# Columbia River Water Use Plan

# Kinbasket Reservoir Fish and Wildlife Information Plan

# Total Gas Pressure Monitoring Downstream of Mica Generating Station

## Implementation Year 1

## Reference: CLBMON-1 (CLBMON-62)

**Study Period: April to June 2015**

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# EXECUTIVE SUMMARY

In this study, Total Gas Pressure (TGP) in Revelstoke Reservoir below Mica Dam was monitored under combinations of the three operating modes (generating, idling and Synchronous Condense or SC) for each of the five turbines installed in Mica Dam from April 7 to June 16, 2015. Generator 1 was mainly operated in the idling and the generating states with frequent SC operations. Generator 2, was mostly operated in the generating state with frequent idling and SC operations. Generators 3 and 4 were mostly idling with frequent generation periods but very few SC episodes. The newly installed Generator 5 was only operated in the generating and idling modes but never in SC mode.

The highest TGP Supersaturation or TGPS was measured when two turbines (mainly turbine 1 and 2) were operated in SC mode while none of the other turbines were generating. For this state, mean TGPS values were measured at 112% with peak values of up to 132%. In this operating scenario, flow out of the dam was generated completely by turbines in the SC mode without any additional flow from generation or spills. No other combinations of different modes of the five generators created TGPS value peaks or hourly means that exceeded the 110% 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 generated by the aforementioned combination of turbine modes dissipated with increasing distance from the dam to values that rarely exceeded BCWQGs (110%) at a distance of 10.5 km when peaks of 132 % were measured at a distance of 0.2 km from the dam.

For future studies, turbines other than turbine 1 and 2 need to be operated in SC mode to assess their effects on TGPS generation. Especially, the effect of the newly installed turbines 5 and 6 operated in SC mode on TGP values needs to be monitored.

As part of the data analysis for this project, we developed a password protected WWW application in a web based software application under the tradename “Shiny App” to allow for real time manipulation of factors that the data graphs for this study were based on. 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”.

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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.

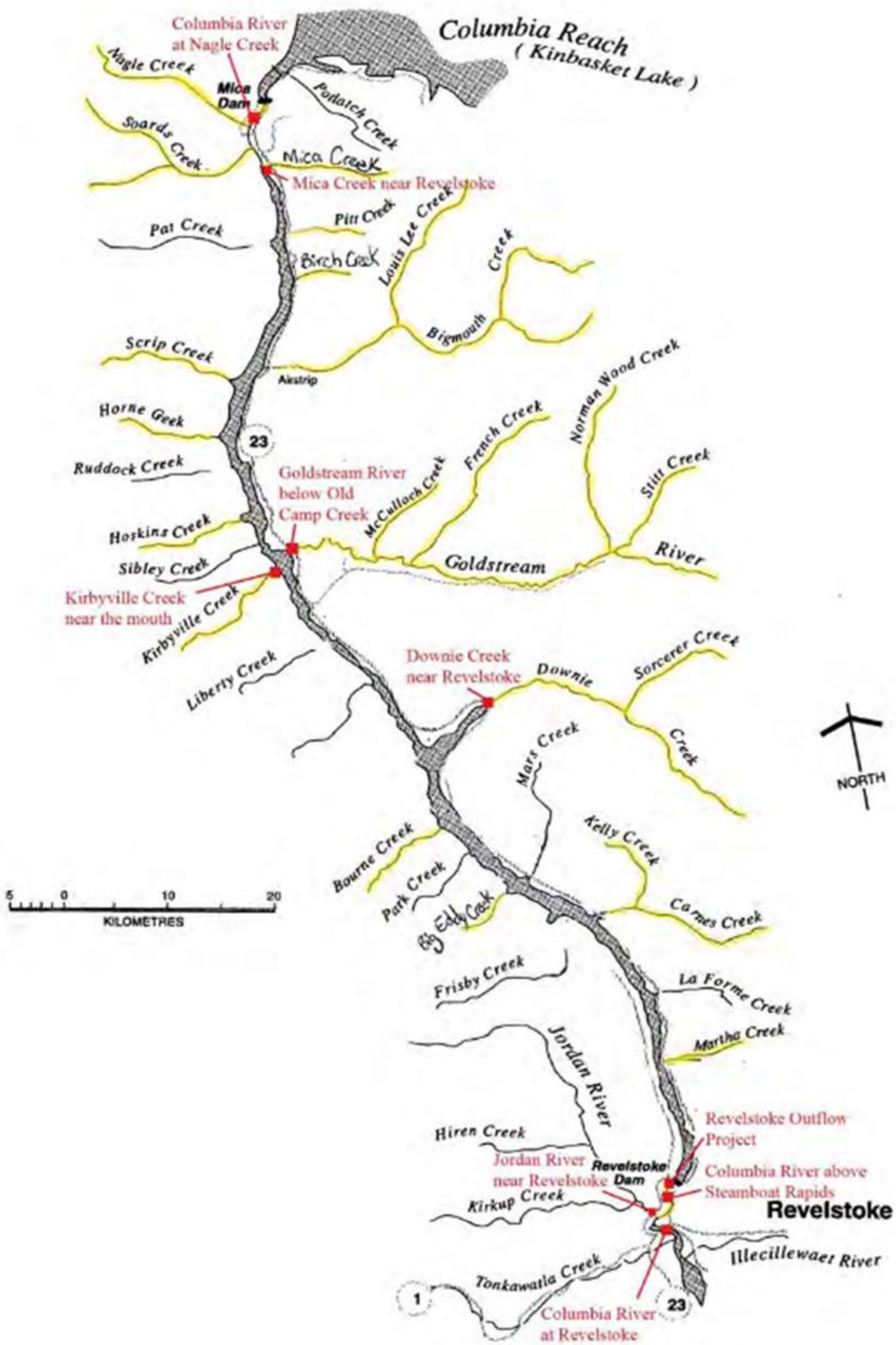


Figure 1 Map of Revelstoke Reservoir and main tributaries. The study area for this project reaches from Mica Dam in the north to the area between the mouth of Birch and Bigmouth Creeks (blue arrow) in the south (from: BC Hydro 2010).

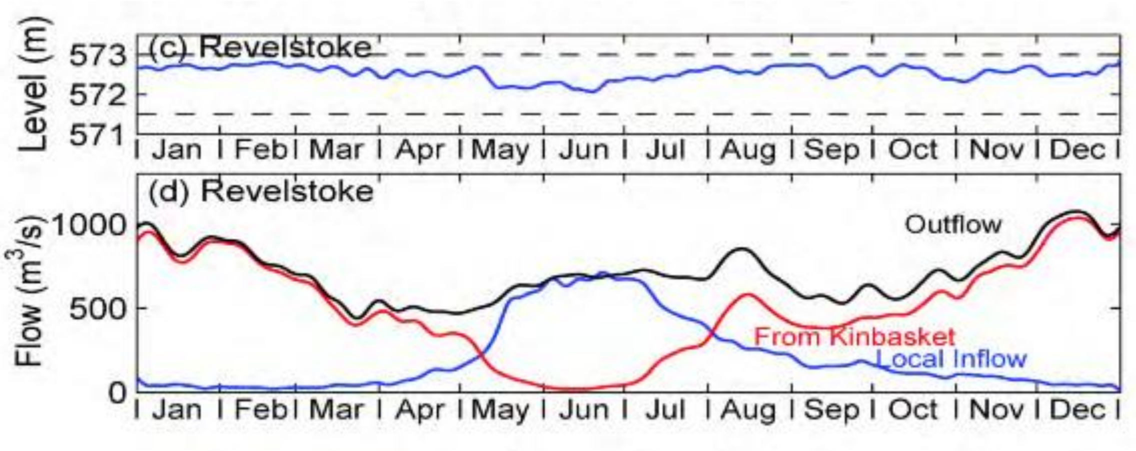


Figure 2 Water level and flow in Revelstoke Reservoir in 2008 typical for other years (from: Bray et al. 2013).

## Mica Generating Station Total Gas Pressure and Fish

Directly downstream of Mica Dam, Rainbow Trout (*Oncorhynchus mykiss*), Kokanee (*Oncorhynchus nerka*), Bull Trout (*Salvelinus confluentus*), Mountain Whitefish (*Prosopium williamsoni*) have all been found (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, all generators at Mica Dam are now capable of preforming Synchronous Condense (SC) operations. Another generating unit (Unit 6) is planned to be online in 2016/17. 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 worthwhile from an economic point of view. 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 when compared to 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. Fish have been shown to hold in the vicinity of 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 SC mode. Should Mica Dam generators be operated in SC mode in October and November when Kokanee are spawning in shallow water (1-3 m) downstream of the Blue Bridge in Revelstoke Reservoir as observed in this study or even right below the dam, extended periods (>24 h) of TGPS at levels >120% could lead to injury or mortality in Kokanee.

High levels of TGP over a prolonged period can cause gas bubble disease (GBD) in fish (Fidler 1988). GBD can cause internal and external bubbles, which affects organ functions and can result in blockage of arteries and death (Fidler 1988). TGP levels lower than 110% are considered safe for fresh water fish in systems deeper than 1 m and lower than 103% in water less than 1 m (Fidler and Miller 1994). As a general rule, for every additional meter of depth that a fish is holding in it can withstand an additional 10% of TGP without physiological effects (Weitkamp 2008). The increasing hydrostatic pressure in deeper water counteracts gas bubble formation and keeps the gases in the bloodstream in solution.

In 1995 BC Hydro investigated fish mortalities in the Mica Dam tailrace and found TGP Supersaturation or TGPS to be 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, 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 5 and the soon to be installed Unit 6 are also capable of operating in SC mode and their effects on the TGP situation downstream of Mica Dam has not yet been investigated. Therefore, BC Hydro initiated a five year Mica Dam TGP 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 or death. In fish, the state of gas bubbles 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 (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 (Figure 3).

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 (Figure 3). TGP levels ranging from of 120 – 140%, typically encountered below dams during water release over spill ways will only lead to GBD in fish that are in the top 2 – 3 m of the water column.

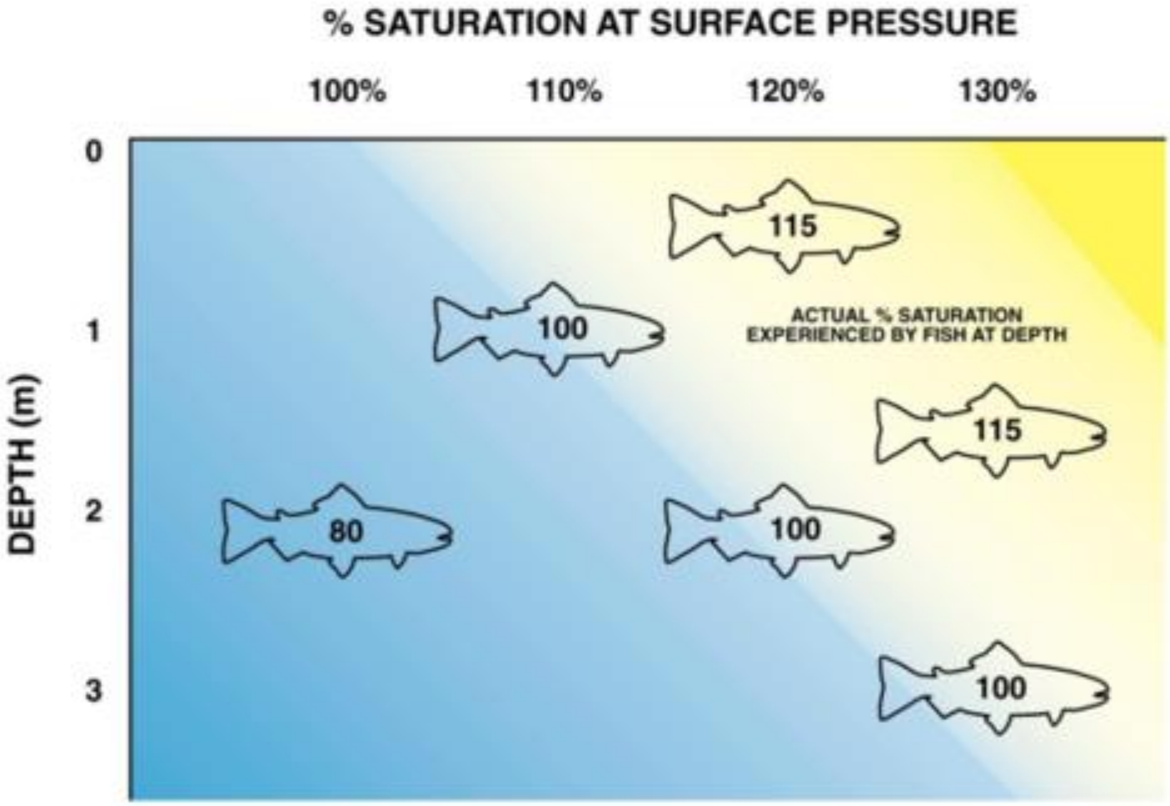


Figure 3. Relationship of measured and actual total dissolved gas levels experienced by fish at various depths in a river or lake (from: Weitkamp 2008).

TGPS in water can result from different causes but in the context of power generation at dams it is commonly related to two 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 were 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 25 TGP measurements carried out between Mica Dam and Revelstoke Dam before 1977, 17 showed

values below 110% while 8 measurements showed values between 110 – 120% (Clark 1977 in Fidler and Miller 1994). 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 species dependent 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, it is unknown how the TGP supersaturated water masses in Revelstoke Reservoir behave. The geographical focus of TGPS related field studies was nevertheless the initial 20 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 needed 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).

# PROJECT OBJECTIVES AND RESULTING ACTIVITIES

**Objective 1:** Determine the causal relationship between Mica Dam generation station operational scenarios and TGP in the 10.5 km of Revelstoke Reservoir downstream of Mica Dam. To achieve this objective, the following activities were carried out:

- Activity 1: Install 6 Total Gas Pressure (TGP) meters at increasing distance up to 10 km downstream of Mica Dam to monitor TGP levels.
- Activity 2: Compare TGP levels below Mica Dam with operational data to identify TGPS causing operational scenarios.
- Activity 3: Start TGP monitoring in 2015 and continue for a minimum of five years to cover the periods of pre and post start-up of Mica Generating Units 5 and 6.

**Objective 2:** Determine if significant changes in the use of Synchronous Condense (SC) operations at Mica Dam occur when Units 5 and 6 come online and how it will affect downstream aquatic environments.

- Activity 1: Collect at least one year of TGP baseline data before Units 5 and 6 are online or operated in the SC mode.
- Activity 2: Collect TGP data downstream of Mica Dam while Units 5 and 6 are idle, generating and in SC mode.
- Activity 3: 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 to may affect downstream aquatic environments.

**Objective 3:** Combine the newly gained TGP knowledge with existing knowledge about the aquatic environment below Mica Dam to suggest effects on fish ecology.

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

**Objective 4:** Determine where and when impacts to fish ecology warrant a remedial response in the operation of the Mica generating stations while meeting intended operational flexibility.

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

# METHODS

## TGP Monitoring

TGP was monitored at 3.5 km (Station 1, Blue Bridge), 10.5 km (Station 2) and 11 km (Station 3) distance from Mica Dam from April 8 to June 15, 2015 (Table 1, Figure 4). In addition, TGP was monitored at a distance of 200 m (Station 0) from Mica Dam from May 11 to June 15, 2015 (Table 1, Figure 4). Pentair Point Four Tracker Total Gas Pressure Meters were used to record TGP levels.

Initially, two meters each, were installed at Stations 1 and 2 at both sides of the Blue Bridge (3.5 km downstream of Mica dam) for a total of four stations at the same distance for Mica Dam. This TGP meter redundancy was meant to counter act the extreme unreliability experienced with TGP meters in past projects. When it was confirmed that the three of the four meters at the Blue Bridge were working reliably, one of the meters was moved to Station 0, 200 m downstream of Mica Dam to create Station 0. One TGP meter each was installed at Station 3 (10.5 km) and Station 4 (11 km) and therefore close enough to each other to compare and identify any inconstancies in the data. 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 information.

| Station Name | 11U UTM East | 11U UTM North | # of TGP Meters | Deployment Period | Downloaded |
|---|---|---|---|---|---|
| Station 0 | 392719 | 5770021 | 1* | 11-May to 15-Jun | 25-May, 15-Jun |
| Station 1 | 390683 | 5767814 | 2 to 1* | 9-Apr to 15-Jun | 24-Apr, 11-May, 25-May, 15-Jun |
| Station 2 | 390786 | 5767739 | 2 | 8-Apr to 15-Jun | 24-Apr, 11-May, 25-May, 15-Jun |
| Station 3 | 392541 | 5761129 | 1 | 9-Apr to 15-Jun | 24-Apr, 11-May, 25-May, 15-Jun |
| Station 4 | 392523 | 5760933 | 1 | 9-Apr to 15-Jun | 24-Apr, 11-May, 25-May, 15-Jun |

*One TGP meter initially installed at Station 1 was moved to Station 0 on May 11, 2015

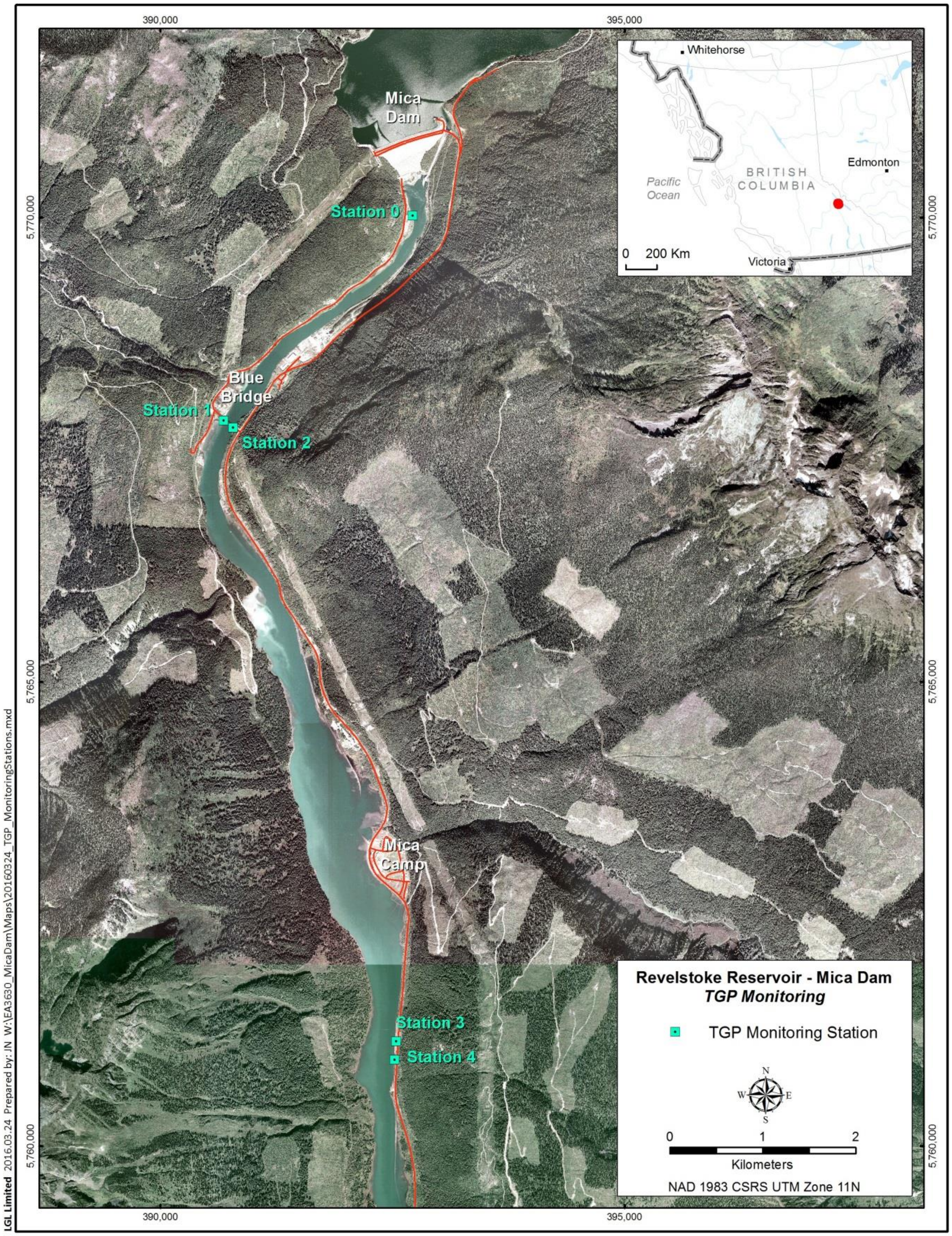


Figure 4. Map of the Revelstoke Reservoir downstream of Mica Dam showing TGP Stations and landmarks.

For deployment, the 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 5).


Figure 5. TGP meter deployment totes, anchoring detail and pipe set-up.

The sondes of the meters were deployed inside a 7 m meter PVC pipe with the measuring membrane end protruding by 10 cm into open water. The PCV pipes were also 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 water end, the pipes were reaching to a depth of 2 – 2.5 m to avoid air exposure during water level fluctuations (Figure 5).

As part of each site visit following the schedule 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

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, to account for measurement error) to the Idle state and positive values to the Generating state. Furthermore, the states of all five generators were combined to create a state of the generating system (e.g., S2 I2 G1 meaning that two generators were in SC mode, 2 were idle and one was generating).

The resulting data file was processed using R to produce the figures shown in Appendix B.

- Figure 7 is a bar graph showing the state frequencies for each generator.
- Figure 8 – Figure 10 are box and whisker plots of TGP for the system states. R uses Tukey boxplots with the following features: line in the box corresponds to the median, top and bottom ends (hinges) of the box to the 25th and 75th percentile, ends of the whiskers to the highest and lowest values within the 1.5*IQR (inter-quartile range) of the hinge and the remaining dots are the outliers (i.e., values above and below the 1.5*IQR).
- Figure 11 – Figure 18 are scatter plots of TGP by date, coloured by the state of the generator or of the entire system.

- Figure 19 is a scatter plot of TGP by temperature. It had been fitted with a liner regression (equation is shown on the figure), minimizing the mean squared error.

## Data Presentation

As part of the data analysis for this project, we developed a password protected WWW application in a web based software application under the trade name “Shiny App” that uses the programming language R to allow for real time manipulation of factors that the data graphs for this study were based on. 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 three distances (200 m, 3.5 km and 10.5 km) from Mica Dam, the data of the three most reliable meters (one for each distance) were chosen to be presented here. Nevertheless, data from the other three TGP meters were important to create redundancy and therefore reliability of data collection for the project. However, data from all stations are available upon request.

## State of Generators

Over the monitoring period from April 7 to June 16, 2015, the five turbines were operated for different frequencies of the three operating states, namely 1) generating, 2) idling and 3) SC mode. Figure 7 shows that generator 1 was mainly operated in the idling state and the generating state with frequent SC operations. Generator 2, was mostly operated in the generating state with frequent idling and SC operations. Generators 3 and 4 were mostly idling with frequent generation periods but very few SC episodes. Generator 5 was only operated in the generating and idling mode but never in SC mode.

## TGP Generated by a Combination of Operating Modes for all Generators

The five generators installed in Mica Dam were operated at a combination of different modes to respond to energy demands. All five turbines were either generating, idling or were operated in SC mode. Figure 8 shows the TGP generated by the combination of operating modes measured at a distance of 0.2 km from Mica Dam. At this location, TGP fluctuations were expected to be more visible when compared to measuring stations that were located at a greater distance from the dam. When none of the turbines were operated in SC mode (S0), the means of the TGP values recorded fluctuated between 100 – 103%, independent of the state of the other turbines (red, brown and green box and whisker plots 1–3 in Figure 8. The same range of TGP value means was observed when one turbine was operated in the SC mode (S1) while one or two other turbines were generating (turquoise and blue box and whisker plots 4–5 in Figure 8. In contrast, two turbines operated in SC mode while none of the other turbines were generating (S2 I3 G0) led to a TGP value mean of 112% (pink box and whisker plot 6 in Figure 8. In this operating scenario, flow out of the dam was generated completely by turbines in the SC mode without any additional flow from generation.

At greater distances from the dam the effects of the S2 I3 G0 combination of operating modes on TGP values was still visible but less pronounced (Figure 9 and Figure 10).

## TGP over Time by Generator

While TGP values were monitored from April 7 to June 16, 2015, turbines were mostly operated in the SC mode in May and June. We therefore plotted the TGP values that were created by different operating modes of each turbine from May 11 to June 16, the period that the closest TGP monitoring station to Mica Dam (Station 0) was operated for. All TGP measurements described in this chapter were taken 0.2 km from the dam at Station 0. Figure 11 shows how TGP values were affected by the three different operating states for turbine 1. As mentioned before, generators 1 and 2 were the two generators that were frequently operated in SC mode (blue dots in Figure 11). From May 11 to 22, generator 1 was mainly operated in the generation (brown dots) and the idling (green dots) mode and TGP values ranged from 100 – 107% (Figure 11). From May 22 – 27, generator 1 was mainly operated in the SC mode and TGP values rose to 130%. During a second period of SC mode operations for generator 1 from May 29 – June 3, TGP values rose even higher to 132%. An almost identical picture was drawn by the rise of TGP values measured when generator 2 was operated in the three different modes (Figure 12). Generators 3, 4 and 5 were rarely or never operated in SC mode and during the TGP peaks they were mostly operated in the idling mode (Figure 13, Figure 14 and Figure 15). To conclude, it appears that the frequent operation of generators 1 and 2 in the SC mode led to the TGP peaks above 110%. Unfortunately, the newly installed generator 5 was never run in SC mode over the 2015 sampling period from April 7 to June 16.

## TGP over Time at Increasing Distances from Mica Dam

As part of this project it was also important to determine whether, and how fast, higher TGP values created by SC mode would dissipate when flowing from Mica Dam into Revelstoke Reservoir. Therefore TGP monitoring stations were installed at 0.2 km (Station 0), 3.5 km (Station 1) and 10. 5 km (Station 4) distance downstream of the dam. Figure 16 shows TGP values created by a combination of generator states measured 0.2 km below Mica Dam from May 11 – June 16. As described before, the highest TGP values recorded during this period reached to 132% and were created when 2 generators were in SC mode, while 3 generators were idling (pink dots). The high TGP events lasted from May 22 – 27 and from May 29 to June 3. For the same two periods measured at a distance of 3.5 km from Mica Dam, TGP values reached highs of 120% each time (Figure 17). At a distance of 10.5 km (Figure 18) during the first period a short term TGP peak of 117% was reached while the TGP peaked at 113% during the second period. In summary, TGP value peaks of 132% measured 0.2 km from the dam dissipated by 15 – 20% to 112−117% when measured 10.5 km below the dam.

## TGP versus Temperature

Aside from the effects of generator operational states in Mica Dam, water temperature also appeared to increase the background TGP values in the water. In Figure 19 TGP values are plotted for the whole study period from April 7 to June 16, 2015 at a distance of 10.5 km from Mica Dam (Station 4). Station 4 was chosen for this analysis because it was the least sensitive to the peaks in TGP values caused by the SC generation mode in generators 1 and 2. TGP values and temperature showed a strong linear correlation with a correlation coefficient $r^2$ of 0.798. Therefore it can be concluded that the TGP background values increased over the study period likely based on increasing water temperatures.

# DISCUSSION

## The Causal Relationship Between the Operational States of Mica Dam Generators and TGP

<u>Combinations of operational modes and TGPS:</u> TGP monitoring results showed that no exceedances of the 110% TGP BC Water Quality Guideline (BCWQG) occurred based on normal operations (idling or generating) of all generators in Mica Dam. In contrast, when two generators were operated in SC mode while the other three generators were idling (S2 I3 G0 mode) for more than 12 – 14 hours TGPS values reached up to 132%. A switch from the SC mode for short periods (<1 h) of generation and flow in the

generator that caused the TGP values appeared to stop the increase of TGP values but only led to decreases to background levels of 100 – 105% when switched to the generating mode for periods > 1 h or when other generators were switched to the generating mode. The flow through generators when generating appears to dilute high TPG levels caused by other generators that are operating in the SC mode.

Individual generators and TGPS: TGPS levels above the BCWQGs were all caused by SC operations of generators 1 and 2. This result is not likely based on the specific propensity of generators 1 and 2 to cause high TGP levels in SC mode but the amount of time that generators 1 and 2 were operated in the SC mode. More TGP data collected over the next four years should show whether generators 3, 4 and 5 will also cause TGPS when operated in the SC mode over longer periods of time. Generators 3 and 4 appeared to have never been operated in SC mode for more than 3 h during the 2015 monitoring period and generator 5 was never operated in SC mode. In summary, it appears as if the continuous (>8 h) operation of two generator in parallel SC mode cause TGP levels to rise when the other three generator are in the idling mode.

Generator 5 and TGPS: Generator 5 was newly installed in Mica Dam before the start of the field period for this project. Therefore it was of particular interest to determine whether generator 5 in the idling, the generating or the SC mode would produce TGPS. Neither when generator 5 was operated in the idling nor when it was operated in the generating mode, was TGPS observed. Generator 5 was never operated in SC mode during the monitoring period and therefore no assumptions can be made about the correlation between generator 5 SC operations and TGP. For future years of this project, it is hoped that TGP can be monitored during SC mode for generator 5, and when it comes online also for generator 6.

Areal extent and rate of travel for TGPS: The TGPS peaks of 132% caused by long periods of SC mode in generators 1 and 2 were measured at 0.2 km of Mica Dam. These same peaks decreased to TGP values of 120% when measured at a distance of 3.5 km from Mica Dam and peak values of 112 – 117% at a distance of 10.5 km from Mica Dam. All of these peaks represent exceedances of the 110% BCWQG but the exceedances decrease from 22% at 200 m from the dam to 2 – 7% at a distance of 10.5 km. Therefore TGPS in Revelstoke Reservoir is most likely to affect fish close to the dam where fish have to be holding deeper than 3 m to escape potential chronic TGPS exposure effects during peak TGP times. At a distance of 3.5 km from the dam, the same fish have to be holding in depth of >2 m to escape TGPS effects while at a distance of 10.5 km fish only have to be holding in depths > 1 m to be safe from TGPS effects.

The rate of travel of the TGPS water masses appears to be approximately 2 hours between the onset of SC operations and the increase of TGP levels at a distance of 0.2 km from the dam. This period appears long and may be prolonged by the installation of the monitoring station in a natural back-eddy below the dam on the river right or west shore. For 2016, it is planned to install an additional measuring station at a distance of 0.2 km from the dam on the river left or east shore or in the direct outflow from the tailrace. Thus it is hoped to reduce the delay that may be introduced by the back eddy on the river right. The travel time to a distance of 3.5 km appears to be approximately 6 h while the travel time to a distance of 10.5 km appears to be approximately 14 – 20 h.

Water temperature and TGP: When plotting TGP values over the whole study period from April 7 to July 16, 2015, at a distance of 10.5 km from Mica Dam it became apparent that the TGP background level slowly increased over time and with increasing water temperatures. Therefore it was investigated whether a linear and positive correlation between water temperatures and TGP values exists and a strong correlation coefficient of $r^2 = 0.798$ was determined (Figure 19). Based on saturation lines of Nitrogen and Oxygen in water shown in Figure 6 below, and their tendency to decrease as water temperatures increase (Fidler and Miller 1994), the observed increase in TGP background values can be easily explained. As water temperatures increase the saturation of 100% TGP level when compared with atmospheric gas pressure decrease (Figure 6). Therefore the relative TGP value of >100% when compared to atmospheric gas pressure measured at 5 °C water temperature at the beginning of the project in April was reached at 22 mg/L of Nitrogen and 16 mg/L of Oxygen (Figure 6). The same relative 100% TGP value was reached at the lower concentrations of 17 mg/L of Nitrogen and 12 mg/L of Oxygen at the end of study period in June at water temperature of 11 °C. In summary, the same concentrations of Nitrogen and Oxygen gases in water at lower temperatures cause lower TGP values than when measured in higher water temperatures.

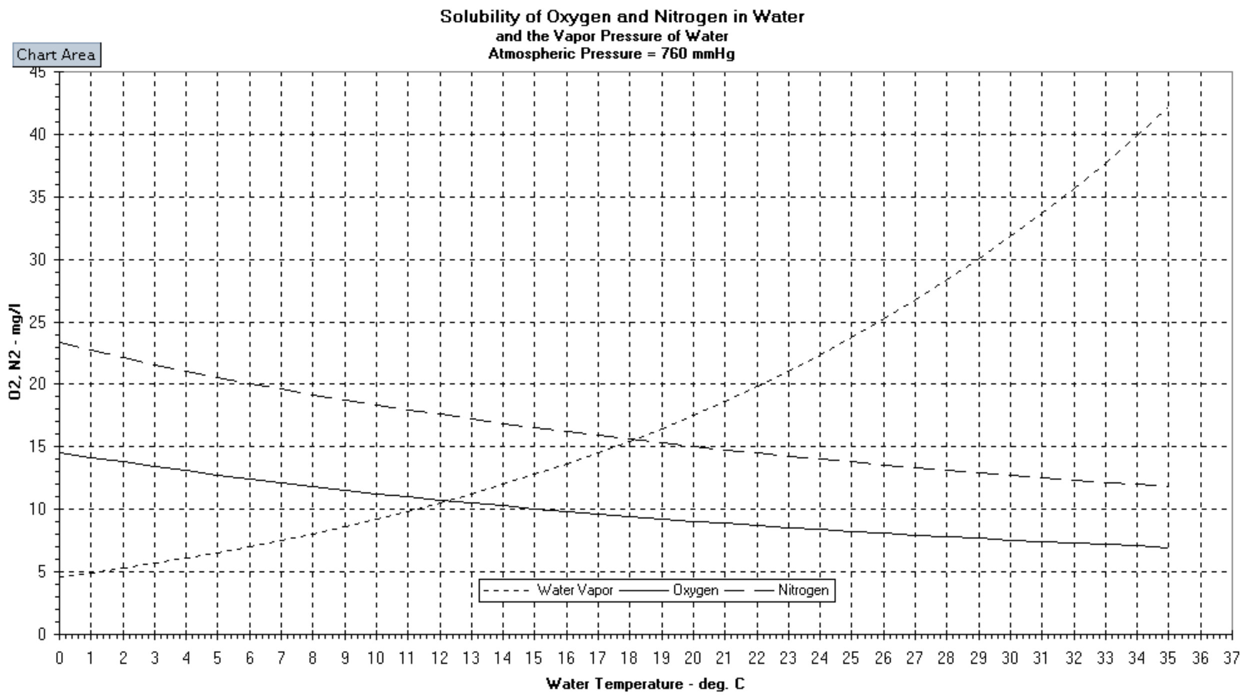


Figure 6. Oxygen (solid line) and Nitrogen (stippled line) saturation lines and temperature (from: Fidler and Miller 1994).

## Possible Mitigation Measures

It appears as if the current practice of interrupting longer (> 8 h) periods of running turbines in the SC mode with shorter periods (> 3 h) of generation in the turbines keeps the TGPS levels to a maximum of 132%. It may be considered to change the ratio of SC operations mode to generation mode for the same turbine in favour of slightly shorter SC periods (< 6 h at a time) with equal periods of generation if it is desired to keep the TGP levels < 110%.

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

## Monitored TGPS Levels and their Potential Biological Impacts

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.) will be used as an indicator (Plate 2014). The time period with the highest potential to impact fish species was May 25' 2015 to June 4, 2015 where two high TGP events occurred. In the first event TGP exceeded 115% for approximately 3 days and peaking at 129% on May 24, 2015 at a distance of 0.2 km from Mica Dam. The second event exceeded 115% TGP for approximately 3 days, including a ~ 12 hour period of lower TGP (< 110%), peaking at 132% on June 1, 2015. At a distance of 3.5 km from Mica Dam the TGP levels were exceeding 115% for only a few hours during each event and peaked at 118% and 121% TGP respectively. At a distance of 10.5 km from the dam, TGP did not exceeded 115%. Since the highest TG levels were recorded at 0.2 km from the dam, the Station 0 scenario will be used to suggest potential impacts on indicator species.

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 of exposure to 125 – 131% TGP (Antcliffe et al. 1997; Marotz et al. 2006; Plate 2014). The first event only exceeded 125% for a very short period of time, but sustained levels of 115 – 125% over two and a half days. Since these values are within the short-term Mountain Whitefish resiliency, it is unlikely the first high TGP event had a significant impact. The longest continuous exposure during this study period was 2 days, approximately 1 day exceeding 125%; after which followed a 12 hour period of low TGP levels (<110%) before increasing above 125% for another few hours. If Mountain Whitefish were able to recover during the 12 hour period of lower TGP levels it is unlikely they would have been severely impacted by one day of 125 – 132% TGP exposure. If they weren't able to recover they would have been exposed to TGP stress for 2 days, which is relatively short in comparison to the 14 days of exposure that caused 85% mortality. Therefore, occurrence of GBD and/or mortality appears unlikely in Mountain Whitefish. As water masses from these two TGPS events travelled downstream, their impacts 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 of exposure to 120 – 130% of TGPS in a laboratory setting all tested Bull Trout were inflicted by GBD (Weitkamp and Katz 1980; Plate 2014). During the first TGPS event in the 2015 monitoring period, TGP levels ranged from 120 – 132% for a period of 2.5 days and may have affected Bull Trout if holding in water less than 2 m deep. During the second TGPS event in 2015, TGP levels of 120 – 132% were reached for 3 days (with a 12 hour period of TGP < 110%) which could have had a greater impact on Bull Trout. However, adult Bull Trout are known to inhabit deeper waters during the day and shallower waters at night (McPhail 2007). Plate (2014) found adult Bull Trout to be holding in water of < 1 m depth at night time in the 5 km closest to Mica Dam in the fall of 2013. Therefore the danger of Bull Trout being exposed to TGPS in Revelstoke Reservoir and experiencing GBD or potential mortality cannot be excluded. Juvenile Bull Trout are known to inhabit the upper 3 meters of the water column in lakes but are most in likely to rear in the tributaries of the Revelstoke Reservoir away from the influence of TGPS (Plate 2014).

Rainbow Trout are known to experience high mortality rates at TGPS of 125% for more than eight days and are typically holding in the top three meters of the water column along the littoral zone (Marotz et al. 2006). Rainbow Trout were found to be holding in the top three meters of the water column in Revelstoke Reservoir in the fall by Plate (2014) and therefore Rainbow Trout may suffer from TGPS effects in the reservoir.

Kokanee have similar tolerances 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 > 120% for more than 12 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 but typically inhabit rocky and weedy littoral zones in water depth of < 2 m (Weitkamp 2008). Therefore it appears unlikely that sculpin species would be affected at the TGPS levels measured in 2015 but would likely be affected by higher TGPS levels due to their preference for shallow water habitats.

# RECOMMENDATIONS

Based on the 2015 field monitoring data and the data analysis the following recommendations are made to gain a better understanding of the TGP levels versus operations mode configurations:

- One of the monitoring stations that was operated at a distance of 3.5 km from Mica Dam at the Blue Bridge should be moved to as close a distance as possible to Mica Dam. A location on the river left or east side of the Columbia River below Mica Dam will be in the direct plume of the turbine discharge and should show TGP changes at a higher temporal resolution.
- Additional field sampling sessions based on analysis of seasonal SC operations frequency during a period with warmer water (August or September) may be useful to see how TGP values react to SC mode in warm water.
- During the one or two 2016 TGP sampling periods all turbines should be operated in SC mode. Of special interest will be periods when the new generators 5 and 6 will be operated in SC mode.
- In addition to the permanently installed TGP monitoring stations, we are recommending TGP spot measurements in the Mica Dam forebay and Nagle Creek.

# LITERATURE CITED

Antcliffe, B., Kieser, D., Thompson, J., Lockhart, W., Metner, D., and Roome, J. 1997. Monitoring of Mountain Whitefish *Prosopium williamsoni*, from the Columbia River system near Castlegar, British Columbia: Fish Health Assessment and Contaminants in 1994. Prepared by Department of Fisheries and Oceans, Eastern B.C. Habitat Unit, 555 West Hastings Street, Vancouver, B.C., V6B 5G3: 74 pp. + appendices.

BC Hydro. 2010. Kinbasket and Revelstoke Reservoirs Ecological Productivity Monitoring. Progress Report Year 1 (2008). BC Hydro, Water Licence Requirements. Study No. CLBMON-3. 4pp. + appendices.

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

Bisset, Irvine, and Thorley. 2015. Columbia River Headpond Drawdown Impacts (Fish Stranding and Water Quality) Monitoring –Interim Report (Year 2). Mica Tailrace Indexing Study (CLBMON 60). Prepared for BC Hydro Generation Resource Management, Burnaby, B.C.

Blackman, B. 1992. Fisheries resources of Williston Reservoir twenty years after impoundment. B.C. Environment Fisheries Branch and B.C. Hydro Environmental Resources.

Bray, K., Sebastian, D., Weir, T., Pieters, R., Harris, S., Brandt, D., and Vidmanic, L. 2013. Kinbasket and Revelstoke Reservoirs ecological productivity and Kokanee population monitoring. 2008–2011 Synthesis Report. Prepared for BC Hydro, under the Columbia River Project Water Use Plan. Study Reference No. CLBMON-2 and CLBMON-3: 105 pp.

Clark, M. 1977. Environmental Protection Dissolved Gas Study: Data Summary – 1977. Ministry of Environment, Pollution Control Branch, Report No. 77-10. 246 p.

Fidler, L. E. 1988. Gas Bubble Trauma in Fish. Ph.D. Thesis, Department of Zoology, University of British Columbia, Vancouver, British Columbia.

Fidler, L., and Miller, S. 1994. British Columbia Water Quality Guidelines for the Dissolved Gas Supersaturation. Prepared for BC Ministry of Environment, Canada Department of Fisheries and Oceans, Environment Canada. Prepared by Aspen Applied Sciences Ltd. Valemount, B.C., V0E 2Z0, Canada. On the Internet: http://www.env.gov.bc.ca/wat/wq/BCguidelines/tgp/index.html#TopOfPage.

Golder Associates Ltd. 2009. Mica Dam Tailwater Seasonal Fish Community Indexing Program. Prepared for BC Hydro Power Supply Environmental Services, 6911 Southpoint Drive (E16), Burnaby, B.C., V3N 4X8. Prepared by Golder Associates Ltd. 201 Columbia Avenue, Castlegar, B.C., V1N 1A8: 48 pp. + appendices.

Hildebrand, L. 1991. Lower Columbia River Fisheries Inventory - 1990 Studies. Vol. 1, Main Report. Contract report by R.L. & L. Environmental Services Ltd., Edmonton, Alberta to BC Hydro, Environmental Resources, Vancouver, B.C.

Marotz, B., Sylvester, R., Dunningham, J., Ostrowski, T., DeShazer, J., Wachsmuth, J., Benner, M., Hensler, M., and Benson, N. 2006. Gas bubble trauma in Kootenay River fish downstream of Libby Dam during the spill of 2006. Prepared for Booneville Power Administration, Division of Fish and Wildlife, P.O. Box 3621, Portland, Oregon, 97208.

McPhail, J. 2007. The Freshwater Fishes of British Columbia. University of Alberta Press, Edmonton, Alberta. 620 p.

Millar, S.A., G.R. Ash, and C.J. Powell. 1996. Seasonal and operational survey of total gas pressure production in the Columbia River Basin, 1995. Prepared for BC Hydro, Burnaby, B.C. by R.L. & L. Environmental Services Ltd., Castlegar, B.C. B.C. Hydro Strategic Fisheries Report No. SFP96-COL-02: p. + 6app.

Pillipow, R., and Langston, A. 2002. Williston Reservoir Fish Assessments 2000, pelagic Netting Summary. Peace Williston Fish and Wildlife Compensation Program, Report No. 261. 43 p.

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 Reservoir. Prepared for BC Hydro, Kathy Miltimore and Guy Martel, Burnaby, B.C.: 77 pp.

Plate, E.M., Bocking, R., and Degan, D. 2013. Williston fish index in the vicinity of W.A.C. Bennett Dam, 2012. Prepared for BC Hydro Michael McArthur, Burnaby, BC, to fulfill the requirements of the: Peace Project Water Use Plan: Monitoring programs for the Peace Spill Protocol (GMSMON-4 WAC Bennett Dam Entrainment Study).

Sebastian, D., Andrusak, G., Scholten, G., and Langston, A. 2008. An index of fish distribution and abundance in Peace Arm of Williston Reservoir based on hydroacoustic and gillnet surveys. BC Hydro, Peace Project Water Use Plan. Williston Fish Index, Reference: GMSMON #13

Weitkamp, D. 2008. Total dissolved gas supersaturation biological effects, review of literature 1980–2007. Prepared for Avista Utilities, 1411 E. Mission, Spokane, Washington, 99220. Chelan County Public Utility District, 327 N. Wenatchee Ave, Wenatchee, Washington, 98801. Douglas County Public Utility District, 1151 Valley Mall Parkway, East Wenatchee, Washington, 98802. Grant County Public Utility District, PO Box 878, Ephrata, Washington, 98823-0878. Tacoma Power, 3628 South 35th Street, Tacoma, Washington, 984409.

Weitkamp, D., and Katz, M. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society, 109 (6): 659–702.

Weitkamp, D., Sullivan, R., Swant, T., and Dos Santos, J. 2003. Gas bubble disease in resident fish of the Lower Clark Fork River. Transactions of the American Fisheries Society 132: 865–876.

White, R., Phillips, G., Liknes, G., Brammer, J., Conner, W., Fidler, L., Williams, T., and W. Dwyer. 1991. Effects of Supersaturation of Dissolved Gases on the Fishery of the Bighorn River Downstream of the Yellowtail Afterbay Dam. Montana Cooperative Fishery Research Unit, Montana State University, Bozeman, Montana. Final report to the US Bureau of Reclamation.

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

Table 2. Maintenance and download record for the 2015 field season from April 8–June 15, 2015.

| Stn # | Unit | Date | Activity | T (°C) at Download | Battery Voltage | | Calibration | | Down Load | New Cart. | Weather |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Old | New | Baro. Press. | Temp. | | | |
| 2 | 404 | 04/08/15 | Station Setup | N/R* | N/A** | 6.36 | Yes | Yes | No | Yes | Sunny |
| 2 | 405 | 04/08/15 | Station Setup | N/R | N/A | 6.36 | Yes | Yes | No | Yes | Sunny |
| 1 | 406 | 04/09/15 | Station Setup | N/R | N/A | 6.4 | Yes | Yes | No | Yes | Sunny |
| 1 | 403 | 04/09/15 | Station Setup | N/R | N/A | 6.36 | Yes | Yes | No | Yes | Sunny |
| 3 | 401 | 04/09/15 | Station Setup | N/R | N/A | 6.42 | Yes | Yes | No | Yes | Sunny |
| 4 | 402 | 04/09/15 | Station Setup | N/R | N/A | 6.4 | Yes | Yes | No | Yes | Sunny |
| 1 | 403 | 04/24/15 | Download/Maintenance | 4.9 | 5.88 | 6.36 | Yes | Yes | Yes | Yes | Sunny |
| 1 | 406 | 04/24/15 | Download/Maintenance | 4.9 | 5.85 | 6.34 | Yes | Yes | Yes | Yes | Sunny |
| 2 | 405 | 04/24/15 | Download/Maintenance | 4.8 | 5.82 | 6.4 | Yes | Yes | Yes | Yes | Sunny |
| 2 | 404 | 04/24/15 | Download/Maintenance | 5 | 5.85 | 6.4 | Yes | Yes | Yes | Yes | Sunny |
| 3 | 401 | 04/24/15 | Download/Maintenance | 5.9 | 5.85 | 6.38 | Yes | Yes | Yes | Yes | Sunny |
| 4 | 402 | 04/24/15 | Download/Maintenance | 5.2 | 5.85 | 6.42 | Yes | Yes | Yes | Yes | Sunny |
| 3 | 401 | 05/11/15 | Download/Maintenance | 6.1 | 5.86 | 6.39 | Yes | Yes | Yes | Yes | Sunny |
| 4 | 402 | 05/11/15 | Download/Maintenance | 7.3 | 5.86 | 6.38 | Yes | Yes | Yes | Yes | Sunny |
| 2 | 404 | 05/11/15 | Download/Maintenance | N/R | 5.85 | 6.4 | Yes | Yes | Yes | Yes | Sunny |
| 2 | 405 | 05/11/15 | Download/Maintenance | N/R | 5.84 | 6.38 | Yes | Yes | Yes | Yes | Sunny |
| 1 | 403 | 05/11/15 | Download/Maintenance | 8.5 | 5.86 | 6.39 | Yes | Yes | Yes | Yes | Sunny |
| 1 | 406 | 05/11/15 | Download/Maintenance | 8.6 | 5.85 | 6.37 | Yes | Yes | Yes | Yes | Sunny |
| 0 | 403 | 05/11/15 | Download/Maintenance | N/R | N/R | 6.38 | Yes | Yes | Yes | Yes | Sunny |
| 0 | 403 | 05/25/15 | Download/Maintenance | N/R | 5.92 | 6.42 | Yes | Yes | Yes | Yes | Sunny |
| 1 | 406 | 05/25/15 | Download/Maintenance | 7.8 | 5.92 | 6.28 | Yes | Yes | Yes | Yes | Sunny |
| 2 | 404 | 05/25/15 | Download/Maintenance | 8 | 5.94 | 6.37 | Yes | Yes | Yes | Yes | Sunny |
| 2 | 405 | 05/25/15 | Download/Maintenance | 7.7 | 5.9 | 6.38 | Yes | Yes | Yes | Yes | Sunny |
| 3 | 401 | 05/25/15 | Download/Maintenance | 9.1 | 5.9 | 6.34 | Yes | Yes | Yes | Yes | Sunny |
| 4 | 402 | 05/25/15 | Download/Maintenance | N/R | 5.9 | 6.21 | Yes | Yes | Yes | Yes | Sunny |
| Stn # | Unit | Date | Activity | T (°C) at Download | Battery Voltage | | Calibration | | Down Load | New Cart. | Weather |
| | | | | | Old | New | Baro. Press. | Temp. | | | |
| 0 | 403 | 06/15/15 | Download/Removal | 7.1 | 5.6 | N/A | No | No | Yes | No | N/R |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 406 | 06/15/15 | Download/Removal | 9 | 0 | N/A | No | No | Yes | No | N/R |
| 2 | 404 | 06/15/15 | Download/Removal | 7.5 | 5.68 | N/A | No | No | Yes | No | N/R |
| 2 | 405 | 06/15/15 | Download/Removal | 7.1 | 5.56 | N/A | No | No | Yes | No | N/R |
| 3 | 401 | 06/15/15 | Download/Removal | 8.1 | 0 | N/A | No | No | Yes | No | N/R |
| 4 | 402 | 06/15/15 | Download/Removal | 8.8 | 5.42 | N/A | No | No | Yes | No | N/R |

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

# APPENDIX B: GRAPHS

## State of generators

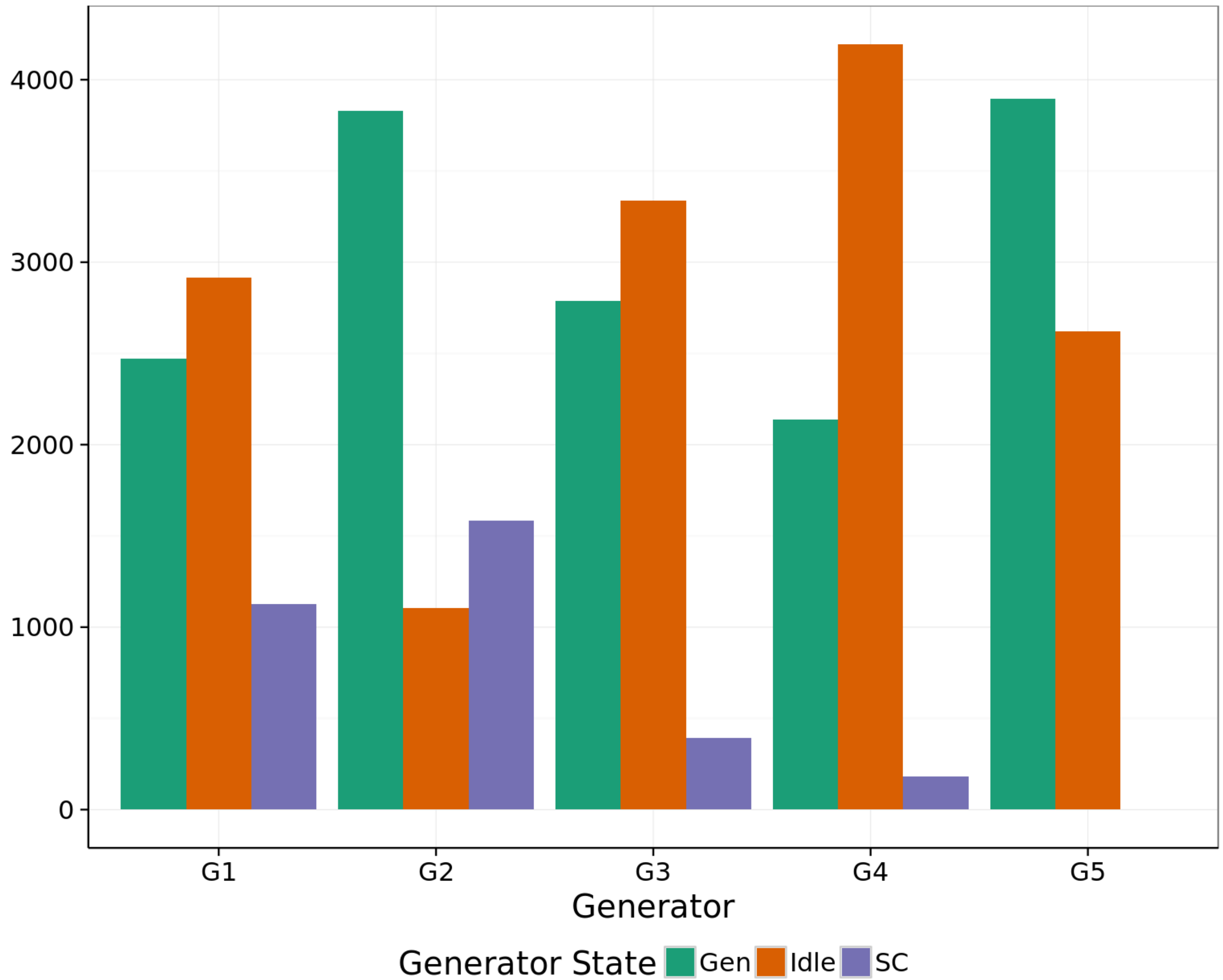


Figure 7. State of generators throughout the monitoring period from April 7 to June 15, 2015 (Gen = Generating; Idle = Idling; SC = Synchronous Condense Mode). The y-axis units are the number (N) of 15 minute time intervals.

**TGP generated by combination of operating modes for all generators measured at 0.2 km downstream of MD**

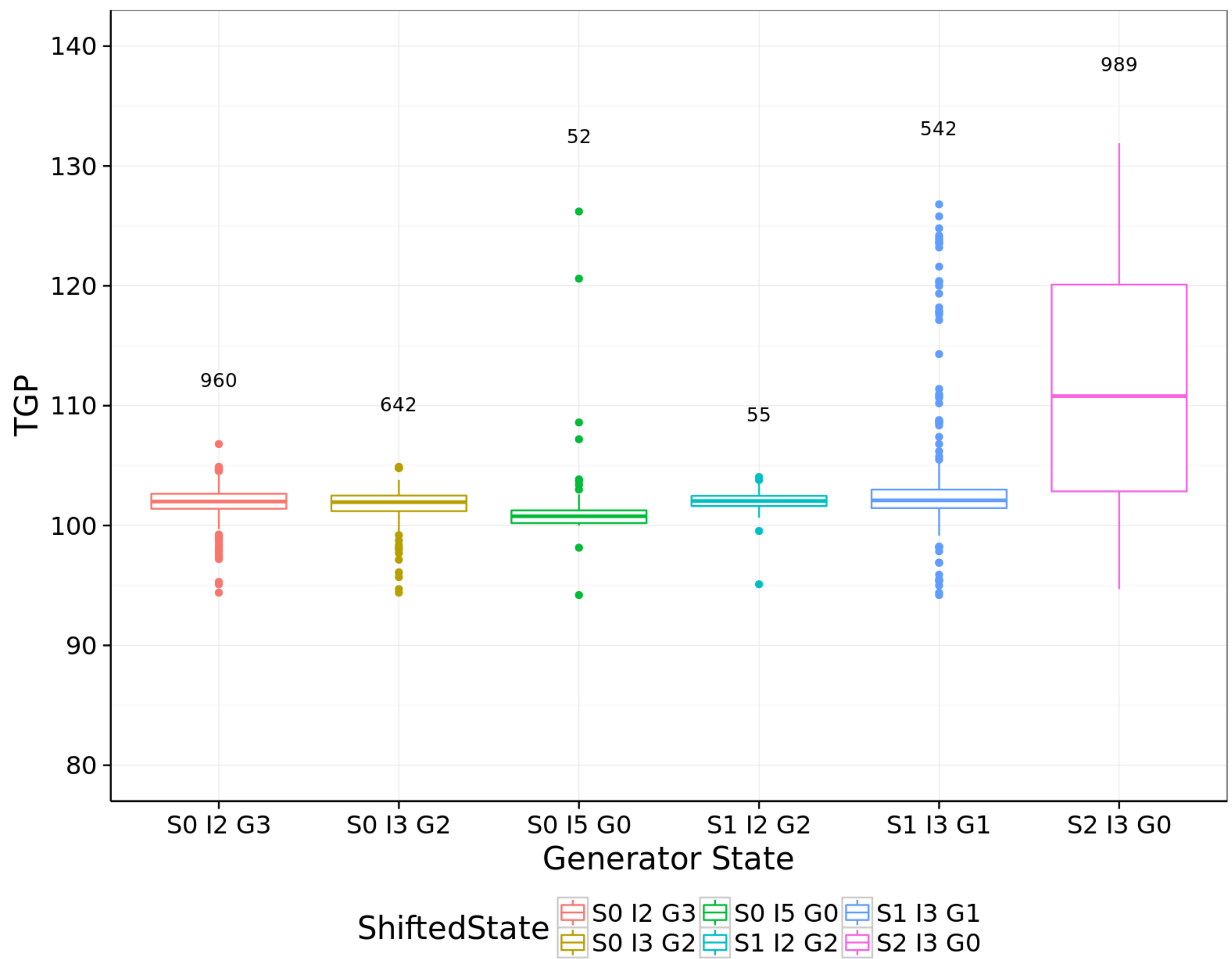


Figure 8. TGP (%) generated by combination of operating states measured at 0.2 km from MD between May 11 and June 16, 2015 (S = Synchronous Condense; I = Idling; G = Generating. Numbers following the generator state indicate the number of units in this state. Numbers above box-plots indicate sample size (N). Only combinations of states that were recorded more than 50 time (N>50) were included.)

**TGP generated by combination of operating states for all generators measured at 3.5 km downstream of MD**

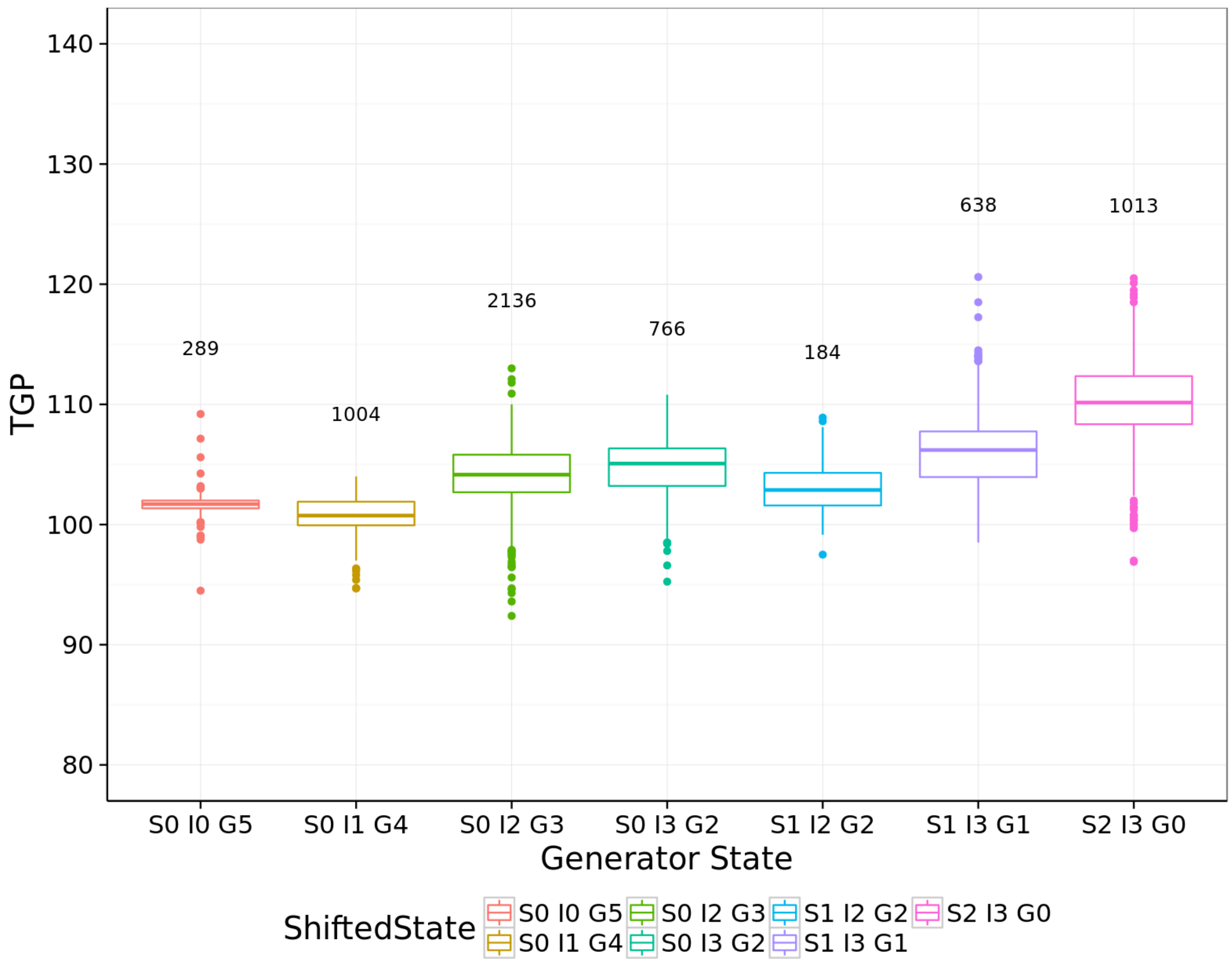


Figure 9. TGP (%) generated by combination of operating states measured at 3.5 km from MD between April 7 and June 16, 2015 (S = Synchronous Condense; I = Idling; G = Generating. Numbers following the generator state indicate the number of units in this state. Numbers above box-plots indicate sample size (N). Only combinations of states that were recorded more than 50 time (N>50) were included.)

**TGP generated by combination of operating states for all generators measured at 10.5 km downstream of MD**

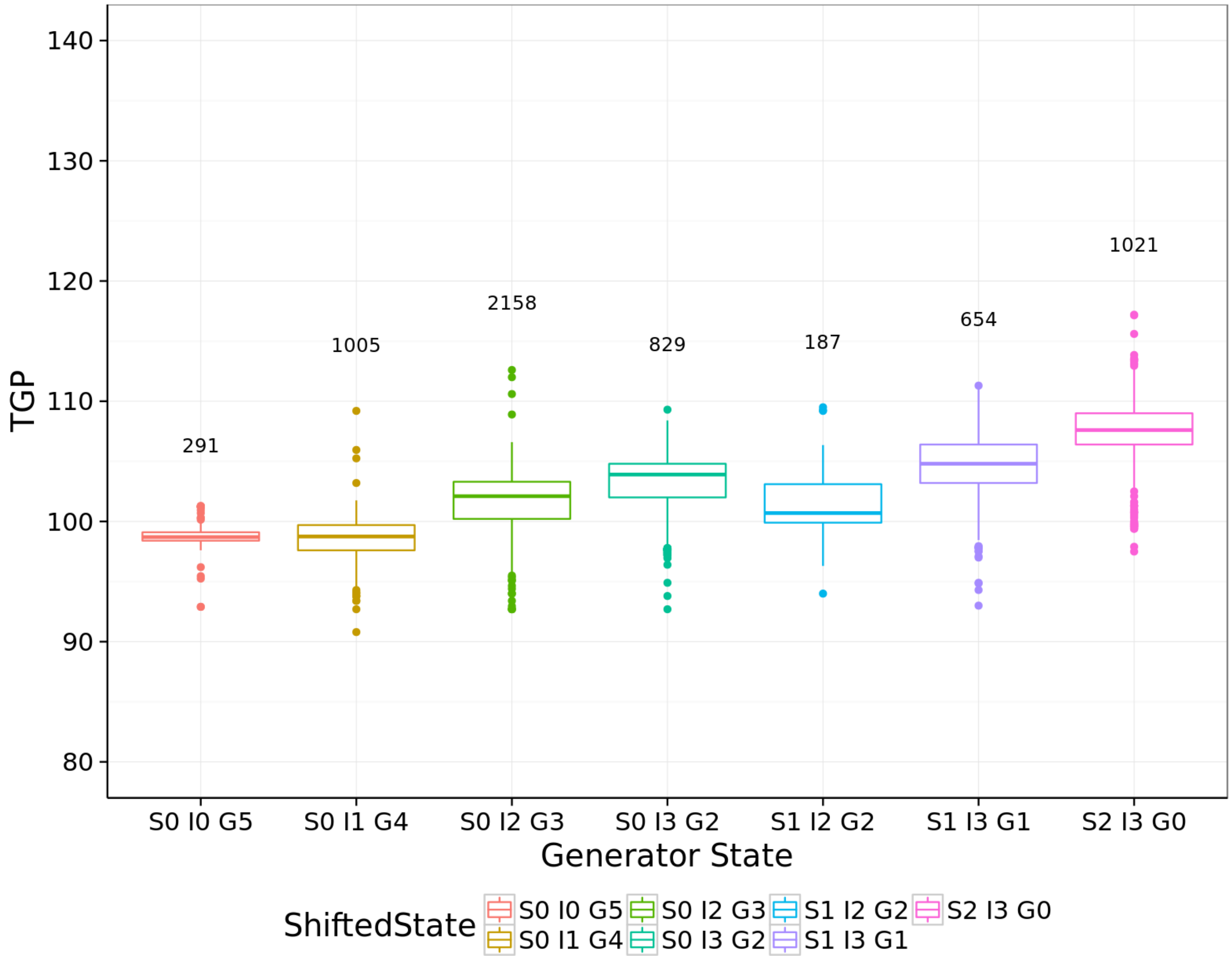


Figure 10. TGP (%) generated by combination of operating states measured at 10.5 km from MD between April 7 and June 16, 2015 (S = Synchronous Condense; I = Idling; G = Generating. Numbers following the generator state indicate the number of units in this state. Numbers above box-plots indicate sample size (N). Only combinations of states that were recorded more than 50 time (N>50) were included.)

**TGP over time by generator: Generator 1 measured at 0.2 km downstream of MD**

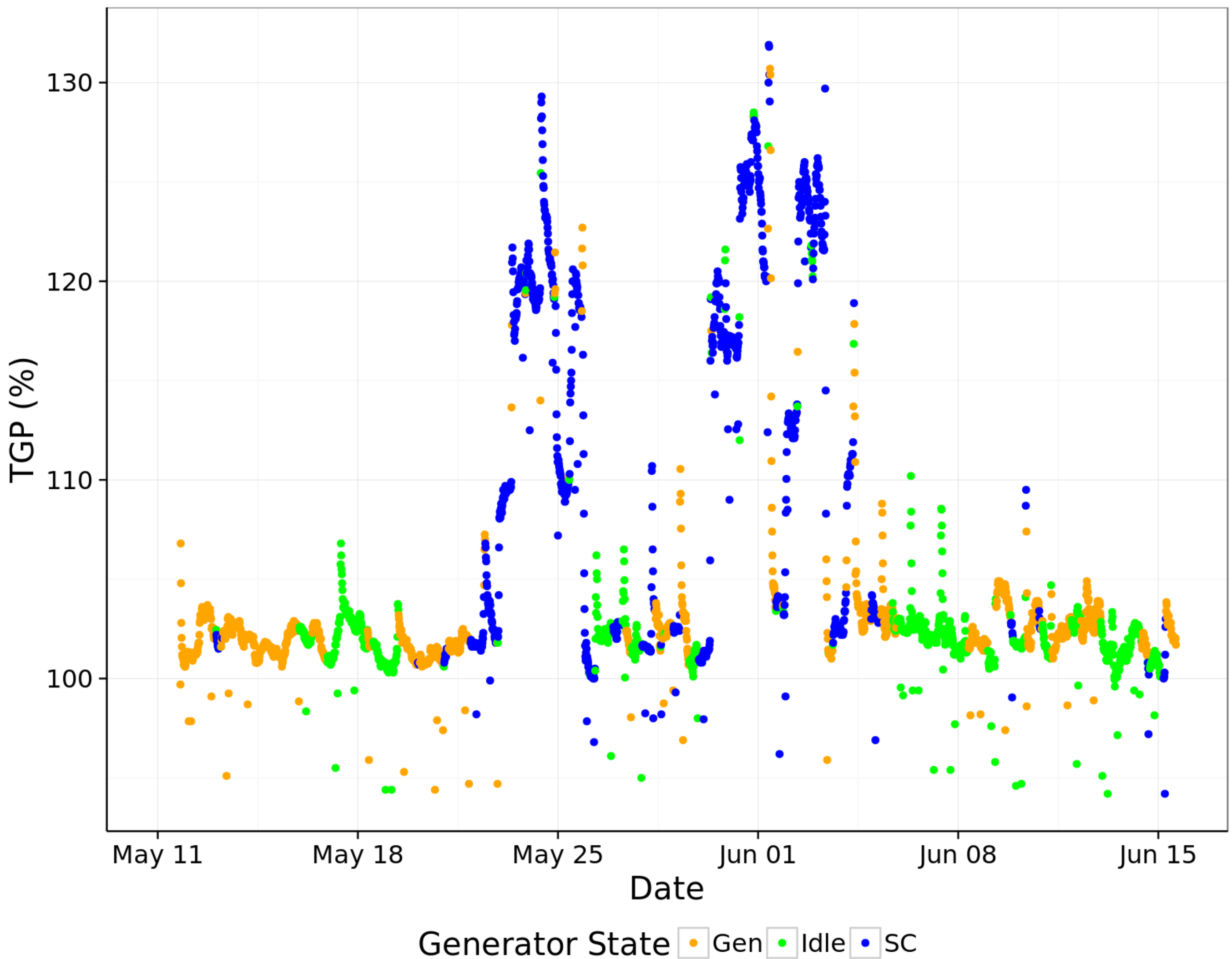


Figure 11. TGP (%) generated by operating generator 1 in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from May 11 to June 16, 2015.

**TGP over time by generator: Generator 2 measured at a 0.2 km downstream of MD**

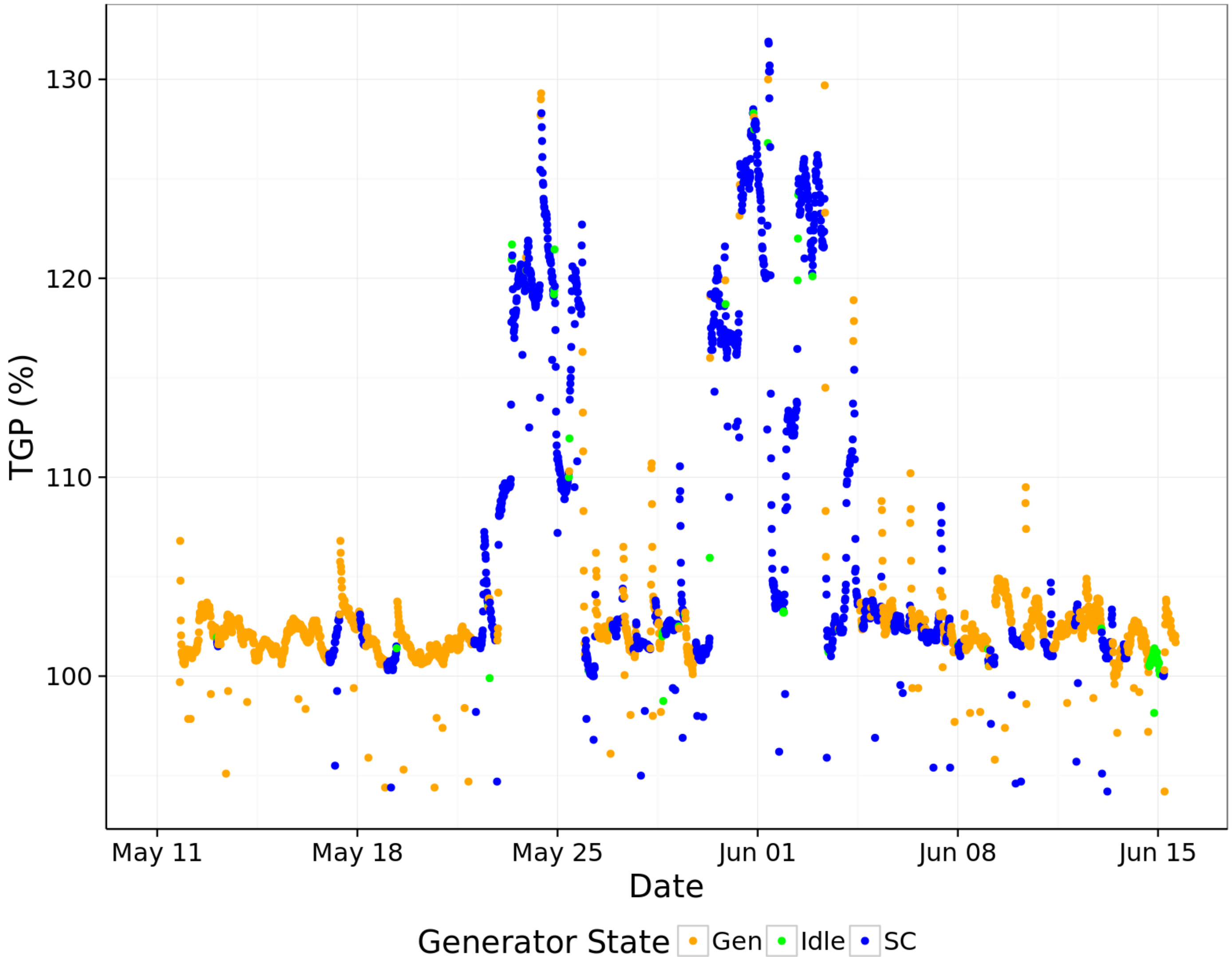


Figure 12. TGP (%) generated by operating generator 2 in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from May 11 to June 16, 2015.

**TGP over time by generator: Generator 3 measured at 0.2 km distance from MD**

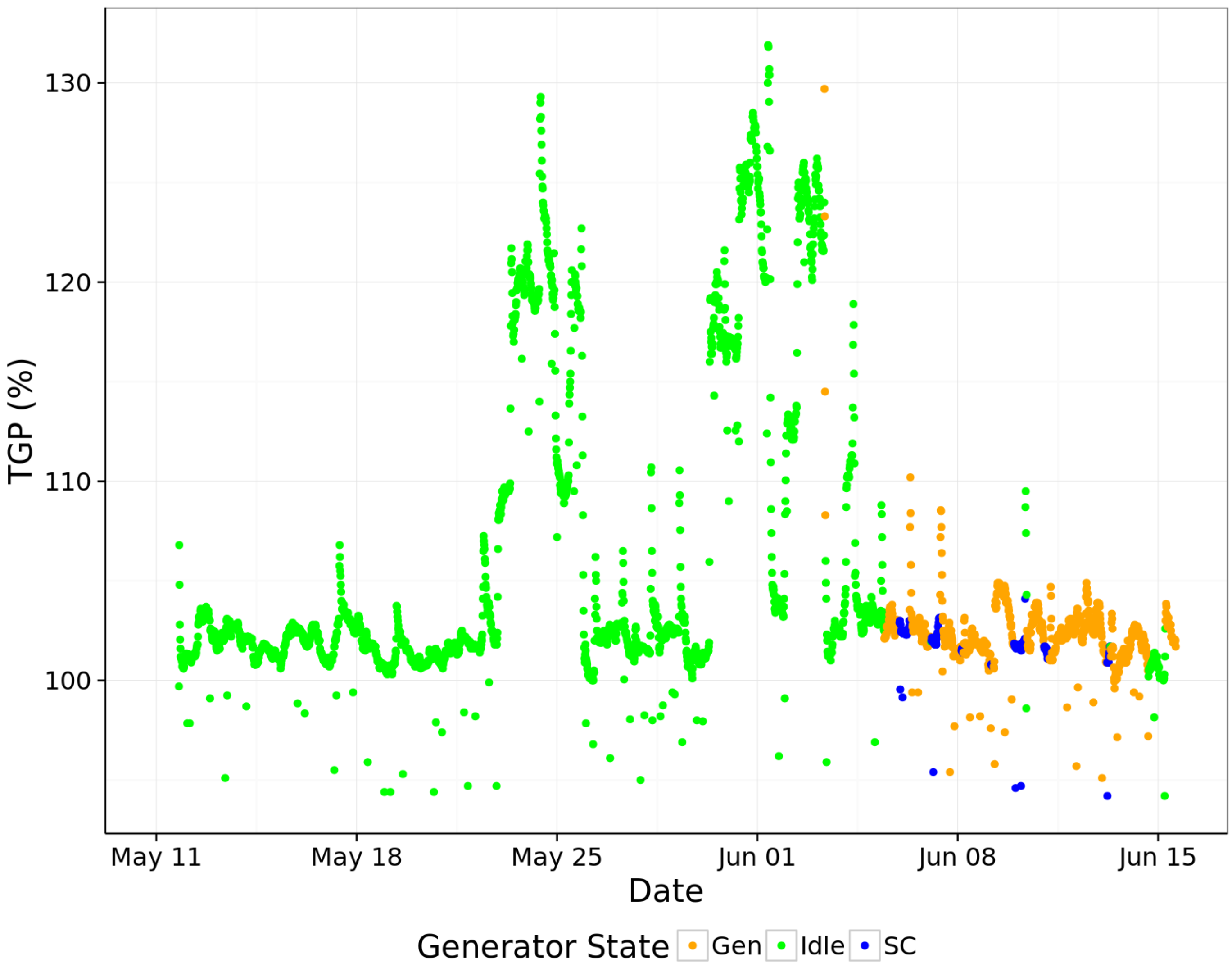


Figure 13. TGP (%) generated by operating generator 1 in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from May 11 to June 16, 2015.

**TGP over time by generator: Generator 4 measured at 0.2 km distance from MD**

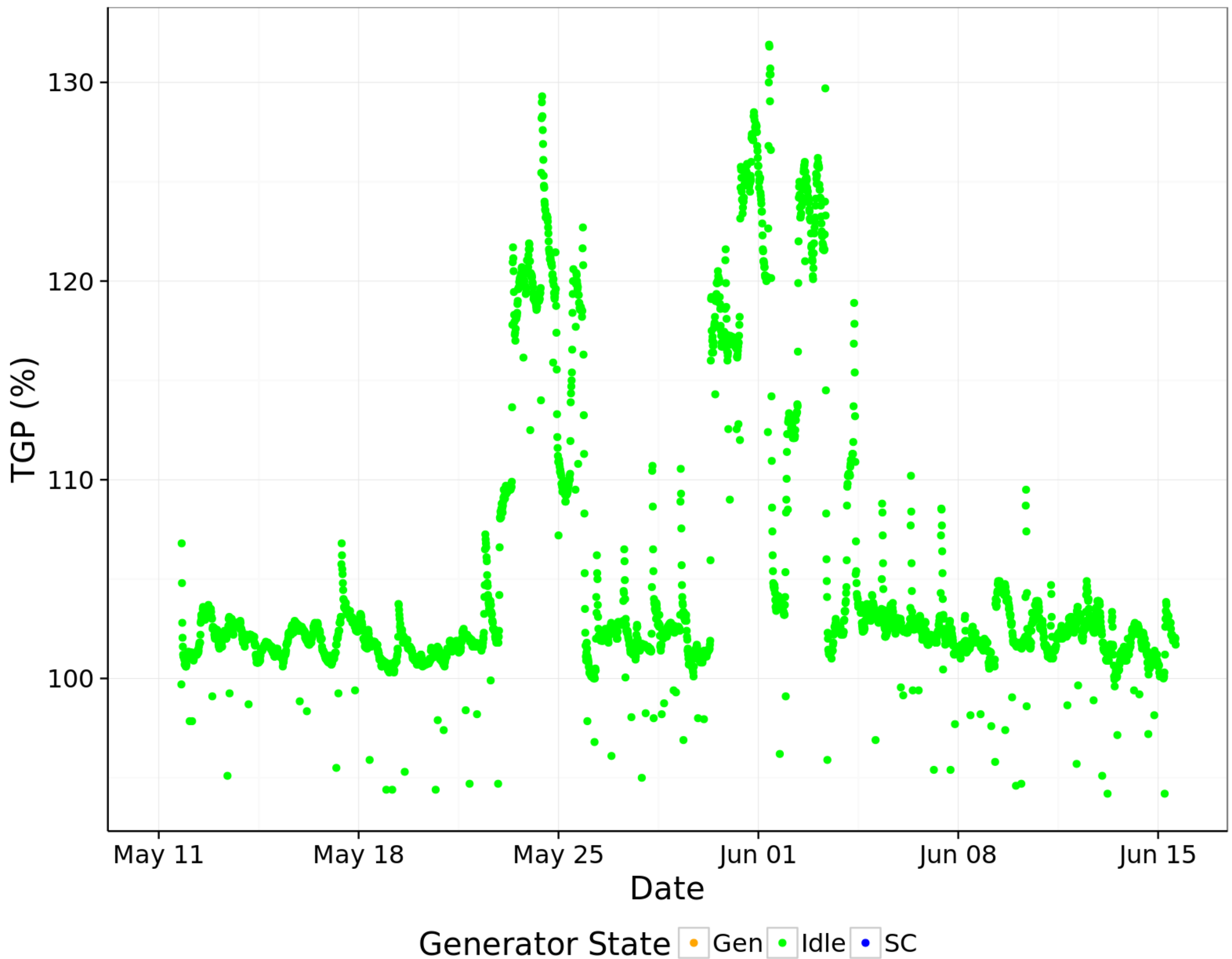


Figure 14. TGP (%) generated by operating generator 1 in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from May 11 to June 16, 2015.

**TGP over time by generator: Generator 5 measured at 0.2 km downstream of MD**

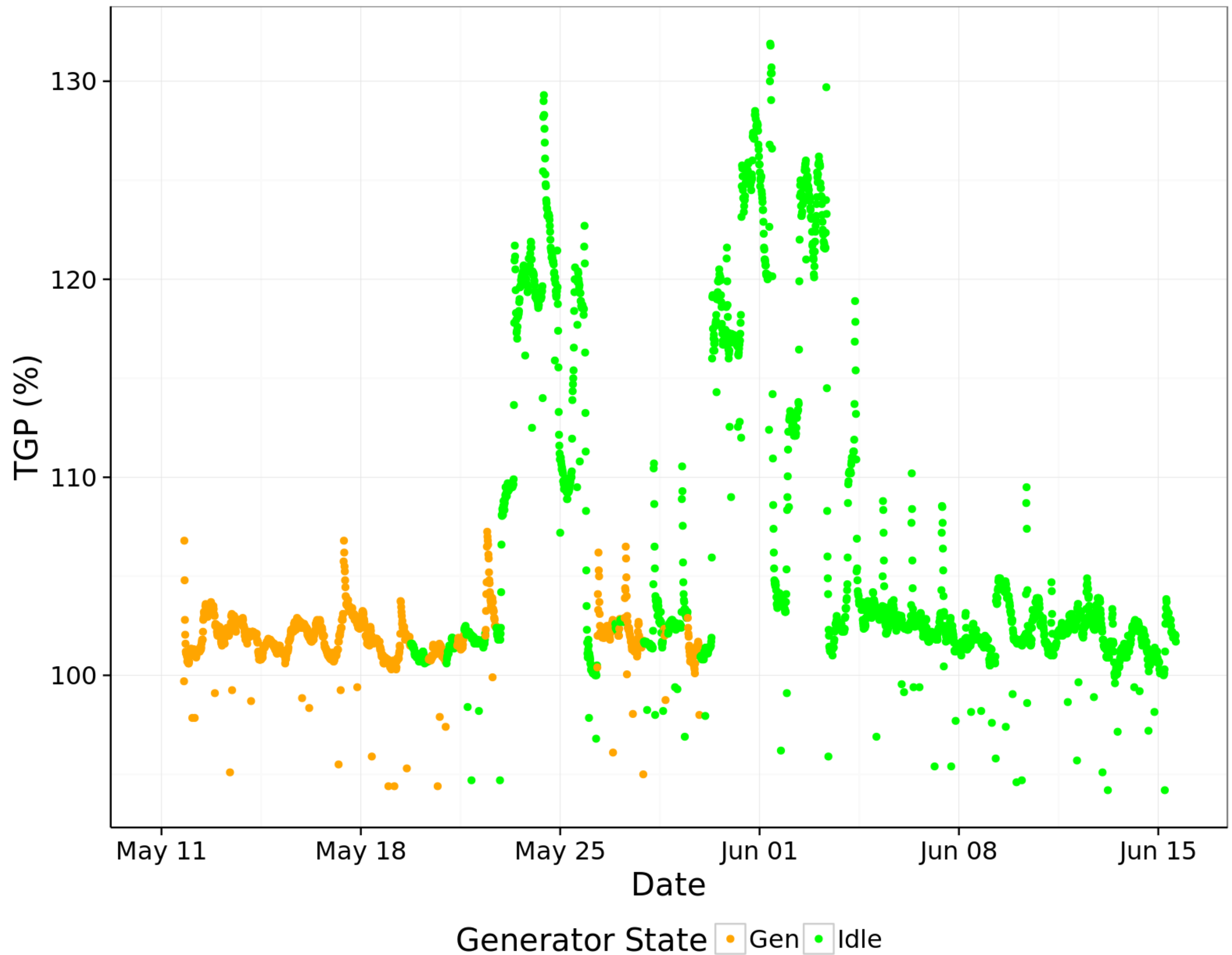


Figure 15. TGP (%) generated by operating generator 1 in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from May 11 to June 16, 2015.

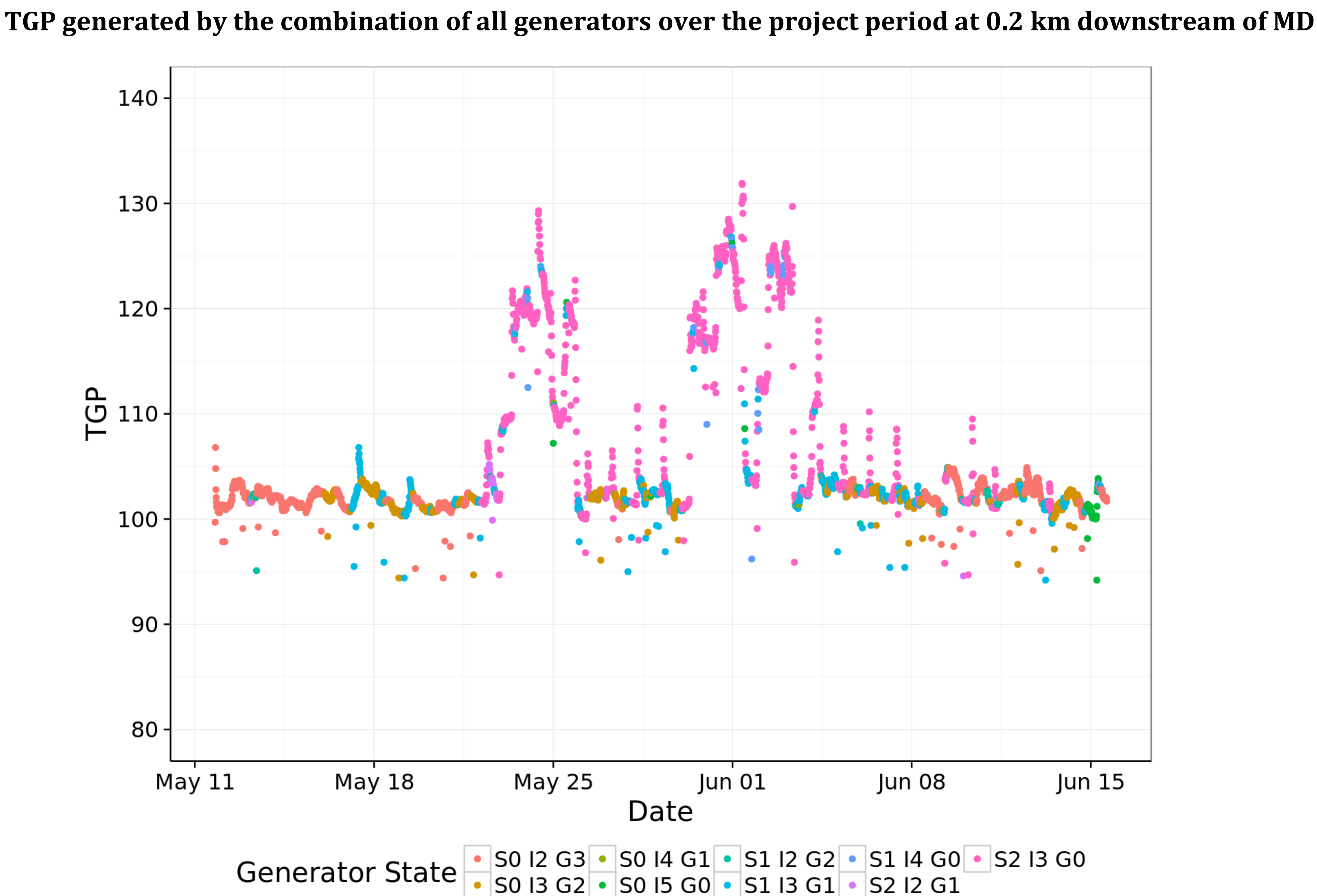


Figure 16. TGP generated by the combination of operating states over time from May 11 to June 15, 2015 measured at 0.2 km distance from MD.

**TGP generated by the combination of all generators over the project period at 3.5 km downstream of MD**

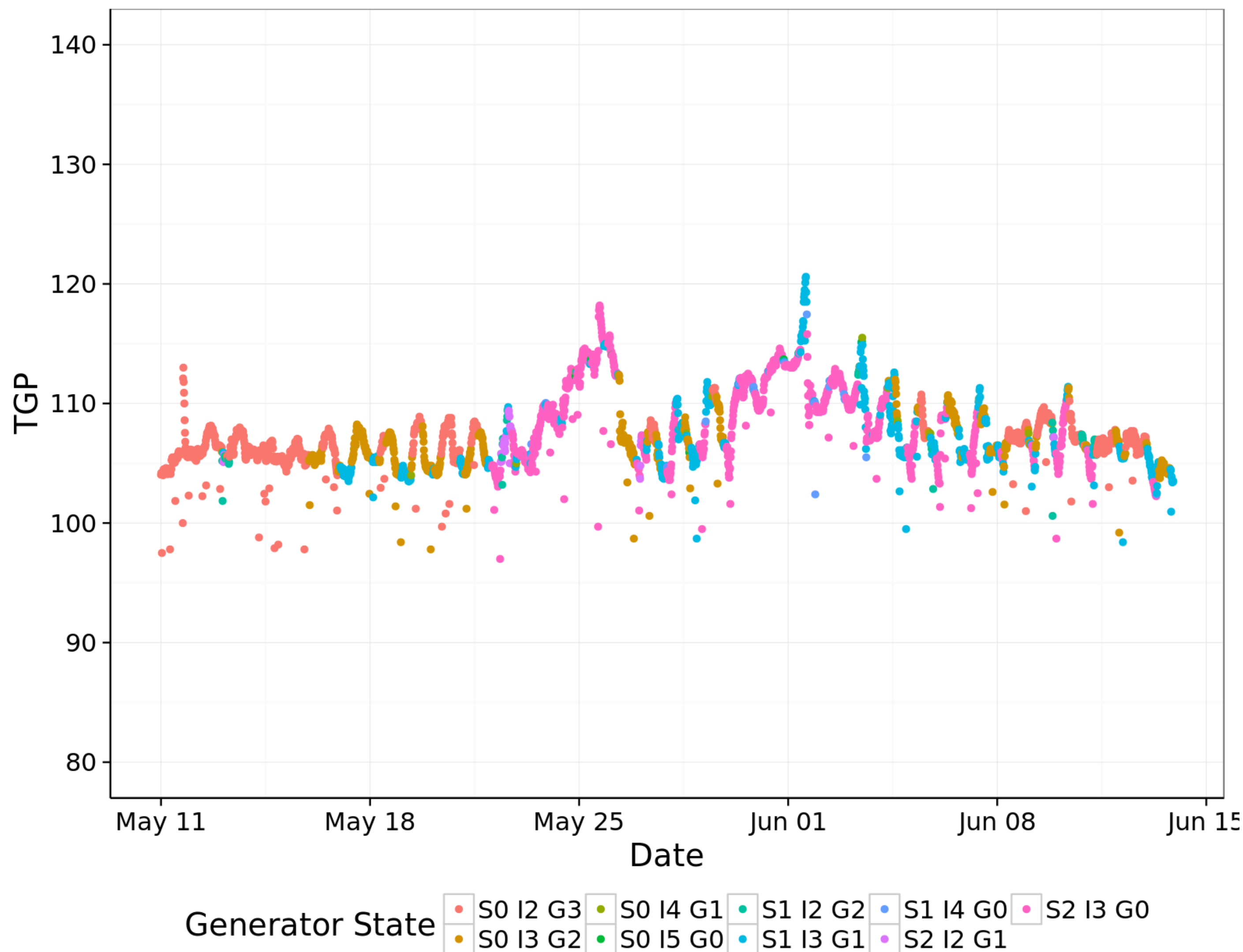


Figure 17. TGP generated by the combination of operating states over time from May 11 to June 15, 2015 measured at 3.5 km distance from MD.

**TGP generated by the combination of all generators over the project period at 10.5 km downstream of MD**

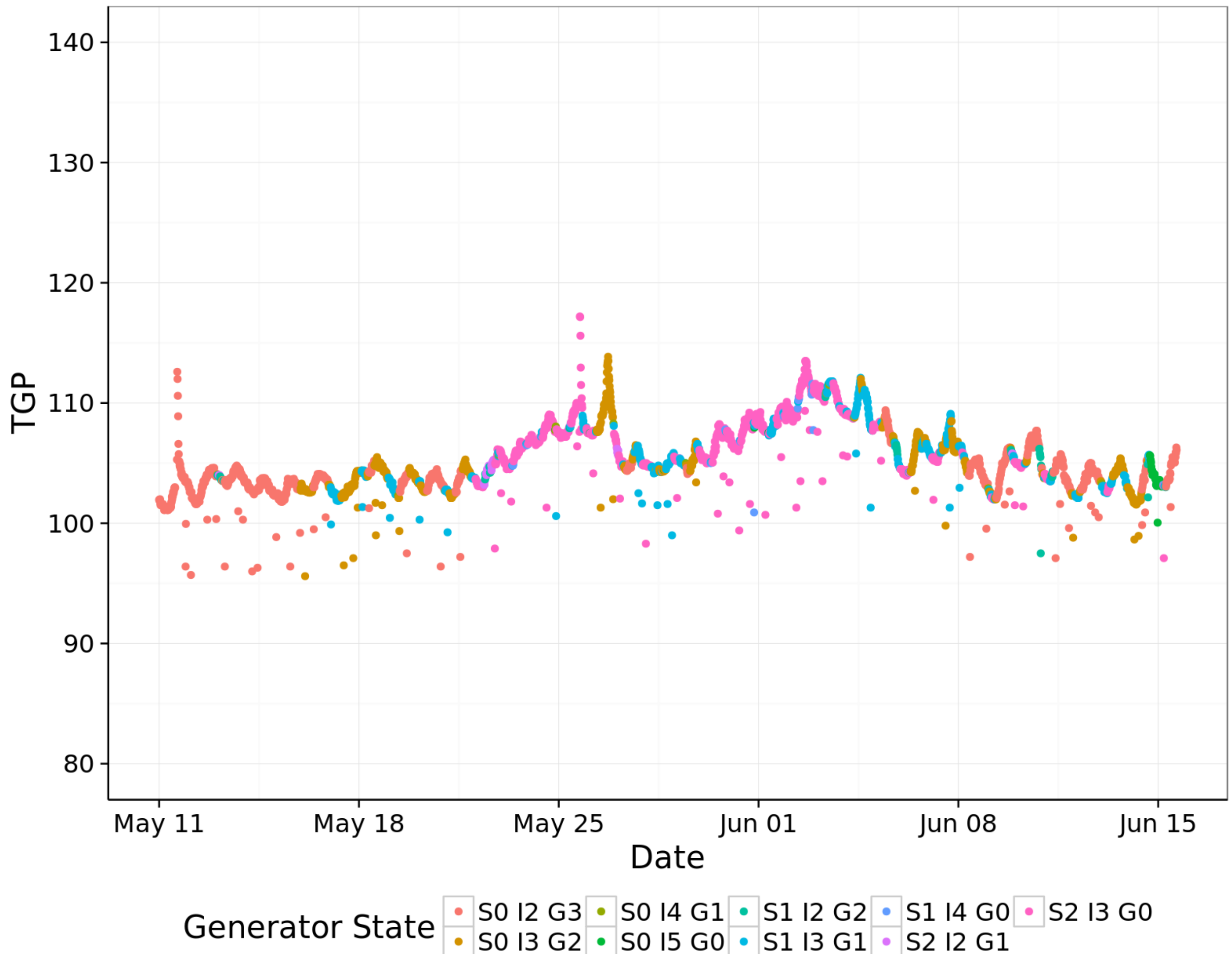


Figure 18. TGP generated by the combination of operating states over time from May 11 to June 15, 2015 measured at 10.5 km distance from MD.

## TGP versus temperature at 10.5 km downstream of Mica Dam

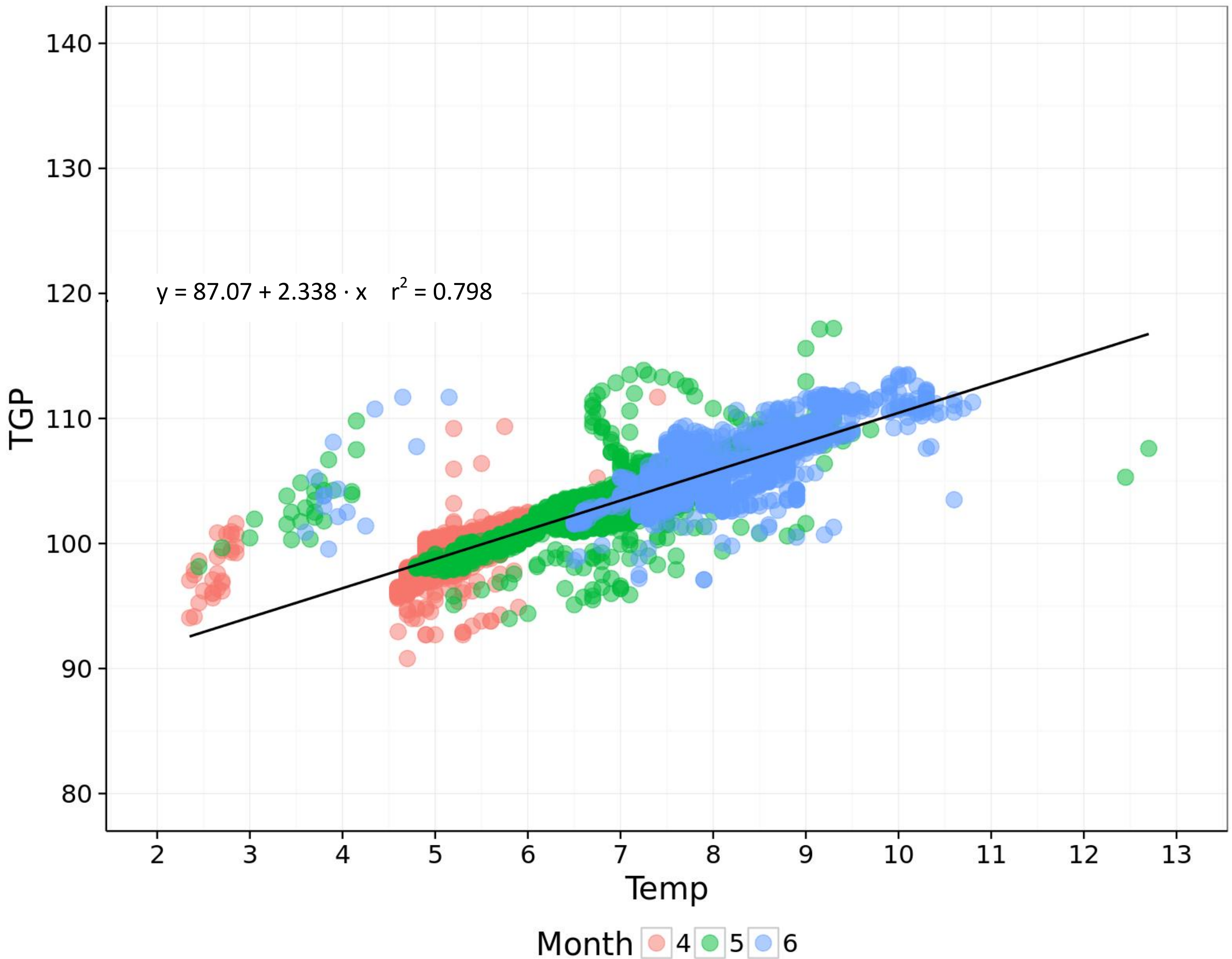


Figure 19. TGP (%) by temperature (°C) (April = pink dots; May = green dots; June = blue dots) recorded at Station 4 (10.5 km from MD) from April 7 to June 16, 2015.

# APPENDIX C: SPECIES SPECIFIC TOTAL GAS PRESSURE EXPOSURE RISK FOR REVELSTOKE RESERVOIR

Table 3. Summary table of TGPS exposure risk for fish species at different developmental stages in Revelstoke Reservoir downstream of Mica Dam 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** | **Situation in Revelstoke Reservoir based on literature review (Plate 2014) and project team observations** | **Inferred Potential TGP Exposure Risk Below Mica** |
|---|---|---|---|---|
| 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 | Juveniles | Summer | Low density throughout reservoir and no observations in shallow water in Mica Dam area | Low |
| Peamouth Chub | All developmental stages | Year-round | No observations in shallow water in Mica Dam area, medium densities in lower and central reservoir | Medium |
| Redside Shiner | 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 | 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 |