is the case for the Mica Dam and Revelstoke Reservoir. Although it is commonly accepted that TGP supersaturated water masses do not easily release their elevated gas pressure, and it is unknown how the TGP supersaturated water masses in Revelstoke Reservoir behave. The geographical focus of TGPS in this study were the initial 11 km below Mica Dam since the contribution of non-TGPS water from tributaries may lead to a gradual drop in TGP. Ideally, and alongside detailed knowledge of fish behaviour, the detailed temporal and spatial distribution of TGP supersaturated water in Revelstoke Reservoir following SC operations mode or a surface spill over Mica Dam needs to be known to assess the extent of possible damage to fish populations. Therefore, BC Hydro commissioned a study to determine how many fish species occupy the shallow and TGPS prone water layer of Revelstoke Reservoir close to Mica Dam in 2013 (Plate 2014). In this study, large (>60 cm fork length) Bull Trout, juvenile Mountain Whitefish, juvenile sculpin species were found to hold in water of <2 m at night and spawning Kokanee Salmon were found to spawn in water of the same depth.

PROJECT MANAGEMENT QUESTIONS AND RESULTING ACTIVITIES

All Management Questions are directly cited from the CLBMON-62 Terms of Reference (BC Hydro 2014).

<u>Management Question 1:</u> 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 condense mode (can all units be treated the same in terms of generation 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 a Plume, what is the rate of travel and hence potential exposure to resident fish?

To address this management question, the following activities were carried out:

Activity 1: Six Total Gas Pressure (TGP) meters at increasing distance up to 11 km downstream of Mica Dam were installed to monitor TGP levels.

Activity 2: TGP levels below Mica Dam were compared with operational data to identify TGPS causing operational scenarios.

Activity 3: Starting in 2015 and continuing for the following five years, TGP was or will be monitoring to cover the periods of pre and post start-up of Mica Generating Units 5 and 6.

Management Question 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?

To address this management question, the following activities were carried out:

Activity 1: Collect TGP data downstream of Mica Dam while Units 5 and 6 are in idle, generating and SC mode.

Activity 2: Review BC Hydro's TGP Strategy and results from previous studies carried out in Revelstoke Reservoir to suggest how TGP levels affected by SC mode applied to Units 5 and 6 may affect downstream aquatic environments.

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

To address this management question, the following activities were carried out:

Activity 1: Use data from completed projects (CLBMON 60, CLBMON 3) in Revelstoke Reservoir and review the general literature to complete a literature review on fish ecology in Revelstoke Reservoir.

Activity 2: Use TGP data collected from 2015 – 2019 and compare to known thresholds, fish behaviour (at different life stages), and environmental factors (cover/invertebrates) to identify impacts.

Management Question 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?

To address this management question, the following activities were carried out:

Activity 1: Identify impacts based on results of Activities 1 and 2 under Management Question 3 and research possible mitigation measures, either through environmental enhancement or operational policies that will have minimal impact to dam operations.

METHODS

TGP Monitoring

Locations

TGP was monitored at 200 m (Station 0 and 0a, called "Tailrace"), 3.5 km (Station 1 & 2, called "Blue Bridge"), 10.5 km (Station 3) and 11 km (Station 4) distance from Mica Dam from May 9 to June 13, 2017 (Figure 3). Short-term (<2 h) spot measurements of TGP were also carried out in Nagle Creek immediately upstream of the road to Mica Dam and in the Mica Dam forebay from the boat ramp, approximately 800 m northeast of the centre of Mica Dam, on May 9, 25, and June 13, 2017. The Nagle Creek and Mica Dam forebay locations were chosen to identify TGP values in water entering the dam and in water entering Revelstoke Reservoir above the Blue Bridge (Table 1; Figure 3). Pentair Point Four Tracker Total Gas Pressure Meters (on the internet: http://pentairaes.com/total-dissolved-gas-pressure-tpg-meter.html) were used to record TGP levels and water temperature at 15-minute intervals.

Station 0a (200 m downstream of Mica Dam, east bank) recorded TGP levels in the tailrace of Mica Dam while Station 0 (200 downstream of Mica Dam, west bank) provided redundancy at close distance. These stations made it possible to compare TGP levels in the tailrace current (Station 0a) versus eddy (Station 0) scenario. One meter each was installed at Stations 1 and 2 on both sides of the Blue Bridge (3.5 km downstream of Mica Dam) for a total of two stations at the same distance from Mica Dam. This TGP meter redundancy was meant to counteract the extreme unreliability experienced with TGP meters in past projects. One TGP meter each was installed at Station 3 (reservoir east shore at 10.5 km distance from dam) and Station 4 (reservoir east shore at 11 km from dam) and therefore close enough to each other to compare and identify any inconstancies in the data. Spot checks lasted for 20 – 60 minutes at Nagle Creek and the Mica Dam forebay. For detailed information with regards to all stations see Table 1. Additional details with regards to downloads are summarized in Appendix A.

Table 1. TGP meter station and spot check information for Year 3 (2017)

Station Name	11U UTM East	11U UTM North	# of TGP Meters	Deployment Period	Downloaded
Station 0a	392855	5770094	1	9-May to 13-Jun	25-May & 13-Jun
Station 0	392719	5770021	1	9-May to 13-Jun	25-May & 13-Jun
Station 1	390683	5767814	1	8-May to 13-Jun	25-May & 13-Jun
Station 2	390786	5767739	1	9-May to 13-Jun	25-May & 13-Jun
Station 3	392541	5761129	1	8-May to 13-Jun	25-May & 13-Jun
Station 4	392523	5760933	1	8-May to 13-Jun	25-May & 13-Jun
Nagle Creek	390693	5768268	1	9-May, 25-May & 13-Jun	9-May, 25-May & 13-Jun
Forebay	393290	5771457	1	9-May, 25-May & 13-Jun	9-May, 25-May & 13-Jun

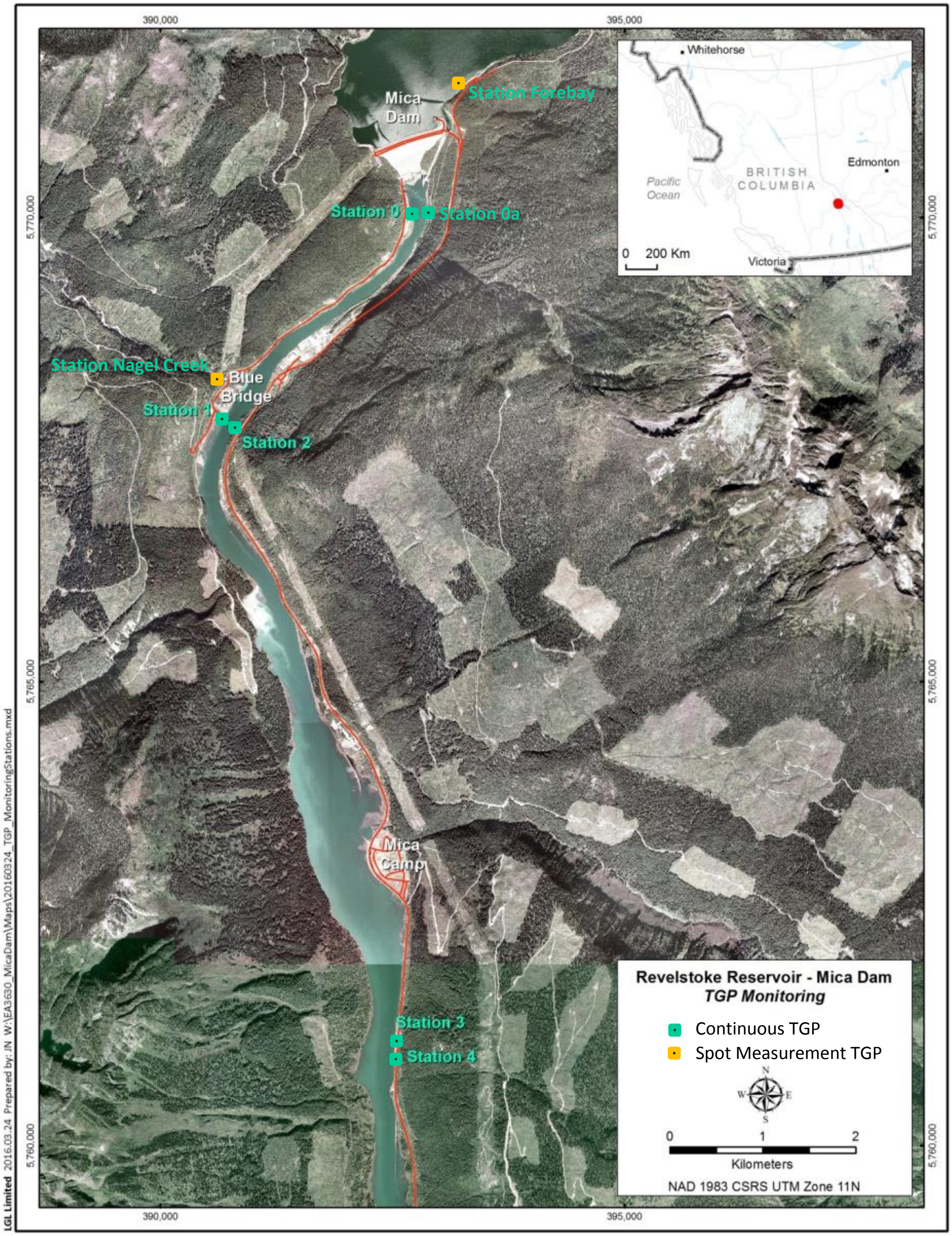

Figure 3. Map of the Revelstoke Reservoir downstream of Mica Dam showing TGP Stations and landmarks.

Deployment

For deployment, TGP meters in waterproof Pelican™ cases were stored in plastic totes and chained to brackets that were fastened with rock anchors to solid rock (Figure 4).

Figure 4. (A) TGP meter set-up at a station including pelican case, tote, chain and lock, and probe entering standpipe. (B) Example of an anchor for the standpipe. (C) Completed Station set-up with standpipe extending from TGP meter into the water. (D) Sonde extending 10 cm out of standpipe under water.

The sondes of the meters were deployed inside a 7 m and 5 cm diameter PVC pipe with the measuring membrane end protruding by 10 cm into open water (Figure 4). The PCV pipes, in turn, were fastened with brackets and rock anchors to solid rock and ended on the meter end inside the deployment tote. Thus all of the cable connecting the meter with the sonde was protected from physical or rodent damage. On the submersed end, standpipes were reaching to a depth of 2 – 2.5 m to avoid air exposure during water level fluctuations (Figure 4D).

Data collection was planned and executed to coincide with planned SC operations based on conversations with Mica Dam Operations and as indicated by past monitoring efforts (Plate et al. 2016 and Plate et al. 2017). The detailed TGP meter deployment schedule was therefore designed to cover a period of high SC operations likelihood. The details of the schedule are shown in Table 1. TGP data were downloaded from TGP meters onto a computer and backed up in the field to an external hard drive. While downloading, the scrolling data were inspected to ensure a proper download had occurred and any abnormalities were noted and fixed. In addition, the last TGP value, the temperature and the battery voltage before download were recorded. Batteries were replaced as part of each download and the water saturated membranes were replaced with cleaned and dried membranes. Then meters were calibrated against the barometric pressure and the sondes were re-deployed. For maintenance and download records see Appendix B. TGP meters were removed at the end of the study period and sent to Pentair Aquatic Ecosystems in Langley, BC for maintenance, recalibration, and repairs.

Data Analysis

Table 5 (Appendix A) shows the maintenance and download record for all TGP meters in 2017.

TGP and temperature data from each of the stations were combined with the Mica Generating Station operation data to obtain a complete picture of the system at 15 minute intervals. To simplify the analysis, the data for the generators, originally provided in megawatts (MW) was mapped to the states, with negative values corresponding to the SC mode, zero (±2 MW, to account for measurement error) to the idle state and positive values to the Generating state. Furthermore, the states of all six generators were combined to create a state of the complete Mica Dam generating system (e.g., S2 I3 G1 meaning that two generators were in SC mode=S, three were idle=I, and one was generating=G).

Data from spot checks in Nagle Creek and the Mica Dam forebay (Table 2) were recorded at 1 minute intervals for 20 – 60 minutes. The last value of each spot check was used to minimize the influence of elevated TGP readings seen when the probe first enters the water. Table 3 and Table 4 show the fish species specific TGPS exposure risk.

Data Presentation

As part of the data interpretation for this project, we developed a password protected web-based application under the tradename “Shiny App” to allow for real time manipulation of factors. In addition, a click with a cursor exported final graphs as picture files for direct inclusion into this report. All data graphs created in this report are examples of the use of the "Shiny App".

RESULTS

Of the six TGP meters that were deployed at four distances (0.2 km, 3.5 km and 10.5 – 11 km) from Mica Dam, the data of the three most reliable (least data gaps or unexplainable outliers) meters for each distance category were chosen to be presented. Nevertheless, data from the other three TGP meters were important to create redundancy and therefore reliability of data collection for the project..

State of Generators

Over the monitoring period of May 9 to June 13, 2017, the six turbines were operated for different frequencies of the three operating states, namely 1) generating, 2) idling and 3) Synchronous Condense mode. **Figure 5** shows that Generators 1 and 2 were mainly operated in idling mode with minimal time in generating and SC modes. Generators 3 and 4 were mostly in SC operations with periods of generation and idling. Generators 5 and 6 were mainly operated in idling mode with short periods of generation. Generator 6 was operated in SC mode for a short period of time (2 h 45 min).

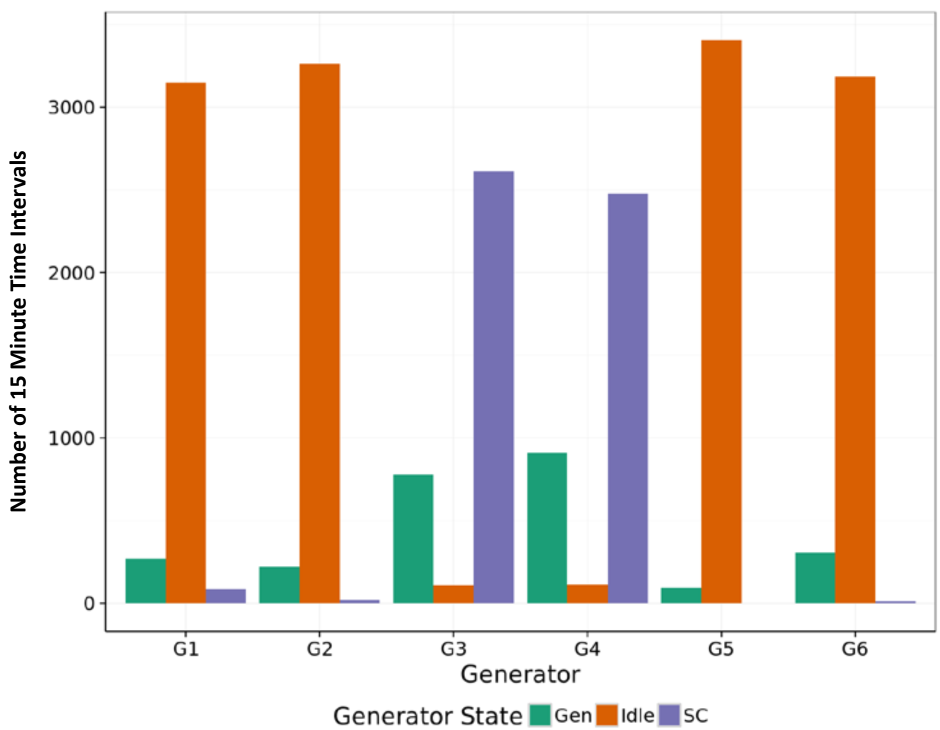

Figure 5. State of generators throughout the 2017 monitoring period from May 9 to June 13 (Gen = Generating; Idle = Idling; SC = Synchronous Condense Mode). The y-axis units are the number (N) of 15 minute time intervals.

TGP Generated by a Combination of Operating Modes for all Generators

The six generators installed in Mica Dam were operated at a combination of different modes to respond to energy demands. All six turbines were either generating (G), idling (I) or were operated in SC mode (S). Operating modes which had one generator in synchronous condense mode and the other five idling, and two in synchronous condense mode and the other four idling (S1 I5 G0 and S2 I4 G0) had the highest TGP mean values at 107% and 108% respectively at 0.2 km below Mica Dam (Figure 6). In these operating scenarios, flow out of the dam was generated completely by turbines in the SC mode without any additional flow from generation to dilute water with TGP values. When no generator was operated in SC mode, the median TGP values were 101%.

The mean TGP values slightly increased with distance from the dam. When SC mode was in operation without any generation (S1 I5 G0 and S2 I4 G0) the mean reached 112%, while the other combinations reached 104.5% (S0 I3 G3), 105% (S0 I4 G2), and 107% (S1 I3 G1; Figure 6, middle panel). TGP means for each state were reduced by the time they reached the farthest site (11 km) with mean values between 101% and 104% (Figure 6, right panel). For the detailed TGP values generated over time by different operations scenarios and for the three distances from Mica Dam see Figure 12 and Figure 13 (**Error! Reference source not found.**). Although the mean values for the SC only modes were higher at a distance of 3.5 km then at a distance of 0.2 km from the dam, the highest peak values were recorded at a distance of 0.2 km (Figure 12, Figure 13).

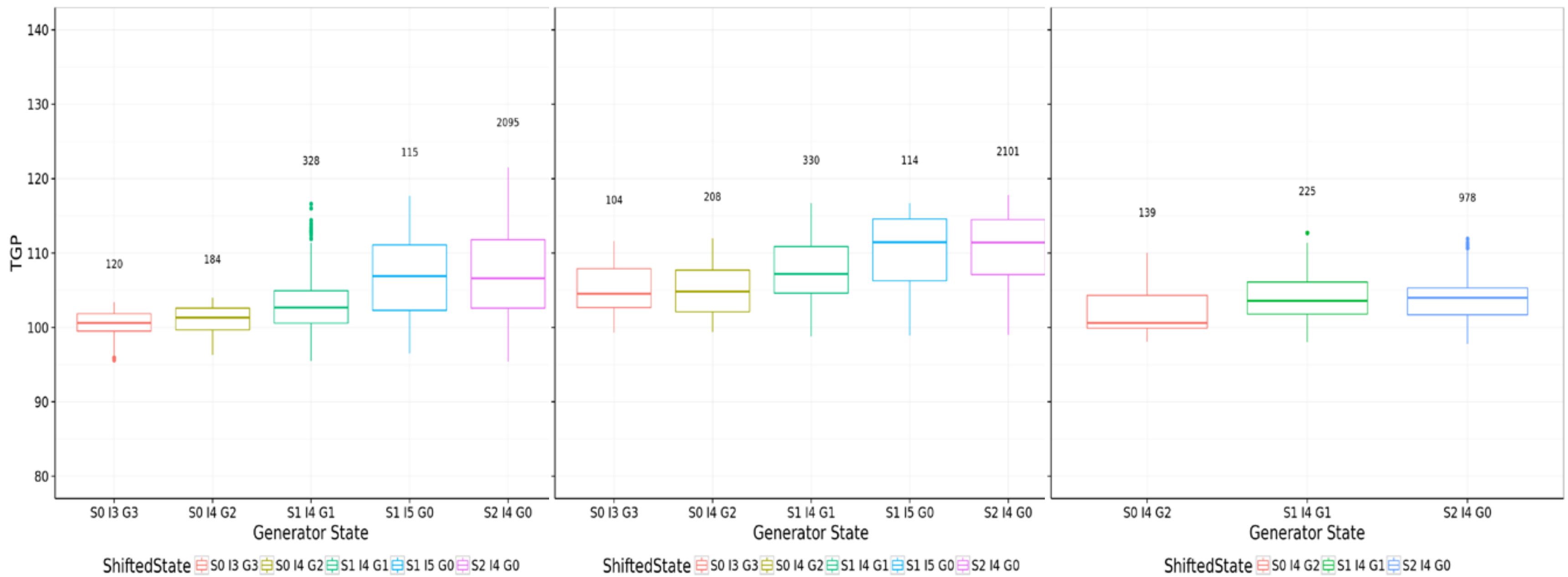

Figure 6. TGP (%) generated by combination of operating states measured at 0.2 km (left), 3.5 km (middle) and 11 km (right) from MD between May 9 - June 13, 2017 (0.2 km and 3.5 km), and May 9 – 26, and June 6 – 13, 2017 (11 km; S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above box-plots indicate sample size (N). Only combinations of states that were recorded more than 100 times (N>100) were included.)

TGP Exceedance of BC Water Quality Guidelines by State of Generators 0.2 km from Mica Dam

TGP values > 110% are exceeding BC Water Quality Guidelines (BCWQGs) for aquatic life and therefore are considered potentially harmful. Frequency of exceedance was greater when one to two generators were operating in SC mode while the other four generators were idling than when one generator was in synchronous condense mode and at least one other generator was generating (Figure 7). For the detailed TGP values generated over time by different operations scenarios see Figure 12 and Figure 13. Based on **Figure 8**, > 110% TGP values in 2017 occurred 32% and 34% of the time that Generators 3 and 4 were in the SC mode. No other generators were operated in SC mode > 300 times.

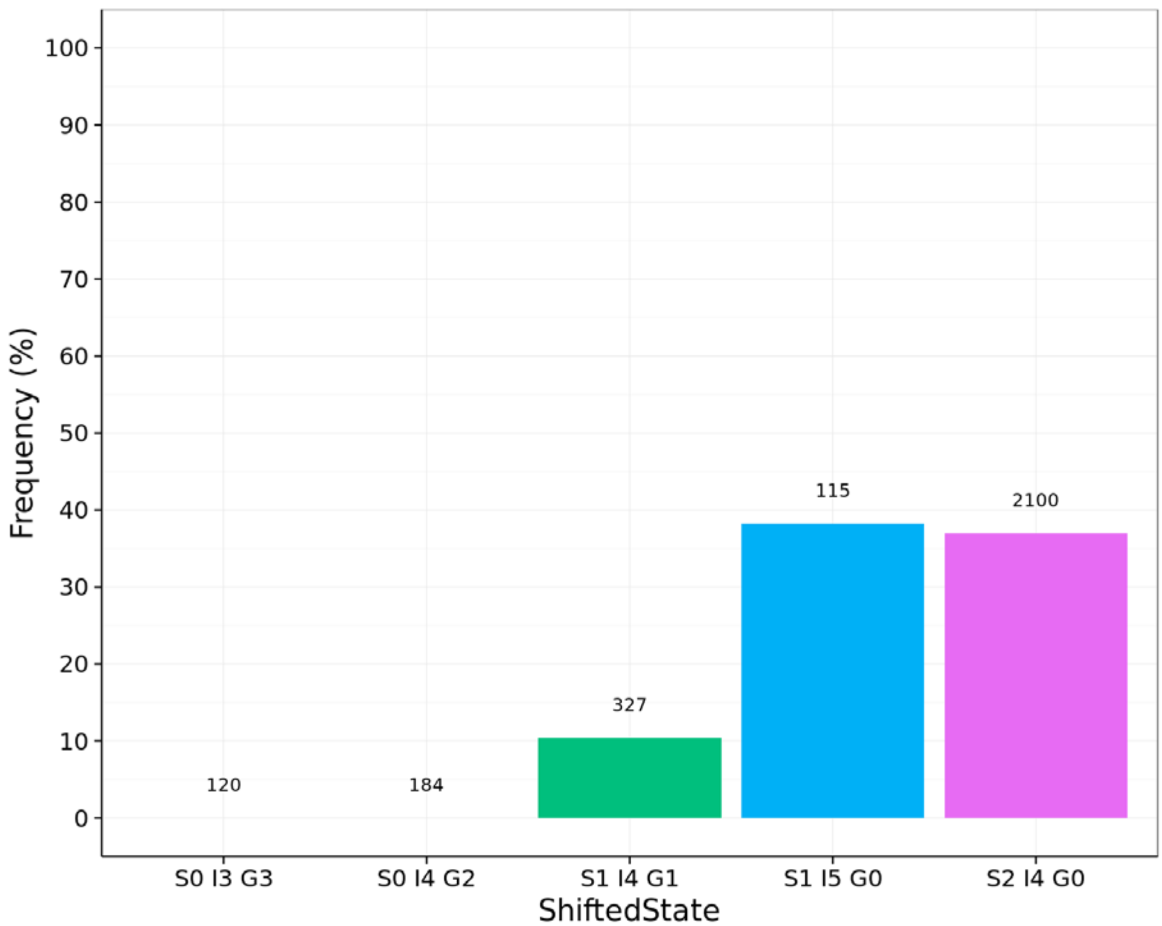

Figure 7. The frequency of TGP (%) values that exceed the BC Water Quality Guideline of 110% 0.2 km from Mica Dam (Stn0) by state of generators on Mica Dam between May 9 – June 13, 2017 (S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above bars indicate sample size (N was set to N > 100).

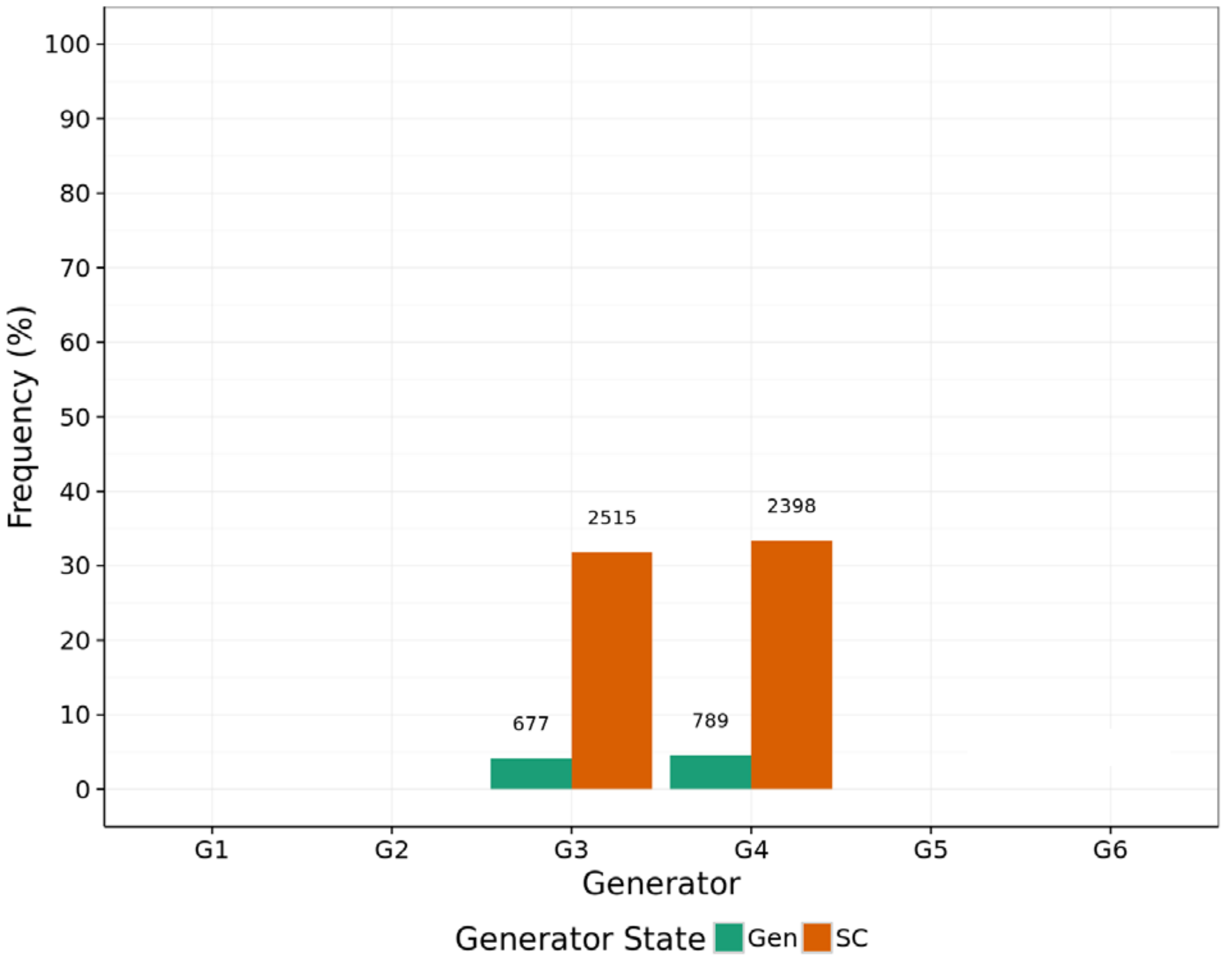

Figure 8. The frequency of TGP (%) values that exceed 110% by individual generator in Mica Dam between May 9 – June 13, 2017 (Gen = generating; SC = synchronous condense). Numbers above bars indicate sample size (N was set to N > 300).

TGP Exceedance of BC Water Quality Guidelines by State of Generators at Increasing Distance from Mica Dam

The frequency of exceedance was found to be similarly high and between 35-45% at Stn0 and Stn2 at distances of 0.2 km and 3.5 km from Mica Dam in the narrow lotic section of Revelstoke Reservoir (Figure 9). Further downstream, at distances of 10.5 km (Stn3) and in the wide lentic section of Revelstoke Reservoir, the TGP exceedance frequency had dropped to 12% when two generators were operated in SC mode and 6% when one generator was operated in SC mode (Figure 10, top panel). At a distance of 11 km (Stn4) this trend continued with exceedance frequencies dropping to 1% and 4% for one and two generators operated in SC mode.

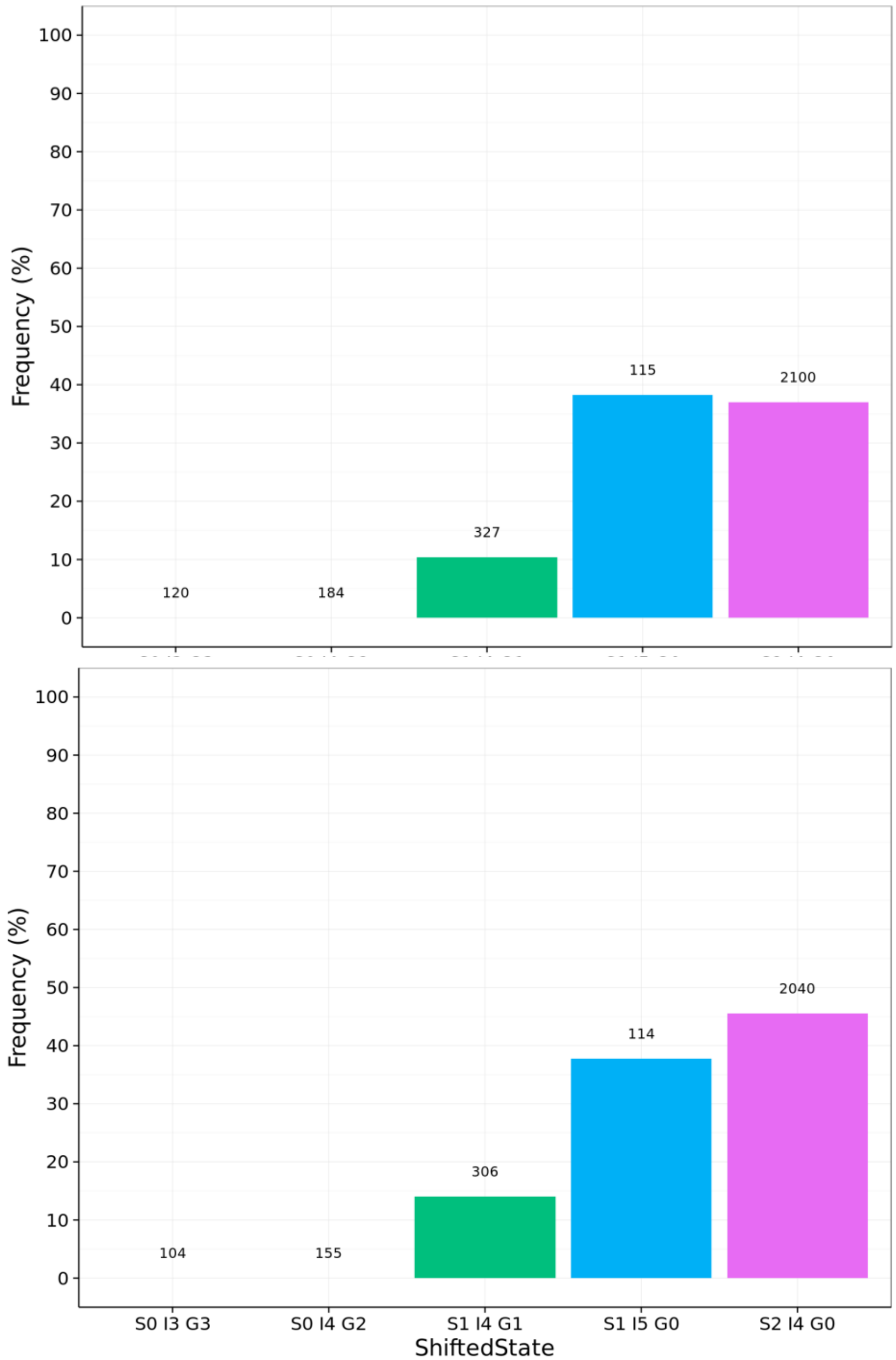

Figure 9. The frequency of TGP (%) values that exceed the BC Water Quality Guideline of 110% 0.2 km (Stn0, top panel) and 3.5 km (Stn2, bottom panel) from Mica Dam by state of generators on Mica Dam between May 9 – June 13, 2017 (S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above bars indicate sample size (N was set to N > 100).

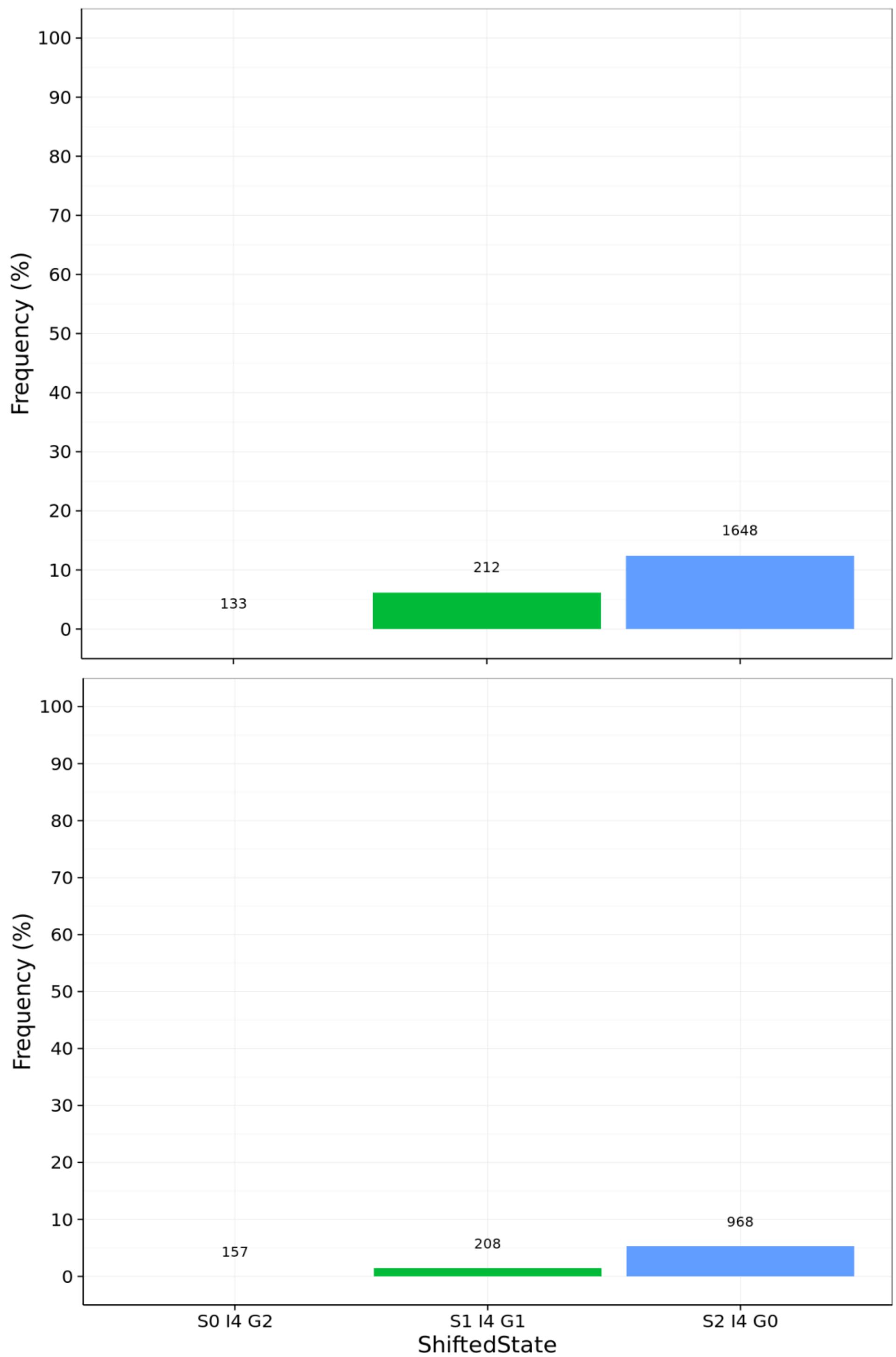

Figure 10. The frequency of TGP (%) values that exceed the BC Water Quality Guideline of 110% 10.5 km (Stn3, top panel) and 11 km (Stn4, bottom panel) from Mica Dam by state of generators on Mica Dam between May 9 – June 13, 2017 (S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above bars indicate sample size (N was set to N > 100).

TGP over Time by Generator

All TGP measurements described in this section were taken 0.2 km from the dam at Station 0. Only Generators 3 and 4 were operated for longer periods of time in SC between May 9 and June 13, 2017 and created high TGP values with peaks of 122% (Figure 11).

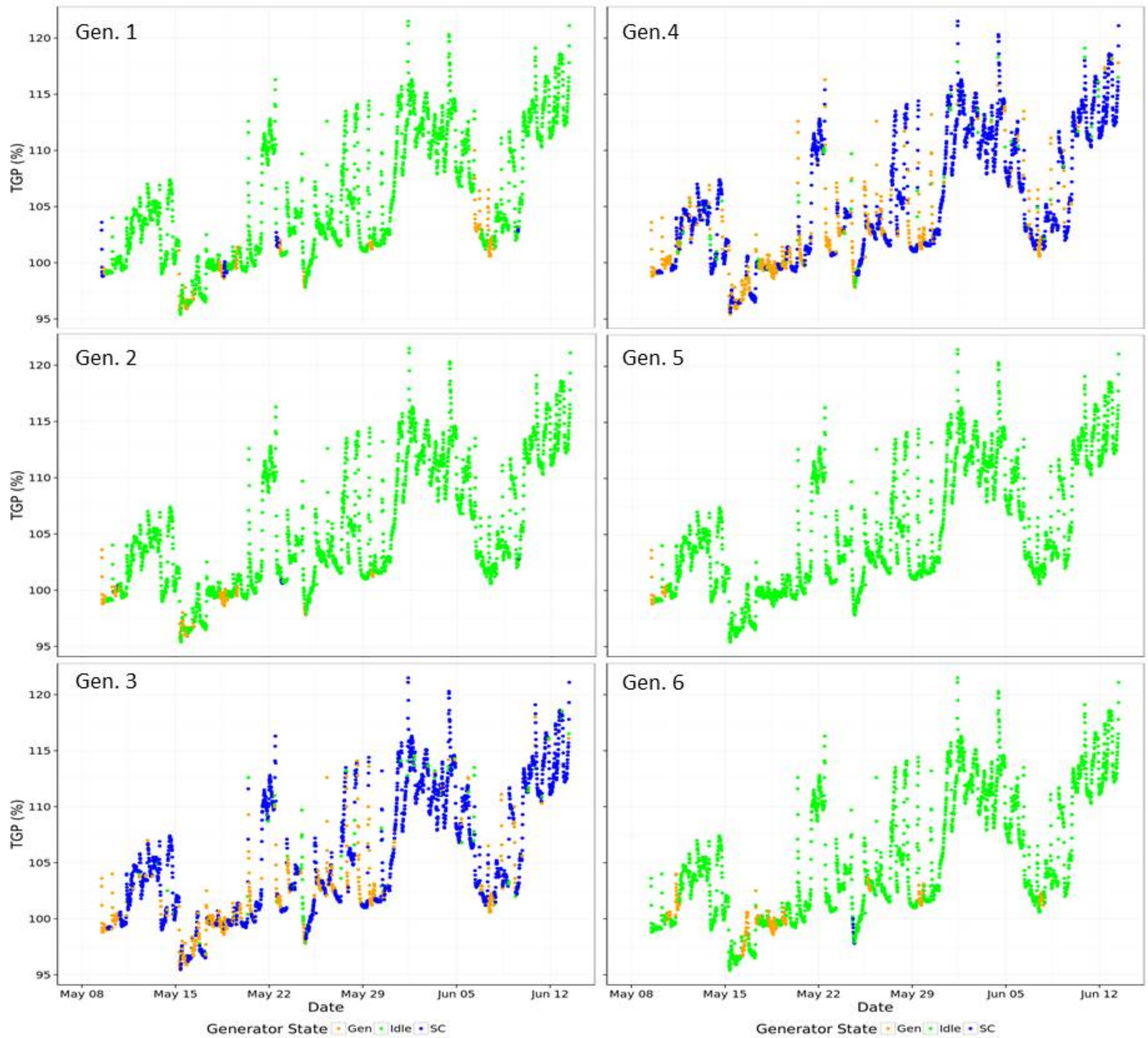

Figure 11. TGP (%) generated by operating Generators 1 -6 in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) at 0.2 km below Mica Dam from May 9 - June 13, 2017.

TGP over Time at Increasing Distances from Mica Dam

The TGP value peak of 122% measured 0.2 km from the dam dissipated by 8 - 10% to ≤ 110% at 11 km below the dam (Figure 12 and Figure 13).

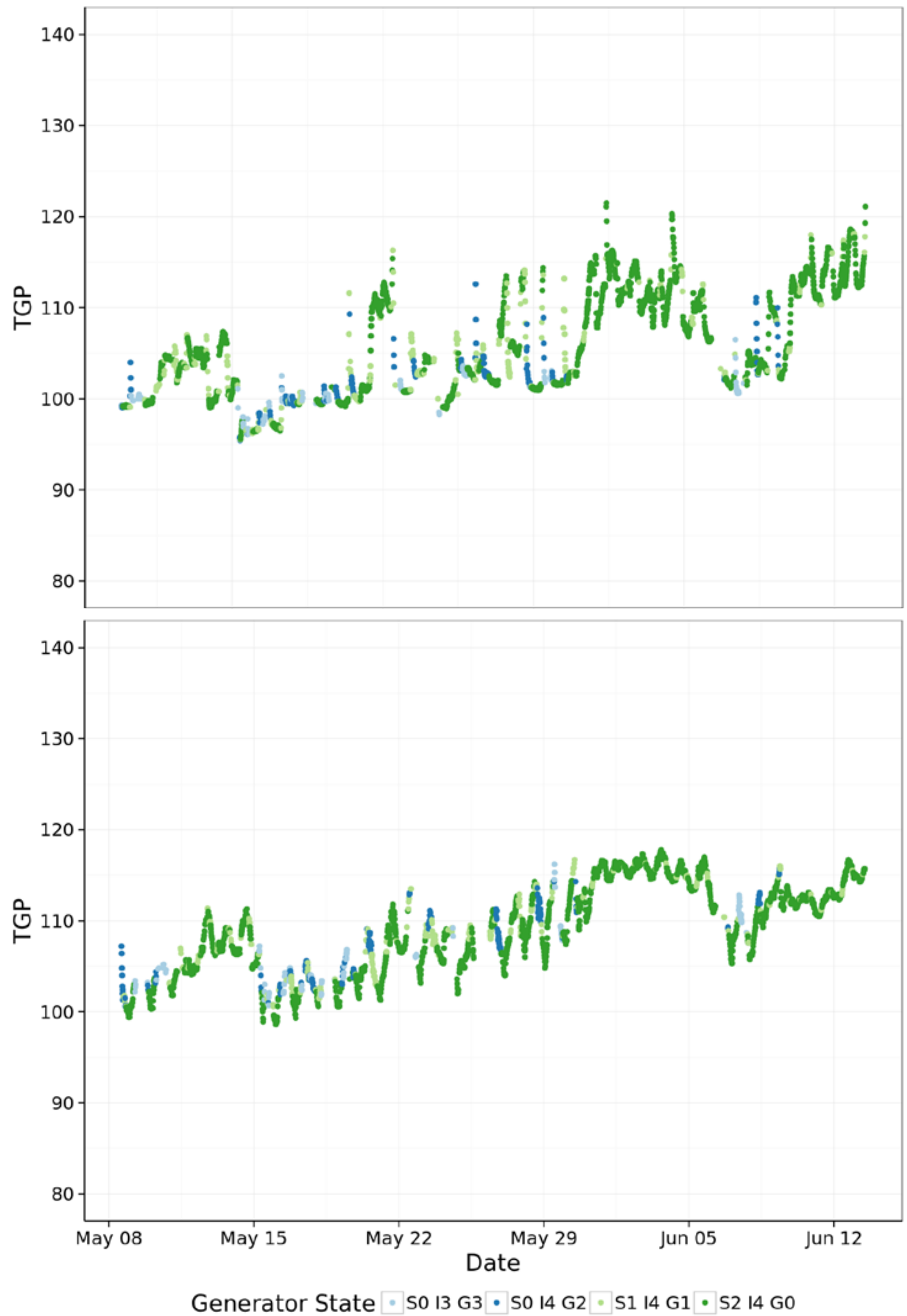

Figure 12. TGP generated by the combination of operating states over time from May 9 - June 13, 2017 measured at 0.2 km (Stn0) distance (top panel) and at 3.5 km (Stn1) distance (bottom panel) from MD.

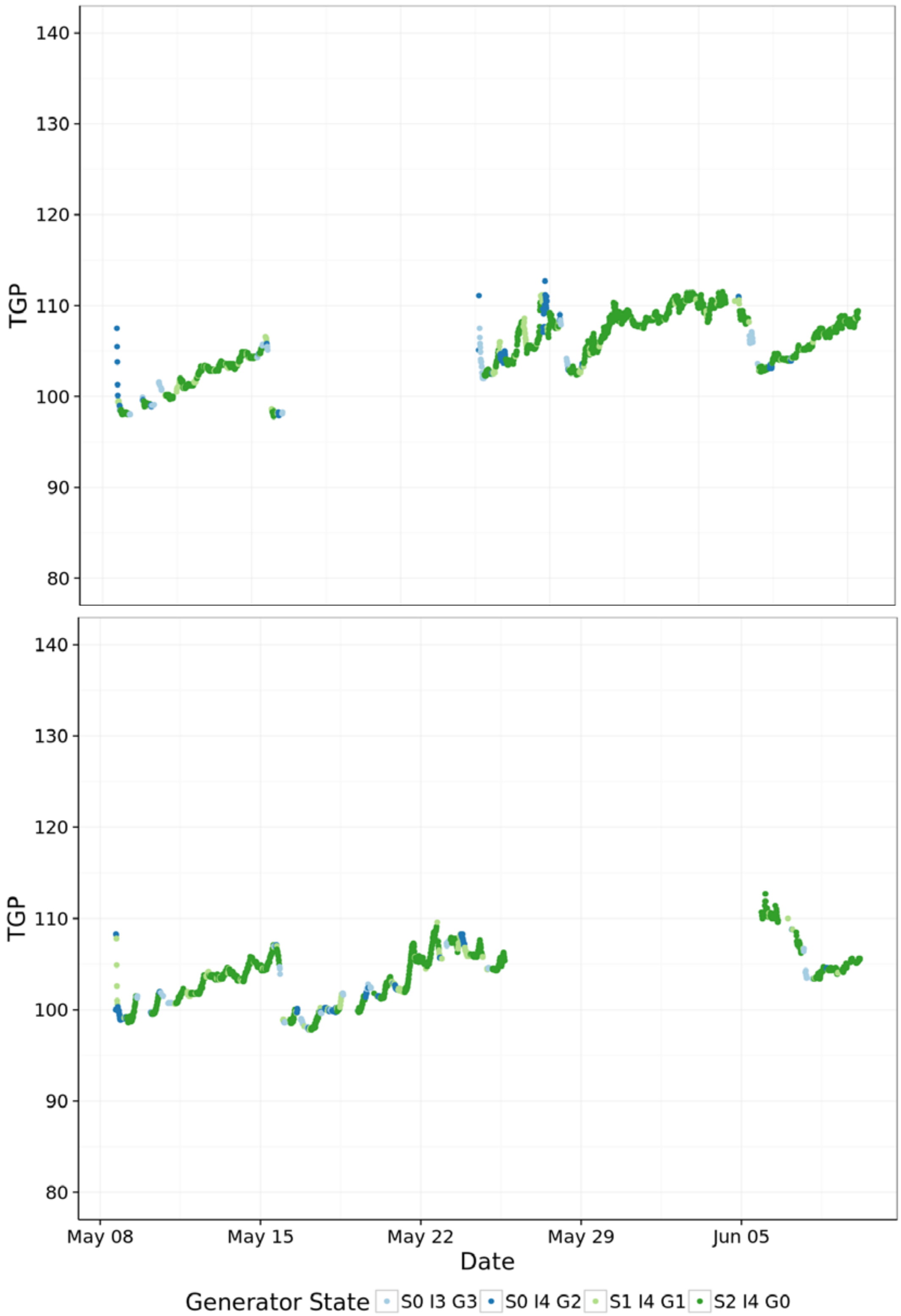

Figure 13. TGP generated by the combination of operating states over time from May 9 - June 13, 2017 measured at 10.5 km (top panel) and 11 km (bottom panel) distance from MD.

TGP by time

Figure 14 shows the detailed TGP response (measured at 0.2 km from dam) to operational changes on May 22 (top panel) and on June 1, 2017 (bottom panel). For both dates, generators were operated in the S2 I4 G0 mode with two generators in SC mode for more than 8 hours before TGP peaks of 117% and 122% were reached. On May 22, Generator 4 was switched from SC mode to generation mode for 2.9 h reducing the TGP measured 0.2 km below Mica damn by 5.5% from 117% - 101.5%. This pattern was repeated on June 1 (bottom panel); Generator 3 was switched from SC mode to generation mode for 1 h reducing the TGP 0.2 km below MD by 5% from 122% to 117%. It therefore appears that there is a direct relationship between length of time in generation mode after long periods of SC mode and the amount of TGP reduction.

To support this assumption, six TGP peaks were analyzed for the amount of TGP reduction (measured at 0.2 km from dam) achieved based on length of a switch from SC to generation mode. The result of this analysis is shown in Figure 15. The duration of switching to generation mode for 1-1.5 h lead to a reduction of 5-8% in TGP while a reduction longer than 2 h achieved TGP reductions of more than 12%, which are needed when Mica Dam is mainly operated in the SC and idling modes.

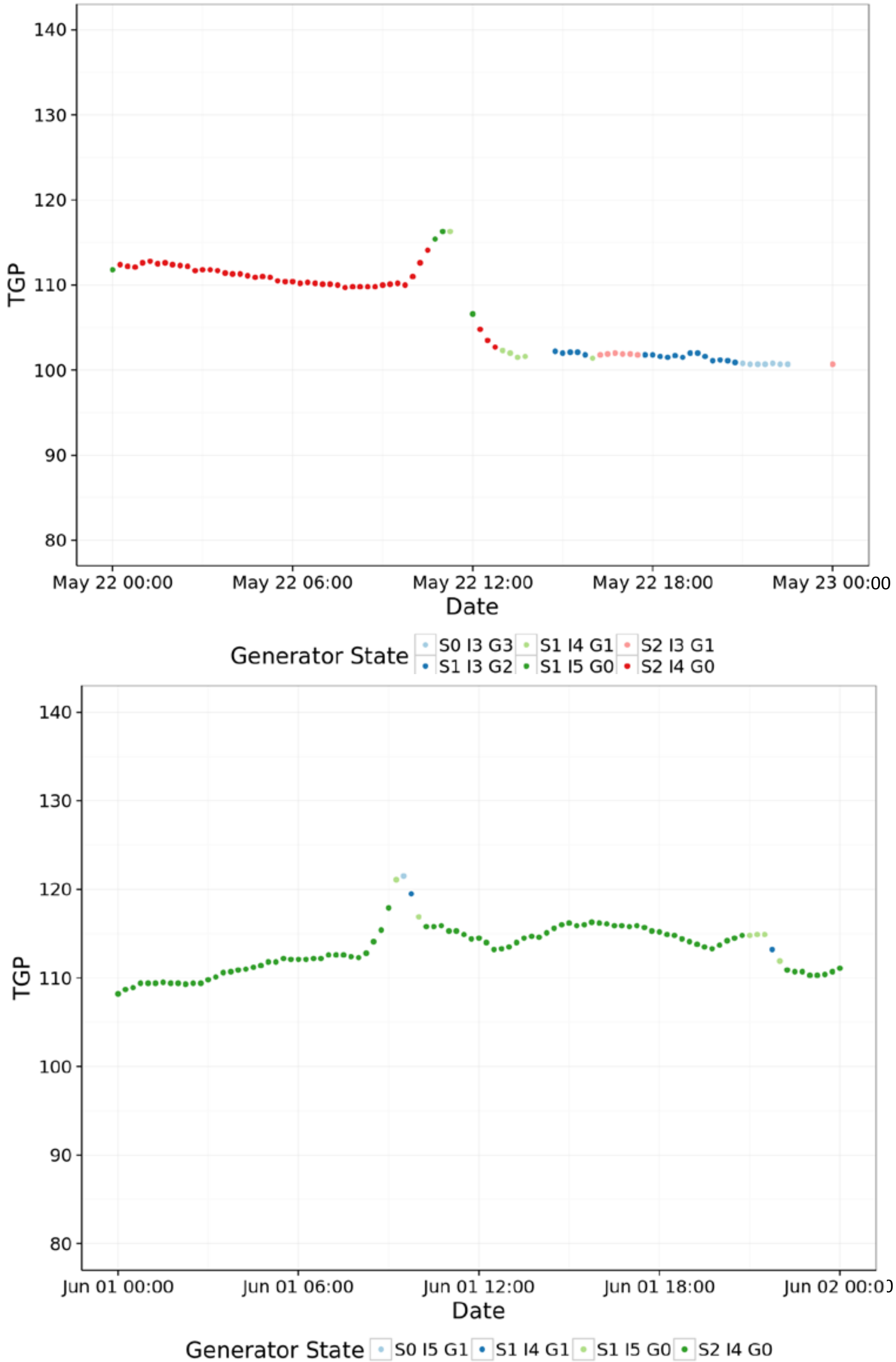

Figure 14. The top panel shows TGP generated by > 8 h of the generator operating combination of S2I4G0 (red dots) followed by 2.9 h of S1I4G1 (light green dots) on May 22, 2017 (0.2 km from MD) leading to a TGP reduction of 15.5%. The bottom panel shows TGP generated by > 8 h of the generator operating combination of S2I4G0 (green dots) followed by 1 h of S1I5G0 (light green dots) and 15 min of S1I4G1 (blue dots) on June 1, 2017 (0.2 km from MD) leading to a TGP reduction of 5%.

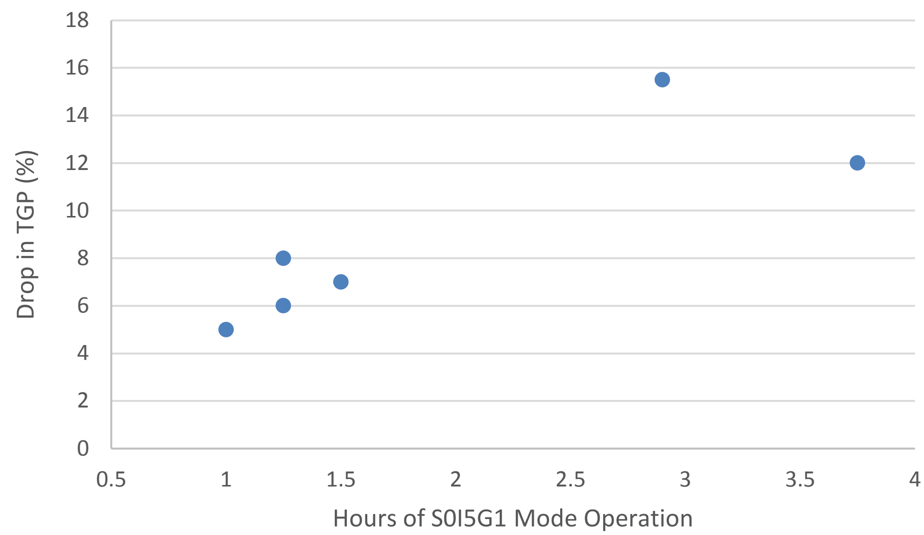

Figure 15. Reduction in TGP (measured at 0.2 km distance from dam) in response to hours of operation in mode generating with one turbine (S0I5G1) following a minimum of 8 h with one or two generators in SC (S2I4G0 or S1I5G0) mode without any generations.

TGP at Nagle Creek and Mica Dam Forebay

Nagle Creek TGP measurements ranged from 105% - 107% (mean = 106%) in 2017, while Mica Dam forebay measurements ranged from 103% - 106% (mean = 104%; Table 2). It appears as if the length of time that the TGP meter sonde was left in the water before a stable measurement was achieved may have been longer than the times that we used in 2017. It is therefore planned to repeat the background measurements for a minimum of 2 h per measurement in 2018.

Table 2. TGP readings from Mica Dam Forebay and Nagle Creek (mouth at 3.4 km distance from dam) during the 2017 field season.

Date	Location	TGP (%)
5/9/2017	Forebay	103
5/9/2017	Nagle Creek	105
5/25/2017	Forebay	104
5/25/2017	Nagle Creek	107
6/13/2017	Forebay	106
6/13/2017	Nagle Creek	106

DISCUSSION

Causal Relationship between Operational States of Mica Dam Generators and TGP (MQ 1)

Individual generators and TGPS (MQ 1a)

TGPS levels above the BCWQGs appear to be independent of the identity of the generator. TGPS for all generators are the result of continuous (>8 h) operation of two generators in parallel SC mode while the other four generators are idling. This result is based on the findings that the BCWQSs were exceeded in similar situations when Generators 3 and 4 (2017) and Generators 1 and 2 (2015) were operated in SC mode for longer periods of time (Plate et al. 2016). More TGP data collected over the next two years will show whether Generators 5 and 6 will also cause TGPS when operated in SC mode over longer periods of time as these generators did not operate in SC mode long enough in 2017 to ascertain their impacts on TGP.

Combinations of operational modes and TGPS (MQ 1b)

A switch from SC mode to short periods (<1 h) of generation and flow through the generator appeared to stop the increase of TGP values and led to TGP reductions of 5-10% and in most cases would bring the TGP value below the BCWQ guideline of 110%. TGP monitoring results showed that exceedances of the 110% TGP BC Water Quality Guideline (BCWQG) did not occur based on normal operations (idling or generating) of any of the six generators in Mica Dam. In contrast, TGPS values reached a peak of 122% when two generators were operated in SC mode while the other four generators were idling (S2 I4 G0 mode) for 12 h. This was most evident 0.2 km downstream of MD on May 19 when, following a 12 h period of SC mode operations in two generators (S2 I4 G0) one generator was switched to generation mode for 3.75 h and TGP values fell by 12% from 112% - 100%, thus reducing TGP values below the BC Water Quality Guideline (BCWQG) value of 110% and to the baseline value of 100%. The flow through generators when generating appears to dilute high TGP levels caused by other generators that are operating in the SC mode and the lengths of generation periods interrupting the SC mode is directly controlling the amount of TGP reduction. In general, TGP levels exceeding BCWQGs were infrequent in 2017 (< 10 events) and can be avoided completely in two ways:

1. Interrupting the SC mode on a generator with generation and thus stopping the discharge of high TGP water; or

2. Leaving one generator in SC mode while generating through another generator and thus diluting the high TGP water with low TGP water.

In general, the frequency of TGP values > 110% and the absolute TGP peak values decreased considerably from 2016 to 2017. In 2016, 23 peaks of TGP values > 110% were recorded (Plate et al. 2017) while only 12 peaks were recorded in 2017. The same general trend was observed for the frequency of time that the operations mode S2I4G0 caused exceedances of the BCWQG of 110% for TGP. In 2016, for 55% of the time in this mode BCWQG was exceeded compared to 37% in 2017. In 2017 also not a single peak value >130% TGP was recorded while in 2016 two such peaks were recorded. The reason for this trend is likely based on the interruption of or addition of low TGP water to long periods in SC mode.

Areal rate of travel for TGPS and BC Water Quality Guideline Exceedances (MQ 1c)

TGPS appears to travel down the Revelstoke reservoir as a cohesive plume at a rate of 0.975 km/h when averaging observed rate of travel between the onset of SC operations and the increase of TGP levels at different distances; which were 1 h to 0.2 km, 5 h to 3.5 km, and 8 h to 11 km.

Therefore, TGPS in Revelstoke Reservoir has the potential to affect fish close to the dam holding in water shallower than 1 m. The TGPS peak of 122% caused by long periods of SC mode in Generators 3 and 4 on May 22 were measured at 0.2 km (Stn0) from Mica Dam. This same peak remained at 117% when measured at a distance of 3.5 km (Stn1) from Mica Dam and had a peak value of 112% at a distance of 10.5 km (Stn3) and 11 km (Stn4) from Mica Dam. Between May 29 and June 13 TGP measured 3.5 km (Station 1) below the dam was similar to values measured 0.2 km (Station 0a) below the dam. The similar values were likely based on little dissipation in the lotic section of Revelstoke Reservoir were the water surface area to volume ratio is low. At distances of 10.5 km (Stn3) and 11 km (Stn4) TGP values were generally lower than at Stations 0 and 1 in the lentic environment of the reservoir where the water surface to volume ratio is much higher and TGP is likely reduced by gas exchange at the water to air interface. This was likely also the reason why the BC Water Quality Guideline TGP value of 110% was exceeded at high frequencies (~40%) in response to SC operations when measured at Stations 0 and 1 and with much lower frequencies at Station 3 (6% with one generator in SC, 12 % with two) and Station 4 (1% with one generator in SC, 4 % with two).

In addition to the 2017 frequency reduction in exceedances of the BC Water Quality TGP Guideline value of 110% at 0.2 km and 3.5 km distances from Mica Dam, TGP values of 120% were only exceeded for a total of 1 h at Station 0 and never downstream of Station 0. Fish holding in water deeper than 1 m would escape potential chronic TGPS exposure effects during peak TGP times. The same is true for a distance of 3.5 km from the dam where fish holding in depth of > 1 m would escape TGPS effects while at a distance of >11 km fish can be holding in all depths and would still be safe from TGPS effects.

Effects of Units 5 and 6 on TGP levels and their individual impacts on aquatic environments (MQ 2)

Changes in SC operations at Mica Dam have not significantly changed since the installation of Generator 5 and 6 as of 2017. Neither generator was operated in SC mode long enough to determine whether they have specific impact on TGP. Generator 5 did not operate in SC mode during the 2017 field season while Generator 6 operated for a total of 2 h 45 min, but its impact on TGP is uncertain as Generator 3 and 4 were generating at that time.

Monitored TGPS levels and their potential biological impacts (MQ 3)

TGP levels measured between May 9 and June 13, 2017 were not high enough to suspect potentially negative biological impacts based on selected indicator species. To assess potential biological impacts in Revelstoke Reservoir, species found to be at a high exposure risk to TGP such as Mountain Whitefish, Bull Trout, Rainbow Trout, Kokanee, and Sculpins (*Cottid* spp.) can be used as an indicator (Table 3) (Plate 2014). During the 2017 study period, > 110% TGP events occurred infrequently in May and more frequently in June. The longest TGPS event exceeded 110% for 6 days (Table 4) from May 31 - June 5 peaking at 122% on June 3 at a distance of 0.2 km from Mica Dam. At a distance of 10.5 km from the dam, TGP levels on June 3-4 did not exceed 111%. Since the highest TGP levels were recorded at 0.2 km from the dam, the Station 0 scenario will be used to suggest potential impacts on fishes.

Zones of species specific exposure risk to TGP supersaturation (>110%) (high = likelihood close to 100%; moderate = likelihood > 50%; low = likelihood < 50%) were assigned throughout the study area based on known habitat usage by indicator species obtained from other CLBMON projects and TGP levels recorded in 2017 (Table 3). The moderate risk zone (risk definition: high = likely mortalities; moderate = likely GBD; low: likely neither mortalities nor GBD) for Bull Trout and Rainbow Trout (Table 4) is located within the first 500 m downstream of Mica Dam in the tailrace area. Downstream of the Blue Bridge 3.5 km below Mica Dam, the remainder of Revelstoke Reservoir can be classified as low risk for TGP damage to fish under the current SC operational mode. Fish usage areas associated with moderate risk include habitats with water depth of less than 1 m, within 500 m proximity of the tailrace, that are known Kokanee spawning sites or areas of known Bull Trout or Whitefish congregation.

Table 3. Summary table of TGPS exposure risk for fish species at different developmental stages in Revelstoke Reservoir 0.2 km downstream of Mica Dam (MD) based on fish presence observations made during field studies carried out over the last 10 years under the CLBMON project umbrella.

Species	Developmental Stage	Season	Presence based on literature review (Plate 2014) and project team observations	Potential TGPS (>110%) Exposure Risk Below MD
Bull Trout	All developmental stages in reservoir	Year-round	Present in shallow water in Mica Dam area from Age -2 to adults	High
Mountain Whitefish	Juvenile	Year-round	Present in shallow water in Mica Dam area in all age classes	High
Rainbow Trout	All developmental stages	Year-round	Present in shallow water in Mica Dam area in multiple age classes	High
Kokanee	All developmental stages	Spring-Fall-Winter	Present in shallow water in Mica Dam area in multiple age classes	High
Longnose Sucker (*Catostomus catostomus*)	Juveniles	Summer	Low density throughout reservoir and no observations in shallow water in Mica Dam area	Low
Peamouth Chub (*Mylocheilus caurinus*)	All developmental stages	Year-round	No observations in shallow water in Mica Dam area, medium densities in lower and central reservoir	Medium
Redside Shiner (*Richardsonius balteatus*)	All developmental stages	Year-round	No observations in shallow water in Mica Dam area, medium densities in lower reservoir	Medium
Sculpins	Juveniles	Year-round	Present in shallow water in Mica Dam area in all age classes	High
Northern Pikeminnow (*Ptychocheilus oregonensis*)	Juveniles	Year-round	No observations in shallow water in Mica Dam area, low densities in lower and central reservoir	Low
Burbot	Juveniles	Year-round	Low densities in shallow water throughout the reservoir	Medium

Table 4. Summary table of high TGP events measured 0.2 km from MD in 2017 and their potential risk by species based on known species tolerances and duration of TGP > 115%.

Species	Occurrence Period	Hours > 115%	Risk
Mountain Whitefish	May 22 2017	0.5	Low
Rainbow Trout	May 22 2017	0.5	Low
Bull Trout	May 22 2017	0.5	Low
Kokanee	May 22 2017	0.5	Low
Sculpin spp.	May 22 2017	0.5	Low
Mountain Whitefish	June 1 2017	1.5	Low
Rainbow Trout	June 1 2017	1.5	Low
Bull Trout	June 1 2017	1.5	Low
Kokanee	June 1 2017	1.5	Low
Sculpin spp.	June 1 2017	1.5	Low
Mountain Whitefish	June 4 2017	1	Low
Rainbow Trout	June 4 2017	1	Low
Bull Trout	June 4 2017	1	Low
Kokanee	June 4 2017	1	Low
Sculpin spp.	June 4 2017	1	Low
Mountain Whitefish	June 12 - 14 2017	2.25	Low
Rainbow Trout	June 12 - 14 2017	2.25	Low
Bull Trout	June 12 - 14 2017	2.25	Low
Kokanee	June 12 - 14 2017	2.25	Low
Sculpin spp.	June 12 - 14 2017	2.25	Low

Mountain Whitefish were found to be resilient to TGP levels 115 – 125% for a short period of time and had a mortality rate of 85% after 14 days (336 h) of exposure to 125 – 131% TGP (Antcliffe et al. 1997; Marotz et al. 2006; Plate 2014). The highest TGP event observed between May 31 and June 5 exceeded 115% for 1.5 h peaking at 122%. Since these values are within the short-term Mountain Whitefish resiliency, it is unlikely this high TGP event had a significant impact. The longest continuous exposure during this study period was 2.25 h. If Mountain Whitefish were exposed to 115 – 122% TGP for 2.25 h it is unlikely they would be severely impacted since TGP exposure is relatively short. Therefore, occurrence of GBD and/or mortality appears unlikely in Mountain Whitefish. As this TGPS water mass travels downstream, its impact would be less significant and probably become insignificant to fish at a distance of > 11 km downstream of Mica Dam.

Bull Trout were found to be less resilient than Mountain Whitefish and Rainbow Trout to TGP levels (Marotz et al. 2006; Plate 2014). After 8 days (192 h) of exposure to 120 – 130% of TGPS in a laboratory setting, all tested Bull Trout were affected by GBD (Weitkamp and Katz 1980; Plate 2014). During the high TGPS event in 2017, TGP levels ranged from 115 – 122% for a period of 2.25 h which would not affect Bull Trout even when holding in water < 1 m deep were they have been shown to rear at night in Revelstoke Reservoir close to Mica Dam (Plate 2014). Therefore the danger of Bull Trout being exposed to TGPS in Revelstoke Reservoir and experiencing GBD or potential mortality is unlikely. Juvenile Bull Trout are known to inhabit the upper 3 meters of the water column in lakes but are most likely to rear in the tributaries of the Revelstoke Reservoir away from the influence of TGPS (Plate 2014).

Weitkamp and Katz (1980) reported that Rainbow Trout experienced mortality rates of 50% between 33 h and 114 h of exposure to TGPS of 120-125% and Weitkamp (2000) found Rainbow Trout mortalities of 20% after 4 days (96 h) of exposure to TGB levels of 123-128%. Rainbow Trout are typically holding in the top three meters of the water column along the littoral zone (Marotz et al. 2006) and Rainbow Trout were found to be holding in the top three meters of the water column in Revelstoke Reservoir in the fall of 2013 (Plate 2014). Nevertheless, the overall low and infrequent TGP peaks > 115% observed in 2017 were unlikely to affect Rainbow Trout in Revelstoke Reservoir.

Kokanee have tolerances similar to other salmonid species and were found to tolerate TGP values 120 − 150% when at adequate depth to reduce the physiologically experienced TGP level to 110% (Weitkamp et al. 2003). Kokanee are also known to inhabit the top 3 m of the water column during all life stages, but retreat to deeper water throughout the day in lakes (Plate et al. 2013; Sebastian et al. 2008; Pillipow and Langston 2002; Blackman 1992; Golder Associates Ltd. 2009). Given that Kokanee diurnally undergo vertical feeding migrations it appears unlikely that Kokanee would have been exposed to TGPS levels > 115% for more than periods of < 1 h at a time and therefore GBD or mortality appear to be unlikely to occur.

Sculpins are known to be more resilient to TGP levels than salmonids and only 15.5% of sculpin species showed signs of GBD after 5 weeks of TGP values between 125-145% in Priest Rapids Reservoir in 1996 (Schrank et al. 1998). Sculpins typically inhabit rocky and weedy littoral zones in water depth of < 2 m and were observed in this depth zone in large numbers by Plate (2014) in Revelstoke Reservoir. Based on their TGP resilience, it therefore appears unlikely that sculpin species would be affected at the TGPS levels measured in 2017 but would likely be affected by higher TGPS levels due to their preference for shallow water habitats.

Possible Mitigation Measures (MQ 4)

Changing the ratio of SC mode to generation mode to favour slightly shorter periods of SC (< 8 h at a time) and longer periods of generation (> 2 h) should keep TGP levels < 110%.

Alternatively, generation (flow) through one turbine while running one or two other turbines in SC mode appears to dilute the high TGP levels to create a combined flow with TGP levels < 110%.

Effects of Nagle Creek and Mica Dam Forebay on TGP

The average TGP recorded in Nagle Creek was 106% (N=3) in 2017 and Nagle Creek was suspected of influencing TGP values at Stations 1 and 2 located approximately 300 m downstream of its confluence with the Columbia River. Individual values for Nagle Creek are available in Table 2. Background TGP at Station 0a and Station 1 was monitored at 101% - 103% in 2017. These background TGP levels are lower than Nagle Creek's. However, small sample size, deployment length, and weather may have affected the values at Nagle Creek.

The average TGP recorded in the Mica Dam forebay was 104% (N=3) in 2017. Individual values for the Mica Dam forebay were similar, but slightly higher than background TGP levels at Station 0a (Table 2). It is important to note water flowing through the Mica Dam generators is taken at depth in Kinbasket Reservoir and therefore TGP and temperature values from the surface may not represent the TGP and temperature levels measured in the Mica Dam tailrace especially when a thermocline has formed that can lead to separation of physical attributes for surface water from deep water masses.

RECOMMENDATIONS

Based on the 2017 study, the following recommendations are made to gain a better understanding of the TGP levels versus operation mode configurations:

- Each one of the six Generators, including the newly installed Generators turbines 5 and 6, should be operated in SC mode for longer than 8 h to assess turbine-specific differences in TGP effects. If that is not possible, at least the newly installed Generators 5 and 6 should be operated in SC mode for longer than 8 h while the other turbines are idling to assess their TGP effects.

- An additional field sampling session in late summer, preferably August of 2018, may be useful to further understand the difference in TGP values at lower temperatures in the spring versus higher temperatures in late summer. A wider variation in temperature during 2017 indicated a possible relationship between temperature and background TGP. This is in contrast to 2016 where there was little temperature variation and a relationship between temperature and background TGP was questionable (Plate et al. 2017). Should the summer of 2018 be as cold as the summer of 2016, a fall session should be postponed to 2019.

- TGP spot measurements in the Mica Dam forebay and Nagle Creek should last longer than 2 h and a thorough comparison between deep and shallow water from a boat should be considered. Such TGP monitoring throughout the water column in the forebay area could become part of BC Hydro water sampling from a boat.

- Install a Barologger in the study area and monitor barometric pressure throughout the 2018 session to account for any influence atmospheric pressure may have on TGP.

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APPENDIX A: MAINTENANCE AND DOWNLOAD RECORD FOR ALL TGP MEASURING STATIONS AND METERS

Table 5. Maintenance and download record for the 2017 field season from May 8 to Jun 13, 2017.

Stn #	Unit	Date	Activity	T (°C) at Download	Battery Voltage		Calibration		Download	New Cart.	Weather
					Old	New	Baro. Press.	Temp.			
0	401	5/9/2017	Station Setup	N/A*	N/A	6.25	Yes	Yes	No	Yes	Overcast
0a	402	5/9/2017	Station Setup	N/A	N/A	6.62	Yes	Yes	No	Yes	Overcast
1	403	5/8/2017	Station Setup	N/A	N/	6.27	Yes	Yes	No	Yes	Overcast
2	404	5/8/2017	Station Setup	N/A	N/A	7.26	Yes	Yes	No	Yes	Overcast
3	405	5/8/2017	Station Setup	N/A	N/A	6.66	Yes	Yes	No	Yes	Overcast
4	406	5/8/2017	Station Setup	N/A	N/A	6.91	Yes	Yes	No	Yes	Overcast
Nagle Ck	407	5/9/2017	Spot Check	4.5	N/A	N/A	Yes	Yes	Yes	Yes	Overcast
Forebay	407	5/9/2017	Spot Check	9.6	N/A	N/A	No	No	Yes	No	Overcast
0	401	5/25/2017	Download/Maintenance	4.8	6.43	7.46	Yes	Yes	Yes	Yes	Partly Cloudy
0a	402	5/25/2017	Download/Maintenance	6.1	6.29	7.47	Yes	Yes	Yes	Yes	Partly Cloudy
1	403	5/25/2017	Download/Maintenance	5.5	6.13	7.18	Yes	Yes	Yes	Yes	Partly Cloudy
2	404	5/25/2017	Download/Maintenance	5.3	6.42	7.15	Yes	Yes	Yes	Yes	Partly Cloudy
3	405	5/25/2017	Download/Maintenance	5.5	Dead	N/R**	Yes	Yes	Yes	Yes	Partly Cloudy
4	406	5/25/2017	Download/Maintenance	4.6	N/R	N/R	Yes	Yes	Yes	Yes	Partly Cloudy
Nagle Ck	407	5/25/2017	Spot Check	5.6	N/A	N/A	Yes	Yes	Yes	No	Partly Cloudy
Forebay	407	5/25/2017	Spot Check	N/R	N/A	N/A	No	No	Yes	No	Partly Cloudy
0	401	6/13/2017	Download	5.6	6.55	N/A	No	No	Yes	No	Sunny
0a	402	6/13/2017	Download	6.8	6.56	N/A	No	No	Yes	No	Sunny
1	403	6/13/2017	Download	6.8	6.48	N/A	No	No	Yes	No	Sunny
2	404	6/13/2017	Download	6.7	6.31	N/A	No	No	Yes	No	Sunny
3	405	6/13/2017	Download	N/R	Dead	N/A	No	No	Yes	No	Sunny
4	406	6/13/2017	Download	N/R	Dead	N/A	No	No	Yes	No	Sunny
Nagle Ck	407	6/13/2017	Spot Check	6.1	N/A	N/A	Yes	Yes	Yes	No	Sunny
Forebay	407	6/13/2017	Spot Check	10.1	N/A	N/A	No	No	Yes	No	Sunny

*N/A = Not Applicable **N/R = Not Reco