Columbia River Water Use Plan

Kinbasket Reservoir Fish and Wildlife Information Plan

Total Gas Pressure Monitoring Downstream of Mica Generating Station

Implementation Year 2

Reference: CLBMON-1 (CLBMON-62)

Study Period: May 2016 to September 2016

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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 six turbines installed in Mica Dam from May 12 to June 13, 2016 and September 6 to 25, 2016. For both periods, Generator 1 was mainly operated idling with short periods of generation in the spring and fall. Generator 2 only operated idling in the spring and was mostly idling in the fall with frequent periods of generation and SC operations. Generators 3 and 4 were mostly operating in SC mode with some generation periods and little idling in the spring. In the fall, Generator 3 was mostly idling with frequent generation periods and some SC operations, but Generator 4 operated mostly in generation mode with some periods of SC operations and little time idling. Newly installed Generators 5 and 6 were idling throughout the spring period and most of the fall period when they were also used for generation. Neither Generator 5 nor 6 were operated in SC mode during 2016.

The highest mean TGP Supersaturation or TGPS was observed when a combination of any two turbines was operated in SC mode while none of the other turbines were generating. For this state, mean TGPS values were measured at 114%. 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 128% were reached. 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 combinations of different modes of the six generators created TGPS value peaks or 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 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 128% were measured close to the dam.

For future studies, the TGP effects of the newly installed Generators 5 and 6 operating in SC mode need to be monitored.

To investigate potential operational adjustments for the reduction of high TGP values, TGP peaks caused by long-term SC operations were analyzed in detail. It appears as if large (>10%) reductions in TGP from TGPO supersaturation (>110%) back to 100% background values cannot be accomplished with periods of SC discontinuation and simultaneous generation shorter than 2 h.

Based on TGP and temperature data collected during the typically warm September period, we also tried to find out whether a general relationship between ambient water temperature and TGP values independent from generator operational scenarios exists. No such relationship could be established in 2016.

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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Okanagan Nation Alliance: Amy Duncan, (Fisheries Biologist) assisted in data downloading and meter maintenance in the field.

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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.

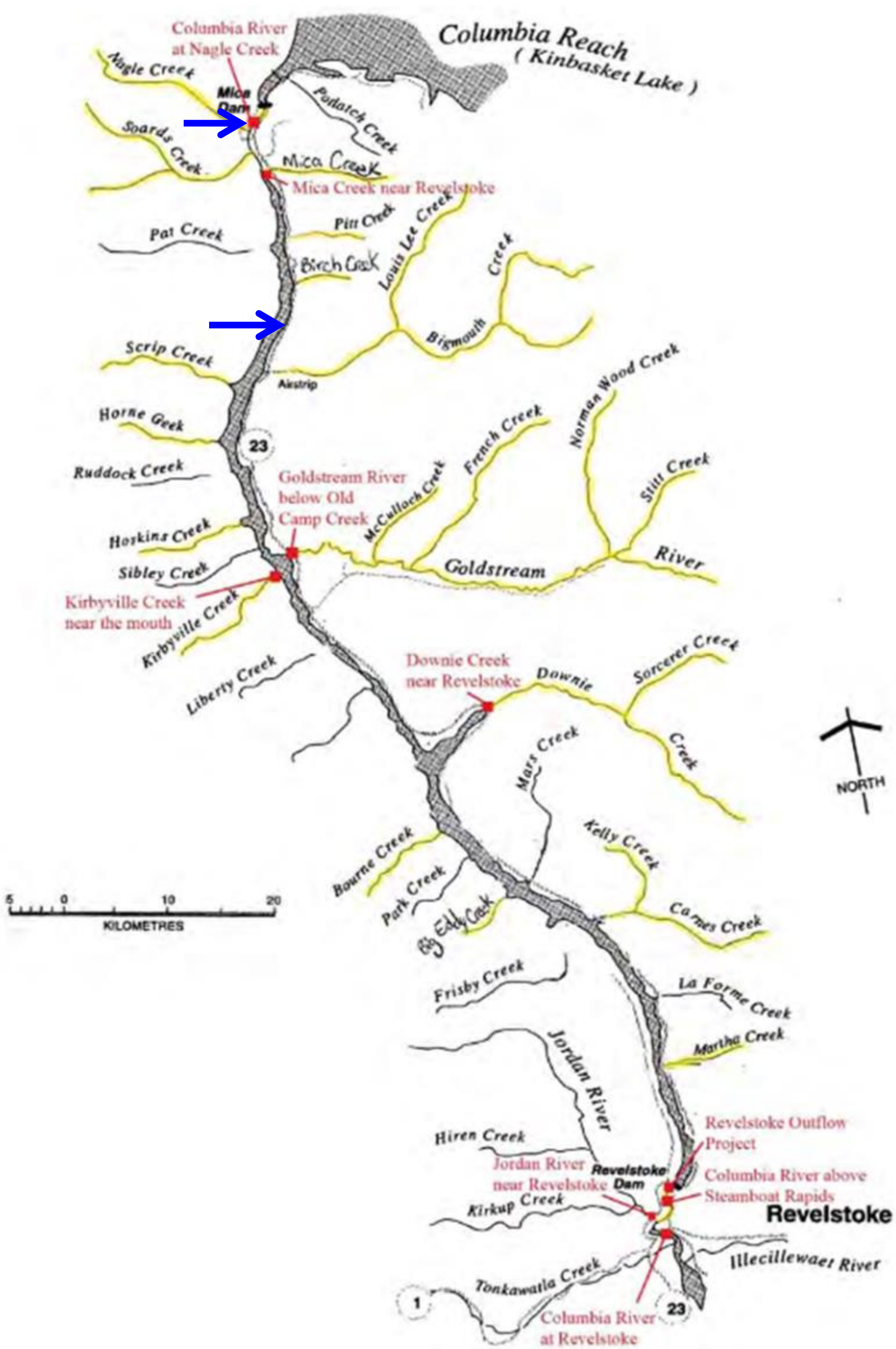

Figure 1 Map of Revelstoke Reservoir and main tributaries. The study area for this project reaches from Mica Dam in the north to the area between the mouth of Birch and Bigmouth Creeks (blue arrows) in the south (from: BC Hydro 2010).

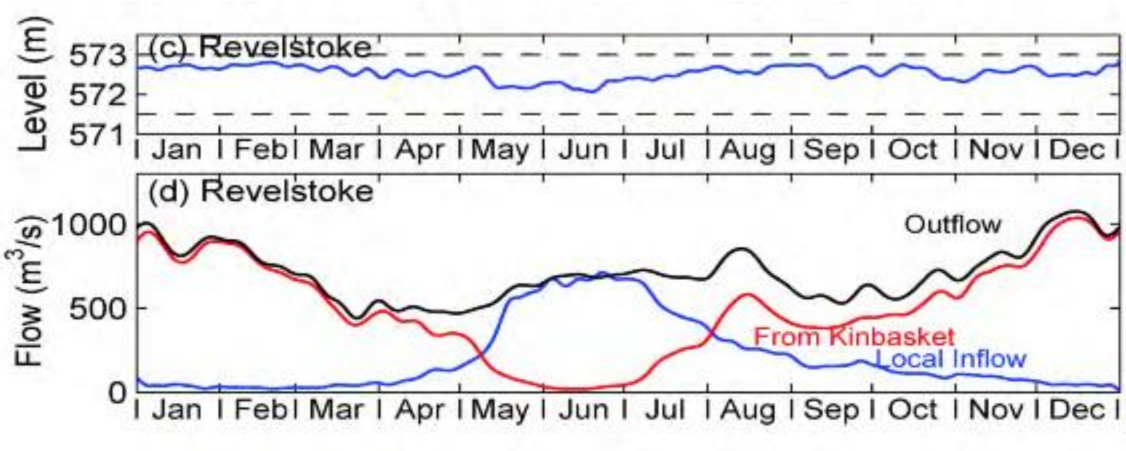

Figure 2 Water level and flow in Revelstoke Reservoir in 2008 typical for other years (from: Bray et al. 2013).

Mica Generating Station Total Gas Pressure and Fish

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 will be 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. 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 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. When Mica Dam generators are 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) downstream of the Blue Bridge in Revelstoke Reservoir, as observed in this study, or even right below the dam.

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. 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 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.

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 the 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, 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). 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 OBJECTIVES AND RESULTING ACTIVITIES

Objective 1: Determine the causal relationship between Mica Dam generation station operational scenarios and TGP in the 11 km of Revelstoke Reservoir downstream of Mica Dam.

To achieve this objective, 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.

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 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

Locations

TGP was monitored at 200 m (Station 0 & 0a, Tailrace), 3.5 km (Station 1 & 2, Blue Bridge), 10.5 km (Station 3) and 11 km (Station 4) distance from Mica Dam from May 12 to June 13, 2016 and September 6 to 25, 2016 (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 12 and 27, June 13, and September 6 and 25, 2016. 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, river left) was added in Year 2 to measure TGP in the direct current of the tailrace. In combination with the TGP Station 0, Station 0a, was installed to record real-TGP levels in the immediate vicinity of the dam. Station 0 (200 downstream of Mica Dam, river right) provided redundancy at close distance to the dam and 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.

Station Name	11U UTM East	11U UTM North	# of TGP Meters	Deployment Period	Downloaded
Station 0a	392855	5770094	1	13-May to 13-Jun & 6-Sep to 25-Sep	27-May, 13-Jun, 25-Sep
Station 0	392719	5770021	1	12-May to 13-Jun & 6-Sep to 25-Sep	13-May, 27-May, 13-Jun, 25-Sep
Station 1	390683	5767814	1	12-May to 13-Jun & 6-Sept to 25-Sep	13-May, 27-May, 13-Jun, 25-Sep
Station 2	390786	5767739	1	12-May to 13-Jun & 6-Sep to 25-Sep	13-May, 27-May, 13-Jun, 25-Sep
Station 3	392541	5761129	1	12-May to 13-Jun & 6-Sep to 25-Sep	13-May, 27-May, 13-Jun, 25-Sep
Station 4	392523	5760933	1	12-May to 13-Jun & 6-Sep to 25-Sep	13-May, 27-May, 13-Jun, 25-Sep
Nagle Creek	390693	5768268	1	12-May, 27-May, 13-Jun, 6-Sep, 25-Sep	12-May, 27-May, 13-Jun, 6-Sep, 25-Sep
Forebay	393290	5771457	1	12-May, 27-May, 13-Jun, 12-Jul, 6-Sep, 25-Sep	12-May, 27-May, 13-Jun, 12-Jul, 6-Sep, 25-Sep

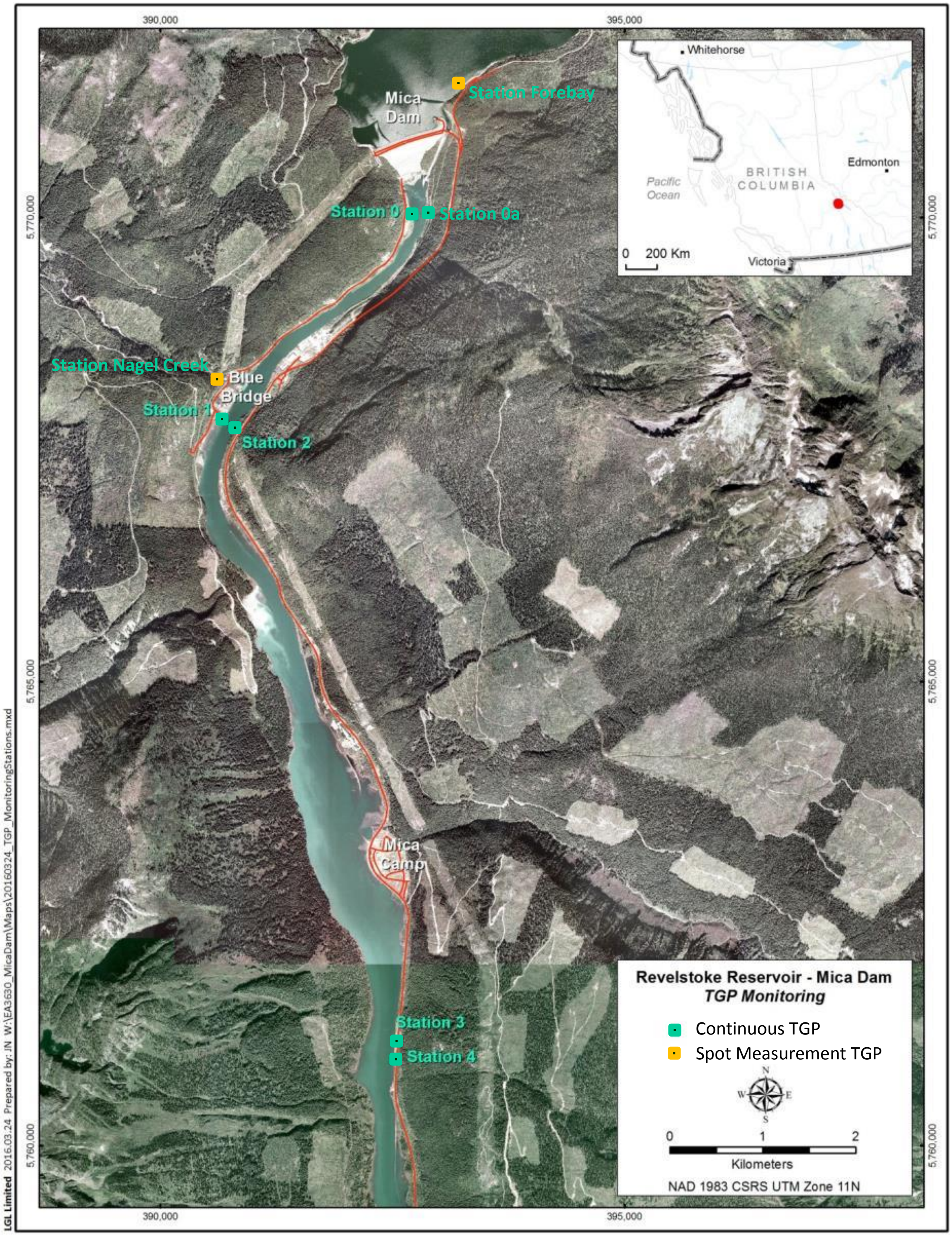

Figure 3. Map of the Revelstoke Reservoir downstream of Mica Dam showing TGP Stations and landmarks.

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 PVC pipe with the measuring membrane end protruding by 10 cm into open water. 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).

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 (Figure 5). 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.

Figure 5. Elmar Plate preparing to download TGP meter at Station 3.

Data Analysis

Table 5 (Appendix A) shows the maintenance and download record for all TGP meters in 2016.

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 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).

The resulting data file was processed using R to produce the following figures shown in the text:

- Figure 6 (top and bottom panel) are bar graphs showing the state frequencies for each generator in spring (May 12 – June 13, 2016) and fall (September 6 – 25, 2016), respectively.
- Figure 7 –Figure 10 are box and whisker plots of TGP for the system states for both spring and fall sessions. 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 outside the 1.5*IQR).
- Figure 11 and Figure 12 are bar graphs showing the frequency of TGP (%) values that exceed the BC Water Quality Guideline of 110% by state of generators on Mica Dam.
- Figure 13 –Figure 22 are scatter plots of TGP by date, coloured by the state of the generator or of the entire system in spring and fall and with increasing distance from Mica Dam.
- Figure 23 is a scatter plot of TGP by temperature in spring and fall. It has been fitted with a linear regression (equation is shown on the figure), minimizing the mean squared error.
- Figure 24 is composed of two scatter plots showing two TGP peaks measured 0.2 km below Mica dam on May 16 and June 5 and the generator state in detail to evaluate period of generation needed to reduce elevated TGP values.
- Figure 25 is a bar graph showing the relationship between time of generation following SC operations and drop in TGP values.

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 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 "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 here. Nevertheless, data from the other three TGP meters were important to create redundancy and therefore reliability of data collection for the project. Data from all stations are available upon request.

State of Generators

Over the monitoring period of May 12 to June 13, 2016, the six turbines were operated for different frequencies of the three operating states, namely 1) generating, 2) idling and 3) Synchronous Condense mode. Figure 6 (top panel) 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. Generator 5 was mainly operated in idling mode with a short period of generation while Generator 6 was completely operated in idling mode.

Over the monitoring period of September 6 to 25, 2016, the six turbines were also operated for different frequencies of the three operating states. Figure 6 (bottom panel) shows Generator 1 mainly operated in idling mode with minimal time in generating mode and no SC operations. Generator 2 mostly operated in idling mode with frequent periods in generation and SC mode. Generator 3 was mostly operating in idling mode and generation mode with some periods in SC mode. Generator 4 was mostly in generation mode with periods of SC operations and minimal idling. Generator 5 and 6 were mostly in idling and generation mode with no SC operations.

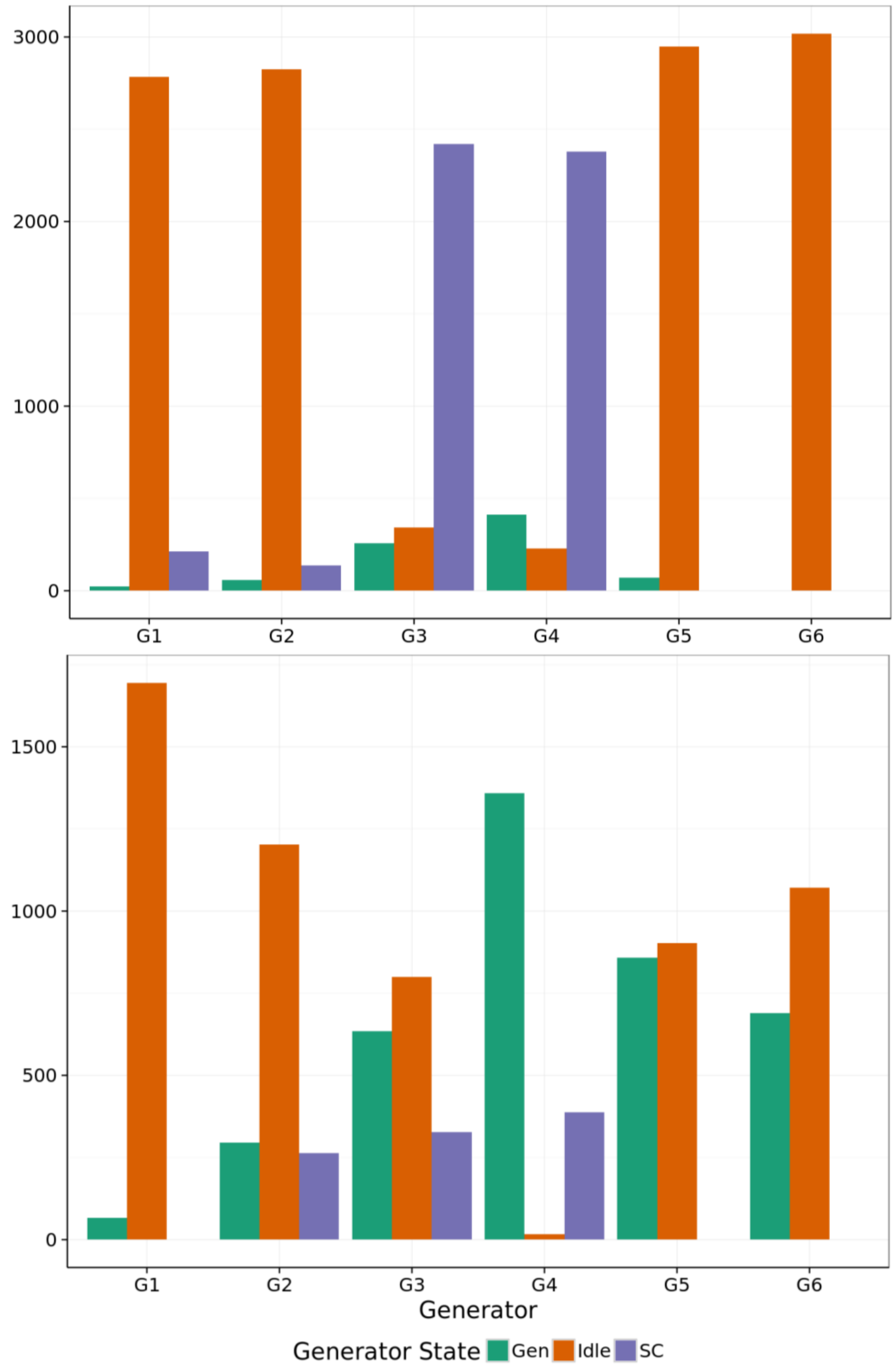

Figure 6. State of generators throughout the spring monitoring period from May 12 to June 13, 2016 (top panel) and the fall monitoring period from September 6 to 25, 2016 (bottom panel) (Gen = Generating; Idle = Idling; SC = Synchronous Condense Mode). The y-axis units are the number (N) of 15 minute 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). Figure 7 (top panel) shows the TGP generated by the combination of operating modes measured at a distance of 0.2 km from Mica Dam from May 12 to June 13, 2016. At this location, TGP fluctuations were expected to be responding quickly to operational changes and be more pronounced when compared to TGP value changes observed at stations located at a greater distance from the dam. When no generator was operated in SC mode, the median TGP value was 102% (red box and whisker plot). With one generator in SC mode and one in generating mode (S1 I4 G1) the median for values was 105% (green box and whisker plot). In contrast, one or two turbines operated in SC mode while none of the other turbines were generating (S1 I5 G0 and S2 I4 G0) led to median TGP values of 112% and 114%, respectively (blue and purple box and whisker plots in Figure 7 (top panel). 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.

At greater distances from the dam the effects of the S1 I5 G0 and S2 I4 G0 combination of operating modes on TGP values was still visible but less pronounced (Figure 7, top panel; Figure 8).

Between September 6 and 25, 2016, the median TGP values were observed to be between 101%-102% regardless of operational mode composition at a distance of 0.2 km from Mica Dam (Figure 9, top panel). The similarity of TGP value means for different operational states and all median values close to 100% were also observed at stations located at 3.5 km and 11 km distance from Mica Dam (Figure 9, bottom panel and Figure 10).

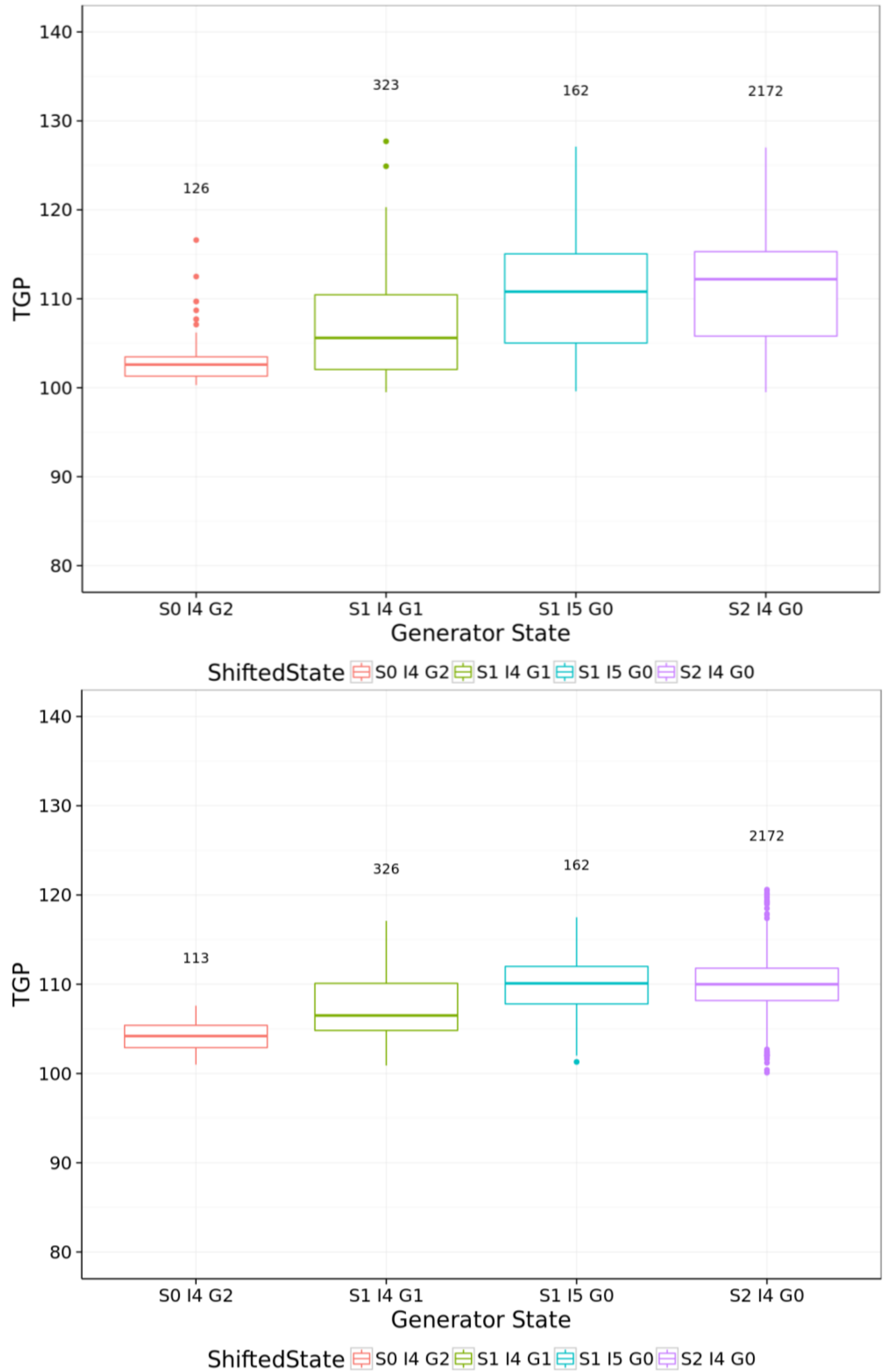

Figure 7. TGP (%) generated by combination of operating states measured at 0.2 km(top panel) and 3.5 km (bottom panel) from MD between May 12 and June 13, 2016 (S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above box-plots indicate sample size (N). Only combinations of states that were recorded more than 60 times (N>60) were included.)

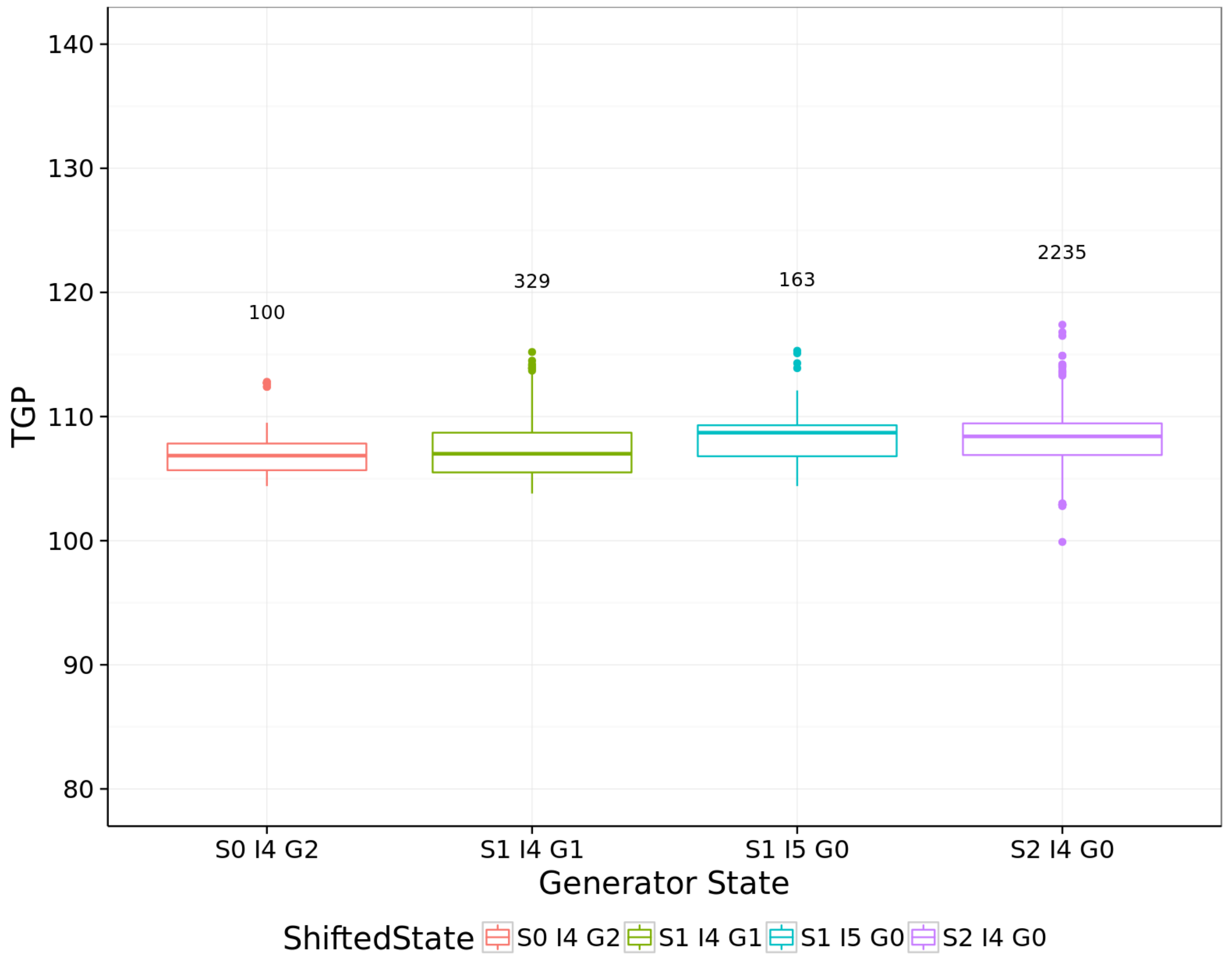

Figure 8. TGP (%) generated by combination of operating states measured at 11 km from MD between May 12 and June 13, 2016 (S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above box-plots indicate sample size (N). Only combinations of states that were recorded more than 60 times (N>60) were included.)

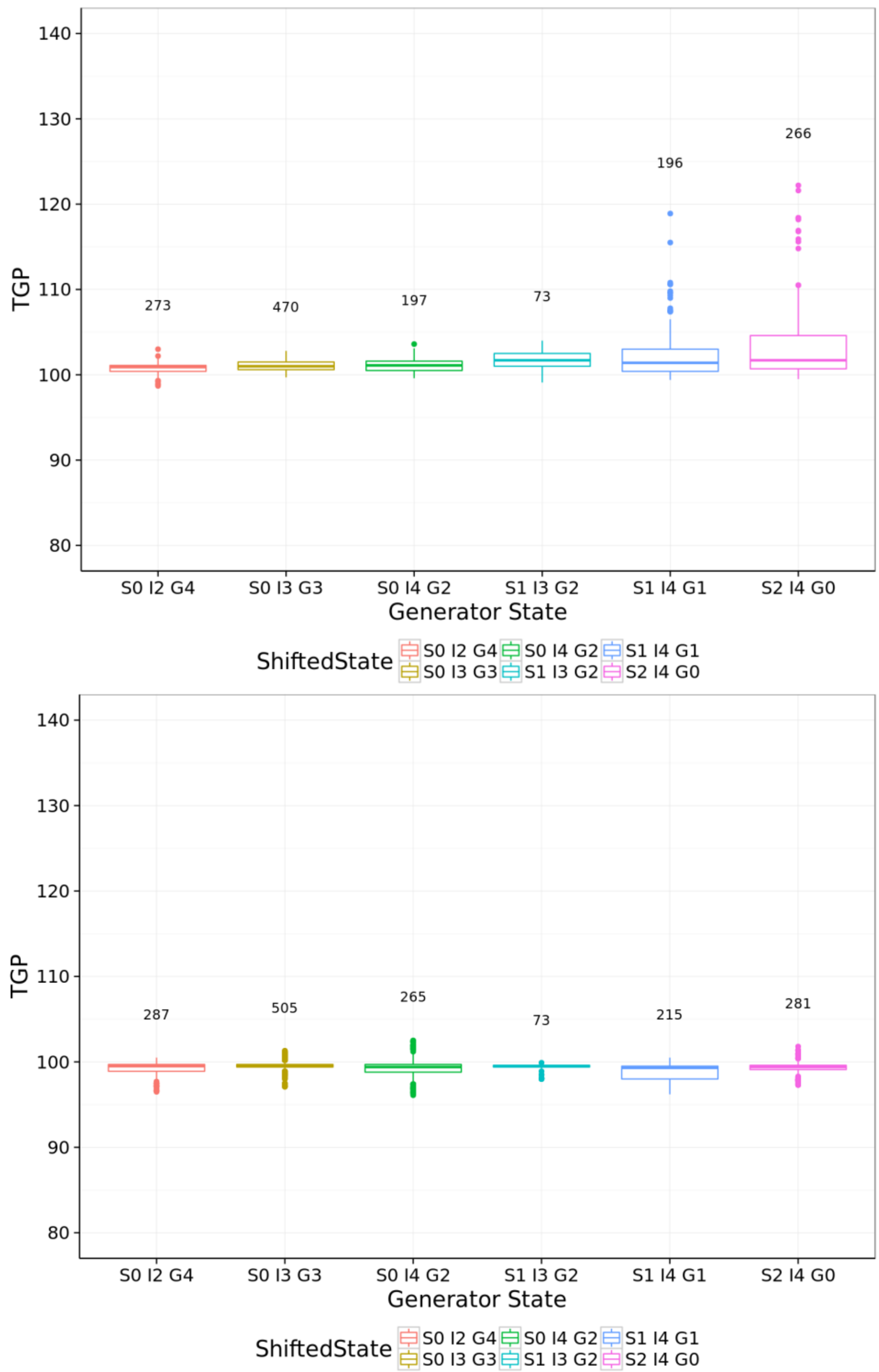

Figure 9. TGP (%) generated by combination of operating states measured at 0.2 km(top panel) and 3.5 km (bottom panel) from MD between September 6 and 25, 2016 (S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above box-plots indicate sample size (N). Only combinations of states that were recorded more than 60 times (N>60) were included.)

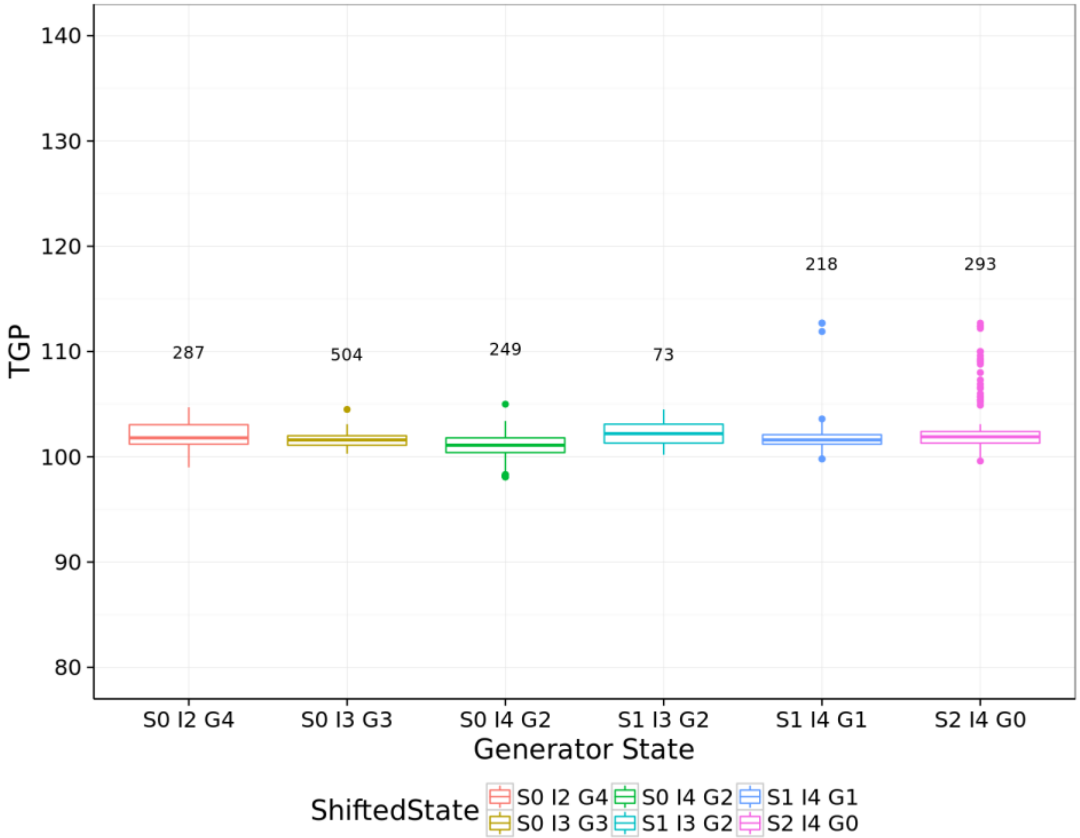

Figure 10. TGP (%) generated by combination of operating states measured at 11 km from MD between September 6 and 25, 2016 (S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above box-plots indicate sample size (N). Only combinations of states that were recorded more than 60 times (N>60) were included.)

TGP Exceedance of BC Water Quality Guidelines by State of Generators

TGP values > 110% are exceeding BC Water Quality Guidelines (BCWQGs) for aquatic life and therefore are considered potential harmful. In

Figure 11, the frequency of this TGPS is shown in relation to the combination of generator states that created it. In the spring period (May 12 – June 13) 56% of the time the six generators were run in the S1I5G0 or S2I4G0 configurations TGP values were > 110% (

Figure 11, top panel). In the fall of 2016, very few extended TGP peaks > 110% were measured and only 2% of the time in the S1I4G1 generator configuration and 4% of the time in the S2I4G0 configuration resulted in TGP peaks > 110% (

Figure 11, bottom panel).

Based on Figure 12 (top panel), > 110% TGP values in the spring period (May 12 – June 3, 2016) occurred 48% of the time that Generator 3 and 49% of the time that Generator 4 were in the SC mode. No other generators were operated in SC mode > 250 times. For the fall period, the total number of > 110% TGP value occurrences was too low to draw significant conclusions (Figure 12, bottom panel).

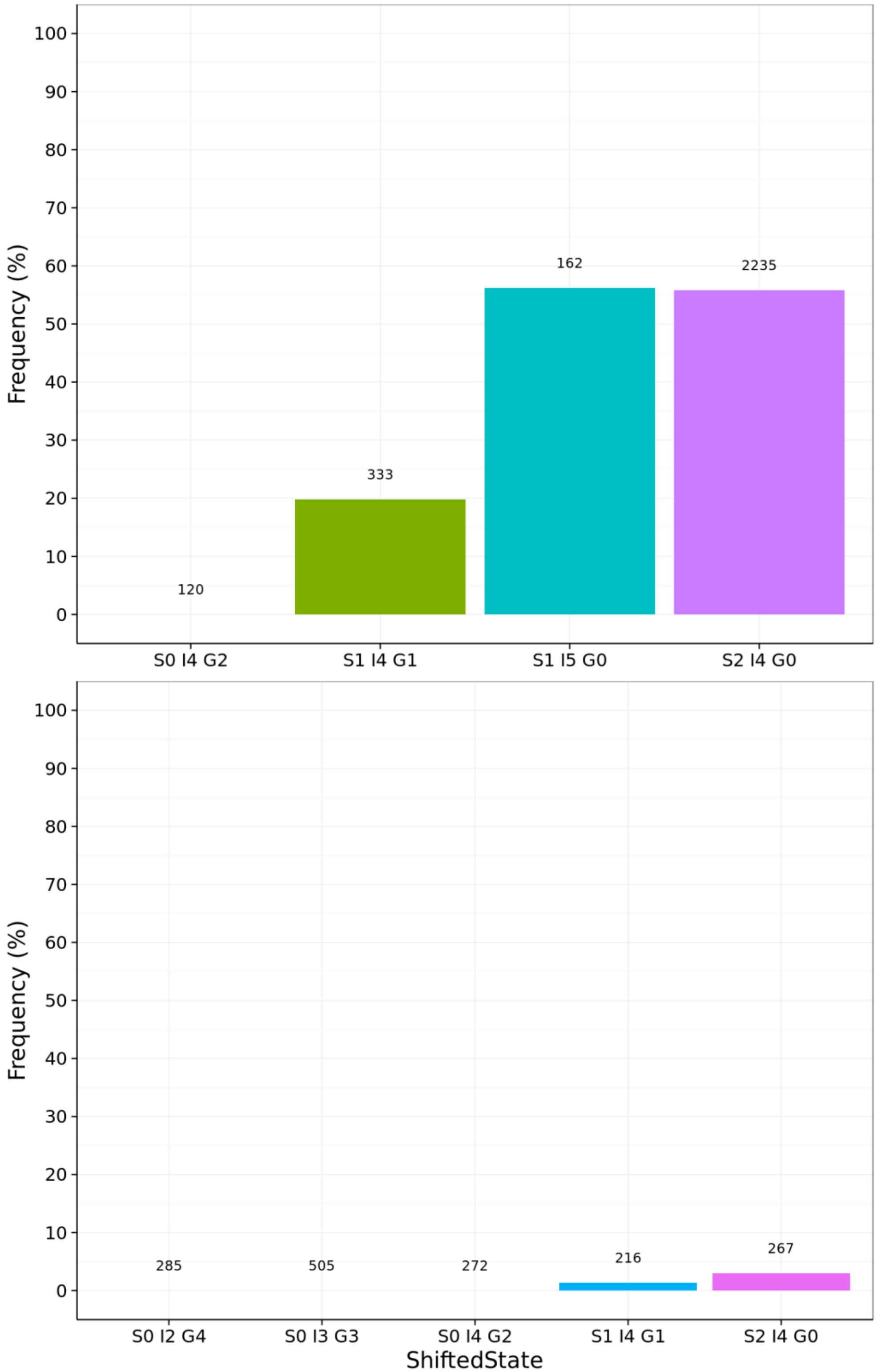

Figure 11. The frequency of TGP (%) values that exceed the BC Water Quality Guideline of 110% by state of generators on Mica Dam between May 12 – June 13, 2016 (top panel) and between September 6 – 25, 2016 (bottom panel) (S = Synchronous Condense; I = Idling; G = Generating). Numbers following the generator state indicate the number of units in this state. Numbers above bars indicate sample size (N was set to N > 60).

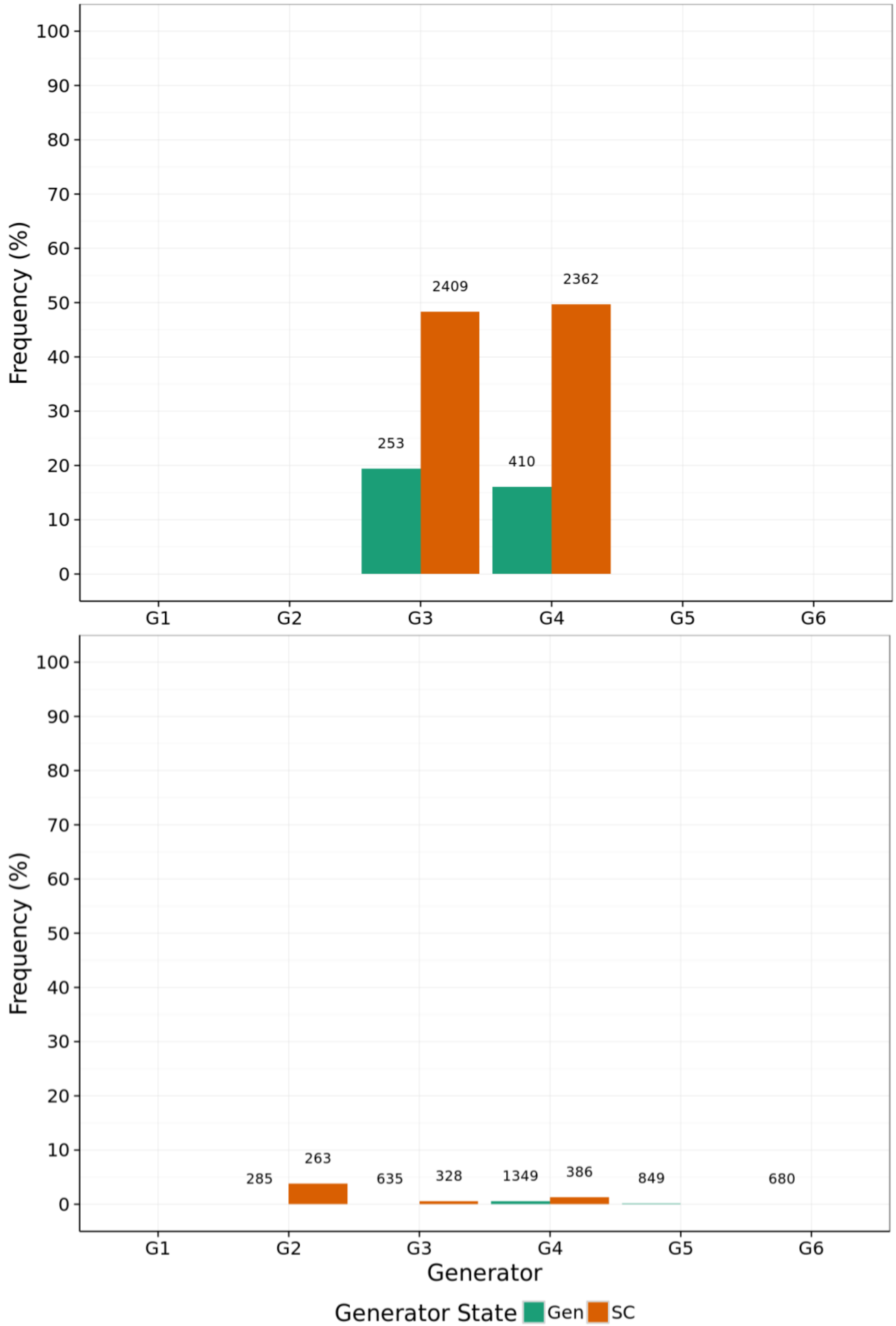

Figure 12. The frequency of TGP (%) values that exceed 110% by individual generator in Mica Dam between May 12 – June 13, 2016 (top panel) and between September 6 – 25, 2016 (bottom panel) (Gen = generating; SC = synchronous condense). Numbers above bars indicate sample size (N was set to N > 250).

TGP over Time by Generator

TGP values were monitored from May 12 to June 13, 2016 and September 6 to 25, 2016, but turbines were mostly operated in the SC mode in May and June when 37 TGP peaks >110% were observed (fall period 3 TGP peaks >110%). All TGP measurements described in this section were taken 0.2 km from the dam at Station 0a. Generators 1 and 2 (Figure 13, top and bottom panel, respectively) were operated in SC mode (blue dots) for only one short period on June 6 and likely contributing to the TGP peak of 128%. For the remainder of the spring period Generators 1 and 2 were operated in the idling mode (green dots). Generators 3 and 4 (Figure 14, top and bottom panel, respectively) were operated in SC mode (blue dots) for the majority of the spring time period and contributed to all TGP peaks up to 127% observed in this period aside from the Peak observed on June 6 that was likely caused by SC operation of Generators 1 and 2. Generators 5 and 6 (Figure 15, top and bottom panel, respectively) were not operated in SC mode in the spring period and therefore did not cause any of the observed TGP peaks. Generators 5 was mostly operated in idling mode (green dots) with very little generation (brown dots) while Generator 6 was operated in idling mode (green dots) for all of the spring period.

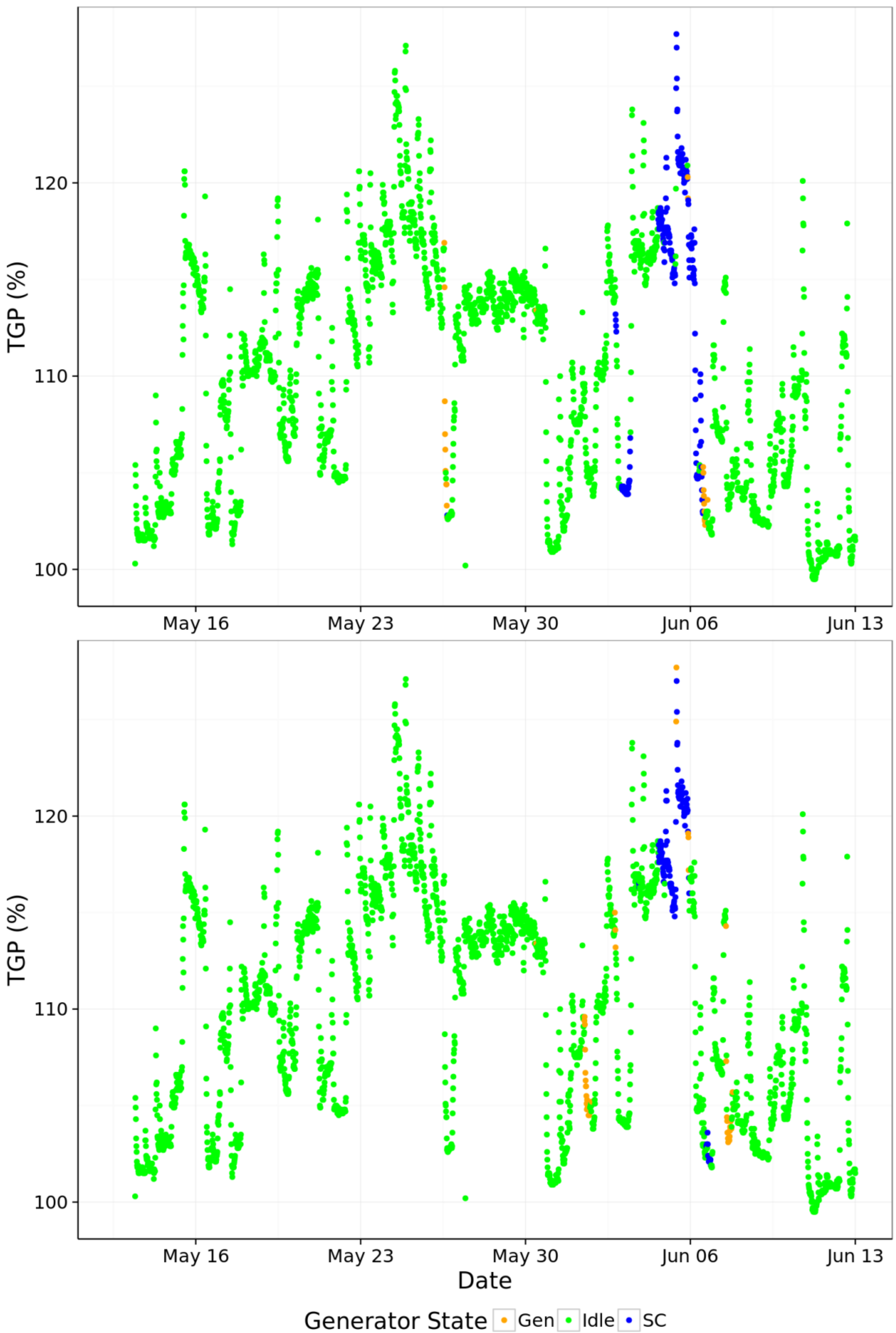

Figure 13. TGP (%) generated by operating Generator 1 (top panel) and Generator 2 (bottom panel) in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from May 12 to June 13, 2016.

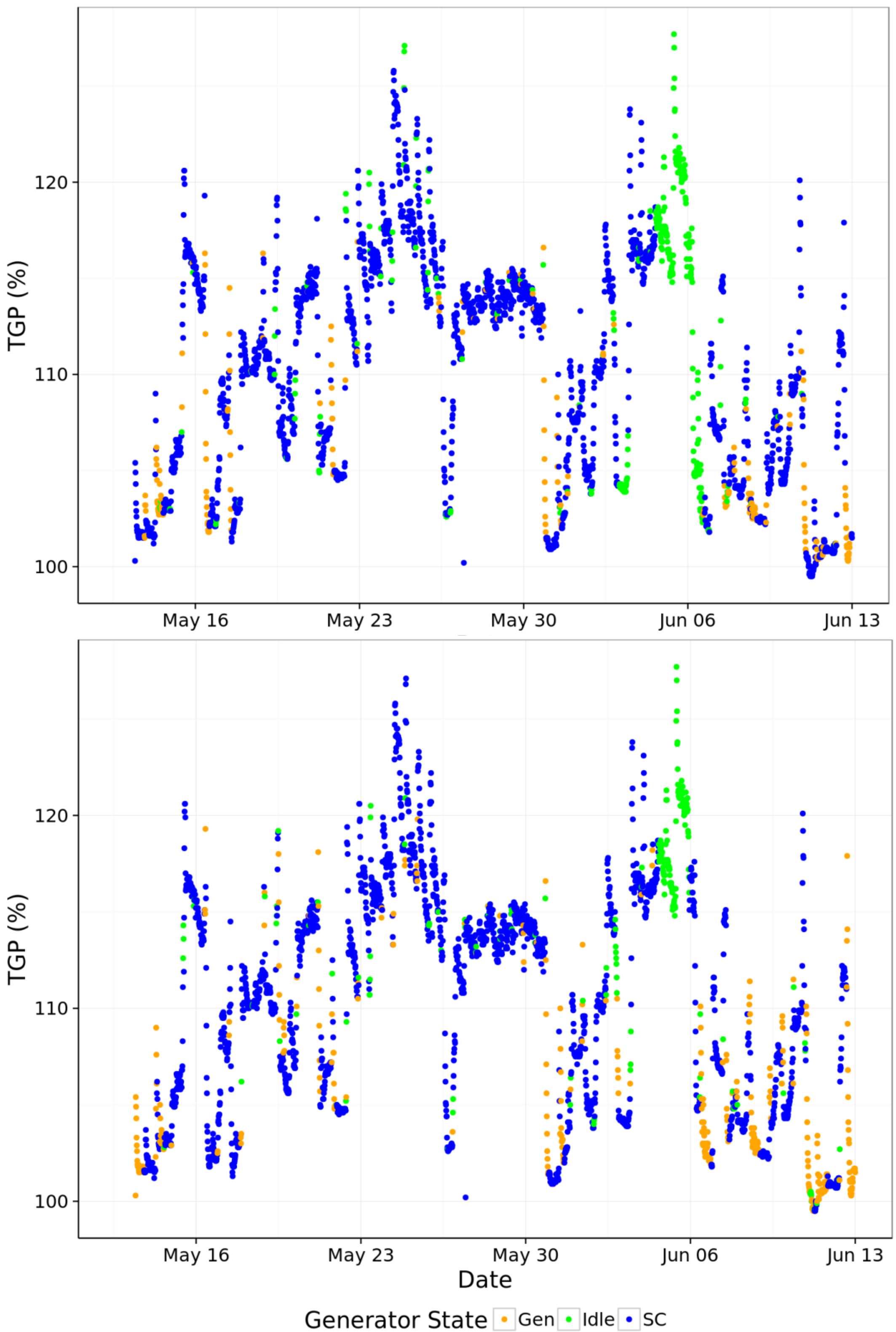

Figure 14. TGP (%) generated by operating Generator 3 (top panel) and Generator 4 (bottom panel) in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from May 12 to June 13, 2016.

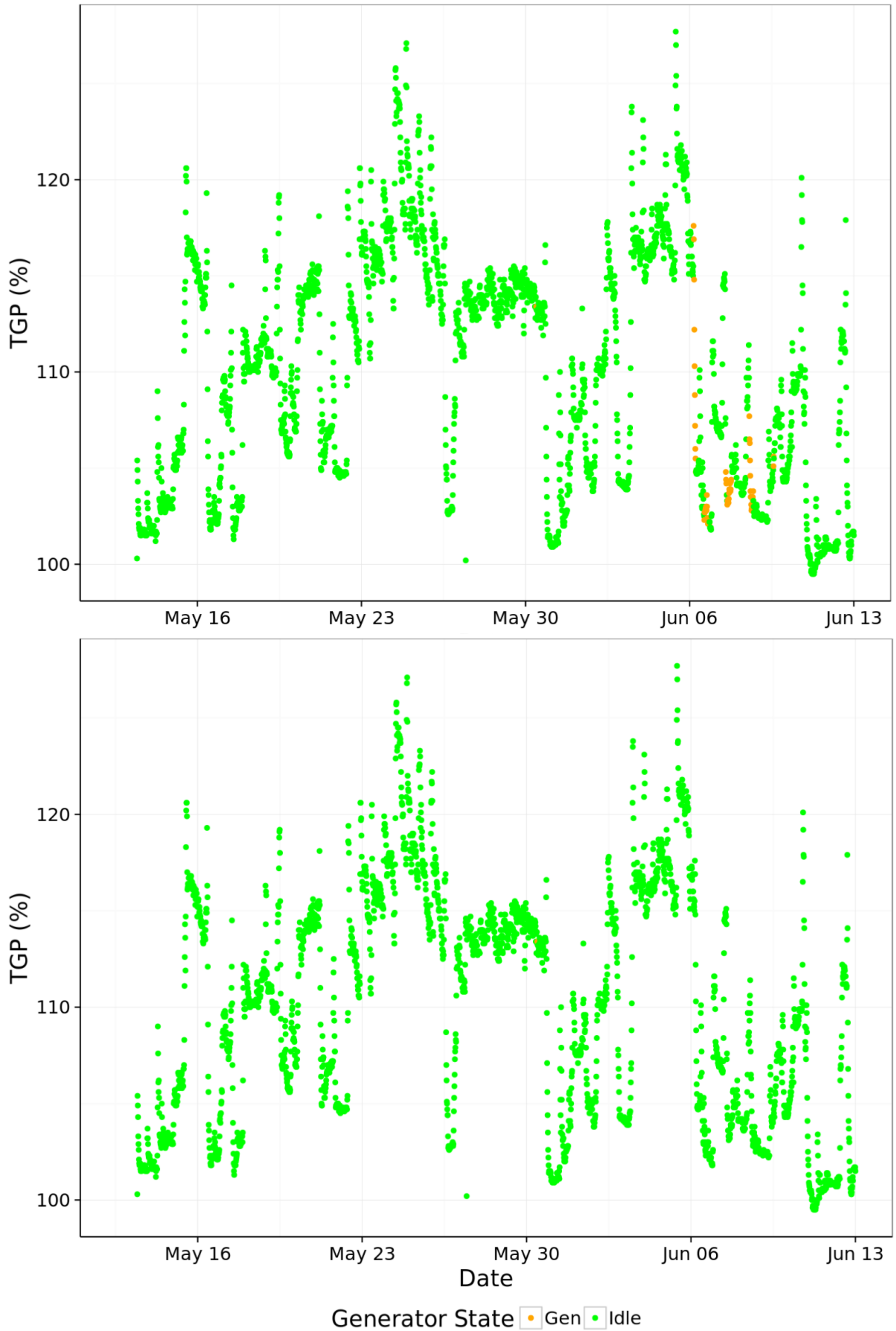

Figure 15. TGP (%) generated by operating Generator 5 (top panel) and Generator 6 (bottom panel) in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from May 12 to June 13, 2016.

For the fall period from September 6 to 25, 2016, only three TGP >110% were observed (Figure 16, top panel). Generator 1 (Figure 16, top panel) was mostly operated in idling mode (green dots) with short periods of generation and did not cause any of the three TGP peaks. Generator 2 (Figure 16, bottom panel), was mainly operated in the idling mode (green dots) but contributed to the 124% and 123% TGP peaks on September 17 and September 18 when operating in SC mode (blue dots). Generator 3 (Figure 17, top panel), contributed to the 118% TGP peak on September 11 when it was operated in SC mode (blue dots). For the remainder of the fall period, Generator 3 was mainly operated in a combination of idling (green dots) and generation (brown dots) with a few short (< 3 h) instances of SC mode (blue dots). Generator 4 (Figure 17, bottom panel) in SC mode (blue dots) contributed to the September 11 and the September 18 TGP peaks but was mostly used for generation (brown dots) for the remainder of the fall period with a few short (< 3 h) instances of SC mode (blue dots). Generators 5 and 6 (Figure 18, top and bottom panel, respectively) were operated for an approximately even amount of time in the idling (green dots) and the generation (brown dots) modes and thus did not contribute to any of the TGP peaks.

To conclude, it appears that the frequent operation of Generators 3 and 4 in SC mode in the spring, and the short and infrequent operation of Generators 2, 3, and 4 in SC mode in the fall, led to the TGP peaks above 110%. The newly installed Generators 5 and 6 did not run in SC mode over the two 2016 sampling periods in the spring and fall but we have now built a good TGP response baseline for the other four generators that will be used as comparison when Generators 5 and 6 are operated in SC mode for the first time in 2017.

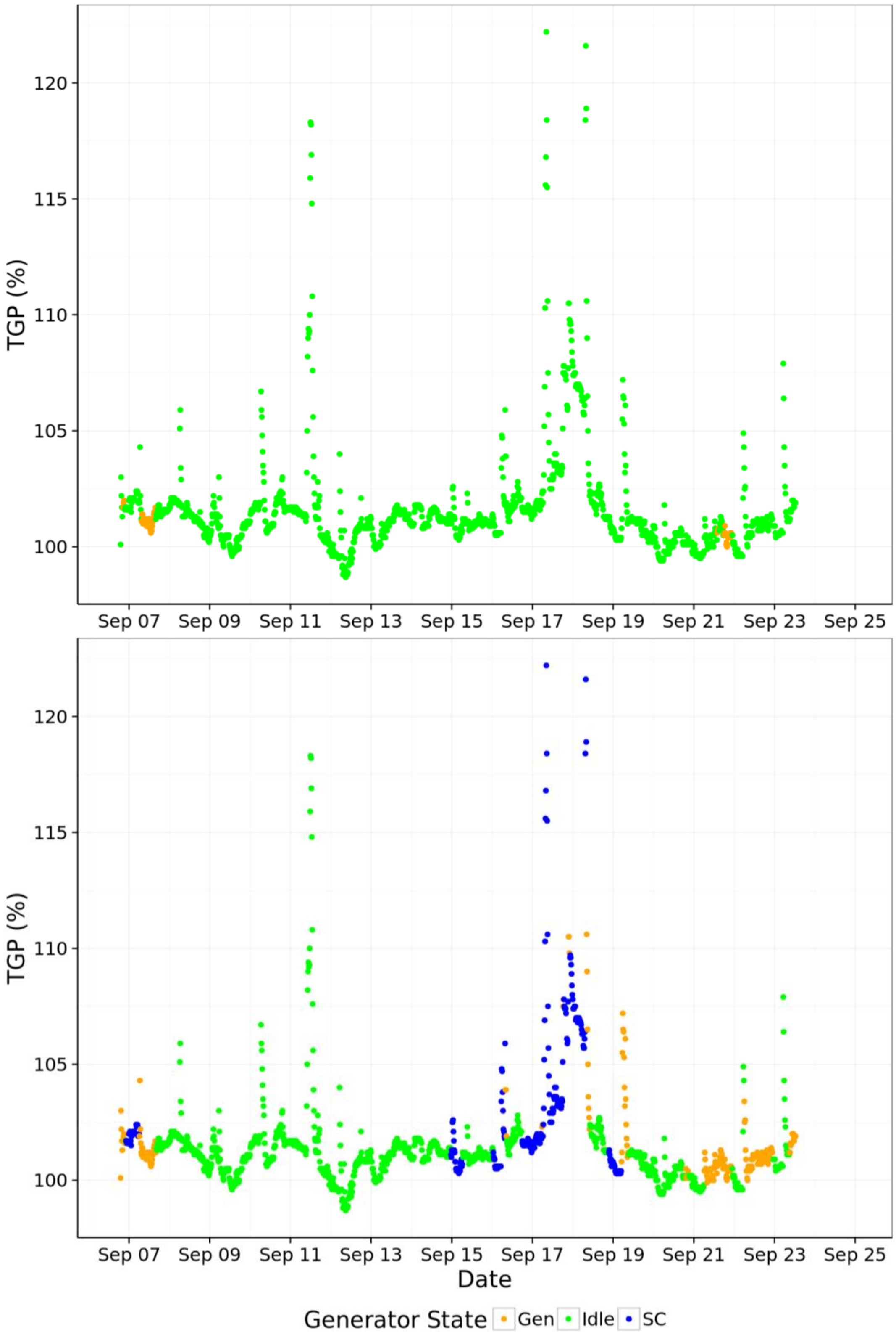

Figure 16. TGP (%) generated by operating Generator 1 (top panel) and Generator 2 (bottom panel) in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from September 6 to September 25, 2016.

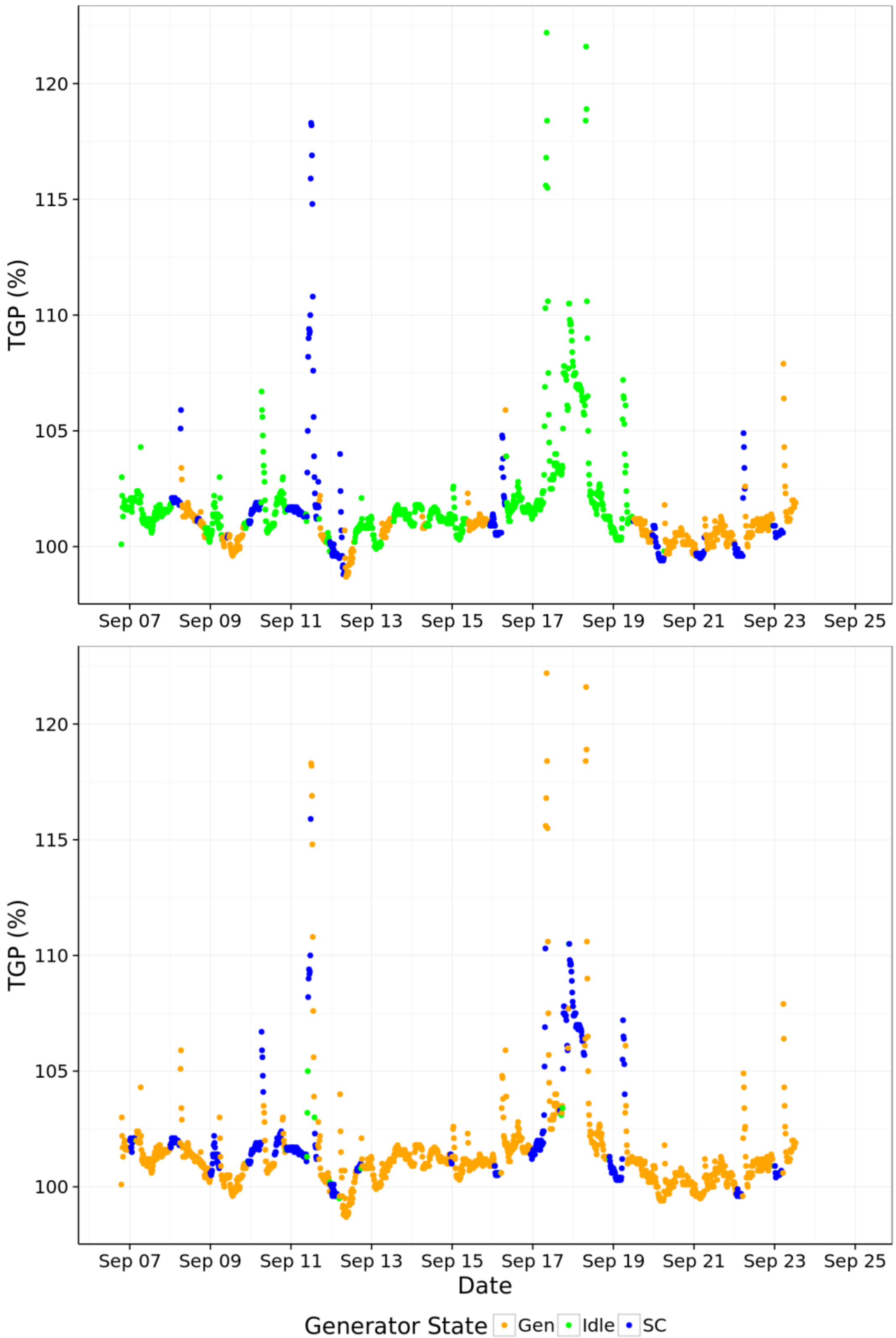

Figure 17. TGP (%) generated by operating Generator 3 (top panel) and Generator 4 (bottom panel) in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from September 6 to September 25, 2016.

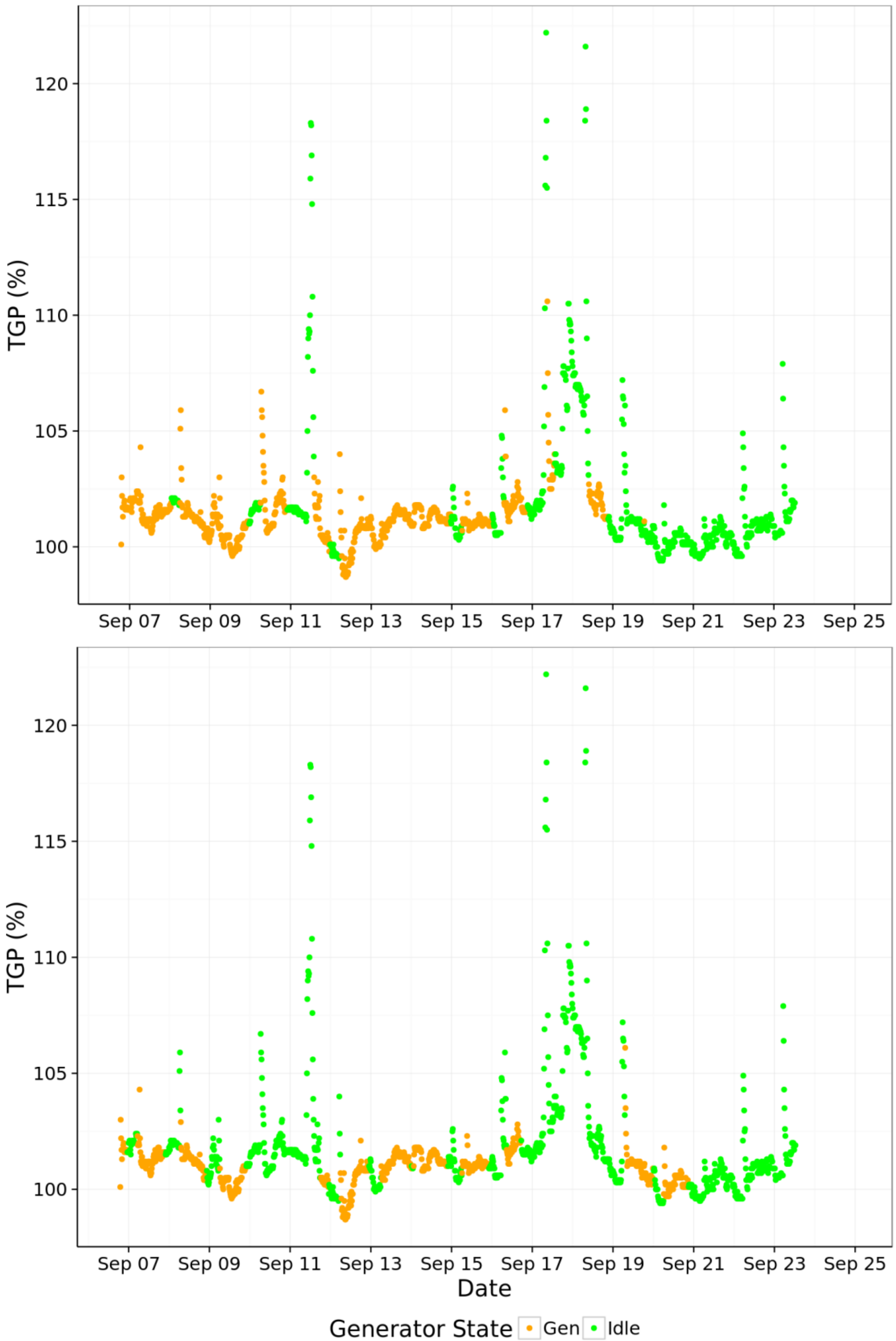

Figure 18. TGP (%) generated by operating Generator 5 (top panel) and Generator 6 (bottom panel) in the generating state (brown dots), the idling state (green dots) or the SC state (blue dots) from September 6 to September 25, 2016.

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 0a), 3.5 km (Station 2), 10.5 km (Station 3) and 11 km (Station 4) distance downstream of the dam.

Figure 19 (top panel) shows TGP values created by a combination of generator states measured 0.2 km below Mica Dam from May 12 – June 13, 2016. As described before, the highest TGP value recorded during this period reached 128% and was created when two generators were in SC mode, while four generators were idling (S2I4G0; pink dots). The highest TGP events (TGP > 120%) lasted from May 15 to May 16, May 23 to May 26 and from June 3 to June 6 (Figure 19, top panel). The same three periods measured at a distance of 3.5 km from Mica Dam (Figure 19, bottom panel), the TGP peaks observed on May 26 and June 6 barely reached 120% and persisted for a much shorter period above 115%. At a distance of 11 km (Figure 20) no more peaks >120% were observed and all other peaks barely exceeded 110% for short periods of time.

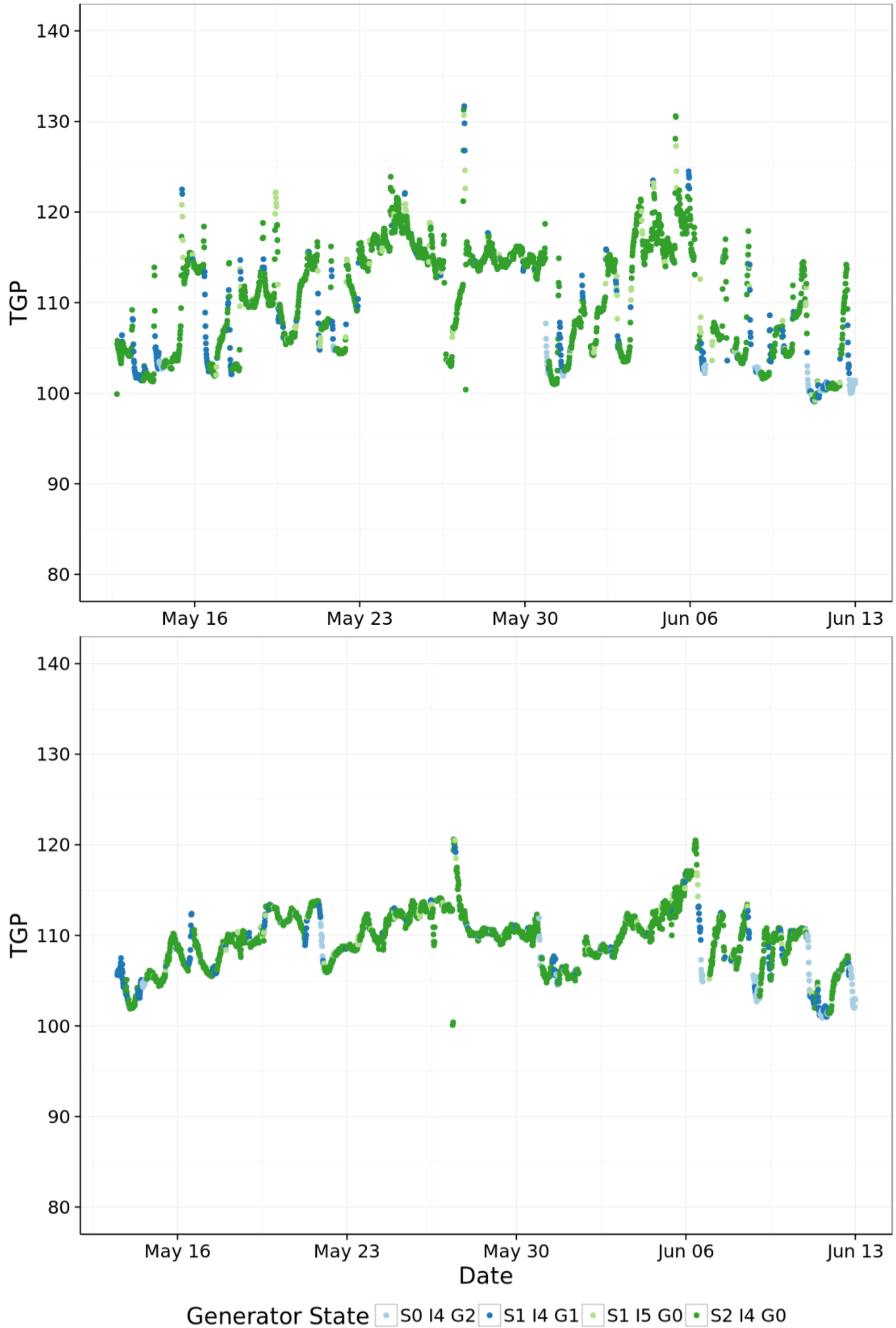

Figure 19. TGP generated by the combination of operating states over time from May 12 to June 13, 2016 measured at 0.2 km distance (top panel) and at 3.5 km distance (bottom panel) from MD

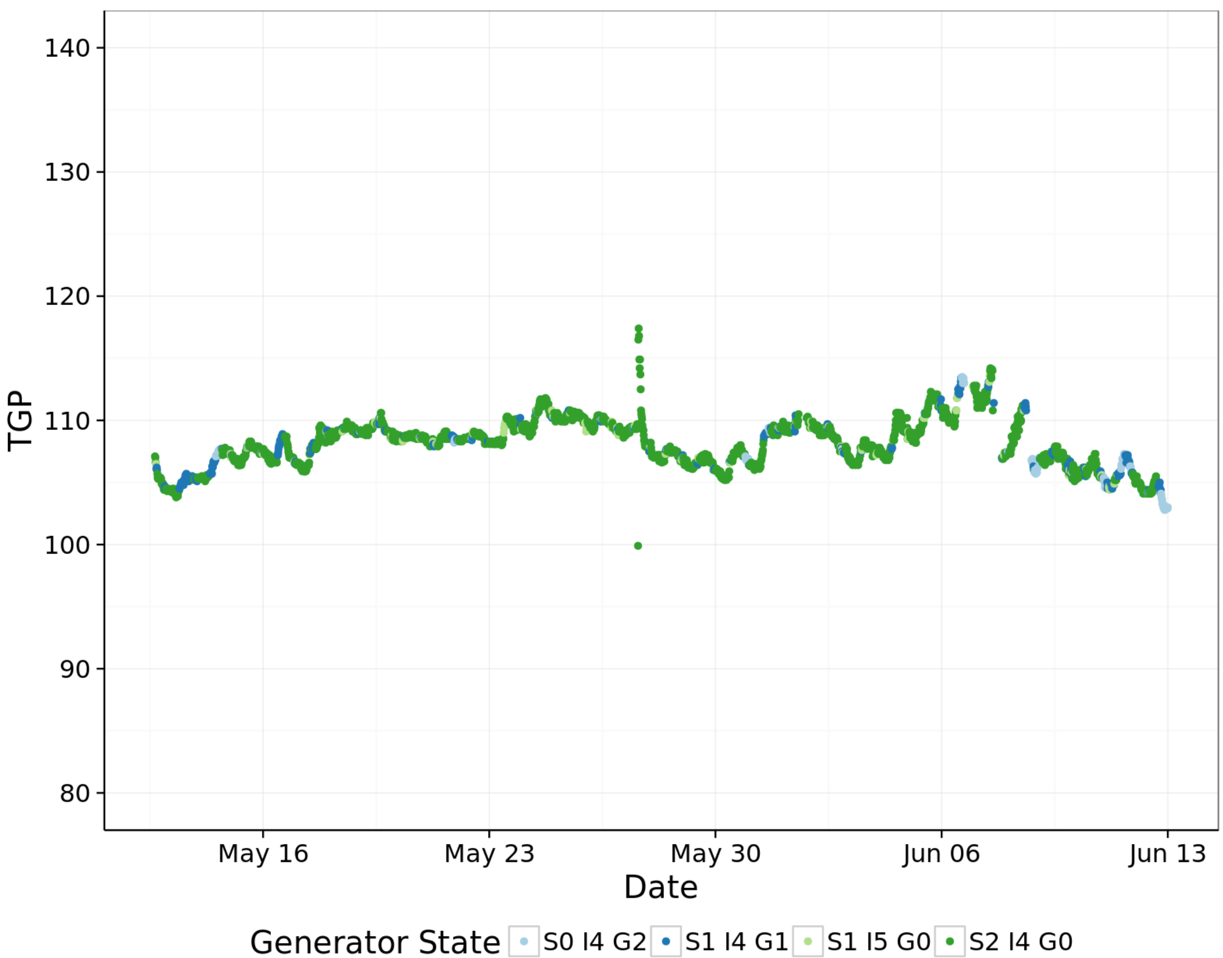

Figure 20. TGP generated by the combination of operating states over time from May 12 to June 13, 2016 measured at 11 km distance from MD

Figure 21 (top panel) shows TGP values created by a combination of generator states measured 0.2 km below Mica Dam from September 6 to 25, 2016. The highest TGP values recorded during this period reached 122% and 121% and were caused by two generators in SC mode, while four generators were idling (S2I4G0; pink dots) on September 17 and 18. The same two periods measured at a distance 3.5 km from Mica Dam (Figure 21, bottom panel) showed TGP values peak at 103%. At a distance of 11 km (Figure 22) the highest peak of TGP was a very similar 104%.

In summary, TGP value peaks of 128% measured 0.2 km from the dam dissipated by 10 - 18% to 110% when measured 11 km below the dam in the spring and TGP value peaks of 122% measured 0.2 km from the dam dissipated by 18% to 104% when measured 11 km below the dam in the fall.

Figure 21. TGP generated by the combination of operating states over time from September 6 to 25, 2016 measured at 0.2 km distance (top panel) and 3.5 km distance (bottom panel) from MD.

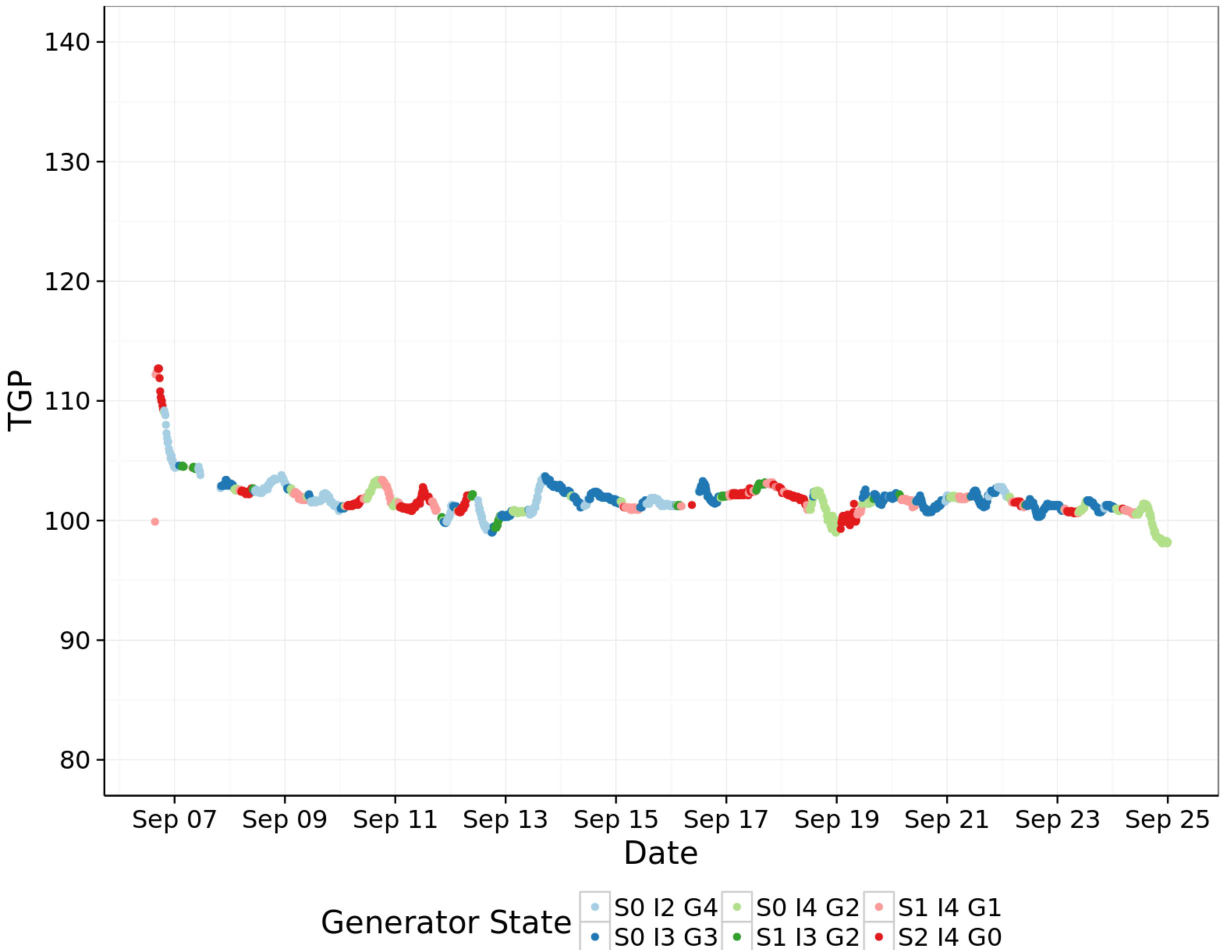

Figure 22. TGP generated by the combination of operating states over time from September 6 to 25, 2016 measured at 11 km distance from MD.

TGP versus Temperature

In the spring, background TGP appeared to be steadily increasing with temperature (Figure 23 top panel; red-orange and blue dots). The same trend was observed in the fall from September 6 to 25, 2016 (Figure 23, bottom panel; red-orange dots). However, the coefficient of determination "r^2" between TGP and temperature was very low in the spring (r^2= 0.135) and in the fall (r^2=0.125) and therefore temperature does not explain much of the variability in TGP values. TGP and temperature data for Station 4, at a distance of 11 km from Mica Dam, was chosen for this analysis because Station 4 was the least sensitive to the peaks in TGP values caused by the SC operations.

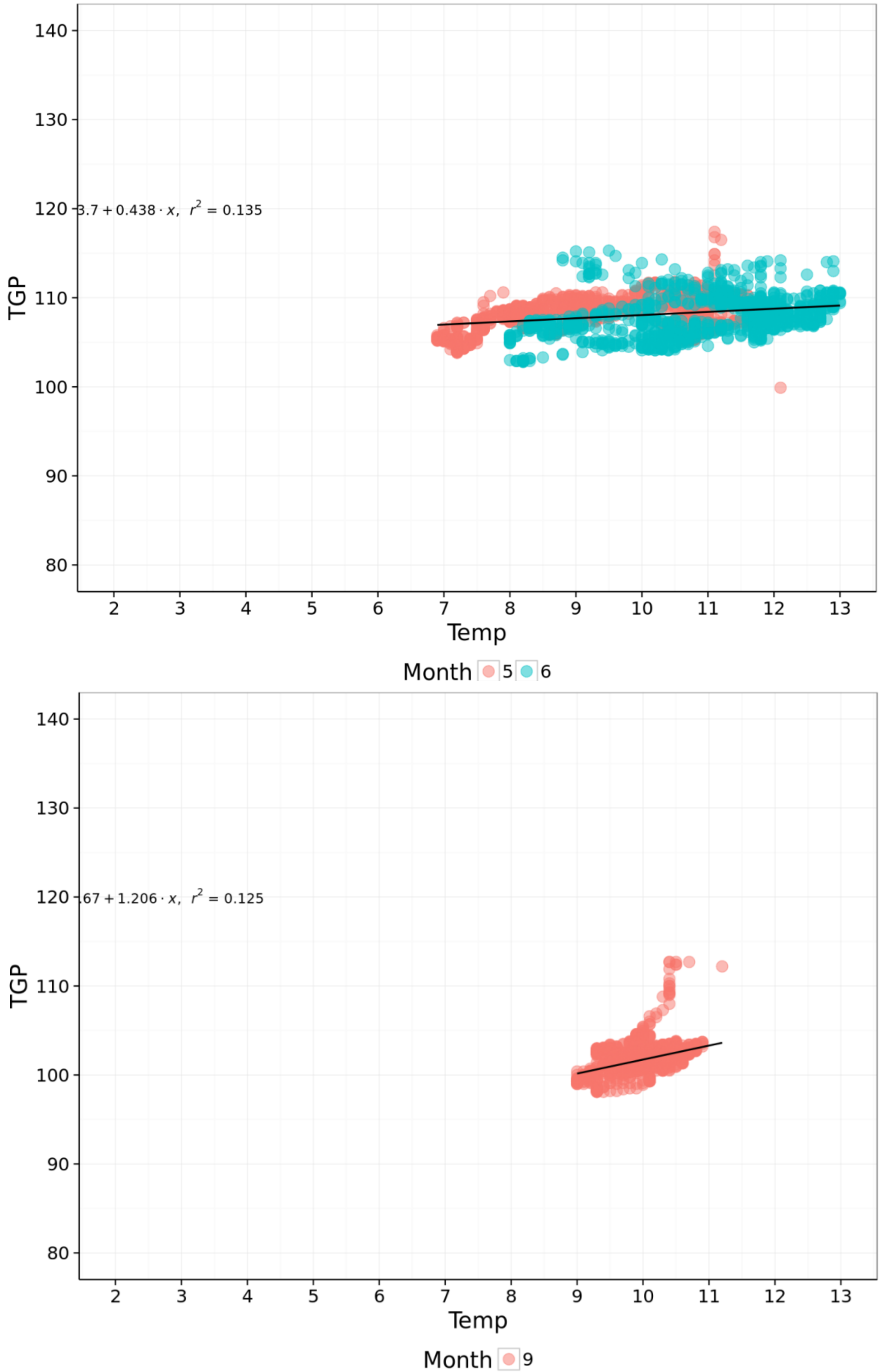

Figure 23. TGP (%) by temperature (°C) (top panel: May–June = red-orange dots; June = blue dots; bottom panel: September = red-orange dots) recorded at Station 4 (11 km from MD) from May 12 to June 13, 2016 and September 6 to 25, 2016.

Detail of TGP by time

Figure 24 shows the detailed TGP response to operational changes on May 16 (top panel) and June 5 (bottom panel). For both dates, generators were operated in the S2I4G0 mode with two generators in SC mode (blue dots) for more than 8 hours before TGP peaks of 119% (May 16, top panel) and 128% (June 5, bottom panel) were reached. On May 16, Generator 3 was switched from SC mode to generation mode (orange dots) for 5 h reducing the TGP measured 0.2 km below Mica Dam by 18% from 119% to 101%. On June 5 (bottom panel), Generator 2 was switched from SC mode to generation mode (orange dots) for 45 min reducing the TGP by 6%. It therefore appears as if a direct relationship between length of time period in generation mode after long periods of SC mode determines the amount of TGP reduction. To support this assumption, eight TGP peaks were analyzed for the amount of TGP reduction achieved based on length of a switch from SC to generation mode. The result of this analysis is shown in Figure 25. It appears as if the duration of switching to generation mode must be longer than 2 hours to achieve TGP reductions of more than 15%, which are needed when Mica Dam is mainly operated in the SC and idling modes.

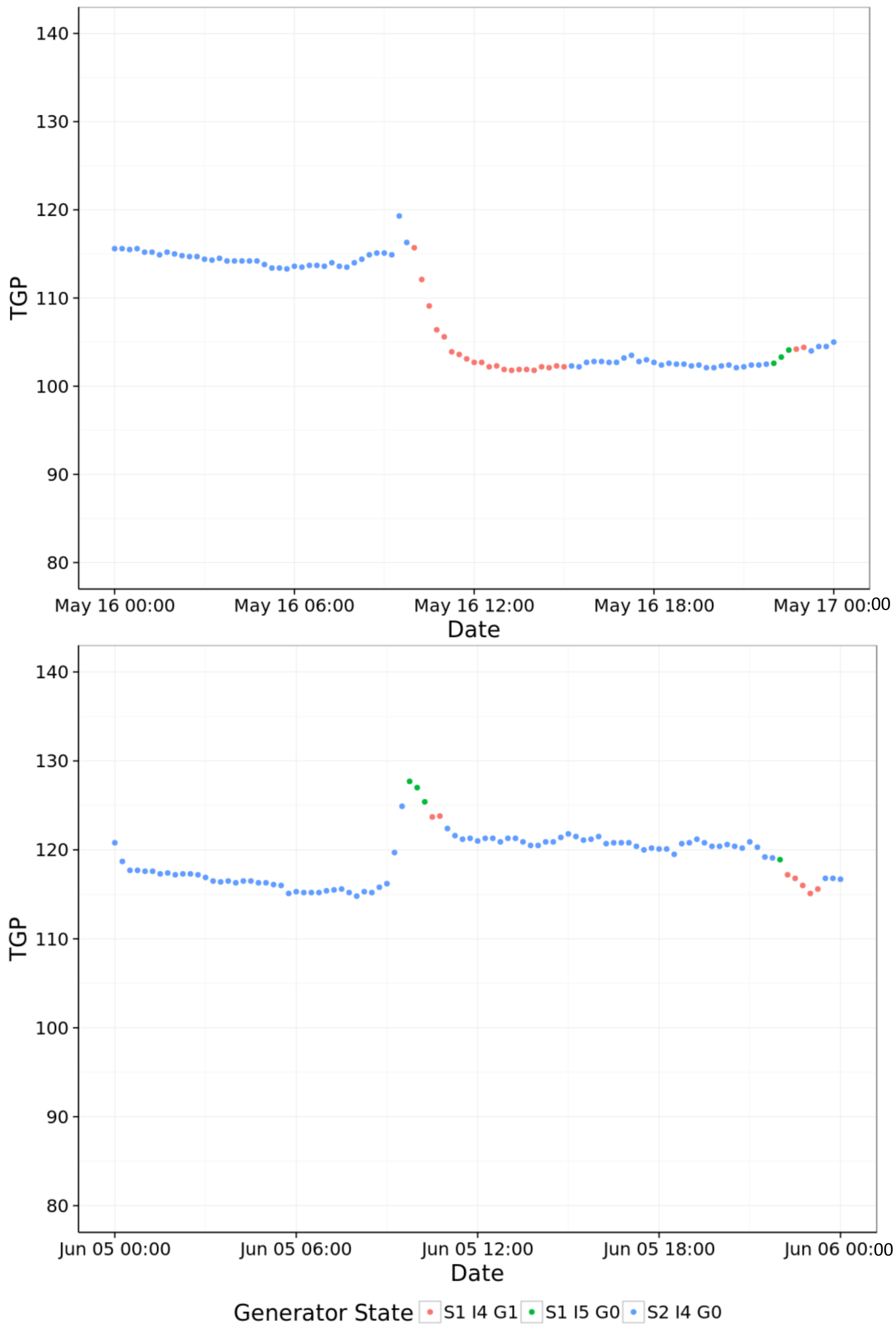

Figure 24. The top panel shows TGP generated by > 8 h of the generator operating combination of S2I4G0 (blue dots) followed by 5 h of S1I4G1 (dark orange dots) from May 16 to 17, 2016 measured at 0.2 km distance from MD leading to a TGP reduction of 18%. The bottom panel shows TGP generated by > 8 h of the generator operating combination of S2I4G0 (blue dots) followed by 45 min of S1I5G0 (green dots) and 30 min of S1I4G1 (dark orange dots) from June 5 to 6, 2016 measured at 0.2 km distance from MD leading to a TGP reduction of 6%.

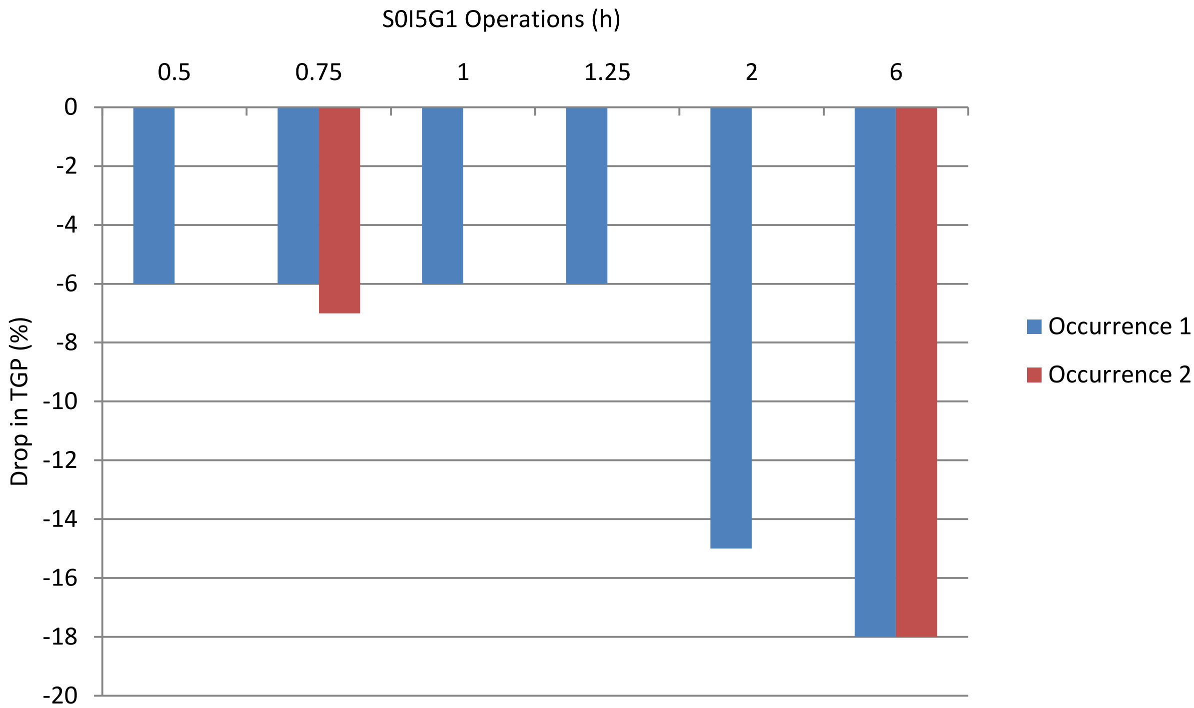

Figure 25 Reduction in TGP in response to hours of operation in mode generating with one turbine (S0I5G1) following a minimum of 8 h with one or two generators in SC (S2I4G0 or S1I5G0) mode without any generations.

TGP at Nagle Creek and Mica Dam Forebay

Nagle Creek TGP measurements ranged from 105.0% - 110.8% in May and 104.1% - 105.0% in September. Mica Dam forebay measurements ranged from 103.0% - 108.4% in May and 103.0% – 111.0% in September (Table 2; Appendix C). It appears to us as if the length of time that the TGP meter sonde is left in the water before a stable measurement is achieved may be longer than the times that we used in 2016. We are therefore planning to repeat the background measurements for a minimum of 2 h per measurement in 2017.

Table 2. TGP readings from Mica Dam forebay and Nagle Creek.

Date	Location	TGP (%)
May 12 2016	Forebay	107.0
May 12 2016	Nagle Creek	105.0
May 27 2016	Forebay	105.0
May 27 2016	Nagle Creek	108.0
June 13 2016	Forebay	108.4
June 13 2016	Nagle Creek	110.8
July 12 2016	Forebay	103.0
September 6 2016	Forebay	103.0
September 6 2016	Nagle Creek	104.1
September 25 2016	Forebay	111.0
September 25 2016	Nagle Creek	105.4

DISCUSSION

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

Combinations of operational modes and TGPS

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, TGPS values reached up to 128% when two generators were operated in SC mode while the other four generators were idling (S2 I4 G0 mode) for more than 12 – 14 h. 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 TGP reductions of 5-10%. This was most evident on June 5 when, following a long period of SC mode operations in two generators (S2I4G0) one generator was switched to generation mode for 45 min and TGP values fell by 6% from 128% to 122%, thus reducing TGP values but leaving them well above the BC Water Quality Guideline (BCWQG) value of 110%. In contrast, the switch from SC mode (S2I4G0) to generation of one of the generators for 5 h reduced TGP levels by 18% from 120% to 102% and therefore well below the BCWQG. The flow through generators when generating appears to dilute high TPG 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 mainly observed in the spring (May and June) when long periods of SC mode were only interrupted with short periods of generation. In the fall a different picture arose and frequent periods of SC mode were always followed by longer periods of generation, thus only exceeding the BCWQG TGP value of 110% for only three short periods over 21 days (0.14 exceedances/day), while 37 periods of exceedance where observed in the spring over a period of 32 days (1.2 exceedances/day).

Individual generators and TGPS

TGPS levels above the BCWQGs were caused by SC operations of Generators 3 and 4 in the spring, and 2, 3, and 4 in the fall. This result is not likely based on the specific propensity of the generators to cause high TGP levels in SC mode but the amount of time that the generators were operated in SC mode. More TGP data collected over the next three years will show whether Generators 5 and 6 will also cause TGPS when operated in SC mode over longer periods of time. Plate et al. (2016) showed that Generator 1 also caused high TGP levels when operated in SC mode. In summary, it appears as if the continuous (>8 h) operation of two generators in parallel SC mode cause TGP levels to rise when the other three generators are in the idling mode.

Generator 6 and TGPS

Generator 6 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 6 in the idling, the generating or the SC mode would produce TGPS. Neither when Generator 6 was operated in the idling nor when it was operated in the generating mode, was TGPS observed. Generator 6 and Generator 5 (installed in 2015) were never operated in SC mode during the 2016 monitoring periods and therefore at this point it is unknown how the SC mode in these two generators will affect TGP values.

Areal extent and rate of travel for TGPS

The TGPS peaks of 128% caused by long periods of SC mode in Generators 3 and 4 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 just above 110% at a distance of 11 km from Mica Dam. Therefore TGPS in Revelstoke Reservoir has the potential to affect fish close to the dam holding in water shallower than 2 m. Fish holding in water deeper than 2 m would 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 >1 m to 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.

The rate of travel of the TGPS water masses appears to be approximately 1 h between the onset of SC operations and the increase of TGP levels at a distance of 0.2 km from the dam. Travel times observed to distances of 3.5 km and 11 km from Mica Dam were approximately 5 h and 8 h, respectively.

Water temperature and TGP

When plotting TGP values over the whole study period from May 12 to June 13, 2016 and September 6 to 25, 2016, at a distance of 11 km from Mica Dam it became apparent that the TGP background level increase over time in the spring may not be directly related to increasing water temperatures. A weak (and non-significant) linear and positive relationship between water temperatures and TGP values was identified with a coefficient of determination of $r^2 = 0.135$ for the spring period and $r^2 = 0.125$ for the fall period. The assumption of the correlation between temperature and TGP was based on saturation lines of Nitrogen and Oxygen in water shown in Figure 26 below. Fidler and Miller (1994) demonstrated that as water temperatures increases, the saturation of 100% TGP level when compared with atmospheric gas pressure decrease (Figure 26). Therefore the relative TGP value of >100% when compared to atmospheric gas pressure measured at 5 °C water temperature is reached at 22 mg/L of Nitrogen and 16 mg/L of Oxygen (Figure 26). 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 a water temperature of 11 °C. In summary, the same concentrations of Nitrogen and Oxygen gases in water at lower temperatures can cause lower TGP values than when measured in higher water temperatures. Based on the TGP and temperature data collected in 2016 in this study, this effect may be masked by the TGP fluctuations caused by SC operations of the Mica Dam generators. Especially in the spring of 2016, increasing background TGP values were likely based on increasing frequency of longer periods of SC operation with short periods of generation. In the fall of 2016, TGP background values at 11 km distance from Mica Dam were in general lower based on less SC mode operations interlaced with more generating periods than in the spring of 2016 and temperature only fluctuated from 9-11 °C, too small a range to draw conclusions. For 2017, we are proposing to repeat a warm water period TGP assessment if water temperatures are warmer than they were in 2016, with a cold summer and fall.

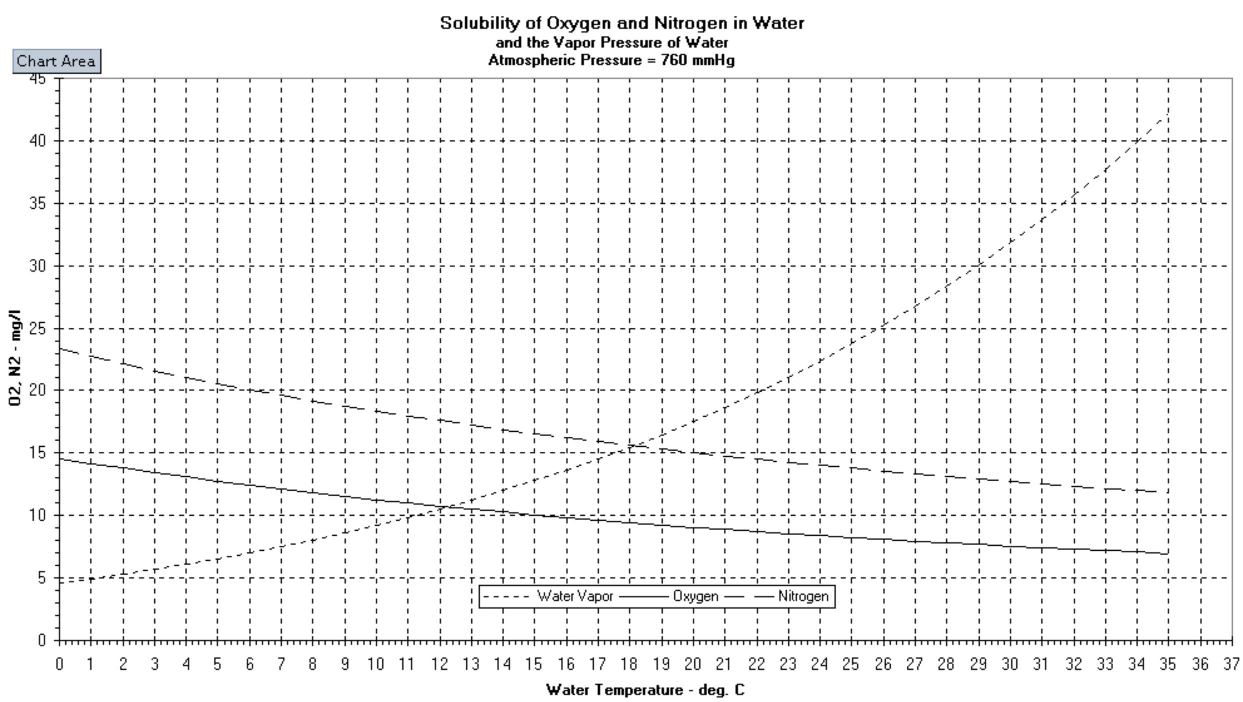

Figure 26. Oxygen (solid line) and Nitrogen (stippled line) saturation lines and temperature (from: Fidler and Miller 1994).

Effects of Nagle Creek and Mica Dam Forebay on TGP

The average TGP recorded in Nagle Creek was 106.5% (N=2) in May, 104.8% (N=2) in September and 106.7% (N=5) for 2016. Previously 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 can be seen in Table 2. In May, background TGP at Station 0a and Station 2 were monitored at 105% - 106%. These background TGP levels are comparable to Nagle Creek and therefore unlikely to have been affected. In September, background TGP values at Station 0a and Station 2 were recorded at 100% - 101%; lower than Nagle Creek's average of 104.8%. However, since background TGP did not seem to change from Station 0a to Station 2 it is unlikely Nagle Creek influenced background TGP at Station 2 in the fall. It is important to note the small sample size at Nagle Creek and the influence of deployment period length and weather conditions at the time may have had an effect on values taken from Nagle Creek.

The average TGP recorded in the Mica Dam forebay was 106% (N=2) in May, 107% (N=2) in September, and was 106.2% (N=6) for 2016. Individual values for the Mica Dam forebay can be viewed in Table 2. These values are similar, but slightly higher than background TGP levels at Station 0a. It is important to note water flowing through the Mica Dam generators is taken at depth in Kinbasket Reservoir and therefore TGP values from the surface may not represent the TGP levels measured in the Mica Dam tailrace. In addition, we are suggesting that length of deployment period may affect TGP readings and we are therefore recommending a minimum TGP sonde deployment period of 2 h for all background measurements in 2017.

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 (> 2 h) of generation in the turbines keeps the TGPS levels to a maximum of 128%. To keep TGP at lower levels in the spring when SC is the predominant mode of operation, it could be considered to change the ratio of SC mode to generation mode for the same turbine in favour of slightly shorter SC periods (< 6 h at a time) with periods of generation that are longer than 2 h 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.) can be used as an indicator (Table 3) (Plate 2014). Of the two time periods monitored in 2016, the spring period from May 22 to June 13 represented the period with the much higher potential for TGP caused harm to fish species. During this period, > 110% TGP events occurred in quick succession and were interrupted with only short periods of TGP percentages between 100-110%. The longest TGPS event exceeded 115% for 65.25 h (Table 4) from June 3-6, peaking at 128% on June 5 at a distance of 0.2 km from Mica Dam. At a distance of 3.5 km from the dam, TGP levels on June 5 did not exceed 120% and at a distance of 11 km they did not exceed 112%. Since the highest TGP levels were recorded at 0.2 km from the dam, the Station 0a scenario will be used to suggest potential impacts on indicator species.

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 Supersaturation (>110%) 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

Table 4. Summary table of high TGP events measured 0.2 km from MD in the 2016 session and their potential risk by species based on known species tolerances and duration (> 8 hours) of TGP > 115%.

Species	Occurrence Period	Hours of TGP >115% at Stn0a	Risk
Mountain Whitefish	May 15-16	23.50	Low
Rainbow Trout	May 15-16	23.50	Low
Bull Trout	May 15-16	23.50	Low
Kokanee	May 15-16	23.50	Low
Sculpin spp.	May 15-16	23.50	Low
Mountain Whitefish	May 22-23	9.5	Low
Rainbow Trout	May 22-23	9.5	Low
Bull Trout	May 22-23	9.5	Low
Kokanee	May 22-23	9.5	Low
Sculpin spp.	May 22-23	9.5	Low
Mountain Whitefish	May 23-26	61.50*	Low
Rainbow Trout	May 23-26	61.50*	Moderate
Bull Trout	May 23-26	61.50*	Moderate
Kokanee	May 23-26	61.50*	Low
Sculpin spp.	May 23-26	61.50*	Low
Mountain Whitefish	June 3-6	65.25	Low
Rainbow Trout	June 3-6	65.25	Moderate
Bull Trout	June 3-6	65.25	Moderate
Kokanee	June 3-6	65.25	Low
Sculpin spp.	June 3-6	65.25	Low

* Includes one very short period when TGP was at 113%

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 highest TGP event observed between June 3-6 exceeded 120% for a maximum of 5.5 h at a time, followed by shorter periods of 2 h 45 min, 2.5 h and 2 h and a total period of 12 h 45 min of TGP values >120% but sustained levels of 115-120% for 65.25 h. 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 2.7 days, approximately 1 hour exceeding 125%. If Mountain Whitefish were exposed to 115 – 120% TGP for 2.7 days it is unlikely they would have been severely impacted by exposure since it 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 this TGPS event travelled 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 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 TGPS event in the 2016 spring monitoring period, TGP levels ranged from 115 – 128% for a period of 2.7 days and may have affected Bull Trout if holding in water less than 2 m deep. 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 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 four days 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 by Plate (2014) and therefore Rainbow Trout may have had some effects from TGPS 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 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 2016 but would likely be affected by higher TGPS levels due to their preference for shallow water habitats.

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 2016 and the results are shown in Table 3. In addition, the resident fish species specific risk of damage based on measured 2016 TGP peak values is shown in Table 4 (risk definition: high = likely mortalities; moderate = likely GBD; low: likely neither mortalities nor GBD). The moderate risk zone for Bull Trout and Rainbow Trout is located within the first 500 m downstream of Mica Dam in the tailrace area. Downstream of the Blue Bridge located 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 habitat 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 Mountain Whitefish congregation.

RECOMMENDATIONS

Based on the 2016 study, the following recommendations are made to gain a better understanding of the TGP levels versus operations mode configurations:

- An additional field sampling session in late summer preferably August of 2017 may be useful to further understand the difference in TGP values at lower temperatures in the spring versus higher temperatures in late summer. September of 2016 was cold in the multi-year comparison and therefore a likely warmer August date is suggested here. Should the summer of 2017 be as cold as the summer of 2016, it should be considered to postpone the warm sampling period to 2018 or 2019.
- During the one or two 2017 TGP sampling periods each one of the six turbines, including the newly installed 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 turbines 5 and 6 should be operated in SC mode for longer than 8 hours while the other turbines are idling to assess their TGP effects.

- TGP spot measurements in the Mica Dam forebay and Nagle Creek should last longer than 2 h.

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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 2016 field season from May 12 – 27, 2016 and September 6 – 25, 2016.

Stn #	Unit	Date	Activity	T (°C) at Download	Battery Voltage		Calibration		Down Load	New Cart.	Weather
					Old	New	Baro. Press.	Temp.			
0	401	05/12/16	Station Setup	N/R*	N/A**	6.29	Yes	Yes	No	Yes	Overcast
1	403	05/12/16	Station Setup	N/R	N/A	6.31	Yes	Yes	No	Yes	Overcast
2	404	05/12/16	Station Setup	N/R	N/A	6.32	Yes	Yes	No	Yes	Overcast
3	405	05/12/16	Station Setup	N/R	N/A	6.35	Yes	Yes	No	Yes	Overcast
4	406	05/12/16	Station Setup	N/R	N/A	6.32	Yes	Yes	No	Yes	Overcast
Nagle Ck	407	05/12/16	Spot Check	7.7	N/A	N/A	Yes	Yes	Yes	Yes	Overcast
Forebay	402	05/12/16	Spot Check	8.7	N/A	N/A	No	No	Yes	No	Overcast
0	401	05/13/16	Test Download	6.2	6.20	6.20	No	No	Yes	No	Sunny
0a	402	05/13/16	Station Setup	N/R	6.25	6.25	Yes	Yes	No	No	Sunny
1	403	05/13/16	Test Download	6.2	6.24	6.24	No	No	Yes	No	Sunny
2	404	05/13/16	Test Download	6.6	6.29	6.29	No	No	Yes	No	Sunny
3	405	05/13/16	Test Download	6.7	6.27	6.27	No	No	Yes	No	Sunny
4	406	05/13/16	Test Download	7.2	6.24	6.24	No	No	Yes	No	Sunny
0	401	05/27/16	Download/Maintenance	6.5	5.67	6.26	Yes	Yes	Yes	Yes	N/R
0a	402	05/27/16	Download/Maintenance	6.9	5.71	6.28	Yes	Yes	Yes	Yes	N/R
1	403	05/27/16	Download/Maintenance	6.6	5.76	6.26	Yes	Yes	Yes	Yes	N/R
2	404	05/27/16	Download/Maintenance	7.8	5.77	6.24	Yes	Yes	Yes	Yes	N/R
3	405	05/27/16	Download/Maintenance	10.2	5.80	6.22	Yes	Yes	Yes	Yes	N/R
4	406	05/27/16	Download/Maintenance	11.0	5.74	6.22	Yes	Yes	Yes	Yes	N/R
Forebay	407	05/27/16	Spot Check	7.6	N/A	N/A	Yes	Yes	Yes	Yes	N/R
Nagle CK	407	05/27/16	Spot Check	7.4	N/A	N/A	No	No	Yes	No	N/R
0	401	06/13/16	Download/Removal	7.2	5.65	N/R	No	No	Yes	No	Rain
0a	402	06/13/16	Download/Removal	7.4	5.68	N/R	No	No	Yes	No	Rain
1	403	06/13/16	Download/Removal	7.4	5.70	N/R	No	No	Yes	No	Rain
2	404	06/13/16	Download/Removal	7.6	5.65	N/R	No	No	Yes	No	Rain
3	405	06/13/16	Download/Removal	9.1	5.53	N/R	No	No	Yes	No	Rain
4	406	06/13/16	Download/Removal	10.7	5.68	N/R	No	No	Yes	No	Rain
Nagle CK	407	06/13/16	Spot Check	8.2	N/A	N/A	Yes	Yes	Yes	Yes	Rain

Stn #	Unit	Date	Activity	T (°C) at Download	Battery Voltage		Calibration		Down Load	New Cart.	Weather
					Old	New	Baro. Press.	Temp.			
Forebay	407	06/13/16	Spot Check	10.0	N/A	N/A	No	No	Yes	No	Rain
0	402	09/06/16	Station Setup	11.5	N/A	6.73	Yes	Yes	No	Yes	Overcast
0a	401	09/06/16	Station Setup	10.7	N/A	6.69	Yes	Yes	No	Yes	Overcast
1	403	09/06/16	Station Setup	12.4	N/A	6.96	Yes	Yes	No	Yes	Overcast
2	404	09/06/16	Station Setup	11.4	N/A	6.64	Yes	Yes	No	Yes	Overcast
3	405	09/06/16	Station Setup	12.0	N/A	6.48	Yes	Yes	No	Yes	Overcast
4	407	09/06/16	Station Setup	13.9	N/A	6.57	Yes	Yes	No	Yes	Overcast
Nagle CK	401	09/06/16	Spot Check	10.0	N/A	N/A	Yes	Yes	Yes	Yes	Overcast
Forebay	401	09/06/16	Spot Check	15.9	N/A	N/A	No	No	Yes	No	Overcast
0	402	09/25/16	Download/Removal	9.7	5.64	N/A	No	No	Yes	No	Overcast
0a	401	09/25/16	Download/Removal	9.7	5.10	N/A	No	No	Yes	No	Overcast
1	403	09/25/16	Download/Removal	N/R	Dead	N/A	No	No	Yes	No	Overcast
2	404	09/25/16	Download/Removal	N/R	5.83	N/A	No	No	Yes	No	Overcast
3	405	09/25/16	Download/Removal	9.2	5.96	N/A	No	No	Yes	No	Overcast
4	407	09/25/16	Download/Removal	9.6	6.00	N/A	No	No	Yes	No	Overcast
Nagle CK	401	09/25/16	Spot Check	7.7	N/A	N/A	Yes	Yes	Yes	Yes	Overcast
Forebay	401	09/25/16	Spot Check	13.9	N/A	N/A	No	No	Yes	No	Overcast

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