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Columbia River Project Water Use Plan

KINBASKET RESERVOIR FISH AND WILDLIFE INFORMATION PLAN

Reference: CLBMON 1-62

Mica Dam Total Gas Pressure Monitoring and Abatement Program and Impacts of Mica Units 5 and 6 on Synchronous Condense Operations and Aquatic Life

Study Period: 2015 – 2021

Final Report

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2015 - 2021

CLBMON 1-62

Mica Dam Total Gas Pressure Monitoring and Abatement Program and Impacts of Mica Units 5 and 6 on Synchronous Condense Operations and Aquatic Life

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Cover photos:	**Top:**	Mica Generating Station from a downstream perspective on May 13 2016 (Photo credit: Evan Smith, Okanagan Nation Alliance).
	Bottom:	Station 0 in relation to Mica Generating Station on May 12 2016 (Photo credit: Evan Smith, Okanagan Nation Alliance).

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EXECUTIVE SUMMARY

In 2007, BC Hydro developed Terms of Reference for Columbia Monitoring Project 1 under the Columbia River Project Water Use Plan – Kinbasket Reservoir Fish and Wildlife Information Plan to monitor total gas pressure supersaturation in relation to synchronous condense operations of Mica Generating Station Units 2 and 4, to supplement data from Units 1 and 2. These Terms of Reference were amended in 2014 for Columbia Monitoring Project 62; to include BC Hydro's commitment in the Environmental Assessment Certificates for Mica Units 5 and 6 to monitor changes in synchronous condense operations and total gas pressure with the installation of Units 5 and 6.

Synchronous condense operations can result in higher localized total dissolved gas pressure due to surface water being exposed to pressurized air which is injected at 16 psi into the draft tube to force water below the turbine and allow it to spin in air. Water surface turbulence from the spinning turbine combined with the increased air pressure forces additional gas into the water column, creating total gas pressure supersaturation. Because the water in the immediate vicinity of the unit is stagnant during synchronous condense operation, supersaturation increases (volume of water supersaturated and level of supersaturation) over time. Total gas pressure supersaturation can increase gas levels in the blood of fish, via gas exchange at the gills, causing the blood to 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 blood vessel blockages. Embolism can decrease 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

Total gas pressure data were collected as a percent of barometric pressure using Pentair Point Four (PT4) Tracker Total Gas Pressure Meters at 300 m, 3.5 km, 10.5 km, and 11 km from Mica Generating Station in 2015 – 2017, 2020, and 2021. Hourly post-Unit 5/6 installation/operation data (2015 – 2022) was compared to baseline (2010 – 2014) operation data to help assess whether changes in operations at Mica Generating Station resulted in increased total gas pressure. All operation data were provided by BC Hydro. 2020 and 2021 data were similar to years under normal operating conditions, but were higher than the respective 12-year average; therefore, it is unclear whether data collected in 2020 and 2021 were typical of normal operations at Mica Generating Station.

Total gas pressure supersaturation increased when synchronous condense without generation was operated in ≥ 8-hour durations with intermittent 1-hour durations of synchronous condense with generation. The specific generators involved in synchronous condense without generation did not appear to influence total gas pressure supersaturation. Operations of synchronous condense with generation and generation without synchronous condense appeared to rapidly decrease total gas pressure supersaturation when operated for > 1 hour at 200 cms or more.

Total dissolved gas typically traveled in a plume; the size of the plume was dependent on the duration of synchronous condense without generation, and frequency and amplitude of flows. The rate of dissipation was determined to be 1%/km.

The average synchronous condense duration increased marginally (~ 1 h) following the installation of Units 5/6 in 2015; as did synchronous condense frequency (~ 7 – 9 events/month).

An increase in general synchronous condense frequency and duration does not result in a higher risk to fish in the Revelstoke Reservoir, as synchronous condense with generation decreased total dissolved gas over longer periods (> 1 hour). Synchronous condense intensity was difficult to quantify, but the frequency of the operation associated with elevated total gas pressure (synchronous condense without generation for ≥ 8-hours duration) increased by ~ 5 – 6 events/month on average following the installation/operation of Units 5/6. This indicated an increased risk to individual fishes in close proximity to the dam outflow. However, the total gas pressure levels and exposure durations observed were not

high enough to cause population impacts in any species based on the literature; though local impacts (behavioural changes, gas bubble trauma, and mortality) were possible.

To reduce impacts on resident fishes (primarily between Blue Bridge and Mica Generating Station), long durations (8 – 12 hours) of synchronous condense without generation should be followed by ≥ 2 hours of operations including generation with ≥ 200 cms of discharge or, alternatively, operations of synchronous condense without generation should occur for < 8 hours with operations including generation in between.

FINAL STATUS OF CLBMON 1-62

MANAGEMENT QUESTION (MQ)	SUMMARY OF KEY RESULTS
MQ-1 What is the impact of synchronous condense operations in Mica Units 1-6 on dissolved gas supersaturation?	Total gas pressure supersaturation increased when synchronous condense without generation was operated in ≥ 8-hour durations with intermittent 1-hour durations of synchronous condense with generation.
a. Is there a difference in dissolved gas supersaturation depending on which of the six units at Mica Generation Station are operated in synchronous condense mode (can all units be treated the same in term of generating high TDG)?	a. All Units can be treated the same in terms of TDG generation. The specific generators involved in synchronous condense without generation did not appear to influence total gas pressure supersaturation. Two units in synchronous condense with the remaining in idle was the most common operation associated with high total gas pressure (97% of the time).
b. For a given combination of units in synchronous condense mode and normal operations, what are the impacts on downstream TGP including magnitude, areal extent, and duration of exposure for a given period of use (hours vs. days vs. weeks)?	b. Observed elevated TGP events were between 110% - 131% in magnitude, ranged in areal extent from just the tailrace area to beyond Mica Camp, and lasted 1 hour to 12.9 days. When Mica Dam operated two units in synchronous condense for > 8-hour periods with intermittent 1-hour durations of synchronous condense with generation (< 200 cms of flow), total gas pressure increased. The magnitude, areal extent, and duration of exposure was directly influenced by the length of these operations and flow from Mica Dam. Operations of synchronous condense with generation and generation without synchronous condense appeared to rapidly decrease total gas pressure supersaturation when operated for > 1 hour at flows > 200 cms.
c. Does the TGP plume generated by synchronous condense operations readily dissipate or mix with the water column, or does it remain as a cohesive plume traveling through Revelstoke reservoir. If as a plume, what is the rate of travel and hence potential exposure to resident fish?	c. TGP remained as a cohesive plume as it travelled through the reservoir. The size and travel rate of the plume was dependent on flow from Mica Generating Station (more frequent discharge events between synchronous condense operations = smaller TGP plumes, and more discharge = faster travel rate). The rate of dissipation was determined to be 1%/km.
MQ-2 With the installation of Mica Units 5 and 6, are there significant changes in the use of synchronous condense operations at the Mica Project and if so, does this represent a significant increase in TDG exposure for downstream aquatic environments?	Duration, frequency, and intensity of synchronous events were statistically higher following the installation of Mica Units 5 and 6, but these increases were not biologically significant. Therefore TDG exposure for downstream environments did not change.
MQ-3 Given what is known of Revelstoke reservoir fish ecology, what is the potential biologic impact of a given high TGP event?	While many fish species temporarily hold in shallow water (< 1 m) within the first 10 km of Mica Generating Station, and would therefore be exposed to total gas pressure supersaturation at levels harmful to fish, the total gas pressure values and exposure durations were not high enough to cause population impact in any species based on the literature; though local impacts (behavioral changes, gas bubble trauma, mortality) were possible.
MQ-4 Where biological impacts warrant response (i.e. population level impacts), are there any opportunities to mitigate impacts to critical fisheries while meeting intended operational flexibility?	Total gas pressure events observed downstream of Mica Generating Station were not severe enough to cause population level impacts; though individual impacts (behavioural changes, gas bubble trauma, mortality) were possible. To reduce impacts on local inhabitants (primarily between Blue Bridge and Mica Generating Station), long durations (8 – 12 hours) of synchronous condense without generation should be followed by ≥ 2 hours of operations including generation with ≥ 200 cms of discharge or, alternatively, operations of synchronous condense without generation should occur for < 8 hours with operations including generation in between.

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List of Abbreviations

CLBMON	Columbia Monitoring Project
cms	Cubic Meters per Second
GBD	Gas Bubble Disease
GBT	Gas Bubble Trauma
MGS	Mica Generating Station
MQ	Management Question
MW	Megawatts
psi	Pounds per Square Inch
PVC	Polyvinyl Chloride
SC	Synchronous Condense
SCUBA	Self Contained Underwater Breathing Apparatus
SxG0	Synchronous Condense without Generation
SxGx	Synchronous Condense with Generation
S0Gx	Generation without Synchronous Condense
TDG	Total Dissolved Gas
TGP	Total Gas Pressure
TGPS	Total Gas Pressure Saturation
TOR	Terms of Reference
WUP	Water Use Plan

Glossary of Terms

Littoral Zone	The zone in a body of water which has sunlight at the sediment level, corresponding with growth of partially to fully-submerged aquatic plants. It is also generally characterized by abundant dissolved oxygen, nutrients, water motion, and alternating intervals of submergence and exposure.
Pelagic Zone	The off-shore zone in a body of water which encompasses the water column (between the surface and the bottom); typically characterized by phytoplankton and zoo plankton rather than aquatic vegetation it is deeper than the littoral zone.
Benthic	The bottom of a body of water.
Supersaturation	A state that occurs with a solution when the concentration of a solute exceeds the concentration specified by the value of solubility at equilibrium. In the case of this report, supersaturation is when total gas pressure in the water column exceeds 100% of barometric pressure.
Total Gas Pressure (TGP)	Dissolved gas in the water column measured as a percent of barometric pressure (where equilibrium is 100% barometric pressure).
TGP environment	Dynamic changes in TGP in the Revelstoke Reservoir resulting from the operation of Mica Dam
Synchronous Condense	An operation at Mica Generation Station used to provide voltage support and quick unit return to service involving the injection of pressurized air into the draft tube to force water below the turbine and allow it to spin in air.

1.0 INTRODUCTION

Mica Generating Station (MGS) currently has six generating units; with Units 1, 2, and 3 discharging into Tailrace 1, and Units 4, 5 and 6 into Tailrace 2 (BC Hydro 2014). Originally, Units 1 - 4 were the only units capable of synchronous condense (SC) operation, which is used to provide voltage support and quick unit return to service. SC capacity at Units 5 and 6 (installed 2015) were online in 2018 and 2021 respectively. SC operations can result in higher localized total dissolved gas pressure (TGP) levels below MGS due to surface water being exposed to pressurized air which is injected at 16 psi into the draft tube to force water below the turbine and allow it to spin in air. Water surface turbulence from the spinning turbine combined with the increased air pressure forces additional gas into the water column, creating total gas pressure supersaturation (TGPS; total gas pressure in water column > 100% barometric pressure). Because the water in the immediate vicinity of the unit is stagnant during SC operation, supersaturation increases (volume of water supersaturated and level of supersaturation) over time.

TGPS can cause elevated TGP levels in the blood of fish, via gas exchange at the gills, causing the blood to 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 blood vessel blockages. Embolism can decrease 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 (Fidler and Miller 1994). Between 1996 and 1998, BC Hydro monitored total dissolved gas (TDG) at MGS during a variety of unit operations and found TDG levels reached 200% TGP in the draft tube when both Units 1 and 2 were operated in SC mode; though a conclusive relationship between TDG levels and hours of SC operation could not be identified (BC Hydro 2014).

Units at MGS operate in SC mode to some extent every month, although this operation occurs primarily during spring/early summer (specifically March to July) and fall (specifically October and November). Bull Trout (*Salvelinus confluentus*), Burbot (*Lota lota*), Mountain Whitefish (*Prosopium williamsoni*), Kokanee (*Oncorhynchus nerka*), and Rainbow Trout (*Oncorhynchus mykiss*) have been observed near the tailrace (Golder Associates Ltd. 2009; Irvine et *al*. 2013) and are presumed to hold in the outflow of the draft tube, as discharge is reduced during SC mode. It is anticipated that due to the higher efficiency of the new units, Units 5 and 6 will be operated in SC mode preferentially to the other four older units (Gillian Kong, pers. comm.).

In 2007, BC Hydro developed Terms of Reference (TOR) for CLBMON 1 under the Columbia River Project Water Use Plan (WUP) – Kinbasket Reservoir Fish and Wildlife Information Plan to monitor TGPS with SC operations of Units 2 and 4, to supplement data from Units 1 and 2 (BC Hydro 2007). These TOR were amended in 2014 to include TOR for CLBMON 62, which addressed BC Hydro’s commitment to monitor changes in SC operations and TGP with the installation of Units 5 and 6 in order to obtain the Environmental Assessment Certificates (BC Hydro 2014). A summary timeline for the development of CLBMON 1-62 is available in Appendix 1.

2.0 STUDY AREA

The MGS is located in south east British Columbia 150 km north of Revelstoke and represents the upstream border of Revelstoke Reservoir; formed by Revelstoke Dam (1984). The Revelstoke Reservoir is the second in a series of three hydroelectric reservoirs, located downstream of Kinbasket Reservoir to the north and upstream of Arrow Lakes Reservoir to the south. Kinbasket Reservoir was formed by the construction of MGS (1973), while the Arrow Lakes Reservoir was formed by the construction of Hugh Keenleyside Dam (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. The majority of inflow into the reservoir is created by discharge from MGS 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 MGS is reduced to maintain a steady reservoir level. The freshet discharge from tributaries is also the biggest contributor of nutrients into Revelstoke Reservoir (Bray et *al*. 2013).

3.0 METHODS

Two primary analyses were conducted: (1) TGP environment in the Revelstoke Reservoir in response to operations of MGS, and (2) MGS operational changes in response to the installation and operation of Units 5 and 6. Appendix 1 provides detailed methods on how TGP data were collected and related to MGS operations, while Appendix 2 provides the methods used to determine if/how MGS operations changed with the installation and operation of Units 5 and 6. A summary of these methods are provided in the following sections. The timeline of this project is summarized in Table 3-1.

Table 3-1. Summary of the timeline and evolution of CLBMON 1-62 (1995 to present).

Date	Event	Source
1995	BC Hydro investigated fish mortalities in the tailrace of Mica Generating Station and identified Total Gas Pressure Supersaturation as one of the causes.	Millar et *al.* 1996
1996 to 1998	BC Hydro monitored Total Dissolved Gas to identify Total Gas Pressure levels during different generator operation regimes and found levels could reach 200% in the draft tube when Units 1 and 2 were operated in Synchronous Condense for long periods of time; thus exceeding the 110% no-effects threshold. In response, BC Hydro created Total Dissolved Gas best management practices.	BC Hydro 2014 Fidler and Miller 1994
2007	Terms of Reference were developed under the Kinbasket Reservoir Fish and Wildlife Information Plan, which included the Mica Generation Station Total Gas Pressure Monitoring and Abatement Program: a 2-year study to determine Total Gas Pressure Supersaturation with Synchronous Condense operations of Units 3 and 4 in relation to the previously monitored Units 1 and 2 (CLBMON 1).	BC Hydro 2007
2008	CLBMON 1 was differed to 2010 based on a review of BC Hydro's 3-year plan.	BC Hydro 2009
2014	Terms of Reference were developed under the Columbia River Project Water Use Plan to assess impacts of new Units 5 and 6 on Synchronous Condense Operations and Aquatic Life (CLBMON 62). These Terms of Reference were incorporated into the CLBMON 1 program and treated as an amendment.	BC Hydro 2014
2015	CLBMON 1-62: Monitoring of Mica Generation Station Units 1-4; Installation of Unit 5	Plate et *al*. 2016
2016	CLBMON 1-62: Monitoring of Mica Generation Station Units 1-5; Installation of Unit 6	Plate et *al*. 2017
2017	CLBMON 1-62: Monitoring of Mica Generation Station Units 1-6	Plate et *al*. 2018
2018	Mica Generation Station Unit 5 becomes Synchronous Condense Capable	
2020	CLBMON 1-62: Monitoring of Mica Generation Station Units 5 Synchronous Condense Operations	
2021	Mica Generation Station Unit 6 becomes Synchronous Condense Capable; CLBMON 1-62: Monitoring of Mica Generation Station Units 6 Synchronous Condense Operations	
2022	CLBMON 1-62 Synthesis Report Completed	

3.1 Total Gas Pressure Data Collection

TGP monitoring stations were created 300 m (Station 0 and 0a), 3.5 km (Station 1 & 2), 10.5 km (Station 3) and 11 km (Station 4) distance from MGS. Short-term (< 2 h) TGP spot measurements were collected at Nagle Creek and in the MGS forebay to record baseline TGP levels uninfluenced by MGS (Figure 3-1). Two stations were installed at each distance to counteract the unreliability experienced with TGP meters in past projects.

Pentair Point Four Tracker Total Gas Pressure Meters (https://pentairaes.com/media/docs/Point-Four-Tracker-PortableTGP-Meter-Manual.pdf), encased in waterproof Pelican cases and placed in a Rubbermaid tote, were used to record TGP levels (as a percent of barometric pressure and in mmHg) and water temperature (°C) at 15-minute intervals. All meters were powered by two independent 6V batteries. The meter sondes were deployed inside a PVC standpipe (7 m length x 5 cm diameter) with the membrane protruding roughly 10 cm into open water. PVC pipes were fastened to boulders with brackets and rock-anchor hardware. On the submersed end, standpipes protruded 2.0 – 2.5 m into the water to avoid air exposure during water-level fluctuations. TGP data were downloaded from the Pentair TGP Meters bi-weekly onto a Panasonic Toughbook using the program HyperTerminal. While downloading, the scrolling data were inspected to ensure a proper download had occurred and any abnormalities were noted and fixed, or the data were re-downloaded. After a successful download, the data were transferred to a one-terabyte external hard-drive as a back up. If the meters were to be re-deployed, the old batteries were replaced with fully charged batteries, and sonde membranes were replaced with new (or clean) ones and were re-calibrated against the barometric pressure. All data were stored on the Okanagan Nation Alliance shared online network when crews returned to the hotel or office.

TGP data collected at Station 0 and 0a were used to identify TGPS during different MGS operational states. This dataset was also used to identify high TGP events (> 110% based on Fiddler and Miller 1994) with discernible “peaks” (instances where TGP rapidly increased and then decreased), which may be visible at downstream stations and were relied upon for plume travel rate/dissipation analyses. TGP events recorded at Stations 0 and 0a were perceived as the initial TGP levels entering the Revelstoke Reservoir. TGP data collected at Stations 1 and 2 were primarily used to assess the TGPS plume extent, travel rate, and dissipation between the MGS tailrace and the Revelstoke Reservoir, while the TGP data collected at Station 3 and 4 were used to assess TGPS plume extent, travel rate, and dissipation into Revelstoke Reservoir.

The assumptions for these datasets were as follows:

1. TGP recorded at Station 0 and 0a were a result of MGS operations within 15 minutes of a change in operational state of all turbines combined,

2. Revelstoke Reservoir tributaries did not increase TGPS within the study area,

3. TGPS values recorded at a given station were representative of TGPS throughout the water column at that location for Stations 0, 0a, 1 and 2. For locations 3 and 4 this assumption is less secure based on the deeper water column.

4. TGP events with discernable peaks observed at Station 0 and 0a were responsible for TGP peaks observed at Stations 1 – 4.

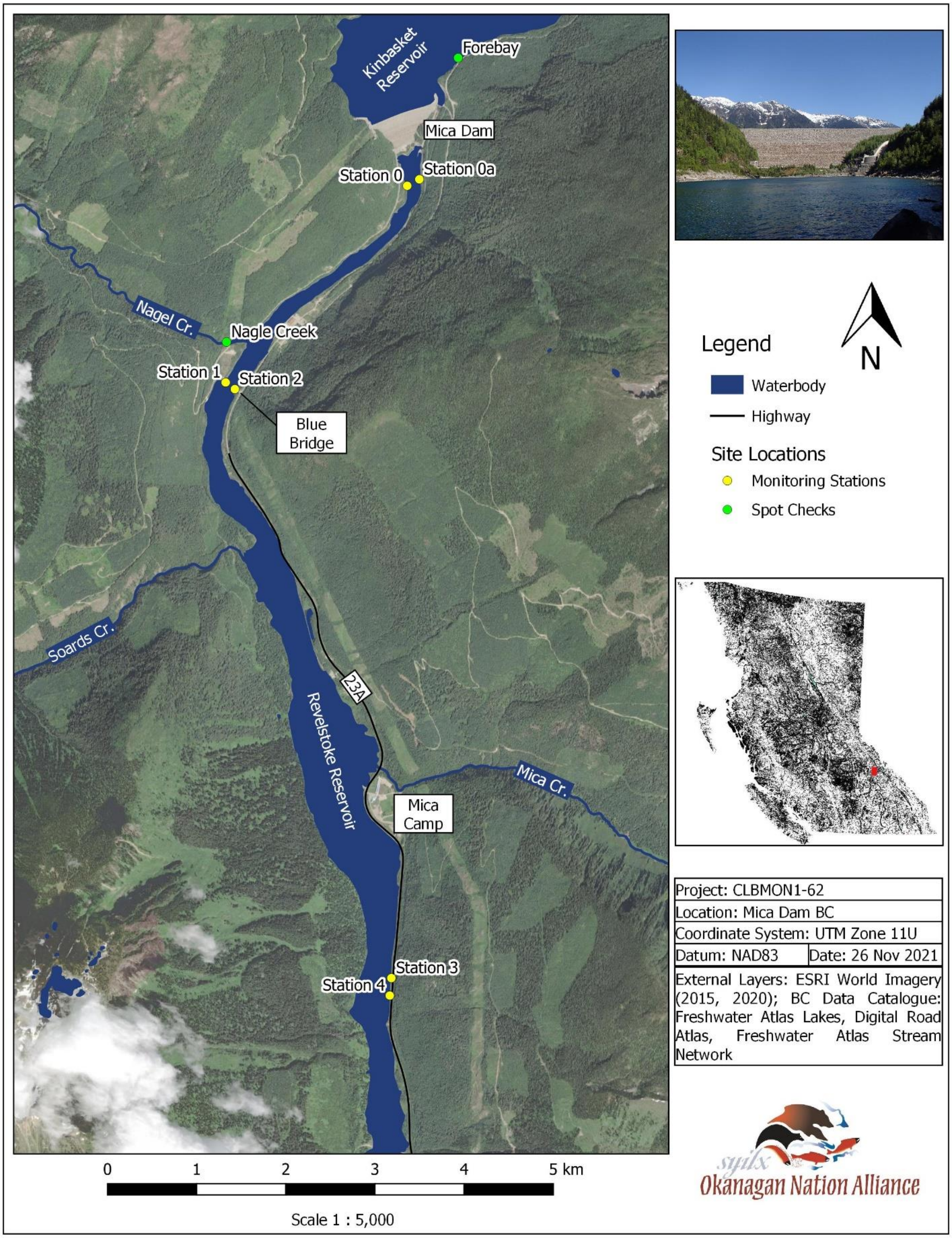

Figure 3-1. Location of TGP monitoring stations used collect data for CLBMON 1-62 between 2015 and 2021.

The monitoring schedule targeted months with high probability of SC operations, identified through conversations with BC Hydro Operations. Monitoring typically occurred in the spring (May – June) 2015 – 2017, and 2020/2021. In 2016 monitoring occurred in September to identify TGP levels during the Kokanee spawning window. To optimize data collection, monitoring did not occur in 2018 or 2019 because Units 6 was not capable of SC operations (capability achieved in 2021). Instead, monitoring occurred in 2020 (focusing on SC operations of Unit 5) and 2021 (focusing on SC operations of Unit 6, and Units 5 and 6 in combination).

3.2 Mica Generating Station Operational Changes

Fieldwork was not required for the collection of MGS operational data. Hourly MGS operational data from 2010 – 2021 were provided by BC Hydro on January 28 2022. The assumptions of this dataset were:

1. Each generator state had an equal probability of running for each hour (e.g. generation operations are not purposefully scheduled between hours),

2. Where consecutive hours display the same operational state, that state was the primary operation for all hours,

3. If operational states changed between hours, there was equal probability of states changing between hours before/after the installation of Units 5 and 6,

4. When a unit displayed positive megawatts (MW), water was flowing through the unit generating power (generating). When the unit displayed zero MW, the unit was neither producing nor using power (idle). When a unit displayed negative MW, the generator was using power to inject air and spin the turbine (synchronous condense). Therefore:

   “Generating (G)” = MW > 0 – Unit is generating power
   “Idle (I)” = MW = 0 – Unit is neither creating nor using power
   “Synchronous Condense (SC)” = MW < 0 – Unit is using power

The MGS operation data were compared before and after Units 5 and 6 were operational and capable of SC operations. The frequency (number of events), duration (length of events in hours), and intensity (frequency of operations which are associated with high TGP [> 110%] based on Appendix 1) of SC events were used to determine differences in MGS operations as it relates to TGPS.

3.3 Mica Generating Station Operations and Total Gas Pressure Impacts on Fish

In 2012, high flows resulting from above average snow pack and rainfall caused BC Hydro to spill water over MGS from July to September, likely resulting in a period of TGPS. In response, a study was completed for BC Hydro in 2014 to assess the TGPS risk of resident fish in the Revelstoke Reservoir (Plate 2015). This study directly contributes to questions in the TOR for CLBMON 1-62, as it consisted of a literature review of the effects of TGPS on fish and an inventory of resident fish species in the Revelstoke Reservoir. Therefore, this analysis included a reiteration of Plate (2015), with emphasis on components that directly relate to CLBMON 1-62.

The results from Plate (2015) regarding Revelstoke Reservoir fish species composition and habitat usage, and the associated literature review on TGP effects on fish, were compared to the Revelstoke Reservoir TGP environment as determined by Appendix 1 (TGP response to MGS operations) and Appendix 2 (MGS operation trends). The methods used by Plate (2015) between 2013 and 2014 to identify resident fish and associated habitat included hydroacoustic surveys, DIDSON imagery sampling, and fish capture sampling; detailed methods are described in Plate (2015). Methods used to determine the Revelstoke Reservoir TGP environment are shown in Appendix 1 and Appendix 2. References to the "Revelstoke Reservoir" in this section are primarily referring to the section of reservoir between the MGS tailrace and Birch/Big Mouth Creek, where all field data were collected (Figure 10-1 in Appendix 3).

3.4 Datasets

The primary datasets collected/utilized for addressing CLBMON-1-62's Management Questions are summarized in Table 3-2. Specific sub-sets of these datasets used in the analyses for the various management questions are described within respective appendices.

Table 3-2. Datasets used to address CLBMON 1-62 Management Questions, including a description of each dataset and the source of the data.

Dataset	Description	Source
MGS Generation 2010 – 2021	Generation (MW) at MGS in hourly intervals for all 6 generation units (when applicable) between January 1 2020 00:00 and December 31 2021 23:00 (102,096 records per unit).	BC Hydro
MGS Generation 2015 – 2021	Generation (MW) at MGS in 15 min. intervals for all 6 generation units during each years respective TGP monitoring period: 2015 – Apr 08, 18:30 to June 15, 15:30 (6,517 records per generator) 2016 – May 12, 13:45 to June 13, 15:45 (3,078 records per generator) 2016 – Sept 06, 15:30 to Sept 25, 14:15 (1,815 records per generator) 2017 – May 08, 00:00 to June 13, 12:15 (3,502 records per generator) 2020 – June 08, 16:00 to June 30, 9:30 (2,087 records per generator) 2021 – June 03, 10:45 to July 09, 13:45 (3,469 records per generator)	BC Hydro
MGS Discharge 2015 – 2021	Hourly average discharge (cms), including discharge from spill events (cms), at MGS during specific high TGP events: 2015 – May 22, 01:00 to May 28, 0:00 (168 records per MGS discharge and spill) 2016 – May 16, 01:00 to June 13, 0:00 (552 records per MGS discharge and spill) 2017 – May 20, 01:00 to May 30, 0:00 (264 records per MGS discharge and spill) 2020 – June 01, 01:00 to June 30, 0:00 (720 records per MGS discharge and spill) 2021 – June 06, 01:00 to July 05, 0:00 (720 records per MGS discharge and spill)	BC Hydro
TGP at MGS Tailrace	TGP Monitored at Stations 0 and 0a at 15 minute intervals (water temperature and barometric pressure in mmHg recorded concurrently) during the following timeframes (21,911 records per parameter): 2015 – May 11, 19:00 to June 15, 14:45 (3,343 records – Station 0 only) 2016 – May 12, 17:00 to May 27, 11:15 (2,763 records – Station 0 and 0a) 2016 – Sept 06, 18:00 to Sept 25, 11:00 (3,402 records – Station 0 and 0a) 2017 – May 09, 11:15 to June 13, 11:15 (6,715 records – Station 0 and 0a) 2020 – June 09, 10:05 to July 05, 11:34 (4,847 records – Station 0 and 0a) 2021 – June 03, 13:43 to July 09, 10:51 (6,884 records – Station 0 and 0a)	Fieldwork
TGP in Revelstoke Reservoir: Riverine Section	TGP Monitored at Stations 1 and 2 at 15 minute intervals (water temperature and barometric pressure in mmHg recorded concurrently) during the following timeframes (45,811 records per parameter): 2015 – Apr 08, 18:45 to June 15, 15:15 (22,361 records – Station 1 and 2) 2016 – May 12, 15:45 to May 27, 12:30 (2,759 records – Station 1 and 2) 2016 – Sept 06, 16:30 to Sept 25, 09:30 (3,447 records – Station 1 and 2) 2017 – May 08, 14:45 to June 13, 11:45 (6,812 records – Station 1 and 2) 2020 – June 09, 12:49 to July 07, 06:06 (4,669 records – Station 1 and 2) 2021 – June 03, 10:53 to July 09, 12:02 (5,763 records – Station 1 and 2)	Fieldwork
TGP in Revelstoke Reservoir	TGP Monitored at Stations 3 and 4 at 15 minute intervals (water temperature and barometric pressure in mmHg recorded concurrently) during the following timeframes (33,891 records per parameter): 2015 – Apr 09, 16:45 to June 15, 15:30 (12,402 records – Station 3 and 4) 2016 – May 12, 13:45 to May 27, 14:15 (2,879 records – Station 3 and 4) 2016 – Sept 06, 15:30 to Sept 25, 11:30 (3,611 records – Station 3 and 4) 2017 – May 08, 16:00 to June 12, 11:45 (4,389 records – Station 3 and 4) 2020 – June 09, 13:34 to July 04, 00:19 (4,610 records – Station 3 and 4) 2021 – June 03, 15:03 to July 09, 13:30 (6,000 records – Station 3 and 4)	Fieldwork

* Dates described in the dataset represent the temporal range of data available in each dataset. The actual range of data used for analysis depended on the analysis.

4.0 MANAGEMENT QUESTIONS

Two sets of Management Questions exist, based on the TOR created for CLBMON 1 (BC Hydro 2007) and CLBMON 62 (BC Hydro 2014). CLBMON 1 focused on the effects of Units 1-4, while CLBMON 62 expanded the scope to include potential impacts by new Units 5 and 6. The TOR for CLBMON 62 were considered an amendment to CLBMON 1 and are here referred to as CLBMON 1-62. For clarity, Management Questions for CLBMON 1 and CLBMON 62 will be discussed separately.

4.1 CLBMON 1 Management Questions (2007)

4.1.1 Management Question 1.

MQ #1: *Is there a difference in dissolved gas supersaturation depending on which of the four units at Mica Generation Station are operated in synchronous condense mode?*

This Management Question from the original TOR for CLBMON 1 was revised in 2014 and incorporated into Management Question 1a in the TOR for CLBMON 62 (an amendment to CLBMON 1); therefore this Management Question, as stated, was removed from the project.

4.2 CLBMON 1-62 Management Questions (2014)

4.2.1 Management Question 1

MQ #1: *What is the impact of synchronous condense operations in Mica Units 1-6 on dissolved gas supersaturation?*

a. Is there a difference in dissolved gas supersaturation depending on which of the six units at Mica Generation Station are operated in synchronous condense mode (can all units be treated the same in term of generating high TDG)?

All Units can be treated the same in terms of TDG generation. The specific generators involved in synchronous condense without generation did not appear to influence TGPS. Operational states involving SxG0 are attributed to higher levels of TGP when compared to SxGX or S0Gx; but TGP is similar between operational states with one unit in SC and those with two units in SC. Instances of high TGP were associated with two units in SC and four units idling 97% of the time. In contrast, Operations of SxGx and S0Gx (generation without synchronous condense) rapidly decreased TGP levels when operated for > 1-hour durations and at discharges > 200 cms. The rate of this reduction is variable and dependant on discharge.

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

Observed elevated TGP events were between 110% - 131% in magnitude, ranged in areal extent from just the tailrace area to beyond Mica Camp, and lasted 1 hour to 12.9 days. When Mica Dam operated two units in synchronous condense for > 8-hour periods with intermittent 1-hour durations of synchronous condense with generation (< 200 cms of flow), total gas pressure increased. The magnitude, areal extent, and duration of exposure was directly influenced by the length of these operations and flow from Mica Dam. Operations of synchronous condense with generation and generation without synchronous condense appeared to rapidly decrease total gas pressure supersaturation when operated for > 1 hour at flows > 200 cms.

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

> TGP remained as a cohesive plume as it travelled through the reservoir. The size and travel rate of the plume was dependent on flow from MGS (more frequent discharge events between SC operations = smaller TGP plumes, and more discharge = faster travel rate) and SC frequency/duration. The rate of dissipation was determined to be 1%/km.

When SxG0 (synchronous condense without generation) occurs for ≥ 8-h durations with intermittent 1-h durations of SxGx (synchronous condense with generation), TGP in the MGS tailrace tends to exceed the BC Water Quality Guideline (110%).

The dataset was limited in the number of generators and generator combinations operating in SC during all combined monitoring periods. Not all possible combinations of units in SC were monitored, or data for those combinations were limiting. For instance, combinations of three generators operating in SC together were rare in the dataset (0.62% of dataset) but are shown to operate in 13% of all SC without generation operations; therefore, this aspect of the operational regime is underrepresented in the current dataset. In addition, monitoring occurred 300 m downstream of the outflow in the MGS tailrace, therefore, the data collected were not independent (TGP values could not be attributed to a specific generator if two generators were operating in SC at the same time).

If determining whether there is a difference in TGPS depending on the specific generator in SC at MGS is a significant priority, then TGP monitoring should occur within the turbine outflow, prior to the tailrace, for more independent data collection.

For details concerning the analysis of Management Question 1 see Appendix 1.

4.2.2 Management Question 2

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

SC duration, frequency, and intensity increased following the installation and SC operation of Units 5/6. SC frequency appeared to have increased by 7 – 9 events/month on average; with the greatest increase in SC frequency occurring in January (an additional 25 events on average). The overall average SC duration appeared to be slightly (1 h) longer after Unit 5/6 were capable of SC operations. A greater increase of average SC duration was detected on a monthly scale, specifically in May (averaged 70-h longer). The operation of SxG0 for ≥ 8-h duration (associated with TGP values > 110%) increased in frequency by 6 events/month on average following the installation/operation of Units 5/6.

An increase in SC duration, frequency, and intensity does not necessarily indicate a greater TGP impact to downstream environments (compared to 2010 – 2014). Not all SC operations increase TGP (Appendix 1); operations including SxGx are shown to decrease TGP in longer durations (> 2 h with discharge > 200 cms). The proportional use of SxGx increased by 11 – 13% following the installation and entry in operation of Units 5/6; this would have contributed to the overall increase of SC frequency and duration but likely had minimal impacts of TGP exposure to downstream environments. Frequency of SxG0 for ≥ 8-h duration is likely the best indicator for increased TGP exposure for downstream aquatic environments from MGS operations. The proportional use of SxG0 increased by 4% following the installation and SC operation of Units 5/6; this could potentially have increased TGP exposure to downstream environments. However, most fish species abundances appeared to be lowest in spring at MGS tailrace when this operation is most likely to occur. Therefore, this increase is not significant at a population level.

The monitoring team requested specific operations of MGS in 2020 and 2021 to collect data for Management Question 1 in relation to SC operations of Unit 5 and 6; due to the delay of Unit 6 SC operations (online in 2021). The requested operations included operations of SxG0 for longer than 8-h durations. Therefore, the increased frequency of ScG0 ≥ 8-h duration, and increased frequency of > 110% TGP records in 2020 and 2021 may not be a product of typical MGS operations.

For details concerning the analysis of Management Question 2 see Appendix 2.

4.2.3 Management Question 3

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

Based on the literature, the high TGP events observed downstream of MGS were not severe enough to cause population level impacts, though individual impacts (behavioural changes, GBD, and mortality) were possible. Mountain Whitefish, Rainbow Trout, Kokanee, Bull Trout, and sculpin (Cottidea) are considered medium risk due to their lower tolerance for TGP, and life history traits. Most species abundances appeared to be lowest in the MGS tailrace in the spring when TGP levels were highest. Based on available surveys and known fish ecology (Plate 2015), it is assumed the majority of the population are in Revelstoke Reservoir (> 10.5 km from MGS) where TGP levels are typically safe. The impact of TGP is reduced by 10% for every meter of depth, and deep water refuge habitat is available and accessible for fish to recover or escape from high TGP levels throughout the study area. It is important to note that all information on fish species composition and behaviour in the Revelstoke Reservoir is based on data collected in 2009 – 2014, and fish populations, behaviours, and composition may have changed in the 7 – 12 years since these studies occurred due to a variety of factors including a change in climate, water temperatures, flows/water levels, and/or stochastic events.

For details concerning the analysis of Management Question 3 see Appendix 3.

4.2.4 Management Question 4

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

TGP events observed downstream of MGS were not severe enough to cause population level impacts; though individual impacts (behavioural changes, GBD, and mortality) are possible.

To reduce impacts on local fish populations (primarily between Blue Bridge and MGS), long durations (8 – 12 h) of SxG0 should be followed by ≥ 2 h of SxGx or S0Gx with ≥ 200 cms of discharge, or SxG0 for < 8 h with SxGx and S0Gx operated in between.

5.0 OTHER RESULTS

All TGP and associated MGS operations data were stored on a password protected web-based application under the tradename “Shiny App”. This application allows for real-time manipulation of factors and figure/graph creation and export.

Link: https://shiny.lglsidney.com/hydro-tgp/

6.0 RECOMMENDATIONS

The following are recommendations for additional data collection and analyses to clarify inconsistencies and fill data gaps, and suggested MGS operations to reduce impacts on fish.

6.1 Additional Data Collection and/or Analyses

1. **Retest Management Question 2** to identify whether there is a significant change in the duration, frequency or intensity of SC operations during a normal operational regime.

   Explanation: The project team requested specific operations at MGS to collect data for Management Question 1. The requests of the project team in 2020 and 2021 may have influenced the results for Management Question 2; artificially increasing SC frequency, duration, and/or intensity.

   Suggested Methods: No field data collection should be required. The generation (MW) data at MGS (in hourly intervals) for all 6 generation units between January 1 2022 00:00 and December 31 2026 23:00 should be compared to baseline conditions (2010 – 2014) using methods in Appendix 2.

2. **Collect TGP data on each respective unit** to clarify whether there is a difference in TGPS depending on which of the six units at MGS are operated in SC.

   Explanation: TGP Monitoring occurred 300 m downstream of the outflow in the MGS tailrace, therefore, the data collected were influenced by variables such as discharge and could not be ascribed to a particular generating unit. This recommendation should only be considered if determining whether a difference in TGPS by generator is important, as the data collected in this study indicates there is no biological difference in TGPS production by generator.

   Suggested Methods: Fieldwork would include the installation of TGP meters in, or immediately downstream, of each turbine chamber with additional monitoring locations at Station 0 and 0a. The accumulation of TGPS by time in each turbine tube could be compared independently to each other and to the “mixed” state recorded at Station 0 and 0a, 300 m downstream of MGS.

3. **Sample fish below MGS** to ground truth the conclusions regarding the potential biological impact of elevated TGP in the tailrace and Revelstoke Reservoir.

   Explanation: Conclusions regarding the biological impacts of monitored TGP downstream of MGS to aquatic life were based on fish behaviour and composition data from 2009 – 2014. Populations, behaviours, and composition of fish species may have changed in the 7 – 12 years since these studies occurred due to a variety of factors including a change in climate and/or water temperatures. In addition, there have not been any direct studies on the effects of TGPS or GBD on fish in the Revelstoke Reservoir. An updated fish population, composition, and behaviour study would be beneficial, but is outside the scope of CLBMON 1-62. Instead, a targeted fish survey during elevated TGP events, focussing on observations of fish behaviour and symptoms of GBD, would improve understanding of biologic impacts of elevated TGP.

Suggested Methods: Fieldwork would include boat electrofishing during periods of elevated TGP (May/June) to observe and capture fish. Fish capture surveys would occur at night. Fish would be identified to species, weighed, measured, and condition/symptoms of GBD if present would be recorded. A subset of fish may be euthanized to inspect gills and organs. TGP monitoring would occur concurrently with fish sampling to document the level of TGPS and duration of exposure.

6.2 Operations to Reduce Impacts of Fish

1. Operations of SxGx or S0Gx[1] should occur for ≥ 2 h with a discharge of ≥ 200 cms following operations of SxG0. The longer SxG0 continually operated, the longer SxGx or S0Gx should operate following.

2. Try to keep operations of SxG0 under eight consecutive hours, and follow operations with SxGx or S0Gx.

3. If possible, use SxGx instead of SxG0.

7.0 REFERENCES

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[1] SxGX – Sync Condense with generation, S0Gx – generation without sync condense, SxG0 – sync condense without generation

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8.0 APPENDIX 1: TECHNICAL REPORT FOR MANAGEMENT QUESTION # 1

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

a. *Is there a difference in dissolved gas supersaturation depending on which of the six units at Mica Generation Station are operated in synchronous condense mode (can all units be treated the same in term of generating high TDG)?*

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

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

8.1 Introduction

This analysis was used to assess the potential impacts of synchronous condense (SC) operations at Mica Generating Station (MGS) on total gas pressure supersaturation (TGPS) in the MGS tailrace and Revelstoke Reservoir. Specifically, this analysis focused on whether TGPS levels are different depending on which turbines are operating in SC, how TGPS disperses into downstream environments, and the rate of TGPS travel and dispersion through downstream environments. The null hypotheses in the Terms of Reference (TOR) are (BC Hydro 2014):

H_01_a: *There is no difference in TGP generation between units during S/C operations.*

H_01_b: *Downstream TGP (% Saturation) does not increase incrementally as the number of units operating in synchronous condense mode increases from 1 to 6.*

H_01_{c1}: *Downstream TGP (% Saturation) does not increase over time as the duration of S/C operations increases.*

H_01_{c2}: *The areal extent of a TGP plume downstream of Mica Dam does not increase with the number of units and during S/C operations.*

This analysis was completed by monitoring TGP (%) downstream of MGS at various distances, and comparing monitored TGP levels to MGS operations at that time.

8.2 Methods

Hypothesis $H_01_{a\text{-}c}$ investigates how TGP is influenced by MGS operations. Therefore, active monitoring of TGP levels in the MGS tailrace and the Revelstoke Reservoir was required. Monitoring occurred from 2015 – 2017 and in 2020 and 2021, primarily from May – July when the occurrence of SC operations was expected to be more frequent; though monitoring did occur in September of 2016 to identify TGP levels during Kokanee (*Oncorhynchus nerka*) spawning. MGS operational data for these time periods were provided by BC Hydro annually. All TGP and associated MGS operations data were stored on a password protected web-based application under the tradename “Shiny App.”. This application allowed for real-time manipulation of factors and figure/graph creation and export.

In 2020 and 2021 the project team requested specific operations at MGS to maximize TGP data collection in relation to SC operations of Units 5 and 6. As a result, MGS operations during this timeframe may not have been within the normal operating regime. The influence of these requests by the project team were considered while interpreting analyses. The following chapters detail methods for TGP data collection and describe each analysis and datasets used to address $H_01_{a\text{-}c}$.

8.2.1 Total Gas Pressure Monitoring

TGP data were collected using Pentair Point Four (PT4) Tracker Total Gas Pressure Meters in individual waterproof Pelican cases with custom fittings that facilitated the connection of computers and sondes (probes) without requiring the meter to be removed from the case. The following parameters were recorded at 15-minute intervals throughout the monitoring period:

- Total Gas pressure (measured, mmHg)
- Barometric Pressure (measured, mmHg)
- Water Temperature (measured, °C)
- Total dissolved gas pressure (derived, % of barometric pressure)

Specifications for the PT4 meter are available in Appendix 2-1. The components of a PT4 meter system included the central unit which recorded and saved the data, a power source consisting of two 6-volt gel-cell (12 Ah) batteries connected in parallel, and a sonde (probe) with an exchangeable membrane.

Monitoring stations consisted of a PVC standpipe (7 m length x 5 cm diameter), anchored to the bank via masonry stainless steel expansion anchors, galvanized 2-hole pipe hanger straps, and a Rubbermaid tote. A Hilti hammer drill powered by a Honda generator was used to install the expansion anchors in boulders/bedrock along the river/reservoir bank. Standpipes were submerged at least 2.0 – 2.5 m into the Columbia River/Revelstoke Reservoir to prevent air exposure during water-level fluctuations and were secured with two to three hanger straps; stations with two PT4 meters had two standpipes. The Rubbermaid tote housed the PT4 meter providing added protection for the cable connections against the elements. The standpipe entered the tote through a 5 cm hole and was attached and weather-sealed to the tote with Gorilla Tape. PT4 meters (one to two per station) were placed in the tote and chained to an anchor point (tree, rock, installed hanger strap) to prevent theft or meter loss from high-water events. The meter's sonde was fed into the standpipe until the membrane protruded 10 cm into the waterbody. To prevent the sonde from falling out of the standpipe, the sonde cable was taped to the tote end of the standpipe (Figure 8-1).

Figure 8-1. TGP monitoring station configuration including: a close up of the PT4 Pelican case anchored within a tote and the cable leading to the sonde through the standpipe (top left), a standpipe secured to a boulder with a hanger strap and expansion anchors (top right), an overview of Station 3 located 10.5 km from MGS (bottom left), and the submerged portion of a standpipe with the membrane protruding into the Columbia River (bottom right). Photos by: Evan Smith, Okanagan Nation Alliance (top left, bottom right) and Elmar Plate, LGL Limited (top right, bottom left).

i) Site Selection and Monitoring Schedule

TGP monitoring occurred between MGS (including forebay) and Revelstoke Reservoir approximately 2.2 km downstream of Mica Camp (Figure 8-2). Three distinct zones were included in the project area:

1. Tailrace: 0 to 0.5 km from MGS – This zone was characterized by the proximity to, and influence of, MGS operations. Located directly downstream of MGS, this zone was assumed to have the highest potential levels of TGP and to be the area with the quickest changes in TGP response to changes in MGS operations.
2. Riverine: 0.5 km to 5 km from MGS – This zone was characterized by riverine features; primarily shallow (relative to the reservoir), with a narrow cross section, and visible flow. This area is influenced by the backwatering of Revelstoke Reservoir at times of the year and is regulated by MGS (as far as discharge and water level). This section was also perceived to have lower TGP than

the Tailrace, and was expected to provide data on dilution and dispersion of TGP (both with time and distance).

3. Reservoir: 5 km to 11 km from MGS – This zone was characterized by the backwatering from Revelstoke Dam, wider banks and increased depth (than the Riverine Section), and absence of visible flow. Due to its distance from MGS and increased volume compared to the Tailrace and Riverine Section, this area was assumed to have the lowest TGP levels. Data collected at this site was used to assess TGP dilution, dispersion (both with time and distance), and whether TGP levels would impact fish in the reservoir.

In 2015, monitoring stations were installed 3.5 km (Stations 1 and 2), 10.5 km (Station 3), and 11 km (Station 4) from MGS. Stations 1 and 2 were located on either side of the blue bridge used to access MGS, while Stations 3 and 4 were south of Mica Camp (Figure 8-2). Two PT4 meters were operational at Stations 1 and 2 for the first monitoring period (April 9 2015 – April 24 2015). This redundancy allowed us to assess the accuracy of the PT4 meters and increase confidence in data collection.

On May 11 2015, an additional station (Station 0) was created 300 m from MGS on the west bank in an attempt to collect TGP data in the immediate MGS tailrace. One PT4 meter, originally located in Station 1, was relocated to Station 0 for this purpose; while Station 2 continued to operate with two meters. These five stations continued to operate for the remainder of the 2015 monitoring program (ending June 15 2015).

On June 13 2016 the final station (Station 0a) was created 300 m from MGS on the east bank. This station was directly in-line with the MGS tailrace outflow, and was suspected to collect real-time TGP levels in relation to MGS operational changes. Therefore, two stations were located in each, the tailrace, riverine, and reservoir sections for the 2016, 2017, 2020, and 2021 monitoring periods providing data redundancy in the event a meter ran out of batteries, a membrane was damaged, or a meter malfunctioned. Specific monitoring periods and activities are available in Appendix 2-2. TGP “spot check” measurements were initiated in 2016 to identify TGP levels in Nagel Creek (located upstream of Stations 1 and 2) and MGS Forebay to document baseline TGP inputs into the monitoring area. These stations consisted of a PT4 meter and probe (without a standpipe and tote) recording every minute for 15 – 60 minutes. Data collection was executed to coincide with planned SC operations based on conversations with MGS Managers. The detailed TGP meter deployment schedule was therefore designed to cover a period of high SC operations likelihood.

ii) Meter Setup, Calibration, Download, and Maintenance

PT4 meters were calibrated by the manufacturer prior to the first monitoring period and were sent for recalibration/inspection annually. Vendors that serviced the meters included Pentair Aquatic Eco-Systems Inc. (Langley BC; 2016 and 2017), Pentair Aquatic Eco-Systems Inc. (Nanaimo BC; 2018), and InWater Technologies Inc. (Campbell River BC; 2021). Prior to deployment, meters were turned on with the sonde and membrane attached to ensure the meter was reading 100% for TGP (equal to barometric pressure), and battery voltage was checked to ensure they were fully charged. Prior to meter installation in the field, a one-point calibration was performed while the sonde membrane was dry. This involved manually inputting the barometric pressure at the time of deployment into the meter. Once calibrated, the sonde was fed into the standpipe until the membrane was protruding 10 cm into the waterbody. All meters were set to auto log every 15 minutes (1 minute for spot checks). The meters internal clock was checked every deployment/download and adjusted if required (one watch was used to adjust all meters). Once logging, crews visually observed the TGP levels and did not leave until the meters recorded at least one data point. Once a meter was confirmed to be logging correctly, the tote lid was secured with zap-straps. Meters would typically be deployed for two weeks between downloads, the estimated battery run time.

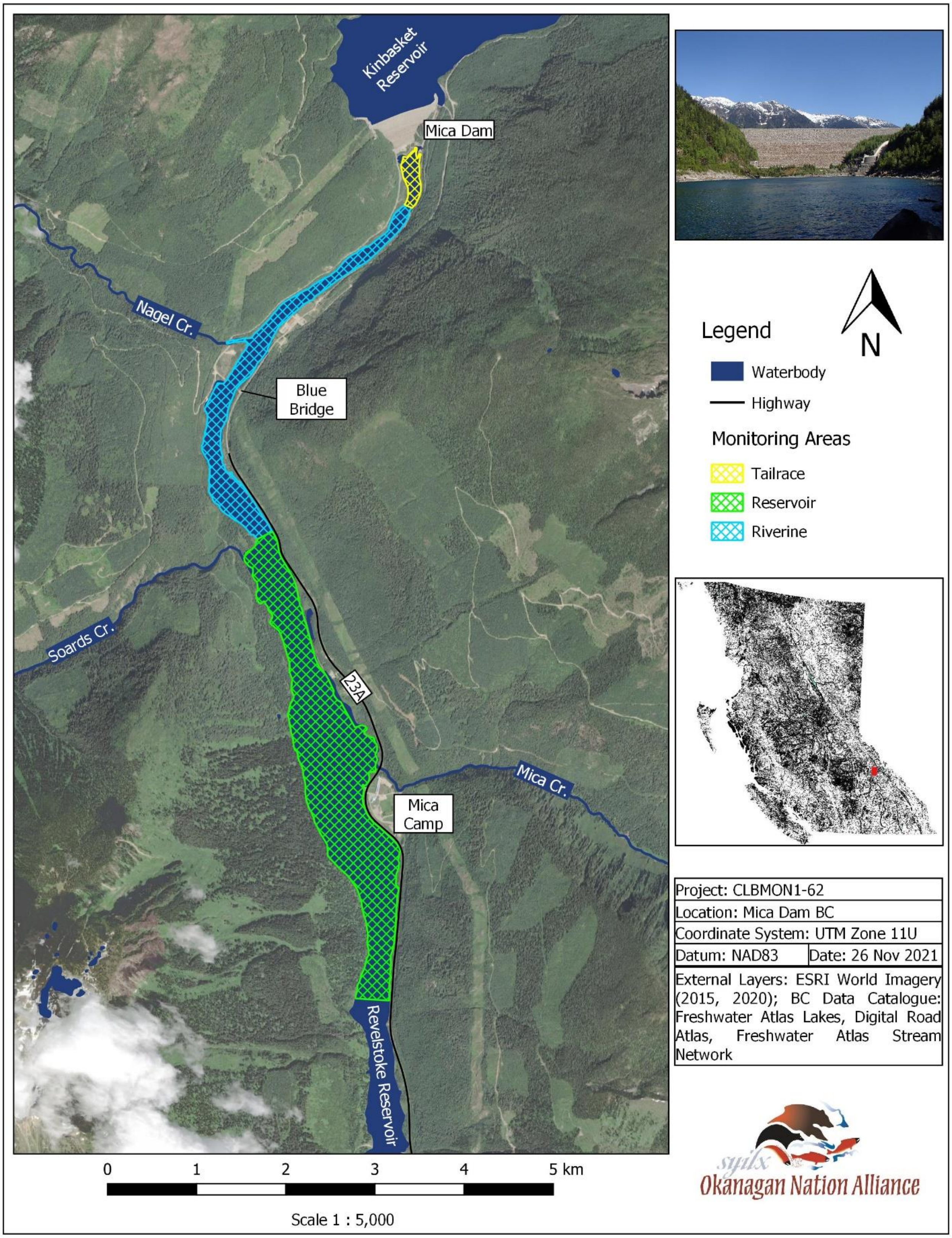

Figure 8-2. CLBMON 1-62 total gas pressure monitoring area distinguishing between the tailrace, riverine, and reservoir zones in relation to MGS and Mica Camp.

TGP data were downloaded from the meter with a Panasonic Toughbook using Hyperterminal Software as per the PT4 meter manual (Pentair 2016; https://pentairaes.com/media/docs/Point-Four-Tracker-PortableTGP-Meter-Manual.pdf). While downloading, crews observed the data for inconsistencies, missing data, or obvious errors. When the download was complete, data were exported as an Excel (2016) comma-separated values (CSV) file into a project folder on the Toughbook. The data were then double checked in the CSV file format to ensure all the data were successfully downloaded. Once a successful download was confirmed, the CSV file was copied onto an external terabyte hard drive as a digital backup. After downloading, membranes were removed from the sonde and replaced with a new/clean dry one. The voltage of PT4 meter batteries was recorded, batteries were replaced, and voltage of the new battery was also recorded. Before re-deployment the one-point field calibration was performed, auto log was confirmed to be set for 15 minutes, and the internal clock was adjusted if required.

In the hotel or at the office, used membranes were cleaned by rinsing in clean water and gently brushing with a soft-bristle toothbrush. Membranes were then tested for holes with a syringe test; membranes were submerged in clean water and injected with air through a task-specific syringe supplied by the manufacturer. If bubbles were observed emanating from the membrane it was punctured and subsequently replaced.

8.2.2 Dataset

Three primary datasets were used for analysis in this section: *MGS Generation (MW) 2015-2021*, *MGS Discharge (cms) 2015-2021*, and monitored TGP data, which can be categorized into three subsets – *TGP at MGS Tailrace* (data collected at Station 0 and 0a)*, TGP in Revelstoke Reservoir-Riverine Section* (data collected at Station 1 and 2)*, and TGP in Revelstoke Reservoir* (data collected at Station 3 and 4). A summary of each datasets scope and sample size is presented in Table 8-1.

Table 8-1. Datasets used in analyses to address $H_01_{a\text{-}c}$ with a description of dataset size, temporal scope, and data source.

Dataset	Temporal Scope and Sample Size	Source
MGS Generation (MW) 2015-2021	Generation (MW) at MGS in 15 min. intervals for all 6 generation units during each years respective TGP monitoring period: 2015 – Apr 08, 18:30 to June 15, 15:30 (6,517 records per generator) 2016 – May 12, 13:45 to June 13, 15:45 (3,078 records per generator) 2016 – Sept 06, 15:30 to Sept 25, 14:15 (1,815 records per generator) 2017 – May 08, 00:00 to June 13, 12:15 (3,502 records per generator) 2020 – June 08, 16:00 to June 30, 9:30 (2,087 records per generator) 2021 – June 03, 10:45 to July 09, 13:45 (3,469 records per generator)	BC Hydro
MGS Discharge (cms) 2015-2021	Hourly average discharge (cms), including discharge from spill events (cms), at MGS during specific high TGP events: 2015 – May 22, 01:00 to May 28, 0:00 (168 records per MGS discharge and spill) 2016 – May 16, 01:00 to June 13, 0:00 (552 records per MGS discharge and spill) 2017 – May 20, 01:00 to May 30, 0:00 (264 records per MGS discharge and spill) 2020 – June 01, 01:00 to June 30, 0:00 (720 records per MGS discharge and spill) 2021 – June 06, 01:00 to July 05, 0:00 (720 records per MGS discharge and spill)	BC Hydro
TGP at MGS Tailrace	TGP monitored at Stations 0 and 0a at 15-minute intervals (water temperature and barometric pressure in mmHg recorded concurrently) during the following timeframes (21,911 records per parameter): 2015 – May 11, 19:00 to June 15, 14:45 (3,343 records – Station 0 only) 2016 – May 12, 17:00 to May 27, 11:15 (2,763 records – Station 0 and 0a) 2016 – Sept 06, 18:00 to Sept 25, 11:00 (3,402 records – Station 0 and 0a) 2017 – May 09, 11:15 to June 13, 11:15 (6,715 records – Station 0 and 0a) 2020 – June 09, 10:05 to July 05, 11:34 (4,847 records – Station 0 and 0a) 2021 – June 03, 13:43 to July 09, 10:51 (6,884 records – Station 0 and 0a)	Fieldwork
TGP in Revelstoke Reservoir: Riverine Section	TGP Monitored at Stations 1 and 2 at 15 minute intervals (water temperature and barometric pressure in mmHg recorded concurrently) during the following timeframes (45,811 records per parameter): 2015 – Apr 08, 18:45 to June 15, 15:15 (22,361 records – Station 1 and 2) 2016 – May 12, 15:45 to May 27, 12:30 (2,759 records – Station 1 and 2) 2016 – Sept 06, 16:30 to Sept 25, 09:30 (3,447 records – Station 1 and 2) 2017 – May 08, 14:45 to June 13, 11:45 (6,812 records – Station 1 and 2) 2020 – June 09, 12:49 to July 07, 06:06 (4,669 records – Station 1 and 2)	Fieldwork

Dataset	Temporal Scope and Sample Size	Source
	2021 – June 03, 10:53 to July 09, 12:02 (5,763 records – Station 1 and 2)	
TGP in Revelstoke Reservoir	TGP Monitored at Stations 3 and 4 at 15 minute intervals (water temperature and barometric pressure in mmHg recorded concurrently) during the following timeframes (33,891 records per parameter): 2015 – Apr 09, 16:45 to June 15, 15:30 (12,402 records – Station 3 and 4) 2016 – May 12, 13:45 to May 27, 14:15 (2,879 records – Station 3 and 4) 2016 – Sept 06, 15:30 to Sept 25, 11:30 (3,611 records – Station 3 and 4) 2017 – May 08, 16:00 to June 12, 11:45 (4,389 records – Station 3 and 4) 2020 – June 09, 13:34 to July 04, 00:19 (4,610 records – Station 3 and 4) 2021 – June 03, 15:03 to July 09, 13:30 (6,000 records – Station 3 and 4)	Fieldwork

* Dates described in the dataset represent the temporal range of data available in each dataset. The MGS Generation and discharge data used in analysis were between the dates described in the TGP at MGS Tailrace dataset.

i) Monitored Total Gas Pressure Datasets

TGP data collected at Station 0 and 0a (*TGP at MGS Tailrace*) were used to identify TGPS during different MGS operational states. This dataset was also used to identify high TGP events (>110%) with discernible "peaks" (instances where TGP rapidly increased and then decreased), which may be visible at downstream stations and were relied upon for plume travel rate/dissipation analyses.

TGP recorded at **Stations 0 and 0a** were perceived as the initial TGP level entering the Revelstoke Reservoir.

TGP data collected at **Station 1 and 2** (*TGP at Revelstoke Reservoir: Riverine Section*) were primarily used to assess the TGPS plume extent, travel rate, and dissipation between the MGS tailrace and the Revelstoke Reservoir, while TGP data collected at **Station 3 and 4** (*TGP in Revelstoke Reservoir*) were used to assess TGPS plume extent, travel rate, and dissipation into Revelstoke Reservoir.

The assumptions for these datasets were as follows:

1. TGP recorded at Station 0 and 0a were a result of MGS operations within 15 minutes of a change in operational state of all turbines combined,

2. Revelstoke Reservoir tributaries did not increase TGPS within the study area,

3. TGPS values recorded at a given station were representative of TGPS throughout the water column at that location for Stations 0, 0a, 1 and 2. For locations 3 and 4 this assumption is less secure based on the larger water depths.

4. TGP events with discernable peaks observed at Station 0 and 0a were responsible for TGP peaks observed at Stations 1 – 4.

ii) Mica Generating Station Operational Data

The dataset *MGS Generation (MW) 2015-2021* was used to identify the operational state of MGS, and which specific generators were in which state, at a given time (with a 15 minute resolution). *MGS Discharge (cms) 2015-2021* was used in conjunction with monitored TGP data to assess TGP level, plume extent, travel rate, and dissipation. Discharge data included the discharge from MGS as a result of operations, and spill discharge; if/when a spill occurred. The assumptions for these datasets are as follows:

MGS Generation (MW) 2015-2021

1. Where consecutive records display the same operational state, that state was active in between records and;

2. When a unit displayed positive MW, water was flowing through the unit generating power (generating). When the unit displayed zero MW, the unit was neither producing nor using power (idle). When a unit displayed negative MW, the generator was using power to spin the turbine and thus inject air (synchronous condense). Therefore:

“Generating (G)” = MW > 0 – Unit is generating power
“Idle (I)” = MW = 0 – Unit is neither creating nor using power
“Synchronous Condense (S)” = MW < 0 – Unit is using power

MGS Generation (MW) 2015-2021 was transformed from MW into operational states in Excel (2016) using the function: =IF(X>0,"G",IF(X=0,"I",IF(X<0,"SC"))), where “X” is each individual cell containing operational data. Units identified as “shutdown” in the dataset were treated as idle units, as the physical impact of these generators on TGP should be similar (no flow or introduction of TGP).

MGS Discharge (cms) 2015-2021

1. MGS discharge/spill is the primary influence on flow throughout the study area (tributary flows were relatively small and consistent through the monitoring periods).

8.2.3 Analyses

The datasets used for analyses were dependent on the H_0 being analyzed. TGP data were compared (via Shiny App.) between stations at each distance to identify anomalies or data gaps. Data anomalies may have occurred due to incorrect calibration or a dirty/punctured membrane. In instances where incorrect calibration occurred, the TGP pattern would be similar between stations at a given distance but one station would have consistently higher or lower TGP levels; whereas a punctured membrane would produce erratic TGP values resulting in frequent high or low outliers. The station with the most consistent data for a given timeframe was used for analysis, and typically one station per distance was used. TGP data collected at Station 0 and 0a between May 8 – 25 2017 were omitted from all analyses due to questionable data (multiple < 100% TGP values) suspected to be resulting from compromised membranes.

i) Data Sorting and Analysis to Assess Total Gas Pressure Production by Generator-Specific Synchronous Condense Operations and Mica Generating Station Operations

To address H_01_a (there is no difference in TGP generation between units during SC operations) and H_01_b (downstream TGPS does not increase incrementally as the number of units operating in SC mode increases from 1 to 6), the TGP (%) data collected 0.3 km from MGS were combined with the corresponding MGS operational data for a given date/time (with 15 minute resolution). The specific station used for a given year was 2015 (Station 0), 2016 (Station 0a), 2017 (Station 0), 2020 (Station 0), and 2021 (Station 0a).

H_01_a specifically related to the TGPS production of individual generators in SC. Therefore, TGP data (hourly average) were sorted by generator or generator combinations (dominant in the given hour) in SC. The dominant generator/generator combination for a given hour was determined by the frequency of operation in that hour (n = 4); a generator/generator combination was considered dominant when it occurred three to four times in the hour. Generators were designated G1-6 and generator combinations were indicated by a “+” between two generator designations (e.g. G1+G4 = Generator 1 and Generator 4 were operating in SC concurrently). MGS discharge (average-hourly discharge from MGS operations, including spill, in cms) was also included to determine whether differences in TGPS by generator were influenced by flow. If generator/generator combinations in SC had high TGPS and low (or no) discharge, and generator/generator combinations in SC had low TGPS and high discharge, then discharge was likely influencing the level of recorded TGP. Only generator/generator combinations with a sample size (n) of 24 h or more were included in analyses (encompassing 75% of possible combinations representing 97% of the total dataset) to reduce variability from less frequent generator/generator combinations in SC.

H_01_b concerned the overall operation of MGS. TGP data were averaged hourly and paired with the dominant operational state for that hour. The dominant operational state was determined by hourly frequency of operation (n = 4); the operational state with the most observed occurrences within the hour was designated the primary operational state. MGS operational data were represented by a serial number, which consisted of the description of an operational state followed by the number of generators in that state: where S = synchronous condense, I = idle, G = generating. Therefore, if an operational state at time X = S2I4G0, then turbines in synchronous condense = 2, turbines idling = 4, and turbines generating = 0. If four different operational states occurred in a given hour (there was not a dominant operational state), the operational state was labelled SxIxGx. Only operational states with a total of 24 h or more over the respective monitoring period were included in analyses (encompassing 53% of observed MGS operational states representing 98% of the data) to reduce variability from uncommon operational states.

Once data were sorted, the files were uploaded to R Project (R i386 4.1.2) to create combination box/violin plots using R libraries ggplot2, ggpubr, broom, AICcmodavg, ggdist, gghalves, ggbeeswarm, and ggforce. These plots were used to compare differences in the levels of recorded TGP between generators and generator combinations in SC (TGP by Generator), and MGS operational states (TGP by Operational State). Statistical analyses to assess the differences in TGP recorded during different operational states was difficult due to the extent of autocorrelation in the dataset, and the small standard deviation of the sample population due to the nature of the data (TGP values range between 100% and 130%, and typically do not change more than 1% from 15 – 30 min). Therefore, conclusions on TGP production by MGS operational states were based on comparison of boxplots. For H_01_a, boxplots were also created for MGS discharge at times when specific generators and generator combinations were in SC; these discharge boxplots were compared to the TGP by Generator boxplots to determine if discharge may have influenced recorded TGP.

ii) Data Sorting and Analyses to Assess Total Gas Pressure by Duration of Synchronous Condense Operations

To address H_01_{c1} (downstream TGP does not increase over time as the duration of SC operations increases), the TGP data collected 0.3 km from MGS were combined with the corresponding MGS operational data for a given date/time (with 15 minute resolution). The specific station used for a given year was 2015 (Station 0), 2016 (Station 0a), 2017 (Station 0), 2020 (Station 0), and 2021 (Station 0a).

To identify operational trends resulting in high TGP events (> 110%), TGP data were averaged hourly and paired with the dominant operational state for that hour. The dominant operational state was determined by the method described in *Section 1.2.3.i*. For observations on general SC operations, operational states were grouped by three common categories: SC without generation (SxG0), SC with generation (SxGx), and generation without SC (S0Gx). Hourly TGP data were graphed by time (h) with the hourly general operational state. Conclusions regarding the cause of monitored high TGP events were based on observations of general or specific operational durations preceding, during, and following elevated TGP.

To determine whether discharge effects TGP levels, hourly TGP and the specific MGS operational state for the given hour were paired with discharge data (average-hourly discharge from MGS operations, including spill, in cms) and graphed over time. Discharge was considered consequential if the correlation between TGP and Discharge was significant.

To identify whether TGP increased over time for a specific operational state, TGP data were sorted by duration events by operational state; where a duration event was a period of time when the operational state (represented by a serial number, as described in *Section 8.2.3.i*) continuously ran. Only operational states with more than 100 total data points over the monitoring period were used to reduce variability from infrequently used operational states. Duration events for these operational states started at time zero, and continued at 15-minute intervals until the duration event was over (when MGS changed operational states). Individual duration events less than 90 minutes (6 data points) were omitted from analyses to reduce the influence of preceding generational states on the recorded TGP. The initial TGP value of any given operational state is heavily dependent on the operational state that preceded it. Therefore, TGP data were also transformed into relative TGP over time by subtracting the initial TGP value of the operational state's duration event from each value in that duration event. This occurred to standardize TGP trends within a duration event and reduce the variability of the initial TGP record. For each operational state, TGP and relative TGP by duration were graphed on a scatter plot with a line of fit, equation, and R^2 value. If the line of fit was positive then TGP increased over time in that generator state; whereas a negative line of fit indicated TGP decreased over time. This process was repeated using duration events which had > 110% at time 0, as a reduction of TGP from > 110% to < 110% is more biologically significant than a reduction of TGP from < 110% to > 100%.

iii) Data Sorting and Analyses to Assess Total Gas Pressure Extent and Residence Time

To address H_01_{c2} (the areal extent of a TGP plume downstream of MGS does not increase with the number of units and during of SC operations), the TGP data from one station at each distance (0.3 km, 3.5 km, and 10.5 – 11 km) were combined with the corresponding MGS operational data for a given date/time (with a 15 minute resolution). At 0.3 km, Station 0a was selected due to its orientation in the MGS tailrace; however, data from Station 0 were used in 2015 and 2020 due to data gaps at Station 0a. Station 2 data were used to represent TGP 3.5 kms from MGS in all years except 2015, when the membrane was damaged or a calibration error occurred resulting in suspect data; here Station 1 data were used. TGP in the Revelstoke Reservoir (10.5 – 11 km from MGS) was primarily represented by Station 3. However, battery failure occurred in 2016 at Stations 3 and 4, but at different times. To estimate the missing TGP data for each respective station, the average difference of TGP between Stations 3 and 4 was calculated. During this timeframe, TGP at Station 4 was found to be 1.78% higher (± 0.09% with 95% CI, n = 527) than Station 3, so 1.78% was subtracted from TGP at Station 4 to represent Station 3 TGP values. The TGP values at Station 3 and 4 were then averaged and used in 2016. In addition, Station 4 data were used in 2021 due to a battery failure at Station 3. MGS operational data were represented by a serial number, as described in *Section 8.2.3.i*. For analyses, TGP values were averaged hourly, and the primary operational state for that hour was identified (methods described in *Section 1.2.3.i*).

Hourly TGP values at each distance (0.3 km, 3.5 km, 10.5 km, and/or 11.0 km) were graphed by time (h) with the dominant MGS operational state for that hour; the specific station used in a given year was identified in the legend. TGP by time graphs were used to estimate TGP plume travel rates, residence time, dissipation rates, and distribution.

TGP Plume Travel Rate/Residence Time

TGP plume travel rate (m/h) and residence time (h) were determined by identifying the time (h) between TGP peaks of individual events at 0.3 km, 3.5 km, and 10.5 km. The travel rates (TR) between 0.3 km and 3.5 km, and 3.5 km and 10.5 km, were estimated by:

$$TR = \frac{\sum\left(\frac{T_{x^1-x^2}}{d_{x^1-x^2}}\right)}{n}$$

Where: $T_{x^1-x^2}$ = Time (h) between peaks at stations x^1 and x^2
$d_{x^1-x^2}$ = Distance (m) between stations x^1 and x^2
n = Sample size

To determine whether MGS discharge influenced TGP plume TR, the average discharge (D) per hour (cms/h) for an event was graphed with the corresponding event TR with a trend line and R^2 value. D was determined by:

$$D = \frac{t_{D^{x^1-x^2}}}{T_{x^1-x^2}}$$

Where: $t_D{}^{x1-x2}$ = Daily discharge (cms) during the time between peaks at stations x^1 and x^2
$T_{x^1-x^2}$ = Time (h) between peaks at stations x^1 and x^2

TGP Plume residence time (h) was determined by multiplying the TR by the length of the monitoring area (10,500 m).

TGP Plume Dissipation Rates

TGP plume dissipation rates were determined by adjusting the peaks of individual events identified at 0.3 km, 3.5 km, and 10.5 km to occur simultaneously on a graph. The adjusted time of record (AToR) for the peak TGP value of a given event were represented at “Time 0” and the TGP values ten hours before (AToR between -10 to -1) and after (AToR between 1 to 10) the peak were included for analyses. The dissipation (% of TGP reduction) between 0.3 km and 3.5 km, and 3.5 km and 10.5 km were determined by:

$$Dissipation = \frac{\sum(TGP_{x^{AToR_y}} - TGP_{x^{AToR_y}})}{n}$$

Where: TGP_x = TGP values (%) at distance x (km)
$AToR_y$ = Adjusted time of record (-10 to 10)
n = sample size

TGP dissipation rate (%/km) was then determined by:

$$Dissipation\ Rate = \frac{TGP_d{}^{x^1-x^2}}{d_{x^1-x^2}}$$

Where: $TGP_d{}^{x1-x2}$ = TGP dissipation (%) between stations x^1 and x^2
$d_{x^1-x^2}$ = Distance (m) between stations x^1 and x^2

Analyses were limited to ten hours before and after the peak TGP value for each event because the TGP trends between stations became more inconstant further from the peak. This is because changes in TGP were more drastic and abrupt at 0.3 km due MGS tailrace proximity; where TGP trends recorded at 3.5 km and 10.5 km were more even. In years where TGP peak events did not occur, the average TGP recorded at 0.3 km were compared to values recorded at 10.5 km.

TGP Plume Distribution

TGP plume distribution (plume extent) was determined by observing TGP values recorded 0.3 km, 3.5 km, and 10.5 km from MGS. Plumes resulting from high TGP events (>110%) were either depicted as a "peak"; where TGP values consistently increased to a maximum value followed by a consistent decrease of TGP values, or a plateau; where TGP values remained relatively consistent over time. TGP plume distribution for peak events were determined by:

$$Plume\ Distribution = T_{>110\%} \times TR$$

Where: $T_{>110\%}$ = Time (h) TGP was > 110% for a given peak event
TR = Travel Rate for that event (m/h)

TGP plume distribution for events that were concurrently detected 0.3 km and 3.5 km from MGS resulted in a minimum plume distribution of 3.5 km.

8.3 Results

TGP at the tailrace exceeded the 110% TGP threshold for 38% of the spring monitoring period (1,270 total hours). Observed TGP values over 115% and 120% TGP were less frequent (15% of dataset representing 498 total hours, and 4% of the dataset representing 134 total hours respectively). Exceedance of 110% TGP appeared to be less frequent in the fall: 1% of dataset representing approximately 5 total hours exceeded 110% TGP in the fall (September) of 2016 compared to 51% of dataset representing approximately 378 total hours exceeded 110% TGP in the spring (May; June) of the same year.

During the monitoring period, 27 elevated (≥ 110%) TGP events were observed 0.3 km from MGS. Events detected at 3.5 km and 10.5 km from MGS varied in frequency with 24 and 34 events respectively (Table 8-3). The duration of monitored elevated TGP events 0.3 km from MGS ranged from a few hours to 310 h (12.9 days; June 2020) and averaged 49 h (± 24 h with 95% CI). The average TGP for these events were between 110% and 121%, with the highest recorded TGP value of 131% (June 1 2015). Fewer events were recorded 3.5 km from MGS, but duration ranged from a few hours to 504 h (21 days; June 2020). The average TGP for these events ranged from 110% to 116%, with the highest recorded value of 123% (June 22 2021). The most occurrences of elevated TGP were detected 10.5 km from MGS (34 events). However, these events appeared to have a shorter duration (maximum duration 67 h and averaging 16 h ± 6 h with 95% CI) and average event TGP (110% to 113%; maximum observed value of 118% on July 1 2021) than those events observed closer to MGS.

Occurrences of consecutive hours with TGP concentrations between 120% and 130% were less frequent overall with 17 events averaging 11 h (± 4 h with 95% CI; longest duration = 31 h) at 0.3 km from MGS, and 5 events averaging 4 h (± 3 h with 95% CI; longest duration = 11 h) at 3.5 km from MGS. Multiple hours of 120 – 130% TGP were not observed 10.5 km from MGS (Table 8-4).

Table 8-2 provides an index of figures and tables associated with specific results and analyses. The following sections describe key findings and may not reference every figure or table in the Appendices.

Table 8-2. Summary results for analyses of TGP production by generator-specific SC operations, MGS operations, duration of SC operations, and TGP plume travel rates, residence time, dissipation rates, and distribution.

Result Topic	Figure/Table Description	Link	Summary of Result
TGP by Generator Sequence	TGP values by generator sequence during SC operations	Figure 8-3	G2+G5 was associated with the highest average recorded TGP. Generator Sequences including two generators tended be associated with higher TGP than single generators.
Duration by Generator Sequence	Duration of SC events for each generator sequence	Figure 8-4	G1+G5 had the highest median duration (9.5 h), most sequences had a median between 5 - 7 h.
Frequency of events ≥ 8 h by Generator Sequence	SC events ≥ 8-h duration for each generator sequence	Figure 8-5	Sequences with only one generator had more ≥ 8-h duration events than sequences with two generators. G3 and G4 had the most events (929 events and 932 events respectively).
Proportion of SxG0 events ≥ 8 h by Generator Sequence	Proportion of SxG0 events ≥ 8 h-duration for each generator sequence	Figure 8-5	G1+G5 had the highest proportion of SxG0 ≥ 8 h-duration (69%); the average proportion of SxG0 ≥ 8 h-duration for all generator sequences was 34%.
Discharge by Generator Sequence	MGS discharge during the operation of each generator sequence	Figure 8-6	Discharge was higher during SC sequences with only one generator.
TGP vs Discharge	Mean TGP by mean MGS discharge and mean TGP by hours of MGS discharge	Figure 8-7	Relationship between TGP and mean discharge was stronger ($R^2 = 0.58$), than TGP and hours of discharge ($R^2 = 0.01$). TGP appeared to decrease as mean discharge increased.
TGP by MGS Operational State (All)	TGP during various MGS Operational States	Figure 8-8	Operational States with SC appear to be associated with higher TGP and are more variable than operational states without SC
TGP by MGS Operational State (≥ 90 consecutive minutes of operation)	TGP during operational states that operated for ≥ 90 consecutive minutes	Figure 8-9	S2I4G0 was the only operational state with a median > 110%. All other operational states had a 75th percentile < 105%.
TGP by Time (2015)	TGP monitored over time with MGS operational operation	Figure 8-10	TGP was below 110% when MGS operated S0Gx and SxGx, but increased above 110% during large durations (> 8 h) of SxG0 interrupted by 1 h of SxGx.
TGP by Time (2016)	TGP monitored over time with MGS operational operation	Figure 8-11	TGP was above > 110% during long durations (> 8 h) of SxG0 interrupted by 1 h of SxGx, but was reduced below 110% when operations with generation (SxGx or S0Gx) were operated for > 1 h.
TGP by Time (2020)	TGP monitored over time with MGS operational operation	Figure 8-12	TGP was above > 110% during long durations (> 8 h) of SxG0 interrupted by 1 h of SxGx.
TGP by Time (2021)	TGP monitored over time with MGS operational operation	Figure 8-13	TGP was above > 110% during long durations (> 8 h) of SxG0 interrupted by 1 h of SxGx, but was reduced below 110% when operations with generation (SxGx or S0Gx) were operated for > 1 h.
TGP and Discharge by Time (2015 and 2016)	TGP and discharged over time with MGS operational operation.	Figure 8-14	TGP appears to be reduced when discharge is > 200 cms; S2I4G0 associated with high TGP.

Result Topic	Figure/Table Description	Link	Summary of Result
TGP and Discharge by Time (2020 and 2021)	TGP and discharged monitored over time with MGS operational operation	Figure 8-15	TGP appears to be reduced when discharge is > 200 cms, but requires > 1 h to reduce TGP below 110%; S2I4G0 associated with high TGP.
TGP by Duration of Operational States S0I1G5 and S0I2G4	TGP and relative TGP by time of duration	Figure 8-16	Operational States do not appear to increase or decrease TGP.
TGP by Duration of Operational States S0I3G3 and S0I4G2	TGP and relative TGP by time of duration	Figure 8-17	Operational States do not appear to increase or decrease TGP.
TGP by Duration of Operational States S1I3G2 and S1I4G1	TGP and relative TGP by time of duration	Figure 8-18	Both states may reduce TGP.
TGP by Duration of Operational States S1I5G0 and S2I3G1	TGP and relative TGP by time of duration	Figure 8-19	S1I5G0 does not appear to increase or decrease TGP while S2I3G1 appears to decrease TGP.
TGP by Duration of Operational State S2I4G0	TGP and relative TGP by time of duration	Figure 8-20	No identifiable trend.
TGP by Duration of events starting > 110% for Operational States S1I3G2 and S1I4G1	TGP and relative TGP by time of duration	Figure 8-21	Both states may reduce TGP.
TGP by Duration of events starting > 110% for Operational States S2I3G1 and S2I4G0	TGP and relative TGP by time of duration	Figure 8-22	S2I3G1 appeared to decrease TGP while there was no identifiable trend for S2I4G0.
Summary of Scatter Plot Data	Summary of trends, R^2, and equations for Operational State Durations	Table 8-5	Summary Table of results for Figure 8-16 to Figure 8-22.
TGP by Time at 0.3 km, 3.5 km, and 10.5 km in May 2015	TGP by time with MGS operational state and discharge	Figure 8-23	TGP Peak occurred on May 24 2015 at 0.3 km and was detected 31 h later at 3.5 km, and again at 10.5 km after an additional 25 h (or total of 56 h). A second TGP peak occurred on June 1 2015 at 0.3 km and was detected 6 h later at 3.5 km, and again at 10.5 km after 28 h.
TGP by Time at 0.3 km, 3.5 km, and 10.5 km in May 2016	TGP by time with MGS operational state and discharge	Figure 8-24	TGP Peak occurred on May 24 2016 at 0.3 km and was detected 72 h later at 3.5 km, and again at 10.5 km after another 110 h. A second TGP peak occurred on June 5 2016 at 0.3 km and was detected 24 h later at 3.5 km, and again at 10.5 km after 11 h.
TGP by Time at 0.3 km, 3.5 km, and 10.5 km in June 2020 and 2021	TGP by time with MGS operational state and discharge	Figure 8-25	Elevated TGP occurred between June 13 - 25 2020 at 0.3 km and was at consistent levels at 3.5 km, and slightly lower at 10.5 km. A TGP peak occurred on June 20 2021 at 0.3 km and was detected 55 h later at 3.5 km, and again at 10.5 km after 71 h.
Description of TGP plume travel timing and conditions	Average-daily discharge per hour, TGP plume travel time, distance between stations, and resulting travel rate for each peak TGP event	Table 8-6	Individual TGP plume travel rates varied between 26 m/h and 133 m/h between 0.3 km and 3.5 km, and 54 m/h and 636 m/h between 3.5 km and 10.5 km

Result Topic	Figure/Table Description	Link	Summary of Result
Description of TGP plume extent and timing	Dates when high TGP events were in the tailrace, and plume extent estimates	Table 8-7	Plume events associated with S2I4G0 were estimated to encompass 2.1 km - 8.5 km.
Travel Time by Average Discharge	TGP peak travel time by average daily discharge	Figure 8-26	Average-daily discharge per hour from MGS influences TGP plume travel rate. The more discharge from MGS the faster the travel rate (0.3 km - 3.5 km $R^2 = 0.99$ and 3.5 km - 10.5 km $R^2 = 0.90$)
TGP by Adjusted time of record for TGP peak events detected 0.3 km, 3.5 km, and 10.5 km - 11.0 km	TGP reduction by distance	Figure 8-27	TGP is typically lower at 10.5 – 11.0 km than 3.5 km, and 3.5 km is typically lower than 0.3 km for the same event. Graphs also show changes in TGP 0.3 km are more abrupt than those at 3.5 km.
Data used to calculate TGP reduction by distance	Peak event standardization	Table 8-8	Results provided in table.
Summary of TGP reduction by distance results	Average TGP reduction between distances	Table 8-9	On average, TGP was 4% lower 3.5 km from MGS than 0.3 km from MGS, and was 10% lower 10.5 km from MGS than 0.3 km from MGS.
Average TGP reduction by Distance	Average TGP reduction between distances	Figure 8-28	TGP is typically reduced by 4% between 0.3 km and 3.5 km, and 3.5 km and 10.5 km. TGP is reduced by 10 - 11% between 0.3 km and 11.0 km.

8.3.1 Total Gas Pressure by Units in Synchronous Condense Operation and Mica Generating Station Operational State

Fifteen generator sequences had more than 24 h of SC operation associated with recorded TGP data, with the combination of G3+G4 occurring the most (905 h). The combination of G2+G5 in SC was associated with the highest average recorded TGP, followed by the combination of G1+G5, G1+G2, and G4+G6; all other generator sequences had an average recorded TGP of 110% or less while in SC (Figure 8-3 in Appendix 1-4).

G1+G5 had the highest median duration (9.5 h); most generator sequences had a median duration of 5 – 7 h. The majority of duration data were distributed around 10 h; with G2+G3, G2+G4, G3+G4, and G5+G6 having a more variable duration distribution (Figure 8-4 in Appendix 1-4). G6 had the longest average duration (11 h ± 4.0 h with 95% CI, n = 158), while all other generator sequences averaged 5 – 8 h. The high average is likely due to two events in 2021, in which G6 was in SC for 174 h and 241 h respectively; this is supported by a low median (5.5 h) for G6 in the boxplot (Figure 8-4 in Appendix 1-4). G3 and G4 had the most SC events ≥ 8h-duration (929 and 932 events respectively), while G2+G4 and G5+G6 had the fewest (48 and 19 events respectively). G1+G5 had the highest proportion of SxG0 events ≥ 8 h-duration, when compared to the total number of SC events (69%; Figure 8-5 [top] in Appendix 1-4), while G2+G4 and G5+G6 had the lowest proportion (11 and 14% respectively; Figure 8-5 [bottom] in Appendix 1-4). Average discharge from MGS during different generator sequences in SC varied from 272 cms (± 26 cms with 95% CI; n = 143), to 8 cms (± 6.8 cms with 95% CI; n = 66; Figure 8-6 in Appendix 1-4).

The correlation between TGP and discharge amplitude was greater than the correlation between TGP and discharge duration, though both had a weak R^2 value ($R^2 = 0.58$ vs 0.01; Figure 8-7 in Appendix 1-4). TGP and discharge amplitude appeared to be negatively correlated. All generator sequences with an average TGP value > 110% were associated with an average discharge of < 25 cms.

Fifteen individual MGS operational states (totalling 3,791 h) were observed during the monitoring period. Of these fifteen, eight operational states (totalling 3,719 h) had more than 24 h of operation in association with recorded TGP data (Figure 8-8 in Appendix 1-4); generator state S2I4G0 was the most frequent (2,337 h; 62% of data). MGS operational states without SC tended to have lower average TGP than operational states with SxGx[2] and SxG0 (Figure 8-8 in Appendix 1-4). Average TGP for combined SxG0 states exceeded 110% TGP (111% ± 0.2% with 95% CI; n = 2,408), while the combined SxGx average TGP did not exceed 110% (106% ± 0.5% with 95% CI; n = 574). Monitored SxG0 events were typically S2I4G0 (97% of the time) followed by S1I5G0 (3% of the time), but average TGP of these states was similar.

8.3.2 Total Gas Pressure by Duration of Mica Generating Station Operational States

Over the monitoring period multiple high TGP events (> 110% TGP) were recorded. These TGP events typically occurred when SxG0 (primarily S2I4G0) operated in > 8-h durations, interrupted by an hour of SxGx. TGP tended to be reduced when SxG0 was interrupted by operational states with generation lasting longer than three hours.

Between May 11 – 22 2015, MGS was mainly S0Gx (79% of the time), with few occurrences of SxGx (17% of the time), and rarely had SxG0 (4% of the time); during this time TGP did not exceed 108% and averaged 102% (± 0.1% with 95% CI; n = 269; hour 0 to 268 – Figure 8-10 [top] in Appendix 1-5). However, between May 23 – 25 2015 TGP increased to 129% and averaged 118% (± 1.4% with 95% CI; n = 48); this coincided with the operation SxG0 (92% of the time) with brief interruptions of SxGx (6% of the time) or S0Gx (2% of the time). During this time S2I4G0 was operated in 10 – 12 h durations interrupted by one hour of S1I4G1 (hour 269 to 316 – Figure 8-10 [top] in Appendix 1-5). Contrary, between May 26 – 30 2015, TGP averaged 102% (± 0.3% with 95% CI; n = 96) when SxG0 occurred in 2 – 8-h durations (27% of operation during this timeframe) interrupted by > 14 h of operational states that included SxGx (34% of operation during this timeframe) or S0Gx (39% of operation during this timeframe; hour 0 to 95 - Figure 8-10 [bottom] in Appendix 1-5), but averaged 118% (± 2.1% with 95% CI; n = 57) after 11 – 35 h of SxG0 (S2I4G0 96% of the time) interrupted by an hour of SxGx (specifically S1I4G1; hour 96 to 152 – Figure 8-10 [bottom] in Appendix 1-5). This pattern is also consistent with data collected in 2016, 2020, and 2021 (Figure 8-11 to Figure 8-13 in Appendix 1-5).

The amount of water discharge resulting from a given operational state appeared to effect the efficacy of TGP reduction; where the higher the discharge the more TGP is reduced (Figure 8-14 and Figure 8-15 in Appendix 1-5). Data collected between May 13 – 27 2016 and June 3 – 16 2021 indicate > 3 h of SxGx and/or S0Gx reduce high levels of TGP to < 110% (hours 180 to 220 and 310 to 335 – Figure 8-11, and hours 100 to 115 and 255 to 300 – Figure 8-13 in Appendix 1-5). For instance, between June 18 – 21 2021 SxGx (specifically S1I4G1) occurred for one hour between 8 – 10 h of SxG0 (specifically S2I4G0); when S1I4G1 discharge was < 100 cms TGP was not reduced below 110%, however when S1I4G1 discharge was ~ 200 cms (with an additional hour of duration) TGP was reduced from 121% to 107% over three hours (see hour 300 – 380 in Figure 8-15 [bottom] in Appendix 1-5). In contrast, discharges during the 2020 monitoring period were frequently < 200 cms and TGP was rarely below 110% (Figure 8-15 [top] in Appendix 1-5).

The relationship between TGP production and duration of MGS operational states was not linear. Nine individual MGS operational states had more than 100 data points and duration events lasting 90 minutes or longer in association with recorded TGP values. S2I4G0 had the most duration events (n = 263). TGP tended to be reduced or remain consistent during the duration of most operational states; however, the

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[2] SxGx = Synchronous Condense with Generation; SxG0 = Synchronous Condense without Generation

correlation (R^2) for TGP and relative TGP was weak ($R^2 < 0.15$; Table 8-3 in Appendix 1-5). In general, S0I1G5, S0I2G4, S0I3G3, and S1I5G0 did not appear to change TGP over time, while S0I4G2, S1I3G2, S1I4G1, and S2I3G1 showed indications of TGP reduction over time when TGP values were elevated above 100% before (Figure 8-20 and Figure 8-22 in Appendix 1-5).

When only assessing duration events that began above 110%, the observable trend and correlation of TGP reduction during duration events of S1I3G2, S1I4G1, and S2I3G1 were stronger (R^2 = 0.68, 0.49, and 0.65 respectively); There was no trend between S2I4G0 and TGP with duration events beginning > 110% (Figure 8-21 and Figure 8-22 in Appendix 1-5). Although S2I4G0 duration events did not result in an identifiable trend of TGP over time, when events began at TGP levels > 110% they remained above 110% the majority of the time (95% of dataset); indicating S2I4G0 does not reduce TGP.

Operational state S2I4G0 likely increased TGP over time, but the relationship is not linear. When comparing TGP values monitored during durations (> 90 minutes) of specific generator states, the median recorded TGP for S2I4G0 was 112%, meaning more than half the data recorded during this operational states was potentially harmful to fish. In comparison, all other operational states had a 75th percentile < 105% TGP, meaning 75% of the TGP values recorded during those operational states were less than 105% and did not impact fish; operational states without SC operations had a 75th percentile < 103% TGP (Figure 8-9 in Appendix 1-4).

8.3.3 Total Gas Pressure Extent and Residence Time

Five elevated TGP events, which could be identified at all three distances (0.3 km, 3.5 km, and 10.5 km) from MGS, were detected during the monitoring period. These events were initially recorded at 0.3 km on May 24 2015 (2015a; Figure 8-23 in Appendix 1-6), June 1 2015 (2015b; Figure 8-23 in Appendix 1-6); May 24 2016 (2016a; Figure 8-24 in Appendix 1-6), June 5 2016 (2016b; Figure 8-24 in Appendix 1-6), and June 20 2021 (Figure 8-25 in Appendix 1-6). TGP data collected during the 2020 monitoring season (June 13 to June 25), when MGS was mostly operated in S2I4G0 state, were more uniform than 2015, 2016, and 2021 data, and were consistently above the provincial guideline of 110% TGP at 0.3 km (Figure 8-25 in Appendix 1-6). This resulted in the absence of peak TGP values and similar TGP levels at 0.3 km and 3.5 km.

The travel time of TGP peaks between 0.3 km and 3.5 km varied between 6 h and 125 h, while travel time of TGP peaks between 3.5 km and 10.5 km were between 11 h and 130 h (Table 8-4 in Appendix 1-6). Based on the distance between stations and average travel time, the average TGP plume travel rate for all five events was 168 m/h (± 183 m/h with 95% CI) between 0.3 km and 3.5 km, and was 264 m/h (± 201 m/h with 95% CI) between 3.5 km and 10.5 km. The TGP plume TR had a high power correlation with the average-daily discharge per hour from MGS (0.3 km to 3.5 km: R^2 = 0.99, and 3.5 km to 10.5 km: R^2 = 0.90; Figure 8-26 in Appendix 1-6), which would explain travel rate variability (the higher the average-daily discharge per hour from MGS, the faster the travel rate). Travel rate for 2020 data was not determined due to the absence of identifiable peaks at the different distances.

Based on the event duration measured at 0.3 km, and individual event travel rates, the TGP plume extent for each event was estimated as follows: 2015a = 4.2 km, 2016a = 4.4 km, 2016b = 8.5 km; and 2021 = 2.1 km (Table 8-5 in Appendix 1-6). The extent of 2015b was estimated to be 27.7 km (based on TR and time TGP was > 110% at 0.3 km), but the instance of sudden generation immediately after the peak TGP value likely accelerated the travel time, influencing the calculation. S2I4G0 was the primary operational state during all the high TGP events. The TGP plume distribution in 2020 was more constant between 0.3 km and 3.5 km, as TGP was consistently > 110% throughout the monitoring period at these locations, TGP was lower 10.5 km from MGS, but was frequently near 110%. S2I4G0 was the most common operational state during this timeframe.

On average, TGP decreased by 4% between 0.3 km and 3.5 km, and by 9% – 10% between 0.3 km and 10.5 – 11.0 km (Table 8-7 in Appendix 1-6). This resulted in an overall TGP reduction rate of 0.8 %/km – 1.0 %/km for identified cohesive plumes. In 2020, the average TGP 0.3 km and 3.5 km from MGS was similar (115% ± 0.4% with 95% CI vs 115% ± 0.2% with 95% CI respectively). However, TGP was 6% lower 10.5 km from MGS averaging levels of 109% (± 0.1% with 95% CI); resulting in an estimated reduction of 0.86 %/km for TGP plumes extending throughout the monitoring area.

8.4 Discussion

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

TGP appears to increase during operations of SxG0, specifically when SxG0 is operated in ≥ 8-h durations with intermittent 1-h durations of SxGx (Figure 8-10 to Figure 8-13 in Appendix 1-5). The number of generators in SxG0 does not appear to be a factor, but the available data is weighted to one operational state (S2I4G0 operated 97% of the time).

The generators involved in SxG0 does not appear to influence TGP. Operations of SxGx appear to decrease TGP when TGP is > 110% at the beginning of operation, therefore generation is a significant factor in TGP management (Figure 8-21 and Figure 8-22 in Appendix 1-6). Operations of SxGx and S0Gx appear to rapidly decrease TGP levels when operated for > 1 h and at discharges > 200 cms following elevated TGP (Figure 8-14 and Figure 8-15 in Appendix 1-5). The rate of TGP reduction is variable, and is likely dependent on discharge.

TGP typically travels in a plume. The size of the plume is dependent on the duration of SXG0, and frequency/discharge of generation. When SxG0 is operated in ≥ 8-h durations with intermittent 1-h durations of SxGx continually, the TGP plume extends to 10.5 km downstream of MGS. The rate of dissipation was determined to be 1%/km. The following sections provide a more in-depth discussion for each sub-null hypotheses.

8.4.1 Implications for Management Question 1a

Is there a difference in dissolved gas supersaturation depending on which of the six units at Mica Generation Station are operated in synchronous condense mode (can all units be treated the same in term of generating high TDG)?

$H_0 1_a$: There is no difference in TGP generation between units during SC operations.

$H_0 1_a$ is accepted under certain conditions. The current dataset does not show a difference in TGP production between units during SC operations, but the dataset was limited in the number of generator and generator combinations operating in SC during all combined monitoring periods. Not all possible combinations of units in SC were monitored, or data for those combinations were limiting. For instance, combinations of three generators operating in SC together were rare in the dataset (0.62% of dataset) but are shown to operate in 13% of SxG0 operations (Appendix 2). Therefore, the current dataset underrepresents S3G0 operations. Four generators operating in SC appeared to be rare (0.20 – 0.28% of SxG0 operations) and five – six generators operating concurrently in SC have not been observed (Appendix 2). Therefore, $H_0 1_a$ is accepted as long as TGP data collected while S3G0 operated was representative of the operation, and SC operations with four to six generators are uncommon.

Although the combination of G2+G5 appeared to coincide with higher recorded TGP values (average = 122%), it also had the lowest discharge and therefore had little dilution of water with high TGP while operating in SC (8.5 cms; Figure 8-3 and Figure 8-6 in Appendix 1-4). In addition, G2+G5 was the primary combination used in S2I4G0 operations in 2020, when TGP was rarely < 110% (Figure 8-15 in Appendix 1-5). During this timeframe, the high TGP was likely due to the infrequency and low duration of operational states including SxGx and S0Gx (as well as low discharge) rather than the specific generators in SC. The G2+G5 SC state dominated (71%) the dataset and likely skewed the results.

In general, generator combinations associated with higher TGP values (G2+G5, G1+G5, G1+G2, and G4+G6) corresponded to low discharge (averaged < 25 cms). TGP values tended to be lower when G2 and G5 where operated in SC mode independently, or with other combinations. The majority (25th to 75th percentile) of TGP values while G2 alone was in SC was between 101% and 103%, but when combined with G5 (G2+G5) the majority of values were between 120% and 125%. This indicates higher TGP is associated with two units in SC, rather than the specific units in SC.

All individual units in SC had median TGP values < 110% and were typically associated with higher discharge (compared to instances with two units in SC). Higher discharge reduced TGP quicker (Figure 8-7 in Appendix 1-4; cf. also TGP over time – Figure 8-14 and Figure 8-15 in Appendix 1-5). Durations of generator combinations appeared to be relatively similar, and data were typically distributed around 10 h. G1+G5 and G4+G6 had the highest median duration (10 h and 9 h respectively) which may have contributed to elevated TGP levels. Most other sequences had a median duration between 5 h and 7 h.

Generators G5 and G6 appeared to be associated with higher TGP values, as they had the highest medians and 75th percentiles out of all individual units despite relatively high levels of average discharge (Figure 8-3 and Figure 8-6 in Appendix 1-4), and G5 was included in the two generator combinations with the highest average TGP. However, G5 and G6 were frequently operated in SC for long durations in 2021 at the request of the monitoring crew to optimize data collection for other null hypotheses in a short timeframe. This operation regime was likely not representative of typical MGS operations and may have resulted in higher associated TGP values with G5 and G6 as a result of SC duration, not the units themselves. Another factor to consider is the baseline TGP level prior to a given generator operating in SC. TGP could have been > 110% prior to any given generator switching to SC operations. In this case, the high TGP would be attributed to that generator; as operations switch frequently, it is difficult to collect independent data. Therefore, factors such as discharge, duration and background TGP levels likely influence the data.

In summary, TGP under certain generator combinations is affected by discharge, duration, and the overall operational regime of MGS rather than the specific generator sequence. TGP recorded during generator sequences was dependent on the overall operation of MGS (how often generation was occurring between SC events, and the amount of discharge).

To obtain independent data on how individual generating units influence TGP, monitoring should occur in each respective units' draft tube. However, based on the current dataset, there is no biological difference in TGP generation between units during SC operations.

8.4.2 Implications for Management Question 1b

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

H_01_b: *Downstream TGP (% Saturation) does not increase incrementally as the number of units operating in synchronous condense mode increases from 1 to 6.*

H_01_b is accepted under certain conditions. Downstream TGP did not increase incrementally as the number of units operating in SC mode increased from one to two. H_01_b eludes to the operation of up to six units operating in SC concurrently. However, the most generators operating in SC simultaneously during the TGP monitoring period was three, and this occurrence was rare (0.62% of dataset). Because of this rarity, operational states with three units in SC were omitted from analyses. S3G0 was operated in 13% of SxG0 operations, therefore the current dataset underrepresents S3G0 operations. S4G0 occurred less frequently (0.20 – 0.28% of SxG0 operations) and S5G0/S6G0 were not observed between 2010 – 2021; though S6G0 was only possible since 2021 (Appendix 2). Conclusions for H_01_b are based on the assumption that SC operations under normal operating conditions primarily involve one or two generators in SC, as indicated by Appendix 2 (87% of SxG0 operations).

TGP values were found to be higher during MGS operational states that included SC operations than during those without SC operations (Figure 8-6 in Appendix 1-4), but downstream TGP did not increase incrementally as the number of units operating in SC mode increased from one to two. The average TGP recorded while two generators were operating in SxG0 was the same as one generator operating in SxG0 (111%); both averages were above the BC Water Quality Guidelines (110%). When comparing all operational states with two units in SC vs one unit in SC, the operational states with two units in SC were associated with higher TGP levels (average 111% with two units and 107% with one unit). However, operational states with two units in operation occurred without generation 97% of the time compared to 12% of the time when one unit was in SC. Therefore, the lower TGP values associated with one unit in SC are likely attributed to more frequent generation, rather than the number on units.

TGP magnitude, areal extent, and duration of exposure appeared to be influenced by discharge. TGP magnitude (or intensity) during high TGP events (> 110%) tended to be reduced to below 110% when discharge occurred; particularly when discharge was ≥ 200 cms (Figure 8-14 and Figure 8-15 in Appendix 1-5). Areal TGP extent also varied by discharge, where short but frequent low-flow discharge events (1 h discharge of 100 – 200 cms for every 12 h of SxG0) reduced TGP peaks > 120% but increased the areal extent of the TGP plume (Figure 8-15 [top] and Figure 8-25 [top] in Appendix 1-5 and 1-6 respectively). The duration of exposure for any TGP plume was correlated with discharge (Figure 8-26 in Appendix 1-6); where higher discharge the lower the duration of exposure to high TGP values.

In summary, operational states involving SxG0 resulted in higher levels of TGP than operational states with SxGx or S0Gx; but TGP was similar between operational states with one or two units in SC. TGP magnitude was influenced by discharge, where discharge > 200 cms reduced TGP values > 120% to below 110%, and frequent (12-h interval) discharge < 200 cms reduced the instance of > 120% TGP. TGP plumes were present from the MGS tailrace throughout the riverine section from blue bridge to Mica camp, and were detectable 10.5 km in Revelstoke Reservoir but tend to be reduced. Increased discharge from MGS over longer periods of time reduced the time of exposure to high TGP values and increase the travel rate of the TGP plume. Plume dissipation rates are addressed in *Section 8.4.3*.

8.4.3 Implications for Management Question 1c

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

H_01_{c1}: *Downstream TGP (% Saturation) does not increase over time as the duration of S/C operations increases.*

H_01_{c2}: *The areal extent of a TGP plume downstream of Mica Dam does not increase with the number of units and during S/C operations.*

H_01_{c1} is rejected under certain conditions. Downstream TGP increases over long periods (≥ 8 h) of SxG0 operations and remains high (> 110%) when only interrupted by short (1 h) occurrences of generation (< 200 cms). However, TGP does not increase during SxGx operations.

Operation of S2I4G0 was associated with increased TGP (S2I4G0; Figure 8-10 to Figure 8-13 in Appendix 1-5); however this increase does not appear to be linear (Figure 8-20 in Appendix 1-6). TGP increased when S2I4G0 is operated in ≥ 8-h durations interrupted by one hour of SxGx operations with discharge < 200 cms. TGP increased rapidly and then stabilized ~ 120%. Because MGS operations alternated between S2I4G0 and SxGx, the data associated with S2I4G0 is highly variable, particularly when SxGx operations were < 2 h or with discharge < 200 cms. When assessing S2I4G0 duration events with the initial TGP record > 110%, TGP was rarely (5% of the time) reduced to below 110%, indicating elevated TGP is related to the S2I4G0 operation.

The variability of the data made it difficult to understand how and why TGP increased at different rates for the same operational state. The proximity of tailrace monitoring stations may explain data variability. Station 0a was positioned approximately 0.3 km from the outflow. The assumption was: this station would detect changes in TGP resulting from MGS operations within 15 minutes. However, there were instances in the data when short-term, abrupt spikes in TGP occurred when MGS increased the number of units in generation (Figure 8-29 in Appendix 1-6). This may indicate the previous operational state increased TGP between the MGS outflow and Station 0a, and the TGP plume only reached the station when generation increased; in-turn the higher TGP values would be attributed to the wrong operational state. Without data from the immediate outflow of MGS, or the draft tubes themselves, it is difficult to adjust the current dataset.

H_01_{c2} is accepted in part. The areal extent of a TGP plume was not determined by the number of units in SC, but was created during SxG0 operations. The TGP plume had the largest areal extent when SxG0 operations were interrupted by only 1 h of SxGx with discharge < 200 cms.

The creation and areal extent of the TGP plume appeared to be related to the duration of SxG0 operations, and appeared to be influenced by discharge. All high TGP events were associated with S2I4G0, but the higher the discharge the smaller the plume (in frequency and magnitude). TGP plumes created by SxG0 operations were lower magnitude and fully dissipated by 3.5 km or 10.5 km depending on discharge. SxGx operations tended to reduce TGP values over time, indicating it was not the number of units in SC, but the amount of discharge that reduced TGPS (Figure 8-21 and Figure 8-22 in Appendix 1-6).

Under most conditions, TGPS appeared to move through the system as a cohesive plume but with decreasing TGP saturation as the distance from MGS increased. This is supported by time series data 0.3 km, 3.5 km, and 10.5 km from MGS which depicts a decrease of TGP levels as the plume travels past the monitoring station (Figure 8-23 to Figure 8-25 in Appendix 1-6). Under some conditions (≥ 8-h duration of SxG0 with intermittent 1-h duration of SxGx < 200 cms discharge) the TGP plume can extend from 0.3 km to 10.5 km into Revelstoke Reservoir, though TGPS levels became lower with distance from MGS. The rate of dissipation was determined to be 0.8 %/km - 1.0 %/km for large cohesive plumes, and 0.9 %/km (between 3.5 km and 10.5 km) when the TGP plume extended throughout the monitoring area; therefore, the TGP dissipation rate is around 1 %/km.

In summary, SxG0 (specifically S2I4G0) increases TGP to levels exceeding the BC Water Quality Guidelines (110%) when operating ≥ 8 h even with intermittent 1-h operations of SxGx. SxGx and S0Gx decrease TGP over time when baseline values were > 110% at the beginning of the operation. The rate of TGP reduction was dependant on discharge. TGPS travelled through the environment in a cohesive plume, the size of the plume and rate of travel depended on the frequency and amount of generation. TGPS typically dissipates at a rate of 1 %/km.

8.5 References

Pentair (Pentair Aquatic Eco-Systems Inc.). 2016. Point Four Tracker Portable TGP Meter. Manual. Pentair Aquatic Eco-Systems, Inc. Apopka, FL. 46 p.

8.6 Appendix 1-1 Pentair Point Four (PT4) Tracker Total Gas Pressure Meter Specifications

Specifications

Measured	**Measurement Range**	**Resolution**
Total Gas Pressure [TGP]	0 - 1550 mmHg	1 mmHg
Barometric Pressure [BP]	0 - 1550 mmHg	1 mmHg
Temperature	0.0°C - 40°C	0.2°C

Derived		
Total Gas Pressure [TGP]	0 - 200%	1%
ΔP [TGP - BP]	1550 - 1550 mmHg	1 mmHg

Probe Dimensions	**Length**	**Width**	**Height**	**Diameter**
Probe	19 cm (7.4 in)	-		4.2 cm (1.6 in)
Handheld	16 cm (5.1 in)	8.5 cm (3.3 in)	3.2 cm (1.3 in)	-

Storage	
Temperature	-10°C to +60°C, in factory container
Relative Humidity	5% to 85% RH at up to +40 5% to 40% RH above +40 up to 60
Altitude	up to 3,000 meters (10,000 feet)

Operation	
Temperature	0°C - 50°C
Relative Humidity	5% to 85% RH at up to +40 5% to 40% RH above +40 up to 60
Altitude	up to 3,000 meters (10,000 feet)

Properties	
Response Time	Typical: 5 minutes (90%) Response time is improved by insuring there is water flow past the probe. However, this is a passive measurement and therefore can require up to an hour for an accurate measurements.
Power	4xAA NiMH rechargeable batteries/ 20 mA (blacklight off), 30 mA (blacklight on). Includes battery charger and adapter.
Battery Life	NiMH cells: 70 hours (blacklight off) 45 hours (blacklight on)
Connector (Left Side Connector) (Right Side Connector)	 6 pin -IP68 rated connector (for probe and data transfer cable) 4 pin -IP68 rated connector (for charger cable)
Probe Cable	Std. 5 m (16.4 ft) four conductor, polyurethane jacketed, with custom lengths available on request.
Charger Cable	Std. 1.5 m (5 ft)
A/C Charger Adaptor	100-240 VAC / 47-63Hz / 12 VDC, 0.85 Amp

More Information Available at: https://pentairaes.com/media/docs/Point-Four-Tracker-PortableTGP-Meter-Manual.pdf

8.7 Appendix 1-2 Total Gas Pressure Monitoring Schedule and Activities

Station	**Unit**	**Date**	**Activity**	**TGP at Download**	**Battery Voltage**		**Calibration**		**Download**	**New Cart.**	**Weather**
					Old	**New**	**Baro. Press.**	**Temp.**			
1	406	4/9/2015	Station Setup	N/A*	N/A	6.40	Yes	Yes	No	Yes	Sunny
1	403	4/9/2015	Station Setup	N/A	N/A	6.36	Yes	Yes	No	Yes	Sunny
2	404	4/8/2015	Station Setup	N/A	N/A	6.36	Yes	Yes	No	Yes	Sunny
2	405	4/8/2015	Station Setup	N/A	N/A	6.36	Yes	Yes	No	Yes	Sunny
3	401	4/9/2015	Station Setup	N/A	N/A	6.42	Yes	Yes	No	Yes	Sunny
4	402	4/9/2015	Station Setup	N/A	N/A	6.40	Yes	Yes	No	Yes	Sunny
1	403	4/24/2015	Download/Maintenance	103	5.88	6.36	Yes	Yes	Yes	Yes	Sunny
1	406	4/24/2015	Download/Maintenance	103	5.85	6.34	Yes	Yes	Yes	Yes	Sunny
2	405	4/24/2015	Download/Maintenance	100	5.82	6.40	Yes	Yes	Yes	Yes	Sunny
2	404	4/24/2015	Download/Maintenance	98	5.85	6.40	Yes	Yes	Yes	Yes	Sunny
3	401	4/24/2015	Download/Maintenance	101	5.85	6.38	Yes	Yes	Yes	Yes	Sunny
4	402	4/24/2015	Download/Maintenance	100	5.85	6.42	Yes	Yes	Yes	Yes	Sunny
0	403	5/11/2015	Station Setup	N/A	N/A	6.38	Yes	Yes	No	Yes	Sunny
1	403	5/11/2015	Download/Removal	106	5.86	6.39	Yes	Yes	Yes	Yes	Sunny
1	406	5/11/2015	Download/Maintenance	107	5.85	6.37	Yes	Yes	Yes	Yes	Sunny
2	404	5/11/2015	Download/Maintenance	103	5.85	6.40	Yes	Yes	Yes	Yes	Sunny
2	405	5/11/2015	Download/Maintenance	121	5.84	6.38	Yes	Yes	Yes	Yes	Sunny
3	401	5/11/2015	Download/Maintenance	103	5.86	6.39	Yes	Yes	Yes	Yes	Sunny
4	402	5/11/2015	Download/Maintenance	103	5.86	6.38	Yes	Yes	Yes	Yes	Sunny
0	403	5/25/2015	Download/Maintenance	122	5.92	6.42	Yes	Yes	Yes	Yes	Sunny
1	406	5/25/2015	Download/Maintenance	115	5.92	6.28	Yes	Yes	Yes	Yes	Sunny
2	404	5/25/2015	Download/Maintenance	114	5.94	6.37	Yes	Yes	Yes	Yes	Sunny
2	405	5/25/2015	Download/Maintenance	109	5.90	6.38	Yes	Yes	Yes	Yes	Sunny
3	401	5/25/2015	Download/Maintenance	109	5.90	6.34	Yes	Yes	Yes	Yes	Sunny
4	402	5/25/2015	Download/Maintenance	108	5.90	6.21	Yes	Yes	Yes	Yes	Sunny
0	403	6/15/2015	Download/Removal	102	5.60	N/A	No	No	Yes	No	Sunny
1	406	6/15/2015	Download/Removal	106	0.00	N/A	No	No	Yes	No	Sunny
2	404	6/15/2015	Download/Removal	116	5.68	N/A	No	No	Yes	No	Sunny
2	405	6/15/2015	Download/Removal	98	5.56	N/A	No	No	Yes	No	Sunny

Station	Unit	Date	Activity	TGP at Download	Battery Voltage		Calibration		Download	New Cart.	Weather
					Old	New	Baro. Press.	Temp.			
3	401	6/15/2015	Download/Removal	106	0.00	N/A	No	No	Yes	No	Sunny
4	402	6/15/2015	Download/Removal	106	5.42	N/A	No	No	Yes	No	Sunny
0	401	5/12/2016	Station Setup	N/A	N/A	6.29	Yes	Yes	No	Yes	Overcast/Windy
1	403	5/12/2016	Station Setup	N/A	N/A	6.31	Yes	Yes	No	Yes	Overcast/Windy
2	404	5/12/2016	Station Setup	N/A	N/A	6.32	Yes	Yes	No	Yes	Overcast/Windy
3	405	5/12/2016	Station Setup	N/A	N/A	6.35	Yes	Yes	No	Yes	Overcast/Windy
4	406	5/12/2016	Station Setup	N/A	N/A	6.32	Yes	Yes	No	Yes	Overcast/Windy
Nagle Creek	407	5/12/2016	Spot Check	105	N/A	6.42	Yes	Yes	Yes	Yes	Overcast/Windy
Forebay	402	5/12/2016	Spot Check	107	N/A	6.27	Yes	Yes	Yes	Yes	Overcast/Windy
0	401	5/13/2016	Test Download	105	6.2	N/A	No	No	Yes	No	Partly Cloudy
0a	402	5/13/2016	Station Setup	N/A	N/A	6.25	No	No	No	No	Partly Cloudy
1	403	5/13/2016	Test Download	114	6.24	N/A	No	No	Yes	No	Partly Cloudy
2	404	5/13/2016	Test Download	106	6.29	N/A	No	No	Yes	No	Partly Cloudy
3	405	5/13/2016	Test Download	104	6.27	N/A	No	No	Yes	No	Partly Cloudy
4	406	5/13/2016	Test Download	105	6.24	N/A	No	No	Yes	No	Partly Cloudy
0	401	6/13/2016	Download/Removal	108	5.65	N/A	No	No	Yes	No	Overcast
0a	402	6/13/2016	Download/Removal	109	5.68	N/A	No	No	Yes	No	Overcast
1	403	6/13/2016	Download/Removal	107	5.7	N/A	No	No	Yes	No	Overcast
2	404	6/13/2016	Download/Removal	107	5.65	N/A	No	No	Yes	No	Overcast
3	405	6/13/2016	Download/Removal	102	5.53	N/A	No	No	Yes	No	Overcast
4	406	6/13/2016	Download/Removal	106	5.68	N/A	No	No	Yes	No	Overcast
Nagle Creek	407	6/13/2016	Spot Check	111	N/A	N/A	No	No	Yes	No	Overcast
Forebay	407	6/13/2016	Spot Check	108	N/A	N/A	No	No	Yes	No	Overcast
0	402	9/6/2016	Station Setup	N/A	N/A	6.73	Yes	Yes	No	Yes	Overcast
0a	401	9/6/2016	Station Setup	N/A	N/A	6.69	Yes	Yes	No	Yes	Overcast
1	403	9/6/2016	Station Setup	N/A	N/A	6.96	Yes	Yes	No	Yes	Overcast
2	404	9/6/2016	Station Setup	N/A	N/A	6.64	Yes	Yes	No	Yes	Overcast
3	405	9/6/2016	Station Setup	N/A	N/A	6.48	Yes	Yes	No	Yes	Overcast
4	407	9/6/2016	Station Setup	N/A	N/A	6.57	Yes	Yes	No	Yes	Overcast

Station	Unit	Date	Activity	TGP at Download	Battery Voltage		Calibration		Download	New Cart.	Weather
					Old	New	Baro. Press.	Temp.			
Nagle Creek	401	9/6/2016	Spot Check	103	N/A	N/A	Yes	Yes	Yes	Yes	Overcast
Forebay	401	9/6/2016	Spot Check	104	N/A	N/A	No	No	Yes	No	Overcast
0	402	9/25/2016	Download/Removal	100	5.64	N/A	No	No	Yes	No	Overcast
0a	401	9/23/2016	Download/Removal	101	5.10	N/A	No	No	Yes	No	Overcast
1	403	9/23/2016	Download/Removal	117	N/R	N/A	No	No	Yes	No	Overcast
2	404	9/25/2016	Download/Removal	100	5.83	N/A	No	No	Yes	No	Overcast
3	405	9/25/2016	Download/Removal	100	5.96	N/A	No	No	Yes	No	Overcast
4	407	9/25/2016	Download/Removal	100	6.00	N/A	No	No	Yes	No	Overcast
Nagle Creek	401	9/25/2016	Download/Removal	105	N/A	N/A	Yes	Yes	Yes	Yes	Overcast
Forebay	401	9/25/2016	Download/Removal	111	N/A	N/A	No	No	Yes	No	Overcast
0	401	5/9/2017	Station Setup	N/A	N/A	6.25	Yes	Yes	No	Yes	Overcast
0a	402	5/9/2017	Station Setup	N/A	N/A	6.62	Yes	Yes	No	Yes	Overcast
1	403	5/8/2017	Station Setup	N/A	N/A	6.27	Yes	Yes	No	Yes	Overcast
2	404	5/8/2017	Station Setup	N/A	N/A	7.26	Yes	Yes	No	Yes	Overcast
3	405	5/8/2017	Station Setup	N/A	N/A	6.66	Yes	Yes	No	Yes	Overcast
4	406	5/8/2017	Station Setup	N/A	N/A	6.91	Yes	Yes	No	Yes	Overcast
Nagle Creek	407	5/9/2017	Spot Check	105	N/A	N/A	Yes	Yes	Yes	Yes	Overcast
Forebay	407	5/9/2017	Spot Check	103	N/A	N/A	No	No	Yes	No	Overcast
0	401	5/25/2017	Download/Maintenance	104	6.43	7.46	Yes	Yes	Yes	Yes	Partly Cloudy
0a	402	5/25/2017	Download/Maintenance	102	6.29	7.47	Yes	Yes	Yes	Yes	Partly Cloudy
1	403	5/25/2017	Download/Maintenance	106	6.13	7.18	Yes	Yes	Yes	Yes	Partly Cloudy
2	404	5/25/2017	Download/Maintenance	103	6.42	7.15	Yes	Yes	Yes	Yes	Partly Cloudy
3	405	5/25/2017	Download/Maintenance	104	Dead	N/R**	Yes	Yes	Yes	Yes	Partly Cloudy
4	406	5/25/2017	Download/Maintenance	105	N/R	N/R	Yes	Yes	Yes	Yes	Partly Cloudy
Nagle Creek	407	5/25/2017	Spot Check	107	N/A	N/A	Yes	Yes	Yes	No	Partly Cloudy
Forebay	407	5/25/2017	Spot Check	104	N/A	N/A	No	No	Yes	No	Partly Cloudy
0	401	6/13/2017	Download/Removal	121	N/A	N/A	No	No	Yes	No	
0a	402	6/13/2017	Download/Removal	111	N/A	N/A	No	No	Yes	No	
1	403	6/13/2017	Download/Removal	115	N/A	N/A	No	No	Yes	No	

Station	Unit	Date	Activity	TGP at Download	Battery Voltage		Calibration		Download	New Cart.	Weather
					Old	**New**	**Baro. Press.**	**Temp.**			
2	404	6/13/2017	Download/Removal	114	N/A	N/A	No	No	Yes	No	
3	405	6/13/2017	Download/Removal	109	N/A	N/A	No	No	Yes	No	
4	406	6/13/2017	Download/Removal	105	N/A	N/A	No	No	Yes	No	
Nagle Creek	407	6/13/2017	Spot Check	106	N/A	N/A	Yes	Yes	Yes	No	
Forebay	407	6/13/2017	Spot Check	106	N/A	N/A	No	No	Yes	No	
0	401	6/9/2020	Station Setup/Test Download	111	N/A	6.56	Yes	Yes	Yes	Yes	Windy
0a	404	6/9/2020	Station Setup/Test Download	106	N/A	6.60	Yes	Yes	Yes	Yes	Windy
1	403	6/8/2020	Station Setup/Test Download	112	N/A	6.59	Yes	Yes	Yes	Yes	Windy
2	407	6/8/2020	Station Setup/Test Download	114	N/A	6.61	Yes	Yes	Yes	Yes	Windy
3	406	6/8/2020	Station Setup/Test Download	116	N/A	6.58	Yes	Yes	Yes	Yes	Windy
4	405	6/8/2020	Station Setup/Test Download	112	N/A	6.60	Yes	Yes	Yes	Yes	Windy
Nagle Creek	401	6/9/2020	Spot Check	108	N/A	N/A	Yes	Yes	Yes	Yes	Windy
Forebay	401	6/9/2020	Spot Check	107	N/A	N/A	Yes	Yes	Yes	Yes	Windy
0	401	7/11/2020	Download/Removal	117	3.58	N/A	No	No	Yes	No	Partly Cloudy
0a	404	7/11/2020	Download/Removal	114	3.44	N/A	No	No	Yes	No	Partly Cloudy
1	403	7/11/2020	Download/Removal	111	3.87	N/A	No	No	Yes	No	Partly Cloudy
2	407	7/11/2020	Download/Removal	112	3.34	N/A	No	No	Yes	No	Partly Cloudy
3	406	7/11/2020	Download/Removal	110	4.82	N/A	No	No	Yes	No	Partly Cloudy
4	405	7/11/2020	Download/Removal	111	3.34	N/A	No	No	Yes	No	Partly Cloudy
0	404	6/2/2021	Station Setup/Test Download	110	N/A	6.64	Yes	Yes	Yes	Yes	Sunny
0a	405	6/3/2021	Station Setup	N/A	N/A	6.48	Yes	Yes	No	No	Sunny
1	402	6/2/2021	Station Setup/Test Download	107	N/A	6.59	Yes	Yes	Yes	Yes	Sunny
2	401	6/2/2021	Station Setup/Test Download	108	N/A	6.61	Yes	Yes	Yes	Yes	Sunny
2	405	6/2/2021	Test Download	106	N/A	6.48	Yes	Yes	Yes	Yes	Sunny
3	407	6/2/2021	Station Setup/Test Download	107	N/A	6.27	Yes	Yes	Yes	Yes	Sunny
4	406	6/2/2021	Station Setup/Test Download	101	N/A	6.59	Yes	Yes	Yes	Yes	Sunny
Nagle Creek	809	6/2/2021	Spot Check	99	N/A	N/A	Yes	Yes	Yes	Yes	Sunny
Forebay	809	6/2/2021	Spot Check	99	N/A	N/A	No	No	Yes	No	Sunny
0	404	6/22/2021	Download/Maintenance	115	5.9	6.28	Yes	Yes	Yes	Yes	Sunny

Station	Unit	Date	Activity	TGP at Download	Battery Voltage		Calibration		Download	New Cart.	Weather
					Old	New	Baro. Press.	Temp.			
0a	405	6/22/2021	Download/Maintenance	116	5.58	6.48	Yes	Yes	Yes	Yes	Sunny
1	402	6/22/2021	Download/Maintenance	120	5.82	6.42	Yes	Yes	Yes	Yes	Sunny
2	401	6/22/2021	Download/Maintenance	120	5.78	6.29	Yes	Yes	Yes	Yes	Sunny
3	407	6/22/2021	Download/Maintenance	114	4.31	5.91	Yes	Yes	Yes	Yes	Sunny
4	406	6/22/2021	Download/Maintenance	111	5.77	6.26	Yes	Yes	Yes	Yes	Sunny
0	404	7/9/2021	Download/Removal	100	5.63	N/A	No	No	Yes	No	Sunny
0a	405	7/9/2021	Download/Removal	104	5.84	N/A	No	No	Yes	No	Sunny
1	402	7/9/2021	Download/Removal	109	6.19	N/A	No	No	Yes	No	Sunny
2	401	7/9/2021	Download/Removal	108	5.61	N/A	No	No	Yes	No	Sunny
3	407	7/9/2021	Download/Removal	N/R	3.91	N/A	No	No	Yes	No	Sunny
4	406	7/9/2021	Download/Removal	110	5.51	N/A	No	No	Yes	No	Sunny

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

8.8 Appendix 1-3 Tables for Observed Elevated Total Gas Pressure Events

Table 8-3. Elevated total gas pressure (TGP) events (> 110%) observed 0.3 km, 3.5, and 10.5 km from Mica Generating Station; including the duration (hours), average TGP of the events, error (Err) of the average with 95% confidence, and the peak TGP value of the event.

Event	Year	Timeframe	# Hours	Average TGP (%)	Err (%)	Peak
Recorded 0.3 km from Mica Generating Station						
1	2015	May 23, 05:00 - May 25, 04:00	48	118	1.3	129
2		May 25, 08:00 - May 25, 21:00	14	116	1.9	121
3		May 25, 09:00 - May 25, 21:01	52	121	1.2	131
4		May 25, 09:00 - May 25, 21:02	33	120	1.8	126
5	2016	May 22, 09:00 - May 26, 13:00	101	117	0.6	125
6		May 27, 00:00 - May 30, 20:00	93	114	0.2	115
7		June 2, 00:00 - June 2, 20:00	21	113	0.5	117
8		June 3, 11:00 - June 6, 04:00	66	118	0.6	125
9	2017	May 27, 14:00 - May 27, 18:00	5	112	1.1	113
10		May 28, 09:00 - May 28, 14:00	6	112	1.2	114
*11	2020	June 9, 10:00 - June 10, 20:00	32	112	0.5	115
12		June 11, 01:00 - June 11, 15:00	15	110	0.1	110
13		June 12, 01:00 - June 12, 09:00	9	110	0.2	110
14		June 12, 15:00 - June 12, 20:00	6	110	0.4	111
15		June 12, 23:00 - June 25, 20:00	310	115	0.2	119
*16		June 26, 04:00 - June 30, 07:00	100	120	0.9	127
*17	2021	June 6, 00:00 - June 7, 06:00	31	112	0.5	114
18		June 7, 10:00 - June 7, 15:00	6	110	0.5	111
19		June 8, 11:00 - June 14, 12:00	146	115	0.4	122
20		June 16, 09:00 - June 17, 18:00	34	115	0.8	120
21		June 18, 08:00 - June 21, 18:00	83	117	0.7	127
22		June 22, 08:00 - June 22, 18:00	11	112	1.3	116
23		June 29, 06:00 - June 29, 15:00	10	115	1.6	121
24		June 30, 10:00 - June 30, 16:00	7	116	1.9	118
25		July 1, 06:00 - July 2, 10:00	29	116	1.2	123
26		July 2, 21:00 - July 4, 18:00	45	117	1.0	127
27		July 5, 09:00 - July 5, 19:00	11	112	1.8	120
Recorded 3.5 km from Mica Generating Station						
1	2015	June 24, 13:00 - June 26, 08:00	44	113	0.5	118
2		May 30, 07:00 - June 1, 20:00	62	113	0.5	120
3		June 2, 04:00 - June 3, 13:00	34	111	0.4	114
4	2016	May 23, 13:00 - May 24, 02:00	15	111	0.4	112
5		May 24, 13:00 - May 30, 22:00	154	112	0.3	120
6		June 3, 05:00 - June 6, 13:00	82	113	0.5	120
7		June 7, 05:00 - June 7, 13:00	9	111	0.7	112
8		June 8, 07:00 - June 8, 14:00	8	112	0.8	113
9		June 9, 15:00 - June 9, 22:00	8	110	0.2	111
10		June 10, 07:00 - June 11, 00:00	18	110	0.1	111
11	2017	May 27, 15:00 - May 27, 19:00	5	111	0.8	112
12		May 28, 11:00 - May 28, 15:00	5	110	0.3	110
13		May 29, 08:00 - May 28, 12:00	5	111	0.7	112
14		May 30, 06:00 - May 30, 11:00	6	112	0.9	113
**15	2020	June 9, 10:00 - June 30, 9:00	504	115	0.2	120
*16	2021	June 6, 0:00 - June 7, 21:00	46	114	0.2	115
17		June 10, 08:00 - June 14, 17:00	106	113	0.2	117
18		June 15, 20:00 - June 23, 15:00	188	115	0.4	123
19		June 23, 20:00 - June 25, 18:00	47	113	0.5	116
20		June 26, 04:00 - June 26, 11:00	8	112	0.8	114
21		June 27, 04:00 - June 27, 16:00	13	113	0.8	115
22		June 28, 01:00 - June 28, 10:00	10	114	1.3	116
23		June 28, 17:00 - June 29, 17:00	19	114	1.1	118
24		June 29, 23:00 - July 5, 20:00	142	116	0.4	119
Recorded 10.5 km from Mica Generating Station						
1	2015	June 26, 13:00 - June 26, 19:00	7	111	1.1	114
2		June 2, 10:00 - June 3, 18:00	33	111	0.3	113
3	2016	May 24, 10:00 - May 26, 01:00	40	110	0.1	111
4		May 27, 15:00 - May 27, 18:00	4	112	2.0	114
5		June 1, 15:00 - June 1, 20:00	5	110	0.1	110
6		June 5, 15:00 - June 5, 23:00	9	110	0.1	110
7		June 6, 11:00 - June 7, 12:00	27	112	0.4	114
8	2017	May 28, 13:00 - May 28, 15:00	3	111	0.7	111
9		May 28, 18:00 - May 28, 20:00	3	110	0.4	110
*10	2020	June 9, 10:00 - June 9, 16:00	7	110	0.2	110

Event	Year	Timeframe	# Hours	Average TGP (%)	Err (%)	Peak
11		June 11, 12:00 - June 11, 23:00	12	110	0.3	110
12		June 12, 08:00 - June 12, 23:00	16	110	0.2	111
13		June 13, 02:00 - June 13, 10:00	9	110	0.2	110
14		June 13, 16:00 - June 13, 22:00	7	110	0.2	110
15		June 18, 14:00 - June 18, 22:00	9	110	0.4	111
16		June 19, 01:00 - June 19, 13:00	13	111	0.4	112
17		June 19, 16:00 - June 22, 07:00	64	111	0.2	112
18		June 22, 10:00 - June 23, 11:00	26	110	0.1	111
19		June 23, 15:00 - June 24, 16:00	26	110	0.2	111
20		June 25, 19:00 - June 27, 16:00	46	110	0.2	112
21		June 27, 21:00 - June 28, 04:00	8	110	0.1	110
22	2021	June 9, 13:00 - June 9, 16:00	4	110	0.4	110
23		June 10, 11:00 - June 10, 13:00	3	111	0.2	111
24		June 18, 12:00 - June 18, 15:00	4	110	0.4	111
25		June 19, 11:00 - June 19, 17:00	7	110	0.2	110
26		June 21, 13:00 - June 22, 07:00	19	110	0.2	111
27		June 22, 11:00 - June 22, 14:00	4	111	0.4	112
28		June 23, 04:00 - June 23, 09:00	6	110	0.3	110
29		June 25, 12:00 - June 25, 22:00	11	110	0.4	111
30		June 27, 15:00 - June 27, 20:00	6	110	0.6	111
31		June 29, 12:00 - June 29, 21:00	10	112	1.0	115
32		June 30, 09:00 - June 30, 15:00	7	110	0.5	111
33		June 30, 18:00 - July 3, 12:00	67	113	0.4	118
34		July 3, 21:00 - July 4, 17:00	21	111	0.4	113

* TGP was elevated prior to monitoring, or was still elevated when monitoring stopped so these events are incomplete and were longer than identified here.

** TGP was elevated for the entire monitoring period.

Table 8-4. Events of elevated TGP between 120 – 130% observed at 0.3 km and 3.5 km from Mica Generating Station; including event timing and the duration (hours).

Event	Year	Timeframe	# Hours
		Recorded 0.3 km from Mica Generating Station	
1	2015	May 23, 14:00 - May 24, 02:00	13
2		May 24, 09:00 - May 24, 18:00	10
3		May 30, 13:00 - May 30, 15:00	3
4		May 31, 09:00 - June 1, 10:00	26
5		June 2, 10:00 - June 3, 8:00	23
6	2016	May 24, 10:00 - May 24, 17:00	8
7		May 24, 21:00 - May 25, 0:00	4
8		May 25, 10:00 - May 25, 12:00	3
9		June 5, 9:00 - June 5, 21:00	13
10	2020	June 27, 23:00 - June 28, 0:00	2
11		June 28, 03:00 - June 28, 22:00	20
12		June 29, 01:00 - June 30, 07:00	31
13	2021	June 17, 12:00 - June 17, 13:00	2
14		June 20, 08:00 - June 20, 17:00	10
15		June 21, 08:00 - June 21, 17:00	10
16		July 1, 09:00 - July 1, 10:00	2
17		July 3, 09:00 - July 3, 15:00	7
		Recorded 3.5 km from Mica Generating Station	
1	2016	May 27, 10:00 - May 27, 11:00	2
2		June 6, 8:00 - June 6, 9:00	2
3	2020	June 25, 15:00 - June 25, 16:00	2
4	2021	June 21, 20:00 - June 22, 06:00	11
5		June 22, 14:00 - June 22, 18:00	5

8.9 Appendix 1-4 Figures and Tables for Total Gas Pressure Production by Generator-Specific Synchronous Condense Operations and Mica Generating Station Operations

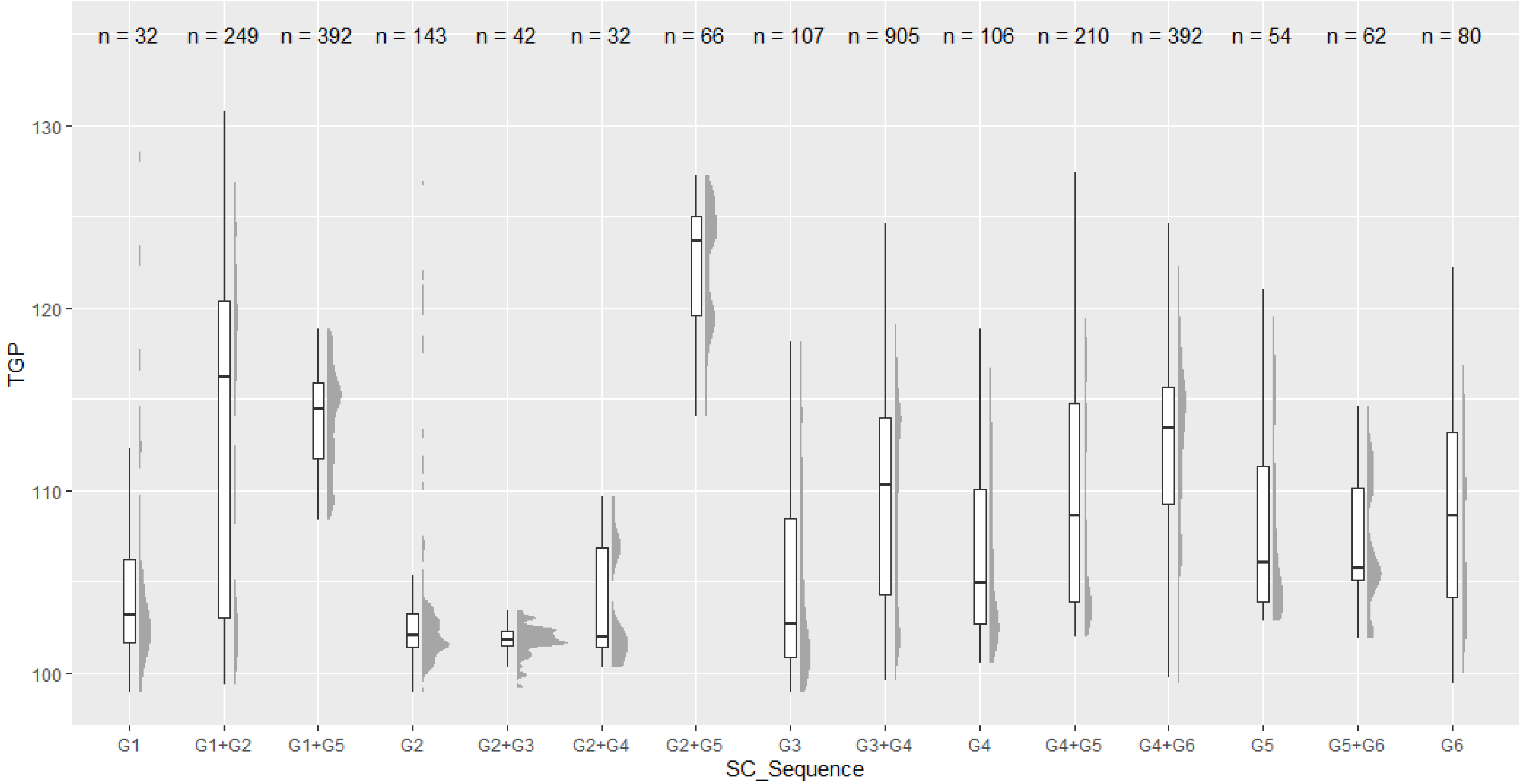

Figure 8-3. TGP (%) while generators or generator combinations were operating in SC; where boxplots depict the median, 25th percentile, and 75th percentile, and violin plots depict data distribution (n = sample size in hours).

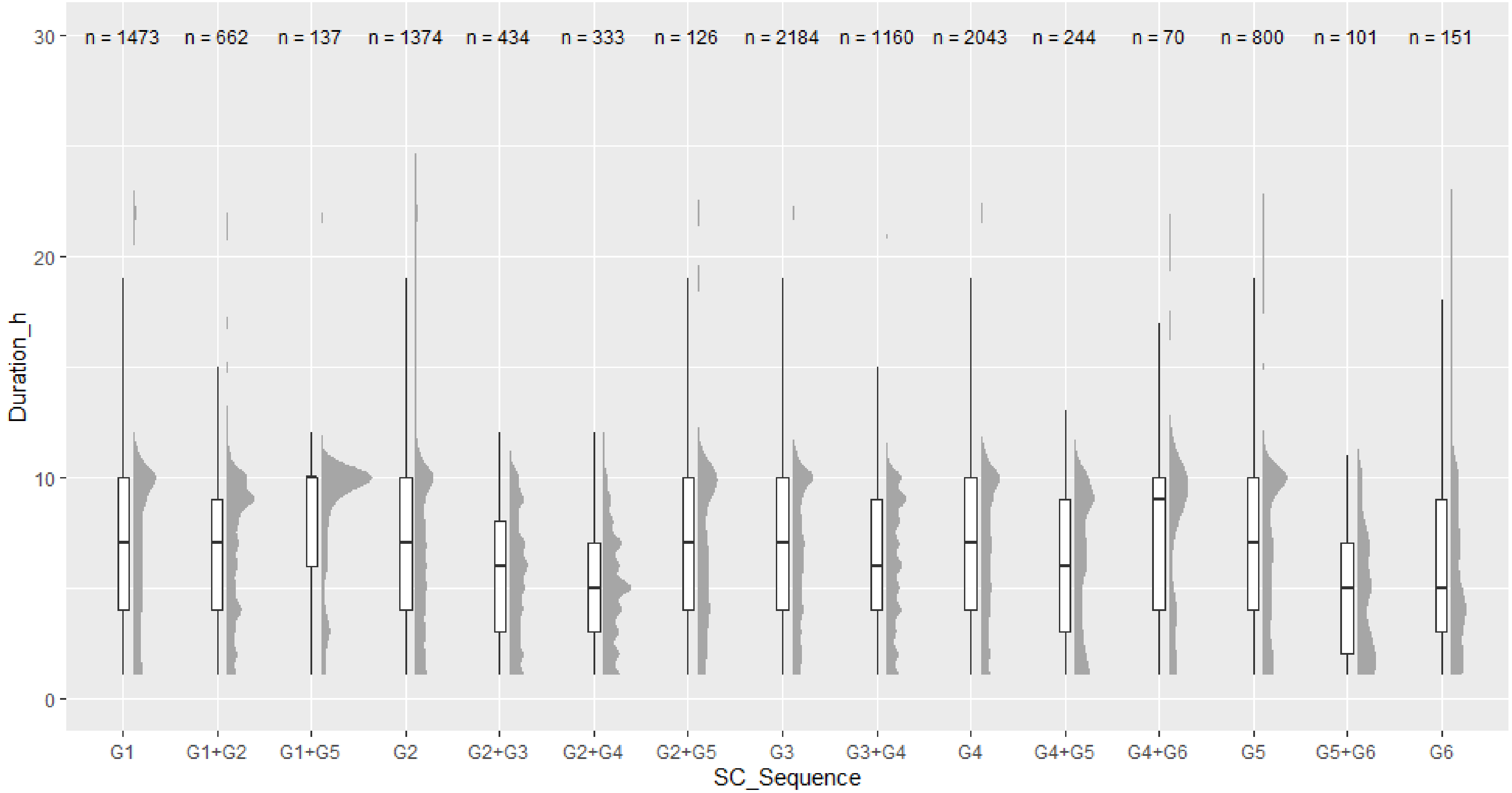

Figure 8-4. Duration (h) for generators or generator combinations operating in synchronous condense (SC); where boxplots depict the median, 25th percentile, and 75th percentile, and violin plots depict data distribution (n = sample size in hours).

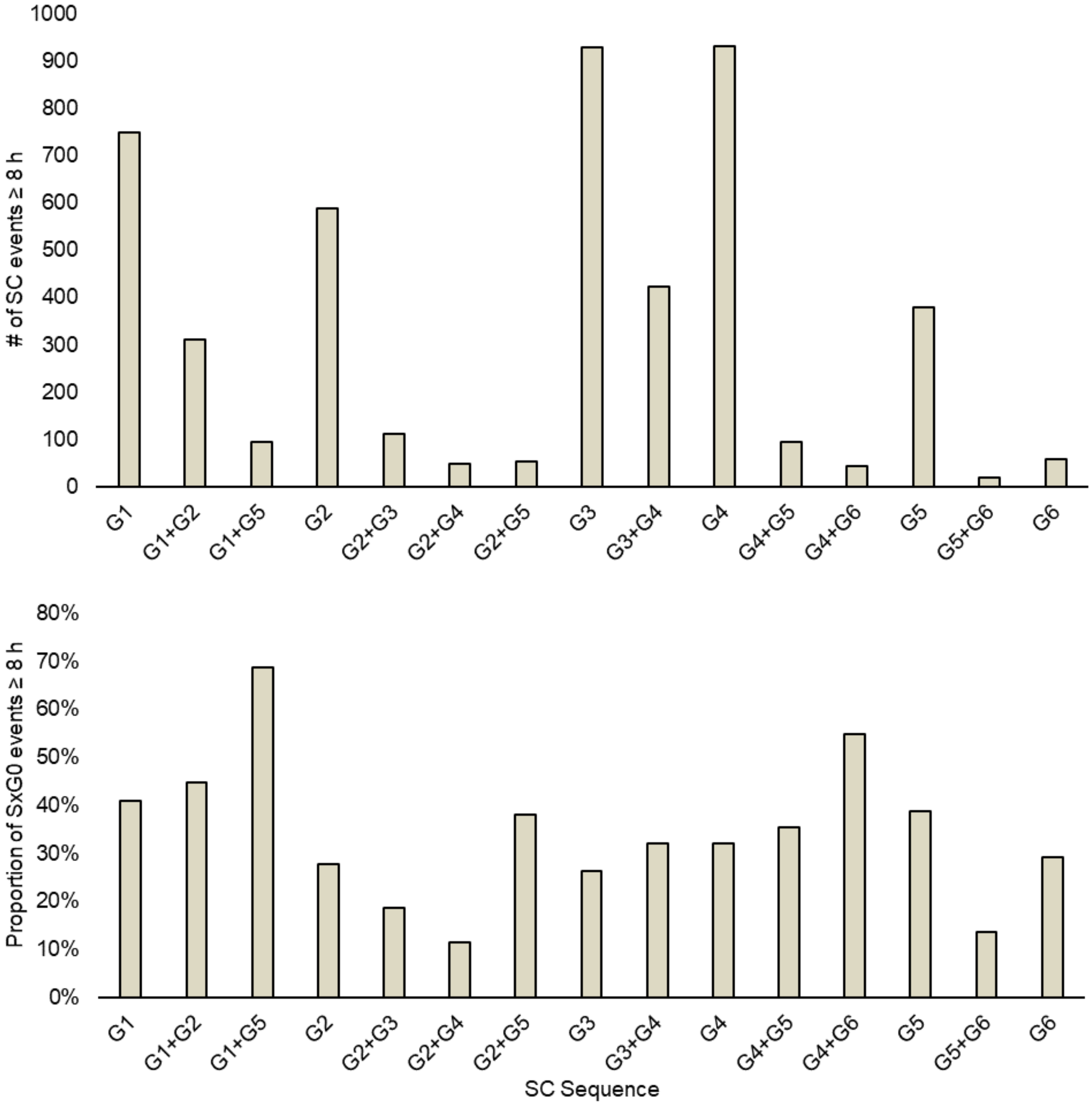

Figure 8-5. (Top) the observed number of synchronous condense (SC) events with ≥ 8-h duration by generator sequence and (bottom) the proportion (%) of observed SC events that included synchronous condense without generation (SxG0) ≥ 8-h duration.

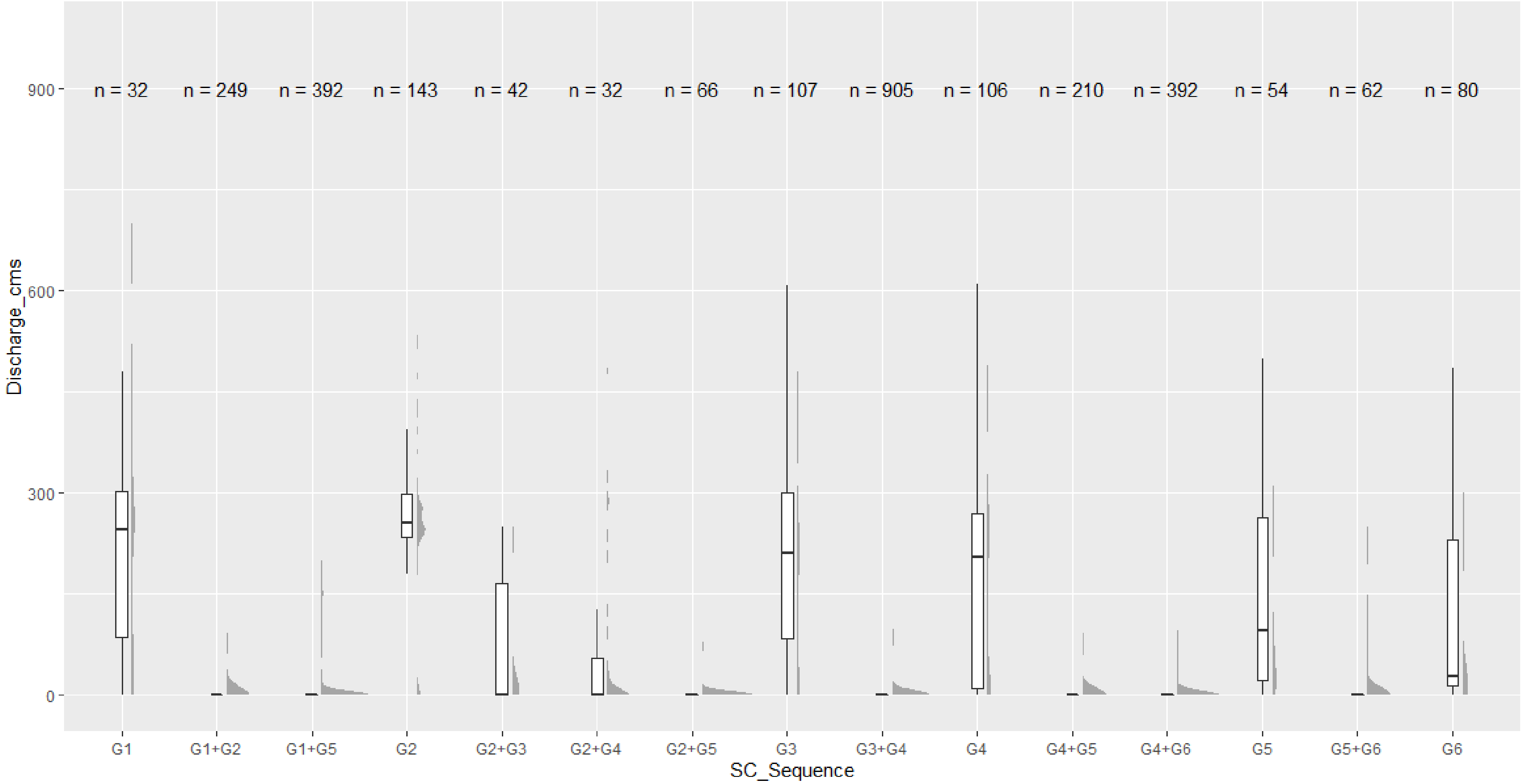

Figure 8-6. MGS discharge (cms) while generators or generator combinations were operating in SC; where boxplots depict the median, 25th percentile, and 75th percentile, and violin plots depict data distribution (n = sample size in hours of duration).

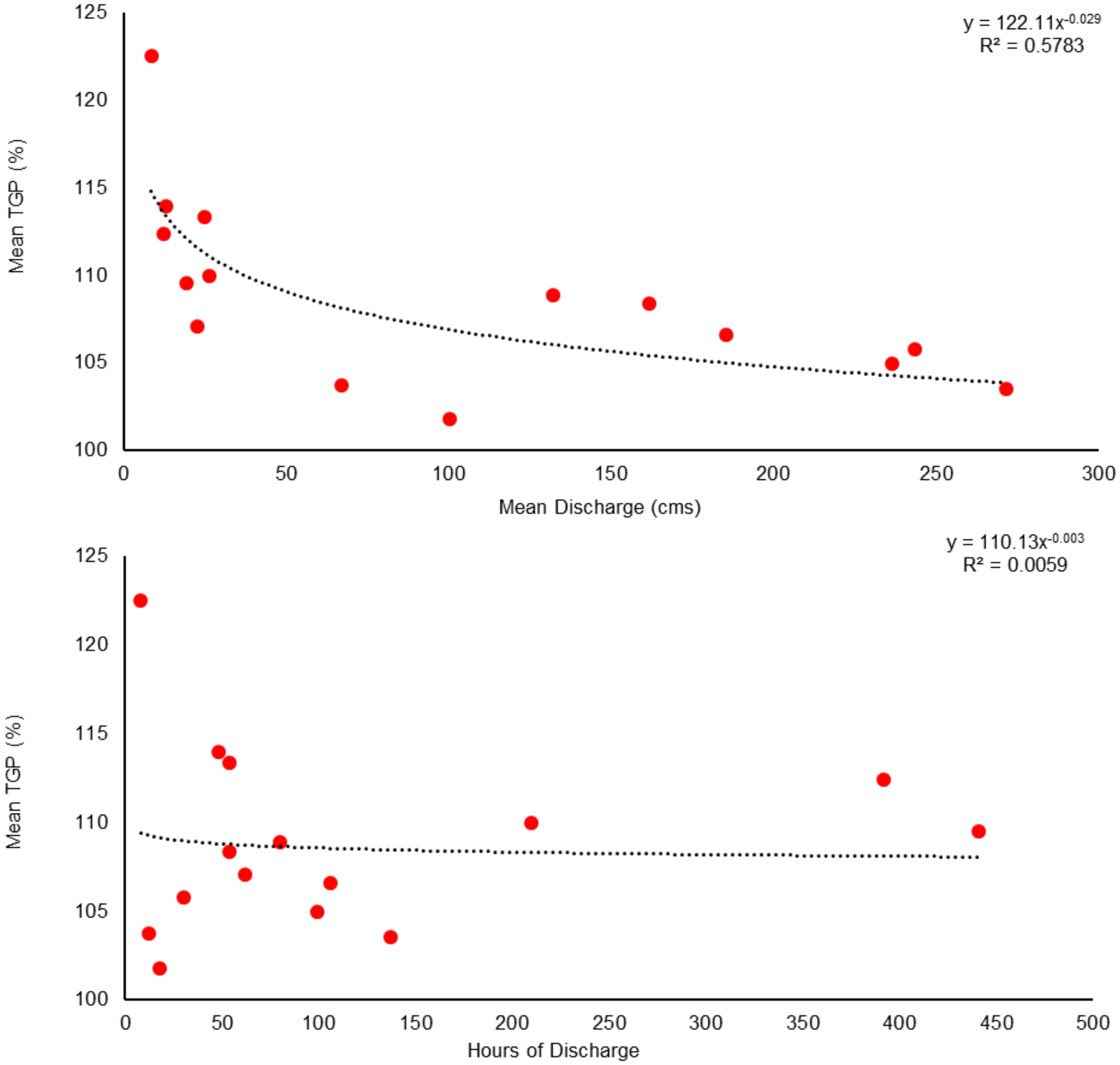

Figure 8-7. Mean TGP (%) for generator/generator combinations in SC by the corresponding mean discharge (cms; top) and hours of duration (bottom).

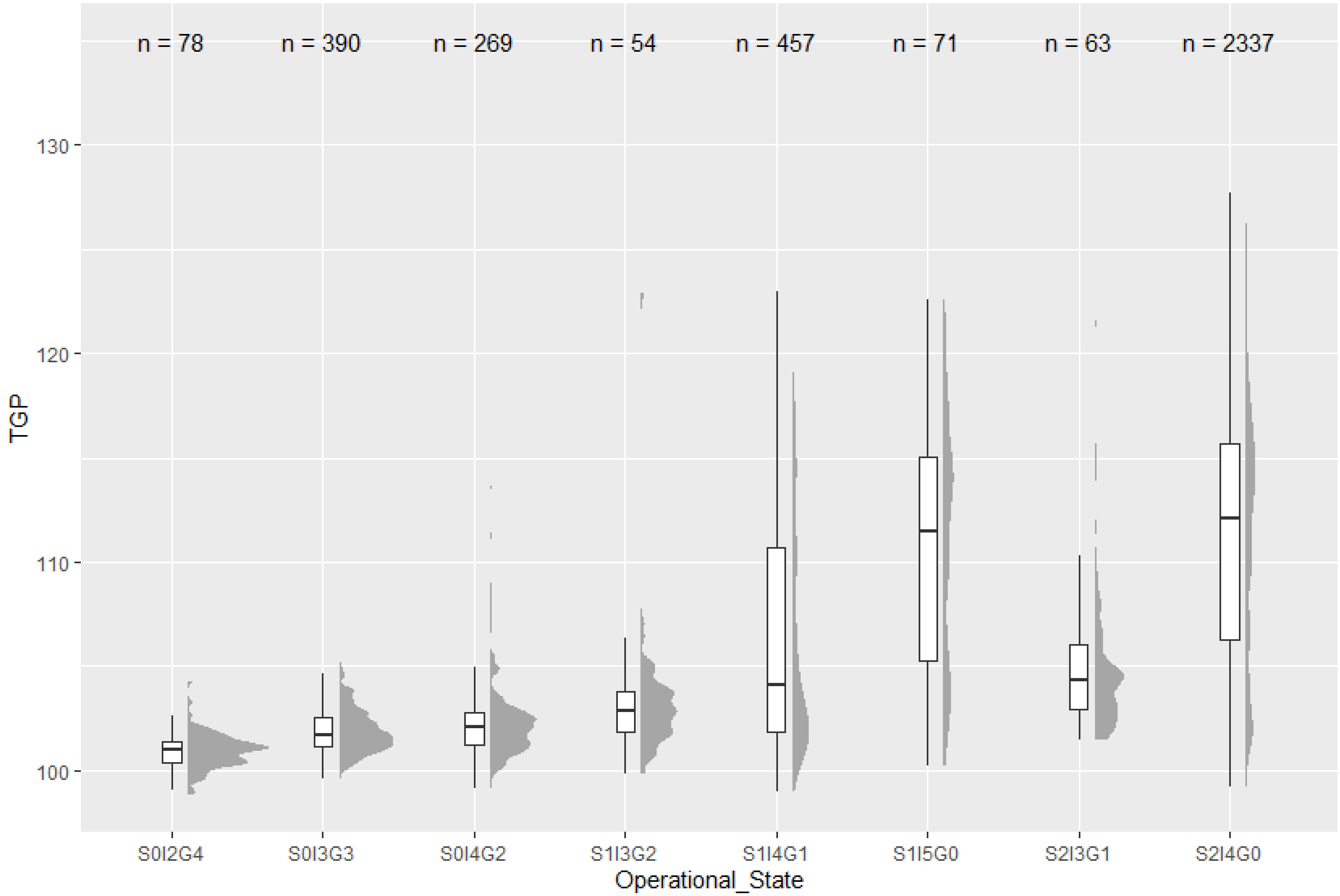

Figure 8-8. TGP (%) recorded during various generator operation combinations at MGS, where boxplots depict the median, 25th percentile, and 75th percentile, and violin plots depict data distribution (n = sample size in hours).

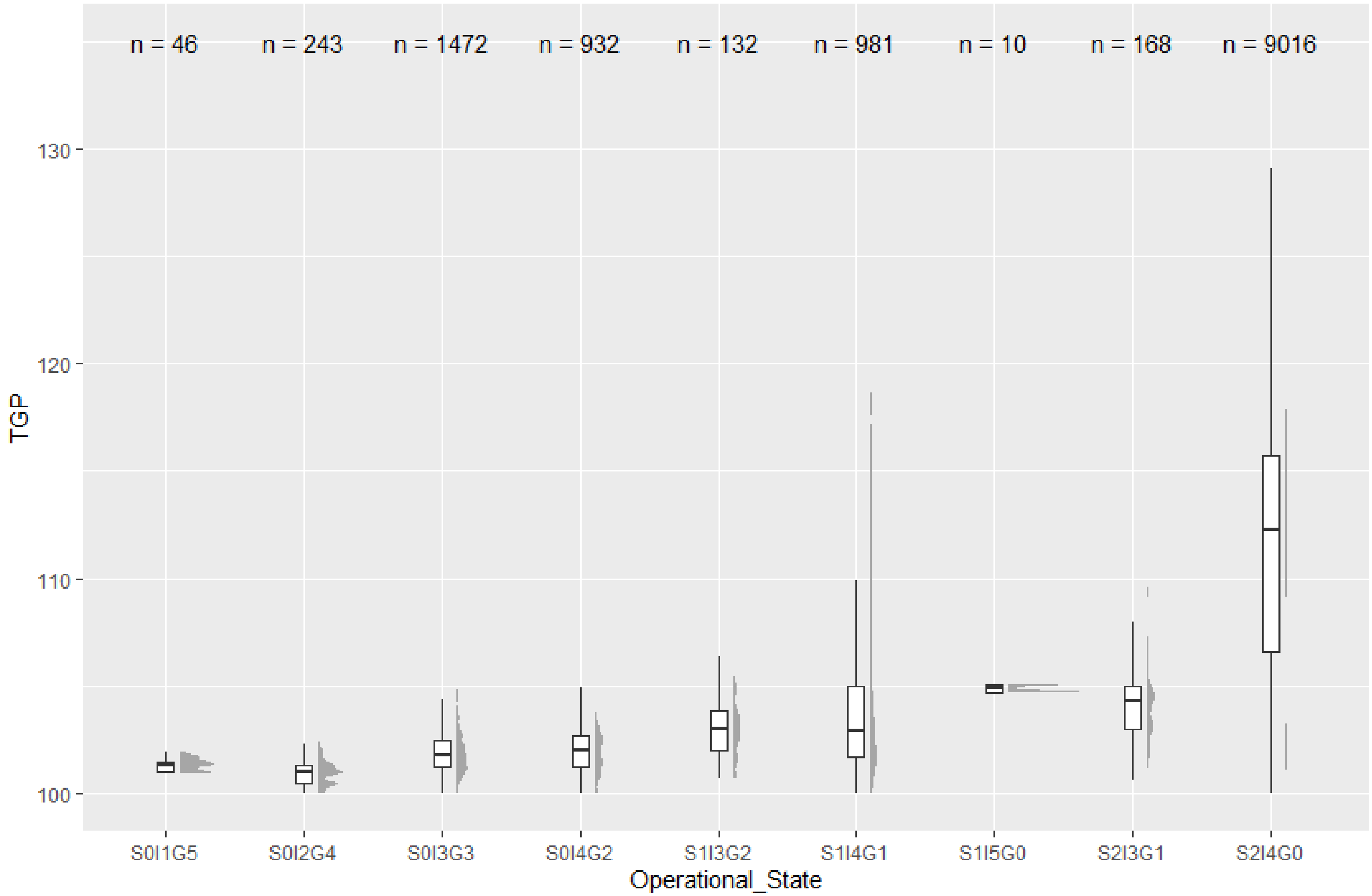

Figure 8-9. TGP (%) recorded during various generator operation combinations operating for at least 90 consecutive minutes, where boxplots depict the median, 25th percentile, and 75th percentile, and violin plots depict data distribution (n = sample size in 15-minute data-points).

8.10 Appendix 1-5 Figures and Tables for Total Gas Pressure by Duration of Synchronous Condense Operations

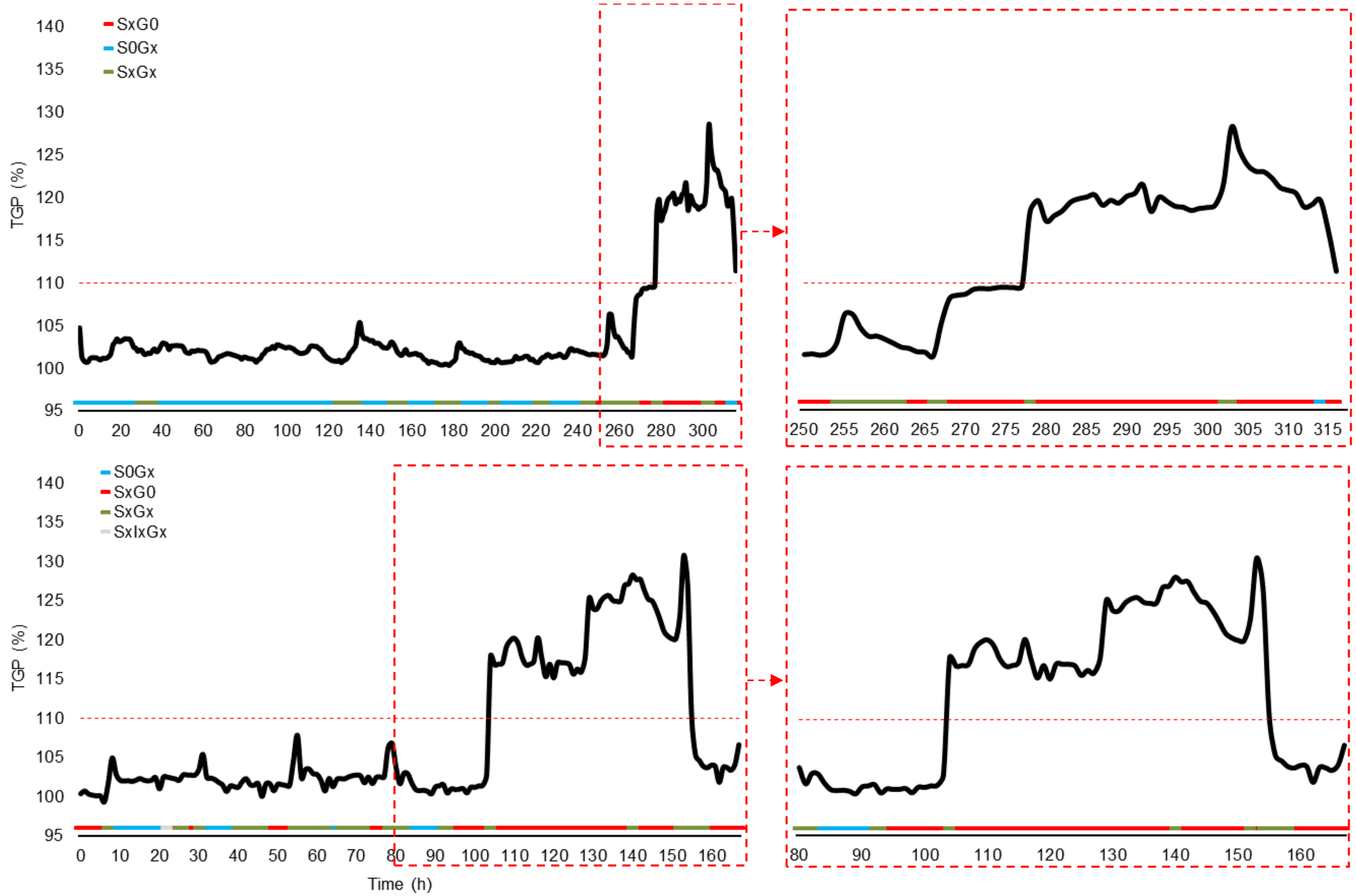

Figure 8-10. TGP (%; black) by time (h) monitored between May 11 – 25 (top) and May 26 – June 02 2015 (bottom) 0.3 km from MGS (Station 0), including the dominant MGS operation for each hour (where: S0Gx = generation without SC, SxG0 = SC without generation, SxGx = SC with generation, and SxIxGx = no dominant operation) and BC Water Quality Guideline (110%; red hatched line). High TGP events magnified to the right of each graph.

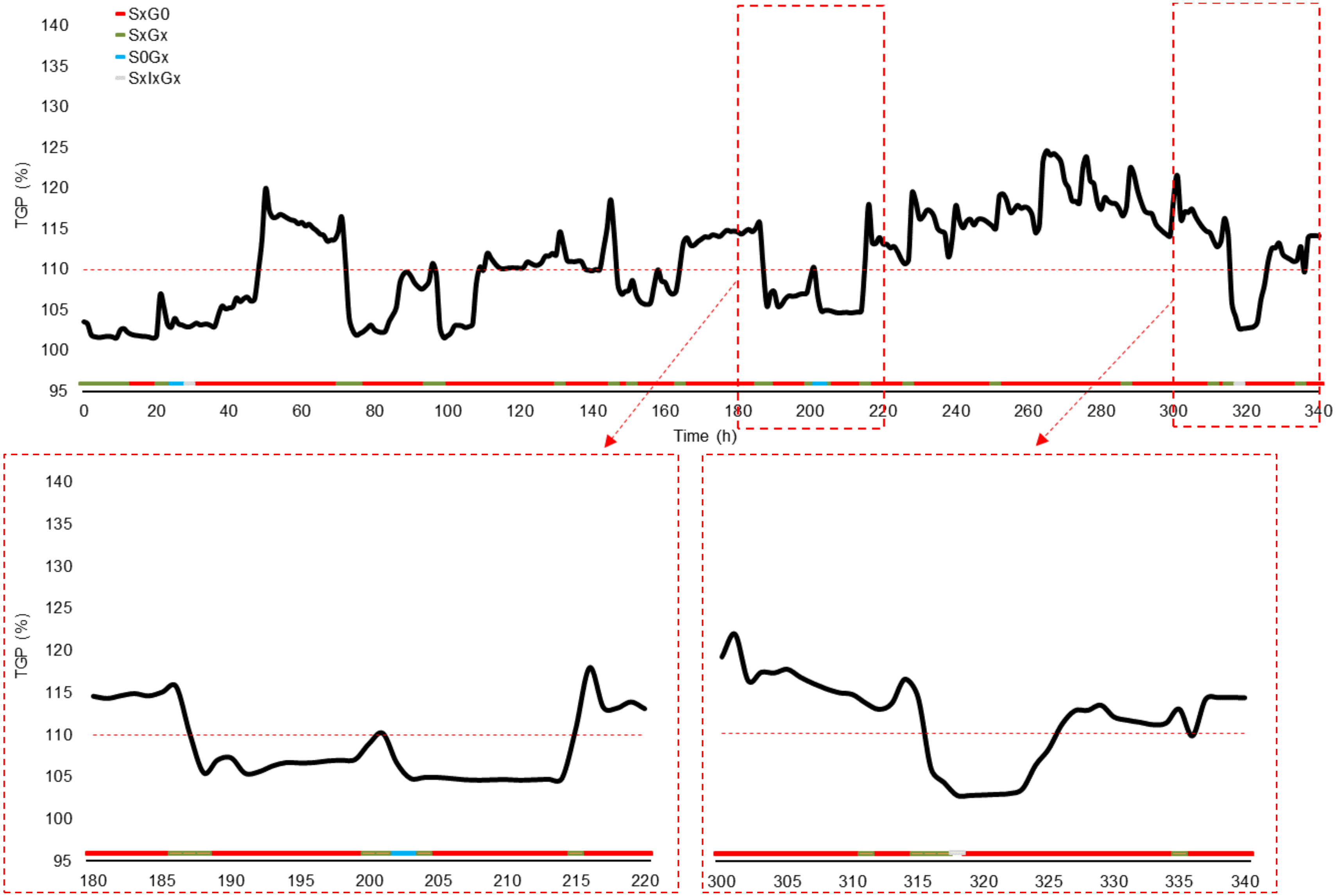

Figure 8-11. TGP (%; black) by time (h) monitored between May 13 – 27 2016 (top) 0.3 km from MGS (Station 0a), including the dominant MGS operation for each hour (where: S0Gx = generation without SC, SxG0 = SC without generation, SxGx = SC with generation, and SxIxGx = no dominant operation) and BC Water Quality Guideline (110%; red hatched line). Select periods of TGP reduction below 100% magnified below.

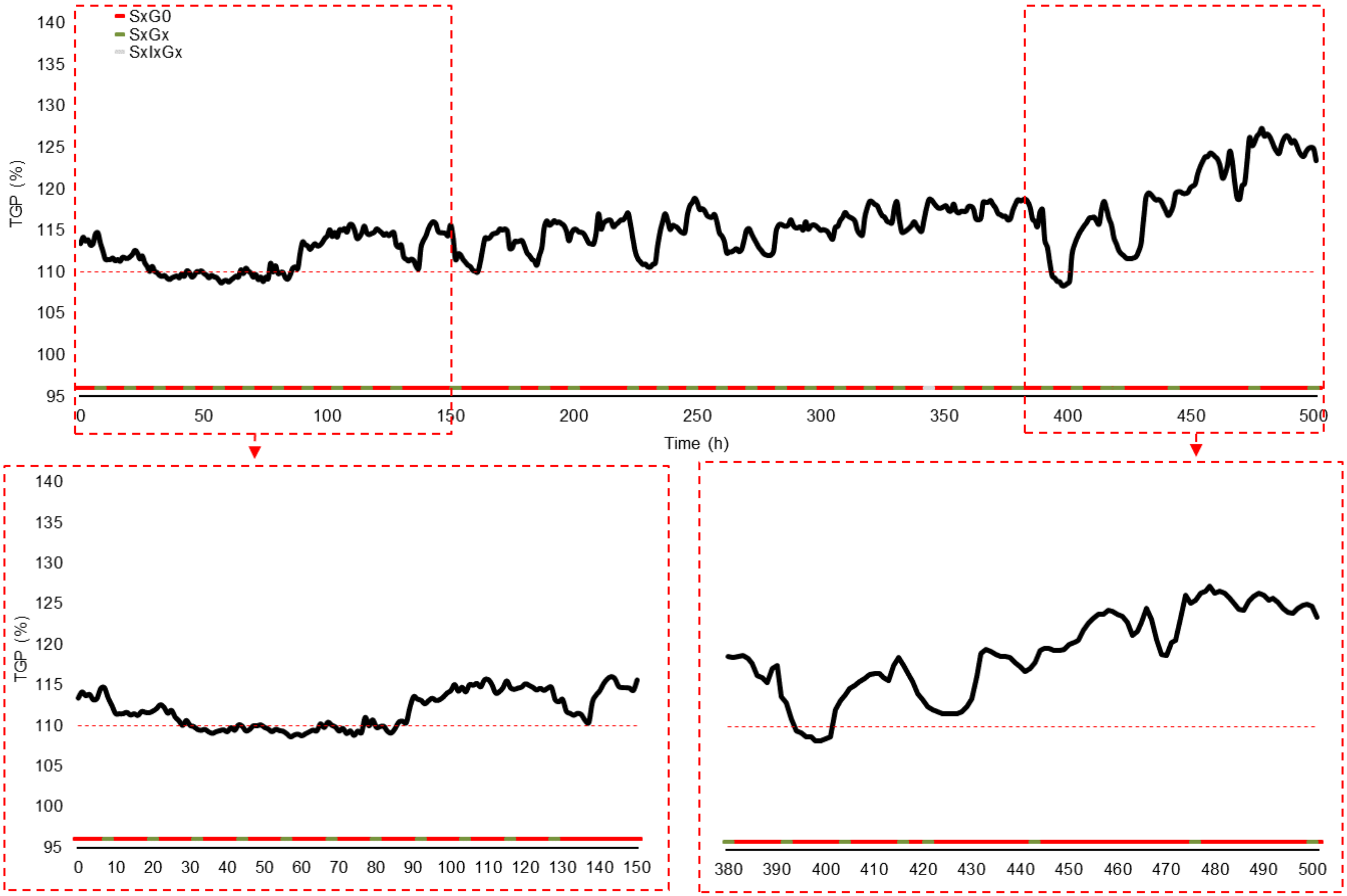

Figure 8-12. TGP (%; black) by time (h) monitored between June 9 – 30 2020 (top) 0.3 km from MGS (Station 0), including the dominant MGS operation for each hour (where: SxG0 = SC without generation, SxGx = SC with generation, and SxIxGx = no dominant operation) and BC Water Quality Guideline (110%; red hatched line). Select periods of TGP reduction below 110% magnified below.

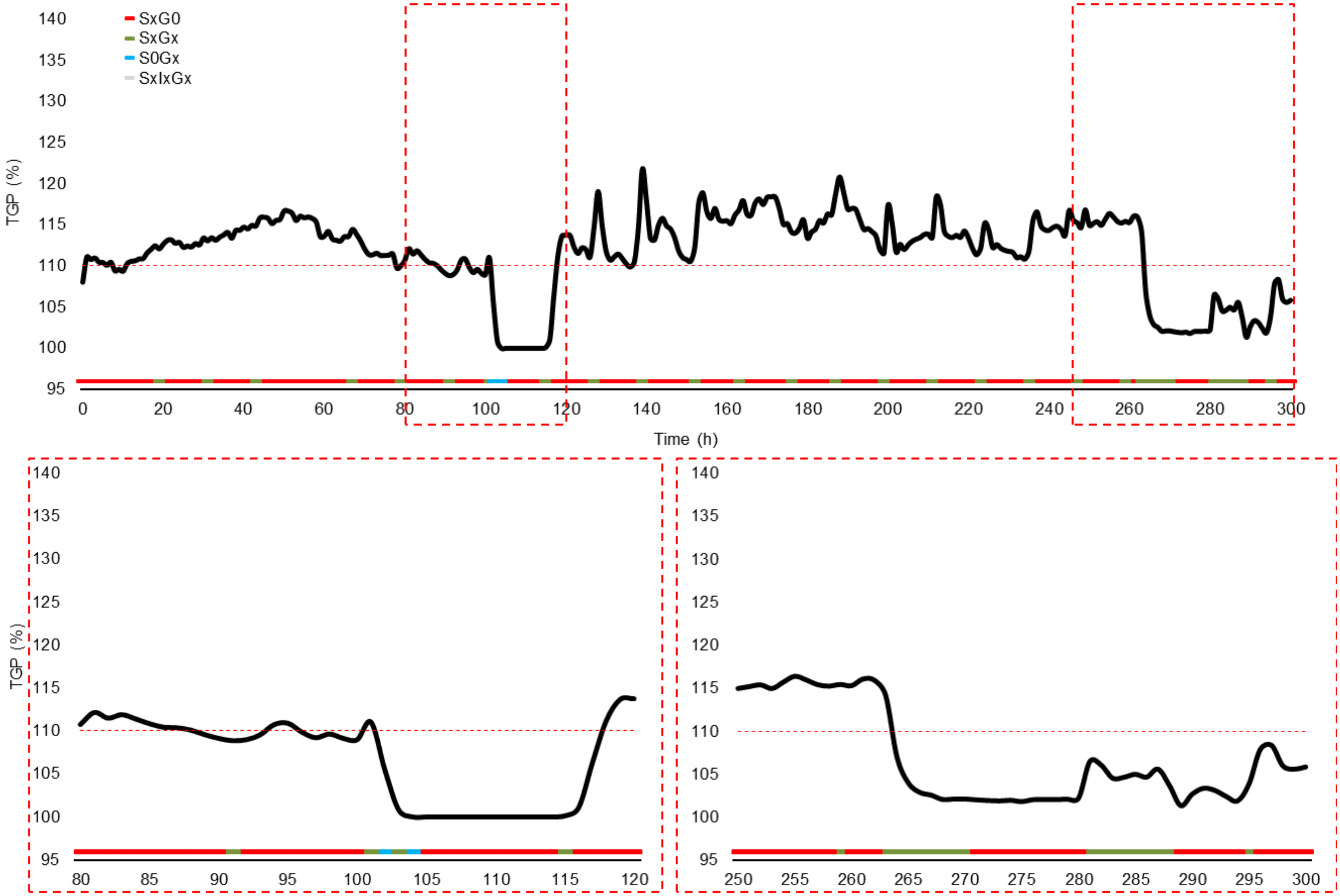

Figure 8-13. TGP (%; black) by time (h) monitored between June 3 – 16 2021 (top) 0.3 km from MGS (Station 0a), including the dominant MGS operation for each hour (where: S0Gx = generation without SC, SxGx = SC with generation, and SxIxGx = no dominant operation), and BC Water Quality Guideline (110%; red hatched line). Select periods of TGP reduction below 110% magnified below.

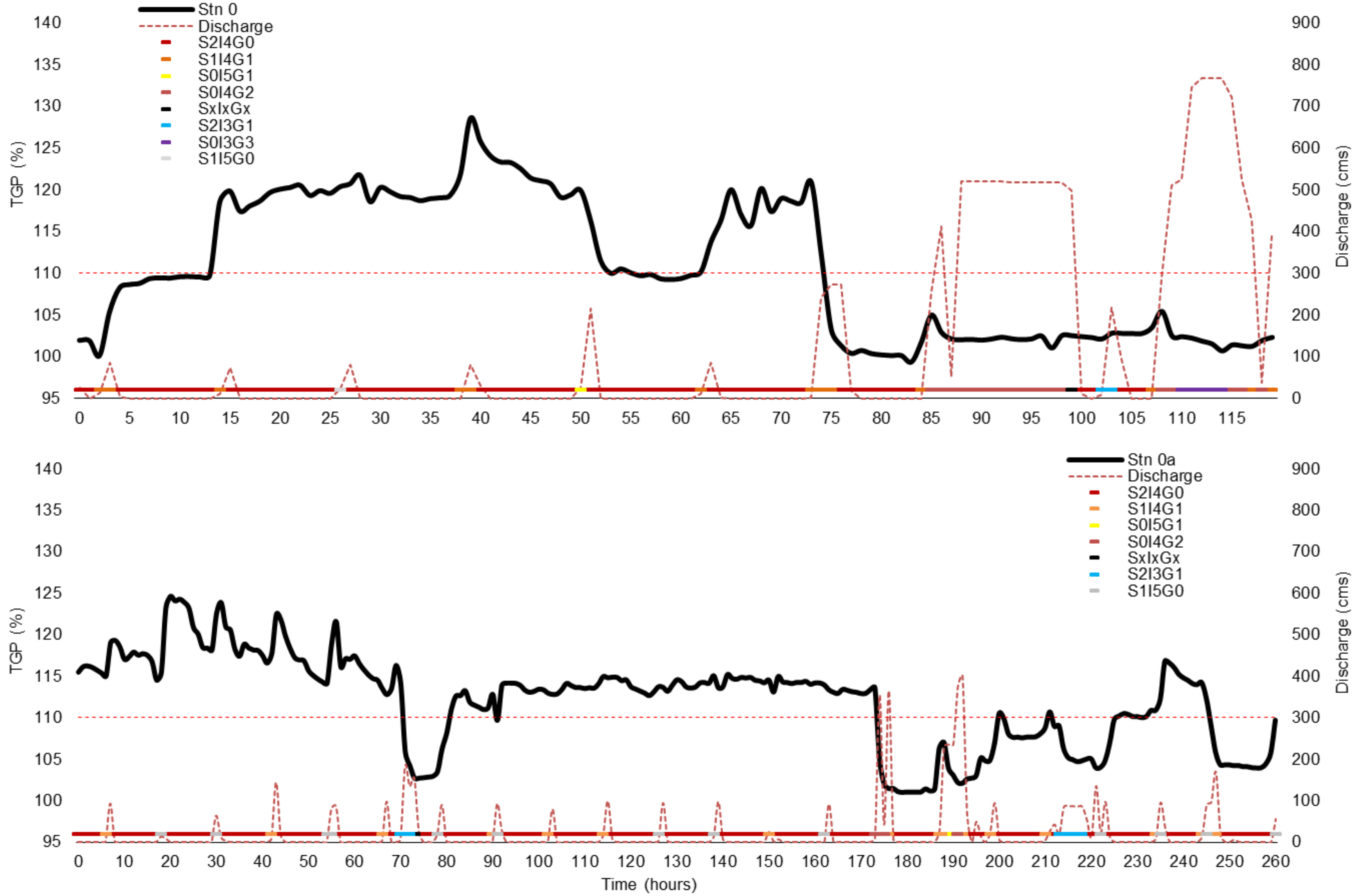

Figure 8-14. Temporal TGP (%; black) response to discharge (cms; orange) between May 22 – 27 2015 (top) and May 23 – June 3 2016 (bottom) measured 0.3 kms from MGS (2015 = Station 0; 2016 = Station 0a), with the dominant operational state of MGS identified for a given hour (S = Synchronous Condense; I = Idle; G = Generating). BC Water Quality Guideline also identified (110%; red hatched line).

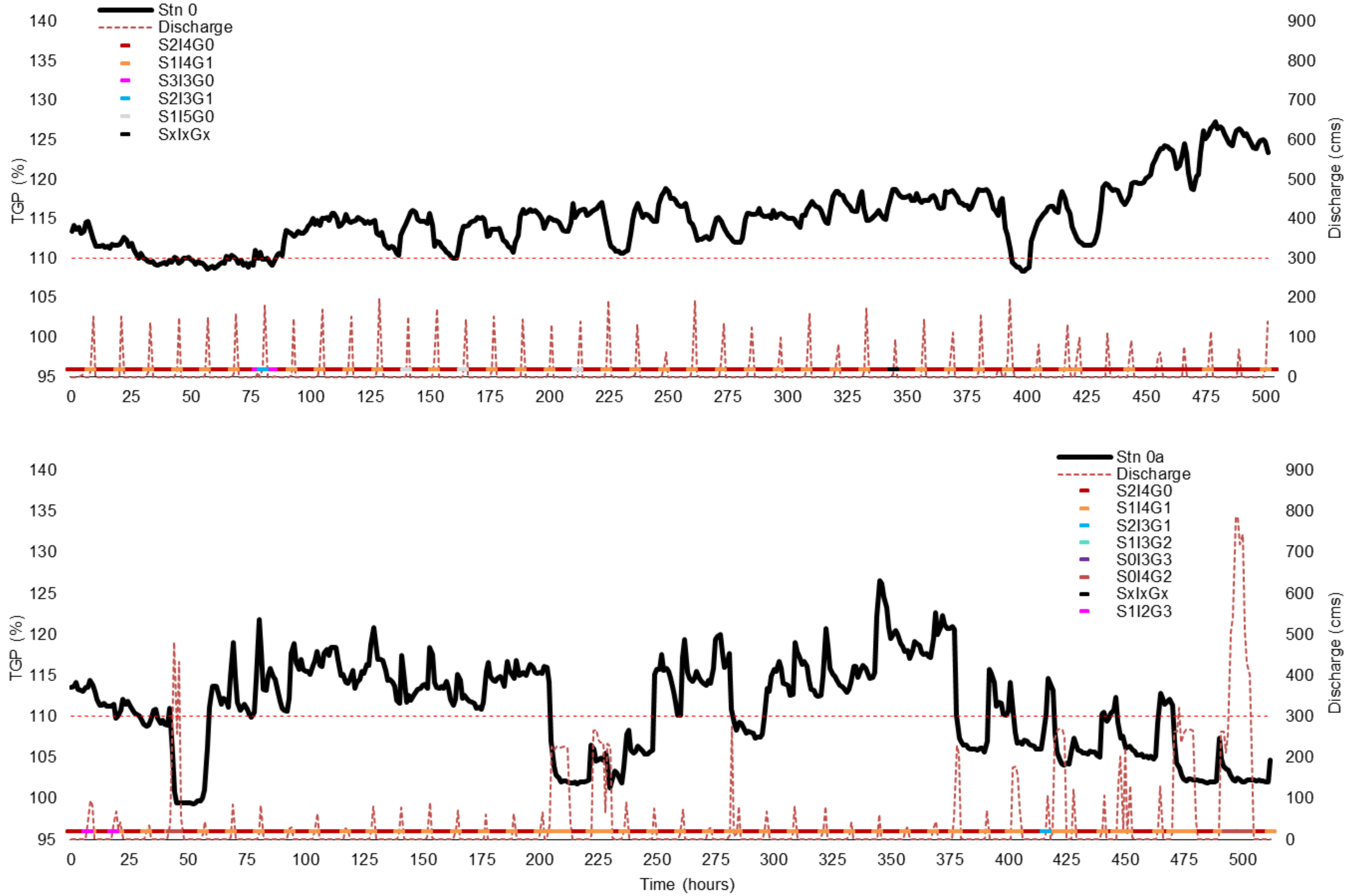

Figure 8-15. Temporal TGP (%; black) response to discharge (cms; orange) between June 9 – 30 2020 (top) and June 6 – July 5 2021 (bottom) measured 0.3 kms from MGS (2020 = Station 0; 2021 = Station 0a), with the dominant operational state of MGS identified for a given hour(S = Synchronous Condense; I = Idle; G = Generating). BC Water Quality Guideline also identified (110%; red hatched line).

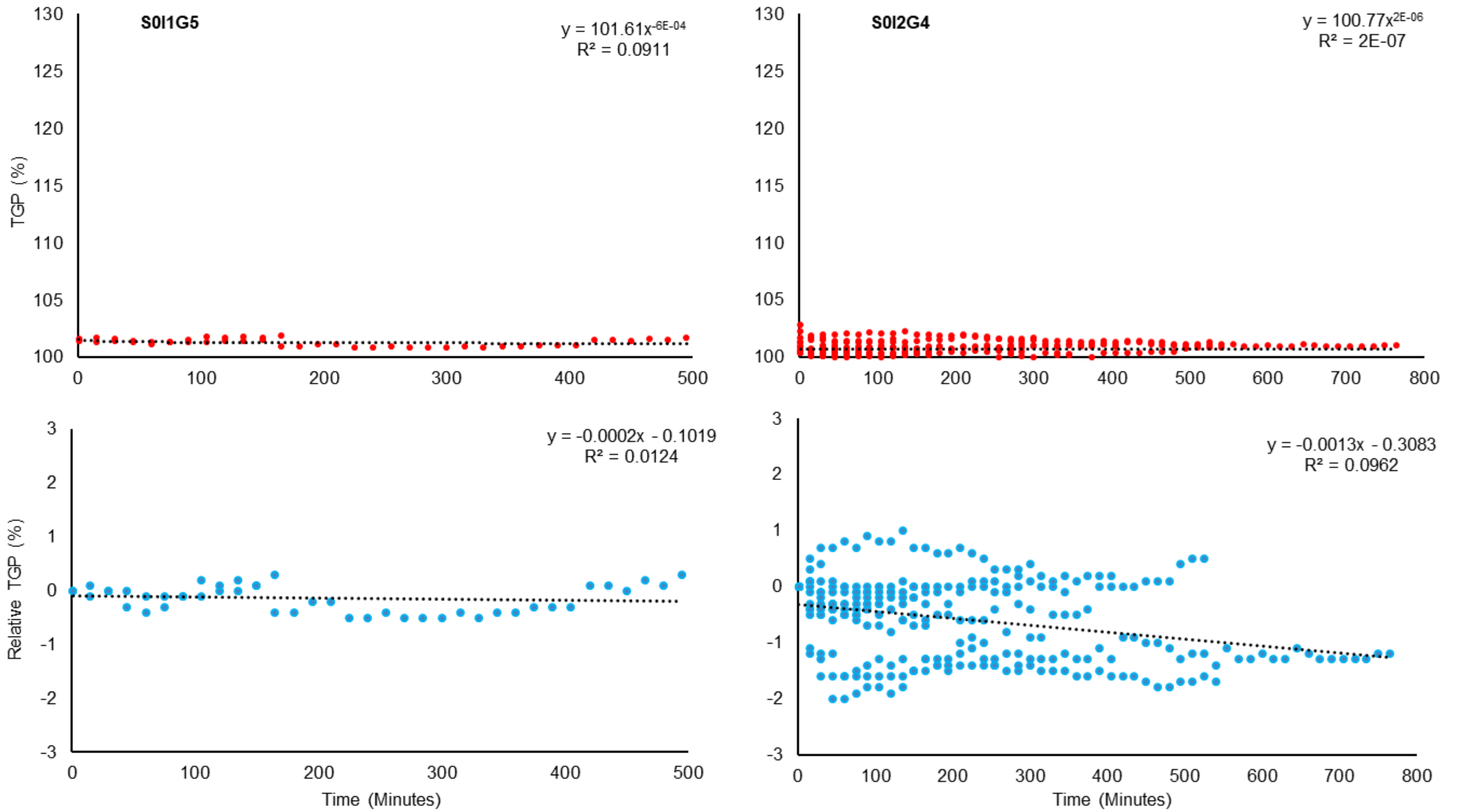

Figure 8-16. (Top) TGP (%) by time (minutes) for all duration events for states S0I1G5 (n = 2; left) and S0I2G4 (n = 13; right), and (bottom) relative TGP by time for MGS operational state S0I1G5 (left) and S0I2G4 (right); with the dotted lines (black) representing the respective linear trends (TGP = power regression, Relative TGP = linear regression).

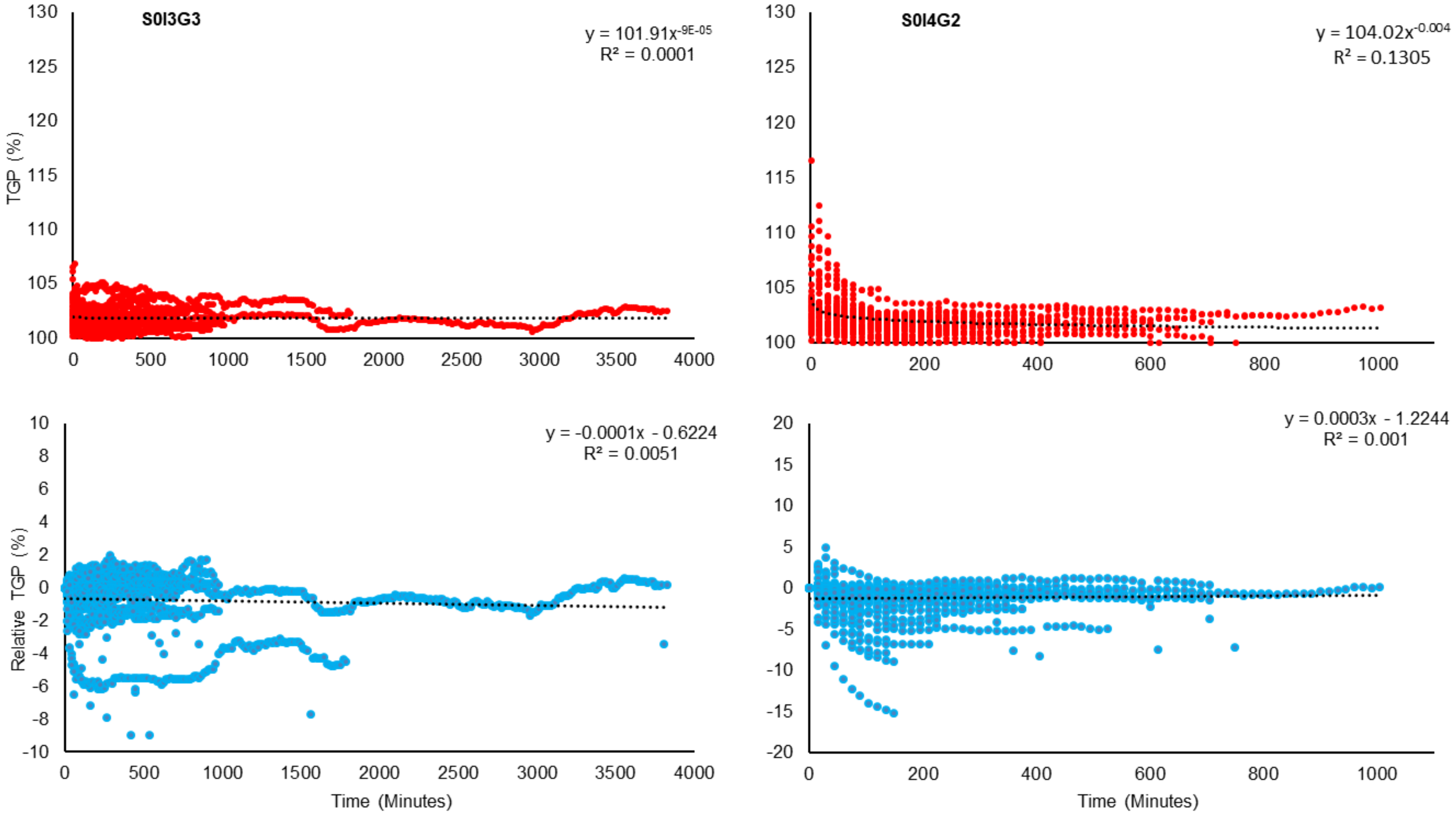

Figure 8-17. (Top) TGP (%) by time (minutes) for all duration for operational states S0I3G3 (n = 40; left) and S0I4G2 (n = 45; right), and (bottom) relative TGP by time for MGS operational state S0I3G3 (left) and S0I4G2 (right); with the dotted lines (black) representing the respective linear trends (TGP = power regression, Relative TGP = linear regression).

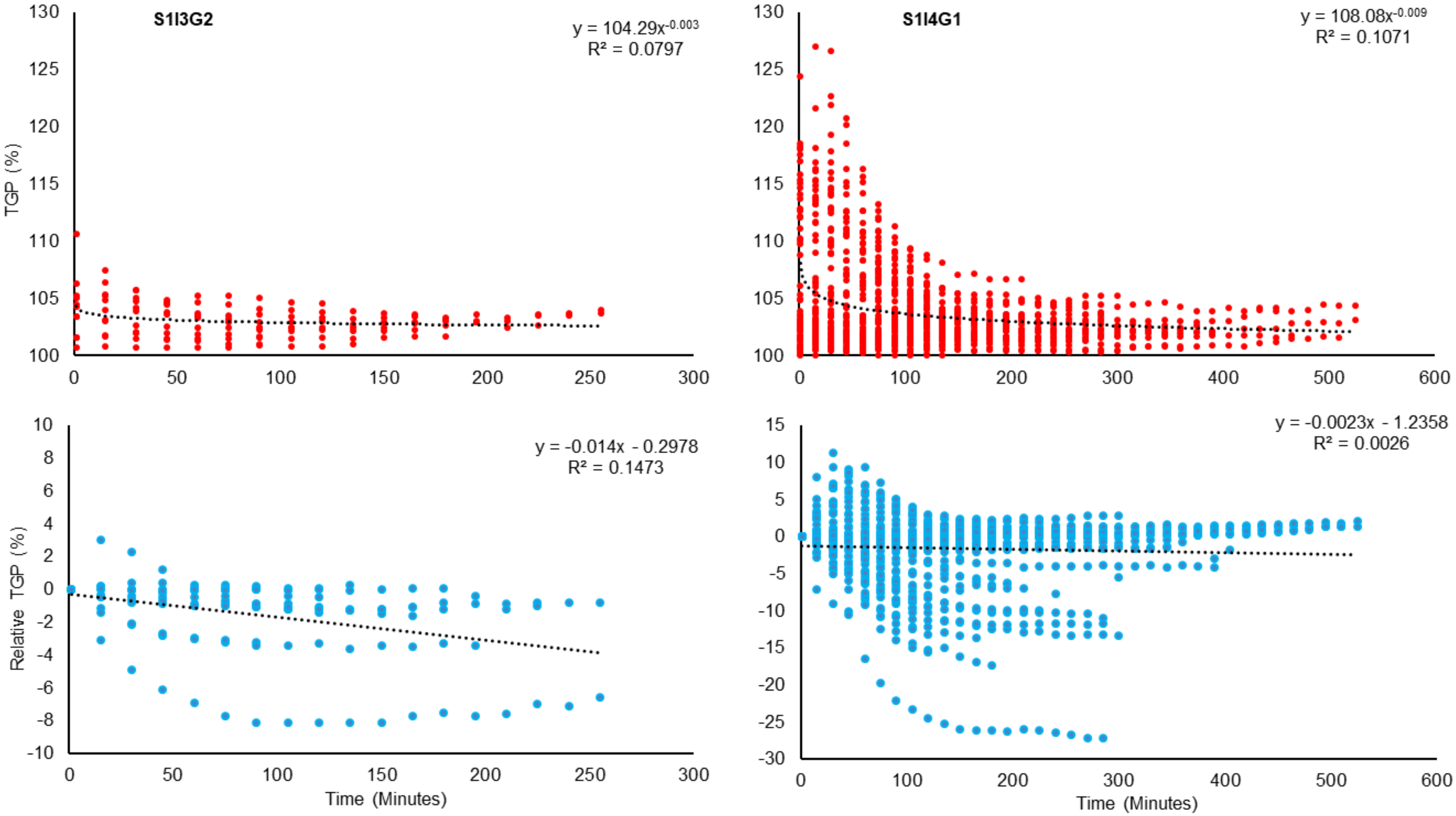

Figure 8-18. (Top) TGP (%) by time (minutes) for all duration events for operational states S1I3G2 (n = 11; left) and S1I4G1 (n = 68; right), and (bottom) relative TGP by time for MGS operational state S1I3G2 (left) and S1I4G1 (right); with the dotted lines (black) representing the respective linear trends. (TGP = power regression, Relative TGP = linear regression).

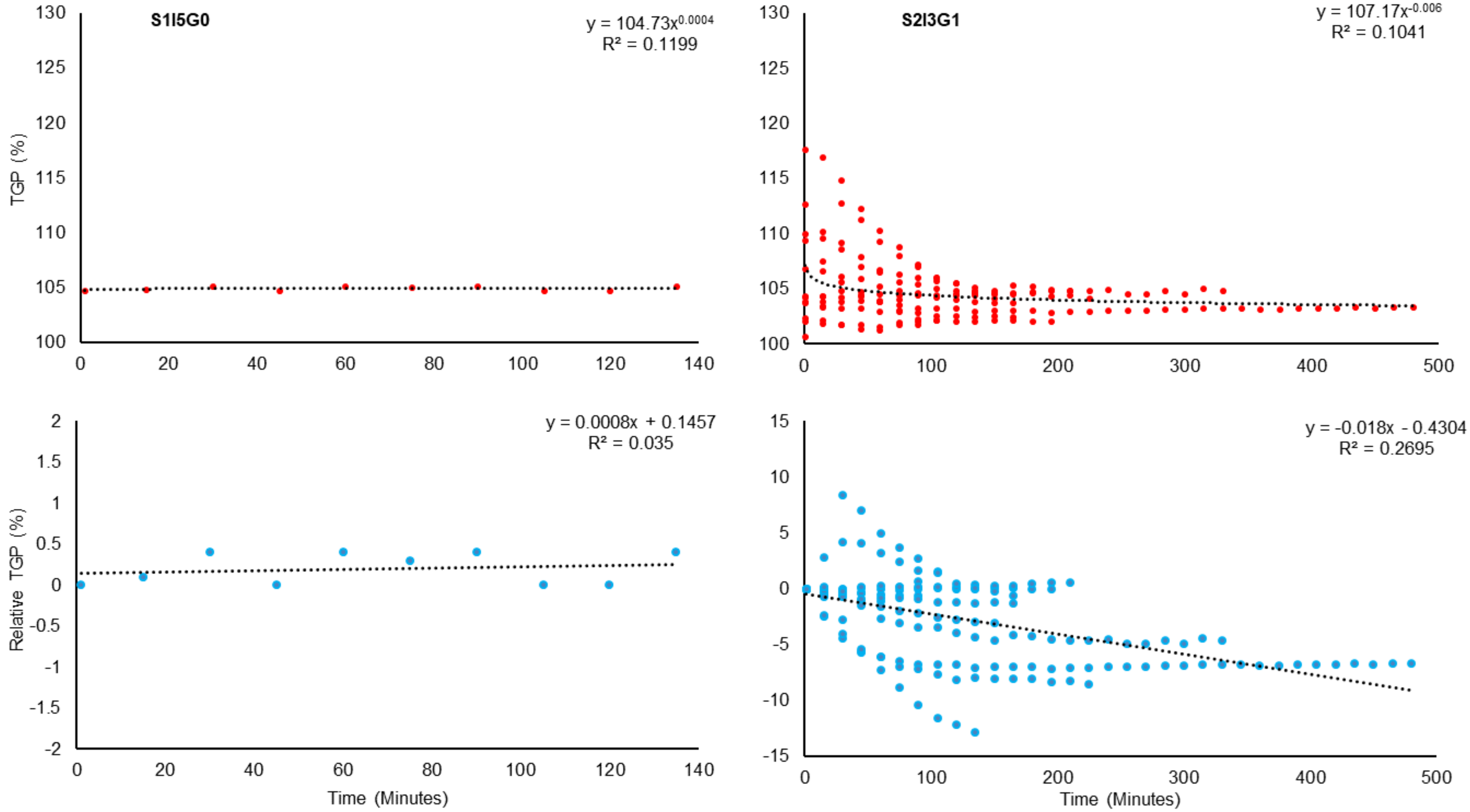

Figure 8-19. (Top) TGP (%) by time (minutes) for all duration events for operational states S1I5G0 (n = 1; left), and S2I3G1 (n = 12; right) and (bottom) relative TGP by time for operational states S1I5G0 (left) and S2I3G1 (right); with the dotted lines (black) representing the respective linear trends. (TGP = power regression, Relative TGP = linear regression).

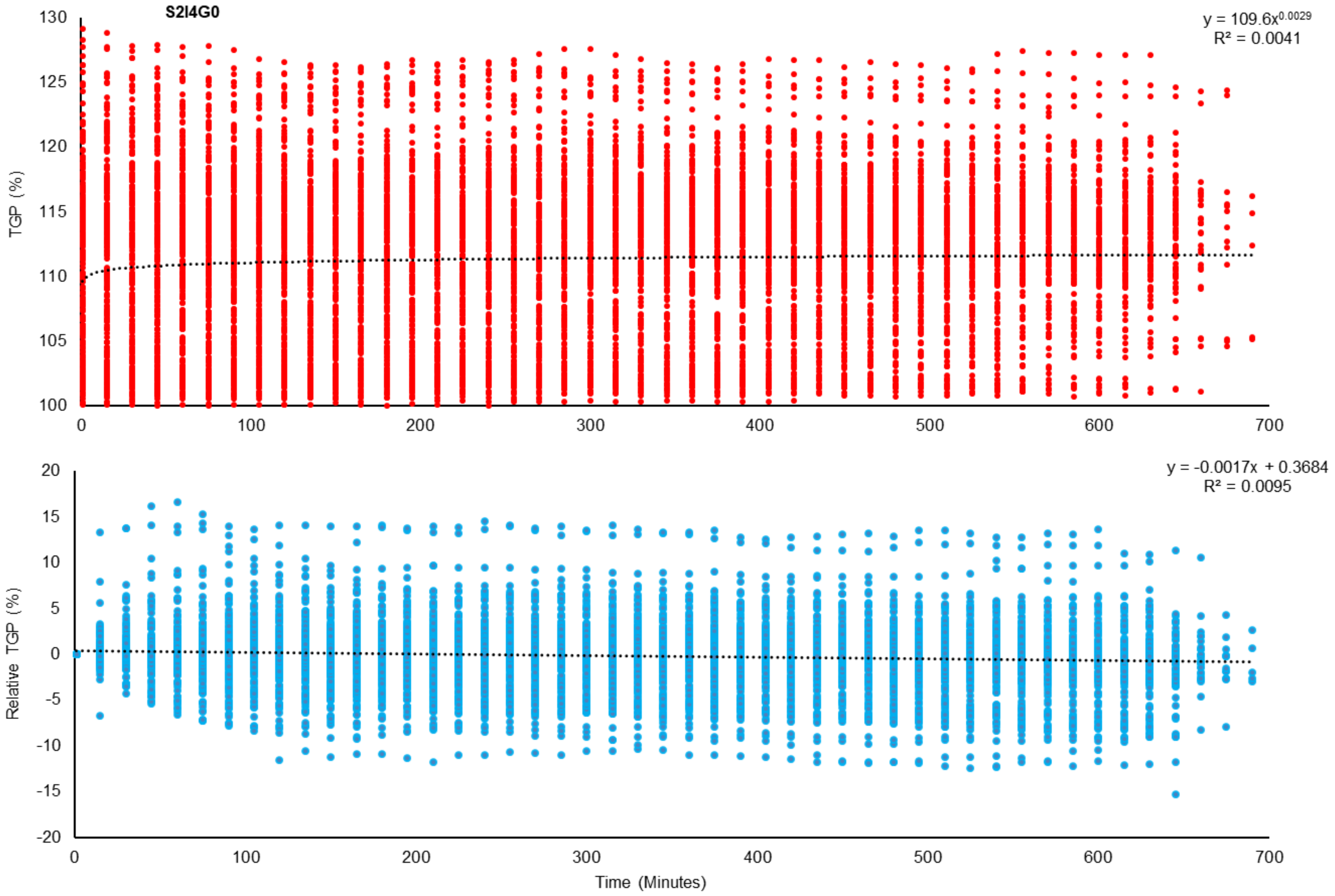

Figure 8-20. (Top) TGP (%) by time (minutes) for all duration events for operational state S2I4G0 (n = 263), and (bottom) relative TGP by time for MGS operational state S2I4G0 with the dotted lines (black) representing the respective linear trends (TGP = power regression, Relative TGP = linear regression).

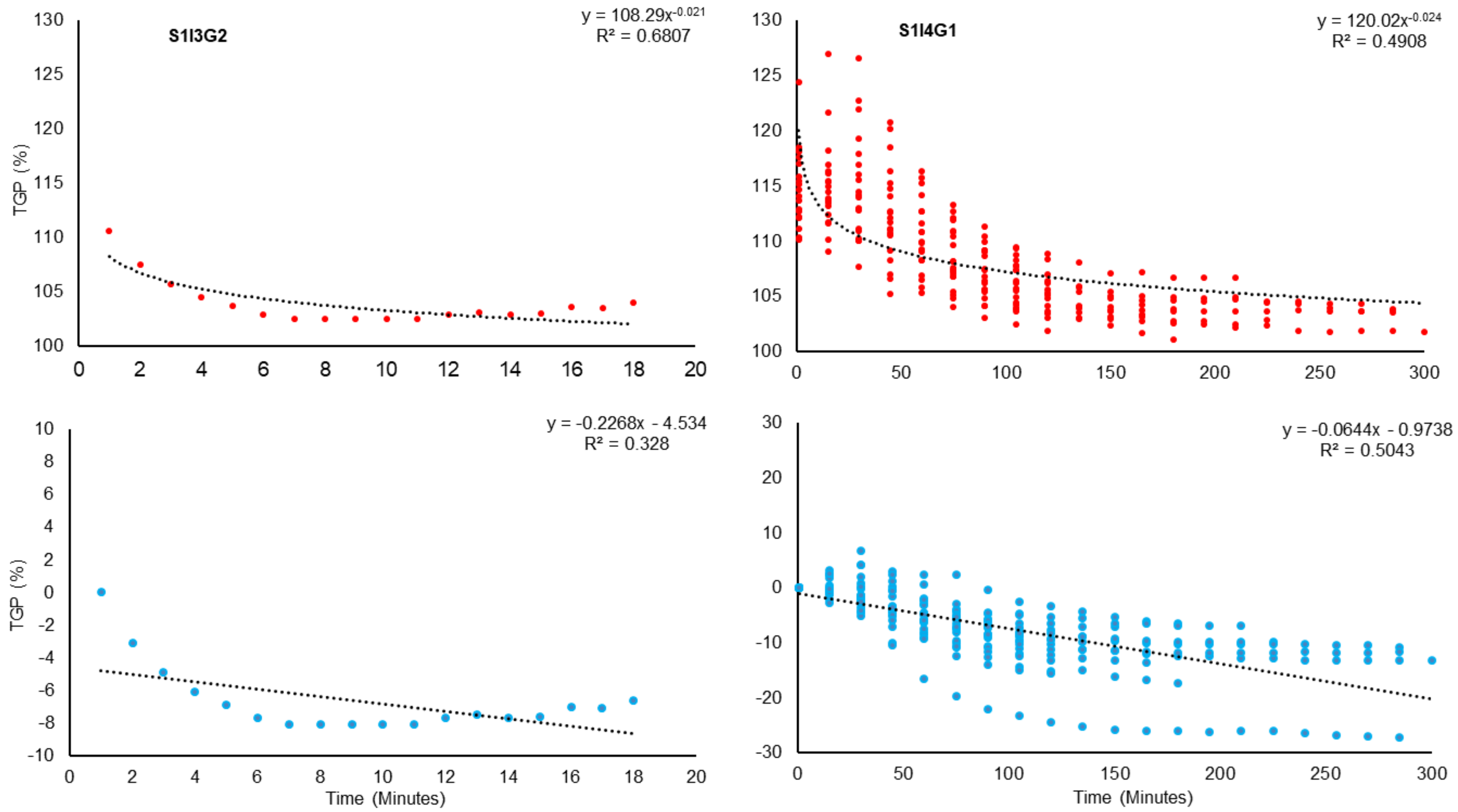

Figure 8-21. (Top) TGP (%) by time (minutes) from duration events which started above 110% for operational states S1I3G2 (n = 1; left) and S1I4G1 (n = 20; right), and (bottom) relative TGP by time for MGS operational state S1I3G2 (left) and S1I4G1 (right); with the dotted lines (black) representing the respective linear trends (TGP = power regression, Relative TGP = linear regression).

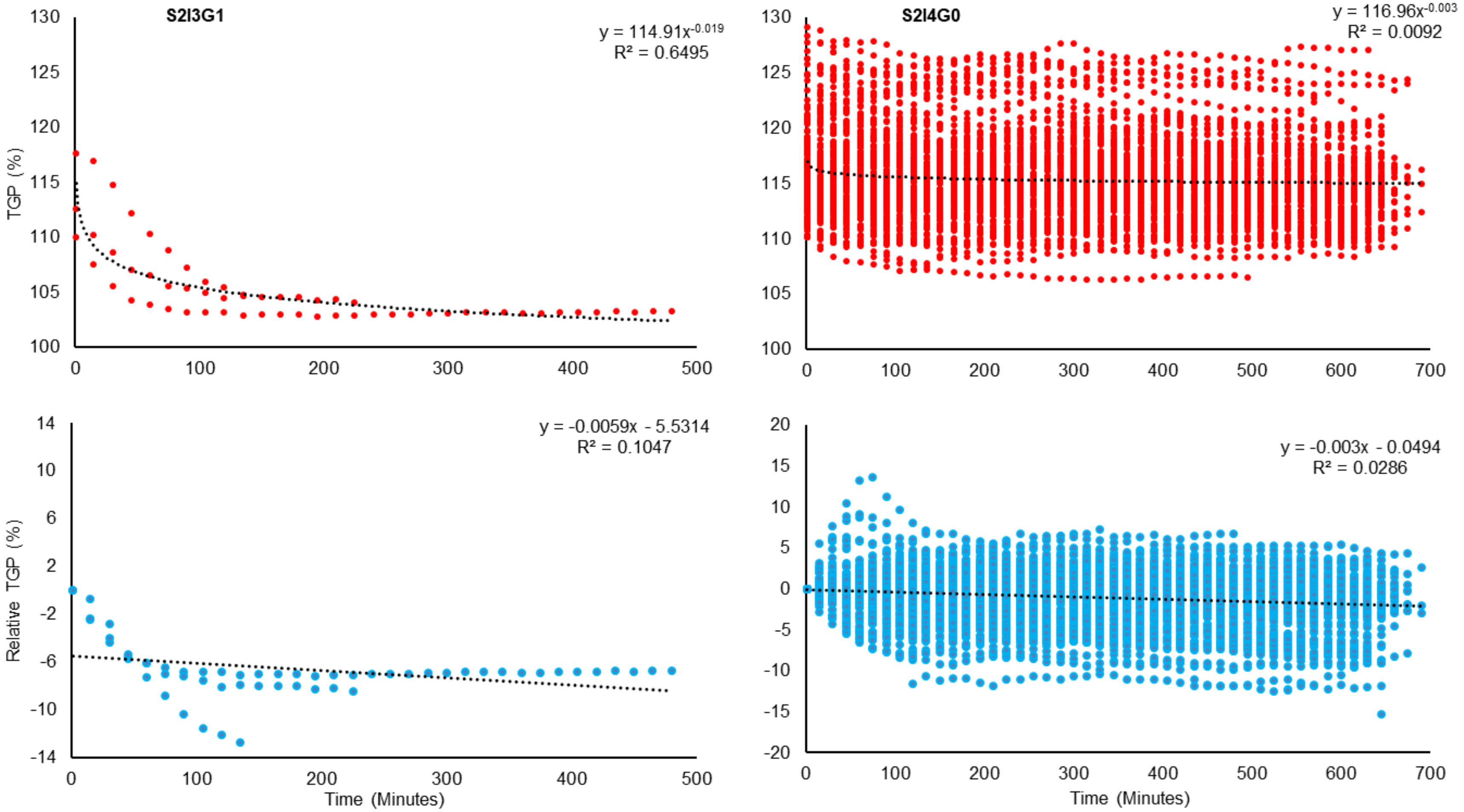

Figure 8-22. (Top) TGP (%) by time (minutes) from duration events which started above 110% for operational state S2I3G1 (n = 3; left) and S2I4G0 (n = 144; right), and (bottom) relative TGP by time for operational state S2I3G1 (left) and S2I4G0 (right); with the dotted lines (black) representing the respective linear trends. (TGP = power regression, Relative TGP = linear regression).

Table 8-5. Summary results for Figure 8-16 to Figure 8-22: TGP and relative TGP (%) by time for Mica Generating Station operational states (All Events) and events which started above 110% TGP (Events > 110% TGP); including the trend of TGP values over time, R^2 and line of fit equations for TGP (power) and Relative TGP (linear), and sample size (n).

Scenario	**State**	**Visual Trend**	**TGP**		**Relative TGP**		**n**
			R^2	**Equation**	**R^2**	**Equation**	
All Events	S0I1G5[3]	None	0.0911	$y = 101.61x^{-0.0006}$	0.0124	$y = 0.0002x - 0.1019$	2
	S0I2G4	None	<0.0001	$y = 100.77x^{0.06}$	0.0962	$y = -0.0013x - 0.3083$	13
	S0I3G3	None	0.0001	$y = 101.91x^{-0.00009}$	0.0051	$y = -0.0001x - 0.6224$	40
	S0I4G2	Some TGP Reduction	0.1305	$y = 104.02x^{-0.004}$	0.001	$y = 0.0003x - 1.2244$	45
	S1I3G2	Some TGP Reduction	0.0797	$y = 104.29x^{-0.003}$	0.1473	$y = -0.014x - 0.2978$	11
	S1I4G1	TGP Reduction	0.1071	$y = 108.08x^{-0.009}$	0.0026	$y = -0.00323x - 1.2358$	68
	S1I5G0	None	0.1199	$y = 104.73x^{0.0004}$	0.035	$y = 0.0008x + 0.1457$	1
	S2I3G1	Some TGP Reduction	0.1041	$y = 107.17x^{-0.006}$	0.2695	$y = -0.018x - 0.4304$	12
	S2I4G0	None	0.0041	$y = 109.6x^{0.0029}$	0.0095	$y = -0.0017x + 0.3684$	263
Events >110% TGP	S1I3G2	TGP Reduction	0.6807	$y = 108.29x^{-0.021}$	0.328	$y = -0.2268x - 4.534$	1
	S1I4G1	TGP Reduction	0.4908	$y = 120.02x^{-0.024}$	0.5043	$y = -0.0644x - 0.9738$	20
	S2I3G1	TGP Reduction	0.6495	$y = 114.91^{-0.019}$	0.1047	$y = -0.0059x - 5.5314$	3
	S2I4G0	None	0.0092	$y = 116.96x^{-0.003}$	0.0286	$y = -0.003x + 0.0494$	144

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[3] Serial Number = Operational State + # Generators:
where S = synchronous condense, I = idle, G = generating (example: S0I1G5 = then turbines in synchronous condense = 0, turbines idling = 1, and turbines generating = 5).

8.11 Appendix 1-6 Figures and Tables for Total Gas Pressure Extent and Residence Time

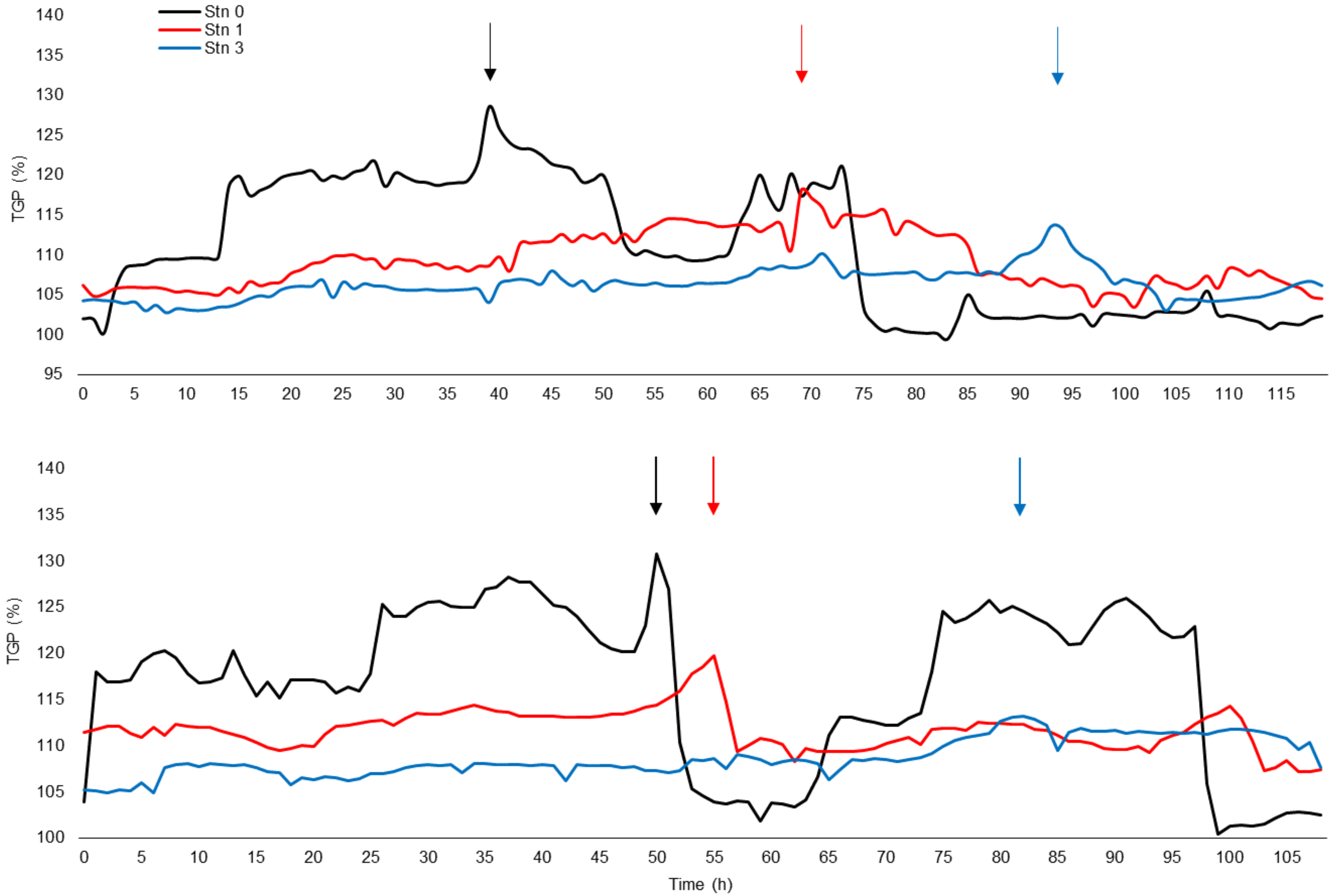


Figure 8-23. Occurrence of elevated TGP events detected on May 24 2015 (2015a; top) and June 1 2015 (2015b; bottom) at 0.3 km, depicting how TGP travelled from 0.3 km (Station 0; black), to 3.5 km (Station 1; red), and 10.5 km (Station 3; blue) from MGS over a period of 54 hours (2015a) and 33 hours (2015b).

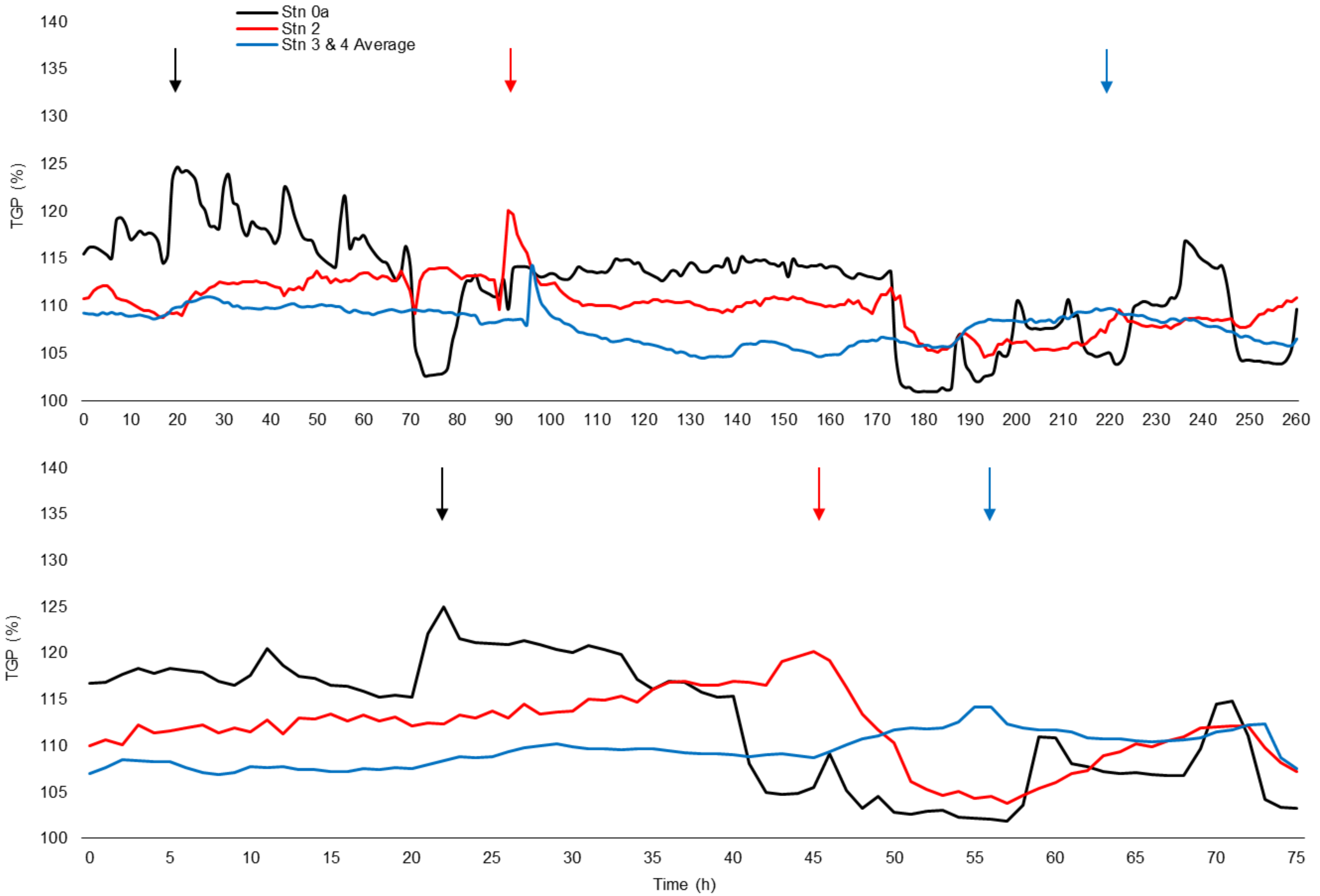


Figure 8-24. Occurrence of elevated TGP events detected May 24 2016 (2016a; top) and June 5 2016 (2016b; bottom) at 0.3 km, depicting how TGP travelled from 0.3 km (Station 0a; black), to 3.5 km (Station 2; red), and 10.5 km (average of Station 3 and 4; blue) from MGS over a period of 200 hours (2016a) and 33 hours (2016b).

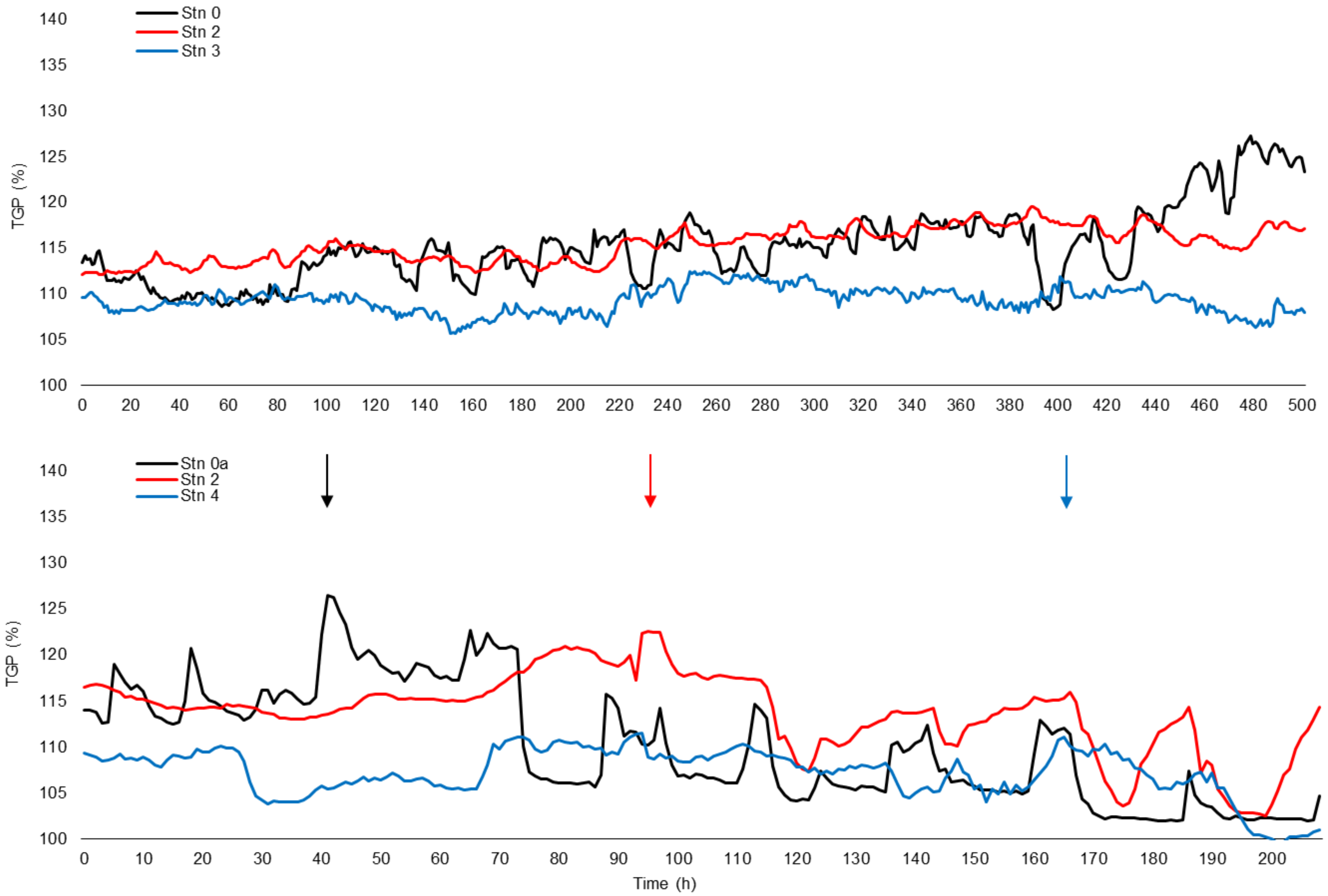


Figure 8-25. Occurrence of consistent elevated TGP detected June 13 – June 25 2020 (top) and an elevated TGP event detected June 20 2021 (bottom) at 0.3 km as it travelled from 0.3 km (2020 = Station 0; 2021 = Station 0a; black), to 3.5 km (Station 2; red), and 10.5 km (2020 = Station 3; 2021 = Station 4; blue) from MGS over a period of 305 hours (2020) and 125 hours (2021).

Table 8-6. Description of the average-daily discharge per hour (cms/h), hours with discharge (h), and travel time (h), between peaks of the same TGP event measured at different distances from MGS; used to calculate travel rate (m/h).

Year	Peak	Average-daily Discharge/Hour (cms)	Hours with Discharge (h)	Travel Time (h)	Distance Between Stations (m)	Travel Rate (m/h)
2015a	0.3 – 3.5	2.08	7	31	3,200	103
2015a	3.5 – 10.5	13.26	14	25	7,000	280
2015b	0.3 – 3.5	31.00	6	6	3,200	533
2015b	3.5 – 10.5	2.71	9	28	7,000	250
2016a	0.3 – 3.5	0.80	21	72	3,200	44
2016a	3.5 – 10.5	0.64	45	130	7,000	54
2016b	0.3 – 3.5	3.99	8	24	3,200	133
2016b	3.5 – 10.5	38.65	10	11	7,000	636
2021	0.3 – 3.5	0.44	10	125	3,200	26
2021	3.5 – 11.0	1.24	29	71	7,000	99

Table 8-7. Temporal description of the five elevated TGP events including the date and time range of the event, date and time of the peak TGP value, the peak TGP value (%), and event duration (h) measure 0.3 km from MGS, and the estimated travel rate (h/m) and plume extent (km).

Year	Date/Time Range	Peak Date	Peak Value	Event Duration (h)	Travel Rate (h/m)	Plume Extent (km)
2015a	May 23, 09:00 – May 25, 02:00	May 24, 10:00	128%	41	103	4.2
2015b	May 30, 08:00 – June 01, 11:00	June 01, 09:00	131%	52	533	27.7
2016a	May 22, 09:00 – May 26, 13:00	May 24, 11:00	126%	100	44	4.4
2016b	June 03, 12:00 – June 06, 04:00	June 5, 10:00	125%	64	133	8.5
2021	June 18, 09:00 – June 21, 18:00	June 20, 09:00	127%	81	26	2.1

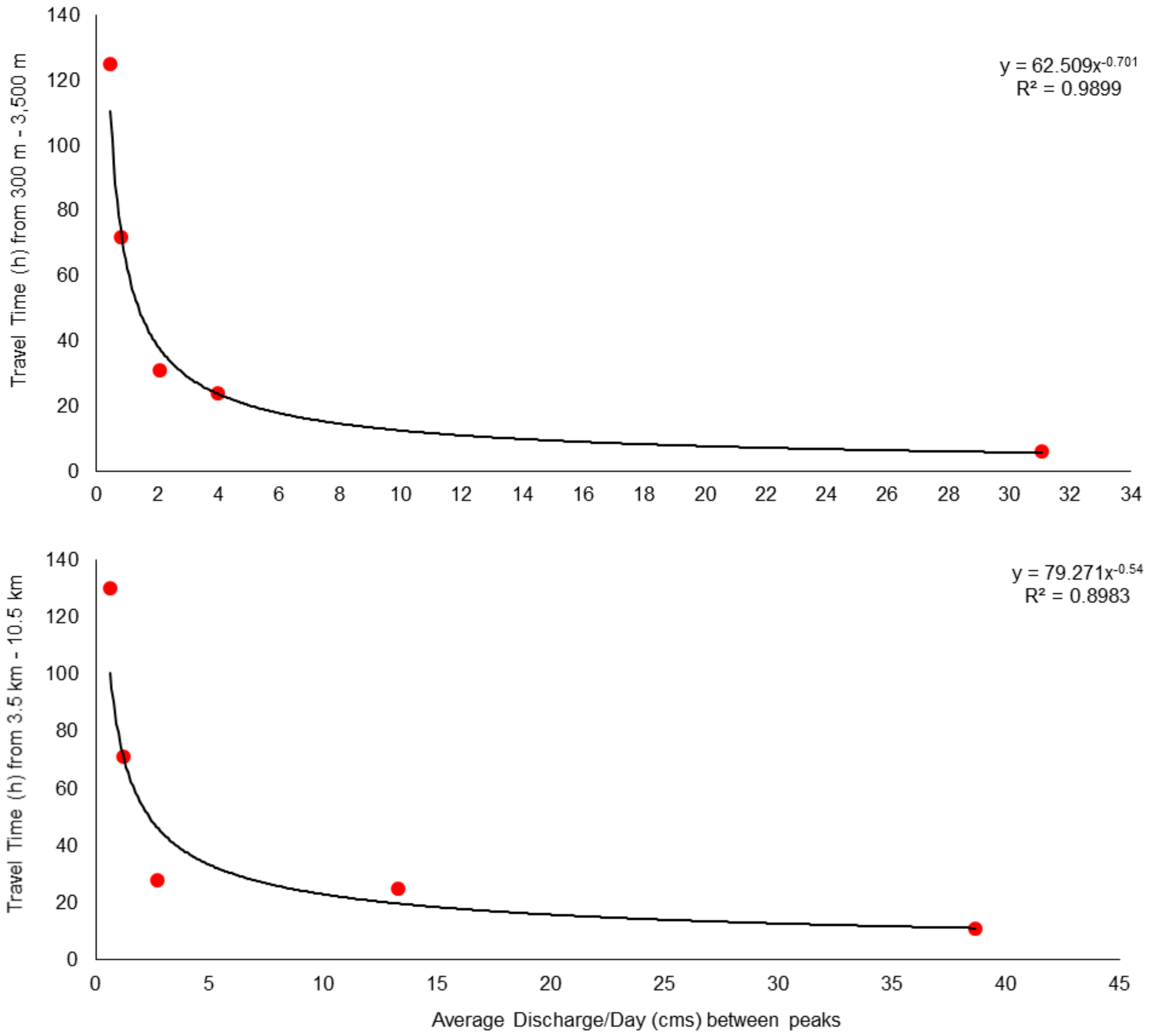


Figure 8-26. Regression equation between the average-daily discharge per hour (cms/h) between peaks of high TGP events (> 110%) and the travel time between 0.3 km and 3.5 km (top), and 3.5 km to 10.5 km (bottom).

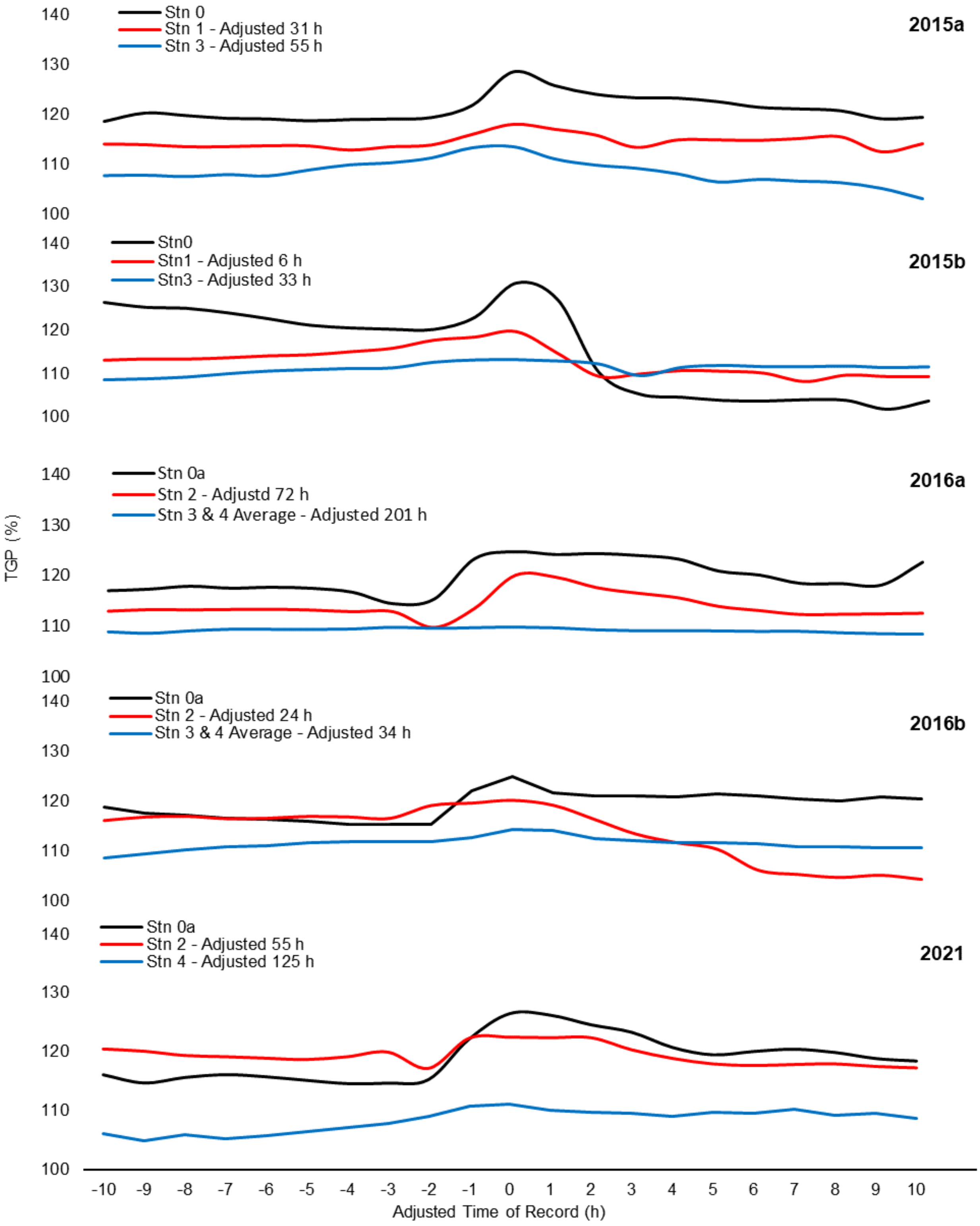


Figure 8-27. Elevated TGP (%) events measured at 0.3 km (Station 0 and 0a), 3.5 km (Station 1 and 2), and 10.5/11.0 km (Station 3 and 4) observed in 2015, 2016, and 2021; with the time of record adjusted to display TGP levels at the different distances concurrently.

Table 8-8. Difference of TGP (%) recorded at various distances (0.3 km, 3.5 km, 10.5 km and 11.0 km) from MGS after adjusting the time of record for TGP values recorded 3.5 km, 10.5 km, and 11.0 km from MGS to reflect the initial event record at 0.3 km.

Timeframe				**TGP at Distance**				**TGP Reduction**					
Year	**Month**	**Day**	**Hour**	**300**	**3,500**	**7,000**	**7,500**	**0.3-3.5**	**3.5-10.5**	**3.5-11.0**	**0.3-10.5**	**0.3-11.0**	**0.3-10.75**
2015	5	24	0	118.55	114.04	107.69		4.51	6.35		10.86		10.86
2015	5	24	1	120.25	113.91	107.76		6.34	6.15		12.49		12.49
2015	5	24	2	119.74	113.49	107.49		6.25	6.00		12.25		12.25
2015	5	24	3	119.18	113.51	107.89		5.66	5.63		11.29		11.29
2015	5	24	4	119.05	113.71	107.61		5.34	6.10		11.44		11.44
2015	5	24	5	118.68	113.66	108.81		5.01	4.85		9.86		9.86
2015	5	24	6	118.91	112.84	109.85		6.07	2.99		9.06		9.06
2015	5	24	7	119.03	113.50	110.26		5.53	3.24		8.76		8.76
2015	5	24	8	119.34	113.85	111.25		5.49	2.60		8.09		8.09
2015	5	24	9	121.83	116.00	113.29		5.83	2.71		8.54		8.54
2015	5	24	10	128.55	118.01	113.50		10.54	4.51		15.05		15.05
2015	5	24	11	125.78	117.03	111.05		8.75	5.98		14.73		14.73
2015	5	24	12	124.04	115.88	109.80		8.16	6.08		14.24		14.24
2015	5	24	13	123.31	113.38	109.16		9.94	4.21		14.15		14.15
2015	5	24	14	123.25	114.86	108.06		8.39	6.80		15.19		15.19
2015	5	24	15	122.53	114.88	106.40		7.65	8.47		16.13		16.13
2015	5	24	16	121.40	114.78	106.91		6.63	7.86		14.49		14.49
2015	5	24	17	121.06	115.15	106.56		5.91	8.59		14.50		14.50
2015	5	24	18	120.70	115.50	106.26		5.20	9.24		14.44		14.44
2015	5	24	19	119.09	112.48	105.11		6.61	7.36		13.98		13.98
2015	5	24	20	119.38	114.10	103.04		5.27	11.06		16.34		16.34
2015	5	31	23	126.34	113.13	108.46		13.21	4.66		17.88		17.88
2015	6	1	0	125.23	113.43	108.70		11.80	4.73		16.53		16.53
2015	6	1	1	124.98	113.39	109.11		11.59	4.27		15.86		15.86
2015	6	1	2	123.95	113.70	109.90		10.25	3.80		14.05		14.05
2015	6	1	3	122.58	114.14	110.53		8.44	3.61		12.05		12.05
2015	6	1	4	121.10	114.39	110.84		6.71	3.55		10.26		10.26
2015	6	1	5	120.48	115.11	111.14		5.36	3.98		9.34		9.34

Timeframe				TGP at Distance				TGP Reduction					
Year	**Month**	**Day**	**Hour**	**300**	**3,500**	**7,000**	**7,500**	**0.3-3.5**	**3.5-10.5**	**3.5-11.0**	**0.3-10.5**	**0.3-11.0**	**0.3-10.75**
2015	6	1	6	120.16	115.91	111.26		4.25	4.65		8.90		8.90
2015	6	1	7	120.15	117.78	112.60		2.37	5.18		7.55		7.55
2015	6	1	8	122.96	118.50	113.11		4.46	5.39		9.85		9.85
2015	6	1	9	130.79	119.73	113.19		11.06	6.54		17.60		17.60
2015	6	1	10	126.96	114.71	112.88		12.25	1.84		14.09		14.09
2015	6	1	11	110.29	109.39	112.18		0.90	-2.79		-1.89		-1.89
2015	6	1	12	105.26	109.95	109.45		-4.69	0.50		-4.19		-4.19
2015	6	1	13	104.59	110.73	111.38		-6.14	-0.65		-6.79		-6.79
2015	6	1	14	103.85	110.58	111.84		-6.72	-1.26		-7.99		-7.99
2015	6	1	15	103.69	110.15	111.54		-6.46	-1.39		-7.85		-7.85
2015	6	1	16	104.01	108.20	111.53		-4.19	-3.33		-7.51		-7.51
2015	6	1	17	103.86	109.69	111.69		-5.83	-2.00		-7.83		-7.83
2015	6	1	18	101.83	109.35	111.33		-7.53	-1.97		-9.50		-9.50
2015	6	1	19	103.73	109.35	111.51		-5.63	-2.16		-7.79		-7.79
2016	5	24	1	117.03	112.88	108.88		4.15	4.00		8.15		8.15
2016	5	24	2	117.33	113.20	108.63		4.12	4.58		8.70		8.70
2016	5	24	3	117.90	113.15	109.06		4.75	4.09		8.84		8.84
2016	5	24	4	117.53	113.23	109.35		4.30	3.88		8.18		8.18
2016	5	24	5	117.70	113.28	109.34		4.43	3.94		8.36		8.36
2016	5	24	6	117.50	113.10	109.30		4.40	3.80		8.20		8.20
2016	5	24	7	116.73	112.78	109.40		3.95	3.38		7.32		7.32
2016	5	24	8	114.50	112.78	109.70		1.72	3.08		4.80		4.80
2016	5	24	9	115.38	109.63	109.53		5.75	0.10		5.85		5.85
2016	5	24	10	123.28	113.47	109.64		9.81	3.83		13.64		13.64
2016	5	24	11	124.63	120.05	109.74		4.58	10.31		14.89		14.89
2016	5	24	12	124.08	119.65	109.60		4.43	10.05		14.48		14.48
2016	5	24	13	124.28	117.58	109.24		6.70	8.34		15.04		15.04
2016	5	24	14	123.90	116.48	109.08		7.43	7.40		14.83		14.83
2016	5	24	15	123.20	115.55	109.11		7.65	6.44		14.09		14.09
2016	5	24	16	120.85	113.83	109.05		7.02	4.78		11.80		11.80

Timeframe				**TGP at Distance**				**TGP Reduction**					
Year	**Month**	**Day**	**Hour**	**300**	**3,500**	**7,000**	**7,500**	**0.3-3.5**	**3.5-10.5**	**3.5-11.0**	**0.3-10.5**	**0.3-11.0**	**0.3-10.75**
2016	5	24	17	120.08	113.00	108.96		7.08	4.04		11.11		11.11
2016	5	24	18	118.45	112.23	108.98		6.22	3.25		9.47		9.47
2016	5	24	19	118.40	112.28	108.71		6.12	3.56		9.69		9.69
2016	5	24	20	118.15	112.35	108.54		5.80	3.81		9.61		9.61
2016	5	24	21	122.58	112.48	108.46		10.10	4.01		14.11		14.11
2016	6	5	0	118.73	116.13	108.69		2.60	7.44		10.04		10.04
2016	6	5	1	117.48	116.83	109.35		0.65	7.47		8.13		8.13
2016	6	5	2	117.25	116.98	110.16		0.27	6.81		7.09		7.09
2016	6	5	3	116.58	116.50	110.78		0.08	5.72		5.80		5.80
2016	6	5	4	116.40	116.58	111.10		-0.17	5.48		5.30		5.30
2016	6	5	5	115.88	116.95	111.68		-1.08	5.28		4.20		4.20
2016	6	5	6	115.23	116.83	111.90		-1.60	4.92		3.32		3.32
2016	6	5	7	115.43	116.58	111.88		-1.15	4.70		3.55		3.55
2016	6	5	8	115.28	119.15	111.93		-3.87	7.22		3.35		3.35
2016	6	5	9	122.13	119.63	112.63		2.50	7.00		9.50		9.50
2016	6	5	10	124.98	120.18	114.24		4.80	5.94		10.74		10.74
2016	6	5	11	121.63	119.18	114.18		2.45	5.00		7.45		7.45
2016	6	5	12	121.13	116.35	112.41		4.78	3.94		8.71		8.71
2016	6	5	13	121.00	113.43	111.99		7.58	1.44		9.01		9.01
2016	6	5	14	120.93	111.68	111.70		9.25	-0.02		9.23		9.23
2016	6	5	15	121.40	110.35	111.71		11.05	-1.36		9.69		9.69
2016	6	5	16	120.95	106.15	111.54		14.80	-5.39		9.41		9.41
2016	6	5	17	120.35	105.28	110.81		15.08	-5.54		9.54		9.54
2016	6	5	18	120.10	104.68	110.78		15.43	-6.10		9.32		9.32
2016	6	5	19	120.80	105.13	110.73		15.68	-5.60		10.08		10.08
2016	6	5	20	120.40	104.30	110.56		16.10	-6.26		9.84		9.84
2017	5	22	1	112.63	105.15			7.47					
2017	5	22	2	112.15	105.15			7.00					
2017	5	22	3	111.68	105.13			6.55					
2017	5	22	4	111.15	105.28			5.88					

Timeframe				**TGP at Distance**				**TGP Reduction**					
Year	**Month**	**Day**	**Hour**	**300**	**3,500**	**7,000**	**7,500**	**0.3-3.5**	**3.5-10.5**	**3.5-11.0**	**0.3-10.5**	**0.3-11.0**	**0.3-10.75**
2017	5	22	5	110.70	106.00			4.70					
2017	5	22	6	110.28	106.60			3.68					
2017	5	22	7	109.98	107.60			2.38					
2017	5	22	8	109.80	108.45			1.35					
2017	5	22	9	110.08	108.58			1.50					
2017	5	22	10	113.28	108.58			4.70					
2017	5	22	11	114.25	109.35			4.90					
2017	5	22	12	104.40	105.70			-1.30					
2017	5	22	13	101.85	104.00			-2.15					
2017	5	22	14	101.93	103.45			-1.53					
2017	5	22	15	102.00	102.33			-0.32					
2017	5	22	16	101.78	102.20			-0.42					
2017	5	22	17	101.85	101.93			-0.08					
2017	5	22	18	101.65	101.48			0.17					
2017	5	22	19	101.78	100.78			1.00					
2017	5	22	20	101.08	100.38			0.70					
2017	5	22	21	100.73	100.35			0.38					
2021	6	19	23	116.18	120.55		106.18	-4.37		14.38		10.00	10.00
2021	6	20	0	114.80	120.18		104.85	-5.37		15.33		9.95	9.95
2021	6	20	1	115.73	119.45		105.88	-3.73		13.58		9.85	9.85
2021	6	20	2	116.20	119.23		105.25	-3.02		13.98		10.95	10.95
2021	6	20	3	115.85	118.98		105.68	-3.13		13.30		10.18	10.18
2021	6	20	4	115.25	118.75		106.40	-3.50		12.35		8.85	8.85
2021	6	20	5	114.70	119.23		107.20	-4.53		12.03		7.50	7.50
2021	6	20	6	114.78	120.03		107.90	-5.25		12.13		6.88	6.88
2021	6	20	7	115.38	117.25		109.00	-1.88		8.25		6.38	6.38
2021	6	20	8	122.23	122.40		110.80	-0.17		11.60		11.43	11.43
2021	6	20	9	126.53	122.58		111.10	3.95		11.48		15.43	15.43
2021	6	20	10	126.25	122.48		110.10	3.78		12.38		16.15	16.15
2021	6	20	11	124.63	122.48		109.70	2.15		12.78		14.93	14.93

Timeframe				TGP at Distance				TGP Reduction					
Year	**Month**	**Day**	**Hour**	**300**	**3,500**	**7,000**	**7,500**	**0.3-3.5**	**3.5-10.5**	**3.5-11.0**	**0.3-10.5**	**0.3-11.0**	**0.3-10.75**
2021	6	20	12	123.35	120.40		109.53	2.95		10.88		13.83	13.83
2021	6	20	13	120.80	118.95		109.05	1.85		9.90		11.75	11.75
2021	6	20	14	119.55	118.00		109.78	1.55		8.22		9.77	9.77
2021	6	20	15	120.13	117.73		109.63	2.40		8.10		10.50	10.50
2021	6	20	16	120.50	117.90		110.30	2.60		7.60		10.20	10.20
2021	6	20	17	119.95	118.00		109.28	1.95		8.72		10.68	10.68
2021	6	20	18	118.93	117.58		109.50	1.35		8.08		9.43	9.43
2021	6	20	19	118.50	117.33		108.63	1.17		8.70		9.88	9.88

Table 8-9. Summary of TGP reduction (%) by distance (km), including summary statistic descriptions, based on Table 8.6 data.

Stat. Description	**TGP Reduction (%) by Distance (km)**					
	0.3 - 3.5	**3.5 - 10.5**	**3.5 - 11.0**	**0.3 - 10.5**	**0.3 - 11.0**	**0.3 - 10.75**
Average	3.71	3.72	11.13	8.84	10.69	9.21
Standard Deviation	5.18	3.84	2.41	6.44	2.59	5.91
n	126	84	21	84	21	105
Error (95% CI)	0.90	0.82	1.03	1.38	1.11	1.13

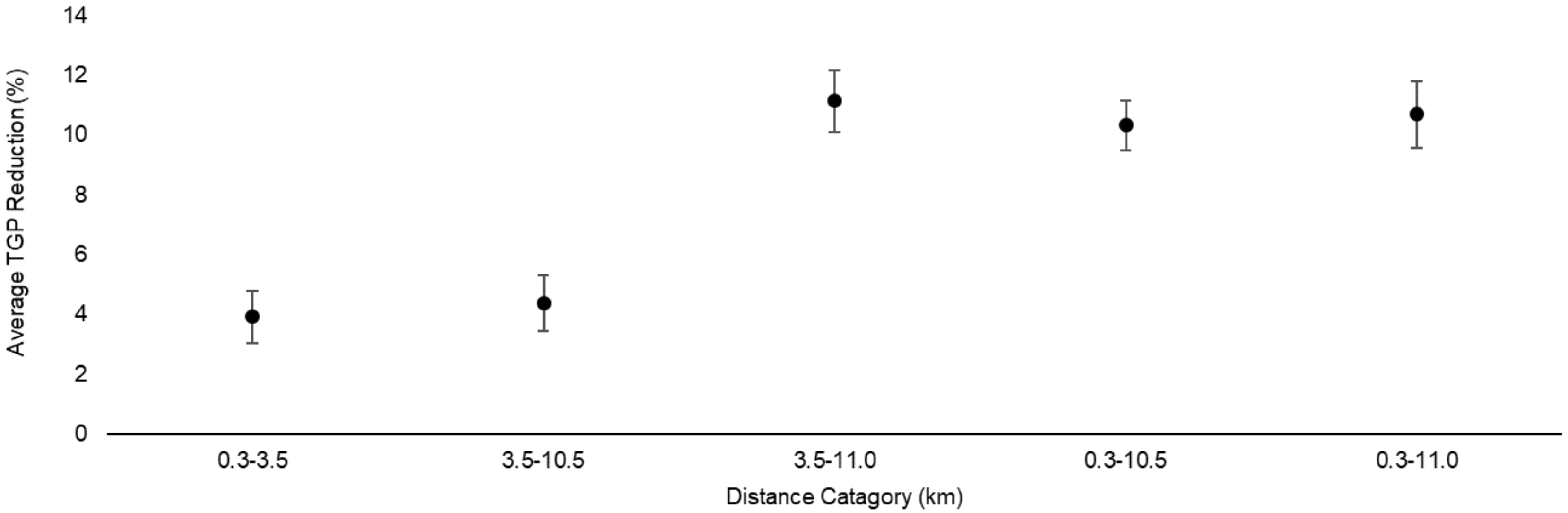


Figure 8-28. Average TGP reduction (%) by distance (km) between station locations at 0.3 km, 3.5 km, 10.5 km, and 11 km.

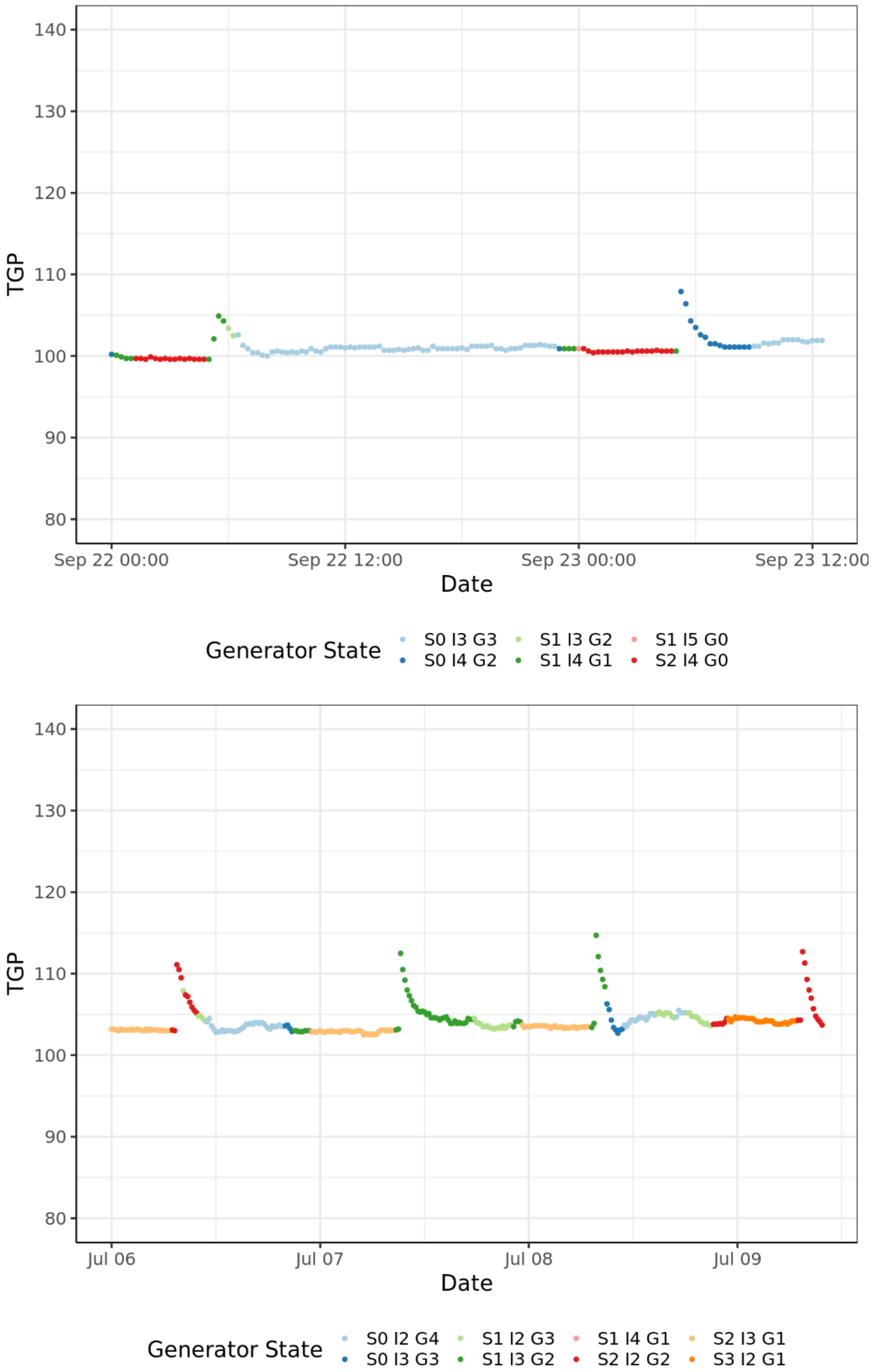


Figure 8-29. Example of instances when short-term, sudden, abrupt spikes in TGP occur (measured at Station 0) following SC operation events and decrease when the number of units in generation increase (top = 2016, bottom = 2021).

9.0 Appendix 2: Technical Report for Management Question # 2

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

9.1 Introduction

This analysis was used to assess whether synchronous condense (SC) operations at Mica Generating Station (MGS) changed with the installation of Mica Units 5 and 6, and whether this change would represent a significant increase in total gas pressure (TGP) exposure for downstream aquatic environments. The null hypothesis in the Terms of Reference (TOR) is as follows (BC Hydro 2014):

$H_{0}2$: *There is no significant change in the duration, frequency or intensity of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use.*

For analysis, this null hypothesis was separated into three separate null hypotheses:

$H_{0}2_{a}$: *There is no significant change in the duration of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use.*

$H_{0}2_{b}$: *There is no significant change in the frequency of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use.*

$H_{0}2_{c}$: *There is no significant change in the intensity of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use.*

The management hypotheses are based on the use of Units 5 and 6, which were online in 2015. However, Units 5 and 6 were not operating in SC regularly (> 50 hours in a year) until 2018 and 2021 respectively. Therefore, $H_{0}2_{a\text{-}c}$ were each separated into three null hypotheses to address the timeline of SC usage of the new units:

$H_{0}2_{a1}$: *There is no significant change in the duration of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 installation/operation in 2015.*

$H_{0}2_{a2}$: *There is no significant change in the duration of synchronous condense operations at the Mica Project resulting from Unit 5 commencing synchronous condense operations in 2018.*

$H_{0}2_{a3}$: *There is no significant change in the duration of synchronous condense operations at the Mica Project resulting from Unit 6 commencing synchronous condense operations in 2021.*

$H_{0}2_{b1}$: *There is no significant change in the frequency of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 installation/operation in 2015.*

$H_{0}2_{b2}$: *There is no significant change in the frequency of synchronous condense operations at the Mica Project resulting from Unit 5 commencing synchronous condense operations in 2018.*

$H_{0}2_{b3}$: *There is no significant change in the frequency of synchronous condense operations at the Mica Project resulting from Unit 6 commencing synchronous condense operations in 2021.*

$H_{0}2_{c1}$: *There is no significant change in the intensity of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 installation/operation in 2015.*

H_02_{c2}: There is no significant change in the intensity of synchronous condense operations at the Mica Project resulting from Unit 5 commencing synchronous condense operations in 2018.

H_02_{c3}: There is no significant change in the intensity of synchronous condense operations at the Mica Project resulting from Unit 6 commencing synchronous condense operations in 2021.

The final null hypothesis was added to address the final aspect of the management question:

H_02_d: There is no significant increase in TDG exposure for downstream aquatic environments from changes in synchronous condense operations at Mica Dam with the installation Unit 5 and 6 (if any).

This analysis was completed by comparing SC operations at MGS before and after the installation of Mica Units 5 and 6 (H_02_{ax} – H_02_{cx}), and using TGP analysis from Management Question 1 (Appendix 1) to assess TDG exposure potential under the new operating regime for null hypothesis H_02_d.

The terms *Duration*, *Frequency*, *Intensity*, *Operational State* and *Significant Increase* had a specific interpretation given their context in the null hypotheses:

Duration	The number of consecutive hours where MGS had at least one of the six generational units in SC mode.
Frequency	The number of SC events at MGS, where an event is an occurrence of SC operation for at least two consecutive hours with at least one of the six units in SC mode. *Note: an occurrence of SC operation for six hours would be a frequency of one and a duration of six.*
Intensity	Intensity of operational state (relating to TGP potential, determined by the frequency and duration of SC events without any other units generating), where more frequent and longer duration SC events without generation equals more intense SC as it relates to potential TGP production.
Operational State	The overall operational state at MGS, accounting for all 6 generators (example: on a given hour there is one unit in SC, two idling, and three generating, therefore, the operational state at MGS is S1I2G3).
Significant Increase	Typically considered statistically significant with 95% confidence (critical value of 0.05) unless considered biologically significant (not statistically significant, but could be interpreted as impactful from a biological standpoint); in which case will be explained in the respective H_0 discussion.

9.2 Methods

Hypotheses H_02_{ax} - H_02_{cx} (no significant change in duration, frequency, or intensity of SC operations) were specific to MGS operations and fieldwork was not required to collect operational data; instead the dataset used for analysis was provided by BC Hydro on January 28 2022. The field methods for TGP data collection are described in Appendix 1. In 2020 and 2021 the project team requested specific operations at MGS to maximize TGP data collection in relation SC operations of Units 5 and 6. These requests may have artificially increased SC operations (duration and frequency) for these specific monitoring periods. In addition, the project team in 2017 recommended a few hours of generation following eight hours of continuous SC operations (without any generation) in an attempt to reduce the frequency of high (> 110%) TGP events. The influence of project team requests/recommendations will be considered while interpreting the results of analysis.

9.2.1 Datasets

The dataset *MGS Generation (MW) 2010-2021* was used for all analysis in this section. This data consisted of hourly generation (in MW) for all six units between January 1 2010 at 00:00 and December 31 2021 at 23:00. Operational data was used to interpret generator states at a given time. The assumptions for this dataset are:

1. Each generator state had an equal probability of running for each hour (e.g. generation operations are not purposefully scheduled between hours),

2. Where consecutive hours display the same operational state, that state was the primary operation between hours,

3. If operational states are changed between hours, there is equal probability of states changing between hours before/after the installation of Units 5 and 6,

4. When a unit displayed positive MW, water was flowing through the unit generating power (generating). When the unit displayed zero MW, the unit was neither producing nor using power (idle). When a unit displayed negative MW, the generator was using power to inject air and spin the turbine (synchronous condense). Therefore:

“Generating (G)” = MW > 0 – Unit is generating power
“Idle (I)” = MW = 0 – Unit is neither creating nor using power
“Synchronous Condense (SC)” = MW < 0 – Unit is using power

The dataset was transformed from MW into operational states in Excel (2016) using the function: *=IF(X>0,"G",IF(X=0,"I",IF(X<0,"SC")))*, where “X” is each individual cell containing operational data. The overall MGS operational state for a given hour was identified by a serial number containing the abbreviated operation followed by the number of units in that operation; therefore, if an operational state at time X = S2I4G0, then turbines in synchronous condense = 2, turbines idling = 4, and turbines generating = 0. If generators were designated a text field for a given hour “Shutdown”, “Timeout”, or “Invalid Data”), they were omitted from the serial number.

In total, the dataset contained 102,100 hours of operational data for generators 1-4 between 2010 and 2021. Units 5 and 6 contain less data since they came online in 2015.

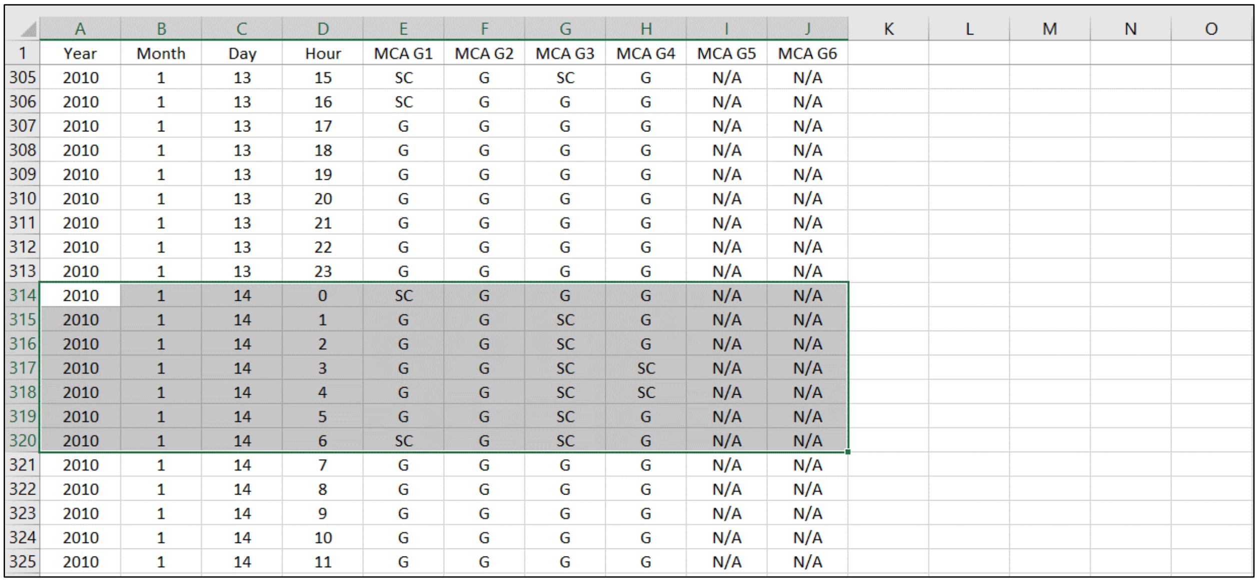
9.2.2 Analyses

Data were sorted and organized depending on the H_0 being analysed. However, all analyses used the operational designations described in *9.2.1 Dataset*.

i) Sorting Data to Assess Changes of Synchronous Condense Use at Mica Generating Station

The process of sorting and preparing the data for analysis was similar for all three variables identified in the null hypotheses (duration, frequency, and intensity of SC operations), with few minor changes. The data were sorted by SC event, where an “event” was an occurrence of at least two consecutive hours where at least one generator was in SC (Figure 9-1). Events were designated an event number in chronological order for each month and year. The number of events became the frequency of SC operations, while the number of consecutive hours were used for duration analysis. If a SC event occurred between months (e.g. the event spanned the last two hours in March and the first ten hours of April), the event would be included in the month it began. SC events that occurred between years (December 2018 into January 2019), were included in the year they began. All variables were sorted into their own tables monthly by year, where the first column contained the specific month for all years (one table for January 2010 – 2021, another for February 2010 – 2021, etc.) and the second column contained the variable (duration in hours or frequency as number of events).

It was assumed that SC operations occurred during the hours that were labelled "SC", however it is possible that the generator state changed briefly between hours (e.g. generator state is SC at 6:00 but was changed to G at 6:15 – 6:30 and changed back to SC at 7:00). The probability of generator states changing between hours is assumed to be the same before and after the installation of Units 5 and 6.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Year	Month	Day	Hour	MCA G1	MCA G2	MCA G3	MCA G4	MCA G5	MCA G6					
305	2010	1	13	15	SC	G	SC	G	N/A	N/A					
306	2010	1	13	16	SC	G	G	G	N/A	N/A					
307	2010	1	13	17	G	G	G	G	N/A	N/A					
308	2010	1	13	18	G	G	G	G	N/A	N/A					
309	2010	1	13	19	G	G	G	G	N/A	N/A					
310	2010	1	13	20	G	G	G	G	N/A	N/A					
311	2010	1	13	21	G	G	G	G	N/A	N/A					
312	2010	1	13	22	G	G	G	G	N/A	N/A					
313	2010	1	13	23	G	G	G	G	N/A	N/A					
314	2010	1	14	0	SC	G	G	G	N/A	N/A					
315	2010	1	14	1	G	G	SC	G	N/A	N/A					
316	2010	1	14	2	G	G	SC	G	N/A	N/A					
317	2010	1	14	3	G	G	SC	SC	N/A	N/A					
318	2010	1	14	4	G	G	SC	SC	N/A	N/A					
319	2010	1	14	5	G	G	SC	G	N/A	N/A					
320	2010	1	14	6	SC	G	SC	G	N/A	N/A					
321	2010	1	14	7	G	G	G	G	N/A	N/A					
322	2010	1	14	8	G	G	G	G	N/A	N/A					
323	2010	1	14	9	G	G	G	G	N/A	N/A					
324	2010	1	14	10	G	G	G	G	N/A	N/A					
325	2010	1	14	11	G	G	G	G	N/A	N/A					

Figure 9-1. Screenshot from Excel (2016) depicting the MGS Generation (MW) 2010-2021 Dataset after conversion from MW to Generational States, highlighting a Synchronous Condense event with a duration of 6 hours between January 14 2010 at 0:00 and January 14 2010 at 6:00.

<u>Deviation: Duration</u>

Instances where a single SC event occurred between G or I events were not considered for duration analysis due to the uncertainty of duration (i.e. if three consecutive hours had operational states of S0I0G6, S2I0G4, S0I0G6 it is less certain that SC was operating for a full hour than if two consecutive hours had SC operations – S2I0G4, S2I0G4, S0I0G6). Therefore, duration data for analysis were the number of consecutive hours of SC in the dataset minus one (adjusted duration), to account for the fact that a unit was not likely operated for all of the hours that the SC state was shown. Therefore, in general, frequency of duration events was lower than the frequency of SC events in the analysis. The specific generator and number of generators in SC mode during an event did not factor into this analysis as it was specifically looking at SC duration.

Deviation: Frequency
For duration, each event represented an individual data point for analysis. In contrast, the frequency data were grouped by month (events per month rather than number of events) to reduce the influence of autocorrelation. Due to the nature of the dataset (operational regime), if a unit was in a particular operational mode, the probability of that unit being in the same mode the following hour was very high. Grouping the number of events by month reduced sample size, but also reduced the influence of autocorrelation.

Deviation: Intensity
Results in Appendix 1 indicated SC without generation (SxG0) was associated with elevated TGP, specifically when operating in ≥ 8 h durations; the number of units in SC without generation did not appear to influence this result. Therefore, an increase of SC intensity was accepted if SxG0 frequency and average duration increased after Units 5 and 6 were installed and/or capable of SC. The frequency of SxG0 events ≥ 8 h durations was also tested. The previous datasets used for SC duration and frequency did not consider the number of generators in SC mode during an event or what operational state the other generators were operating in; for instance the discrepancy between SxG0 and SC with generation (SxGx). Therefore, the sample size for frequency and duration of SC events for intensity were different from other datasets.

ii) Analysis to Assess Changes of Synchronous Condense use at Mica Generating Station

Residuals for duration (# of hours), frequency (# of events), and intensity (frequency and duration of SxG0) were used for comparative analysis to reduce data variability. Values were sorted by month for 2010 – 2021 (January 2010 – 2021 in one column, February 2010 – 2021 in another column, etc.). The 12-year means for each month were subtracted from the individual values in that respective month to obtain the Z-score (residual).

The residual data were then sorted for analysis based on the specific null hypothesis to test:

H_02_{x1} = Comparison of years 2010-2014 (baseline) to 2016-2020 (Test 1: post Unit 5/6 installation)

H_02_{x2} = Comparison of years 2010-2014 (baseline) to 2018-2021 (Test 2: post Unit 5 SC operation)

H_02_{x3} = Comparison of years 2010-2014 (baseline) to 2021 (Test 3: post Unit 6 SC operation)

As Unit 5 was operational in February of 2015 and Unit 6 was operational in December of 2015, the 2015 data was omitted for comparative analyses. These tests were not independent as Test 1 included years (2018 – 2020) when Unit 5 was operating in SC, and Test 2 included a year (2021) when Unit 6 was operating in SC. However, the interest was in the difference between the test and the baseline, not between the tests themselves. Overlapping test years were included to equal the number of years, and maintain a similar sample sizes (ratio ≤ 1.5) to baseline data (2010 – 2014) when possible. Only one year was available for post Unit 6 SC operation, so results for Test 3 were not considered significant. Instead results were considered “consistent” or “inconsistent” to baseline averages.

To test null hypotheses, the residual datasets were uploaded to R Project (R i386 4.1.2) and a two-way analysis of variance (ANOVA) with interaction was completed using R libraries ggplot2, ggpubr, tidyverse, broom, and ALCcmodavg. Interaction was included to identify whether among-month variability concealed the overall effect of the pre/post comparison. Results were deemed significant if the p-value (p) was less than 0.05 (95% confidence).

The assumptions of an ANOVA are as follows:

1. The populations from which the samples are obtained are normally distributed.
2. Observations for within and between groups must be independent.
3. The variances among populations are equal (homoscedastic).
4. Data are interval or nominal.

ANOVA has shown to be robust against Type 1 error when departures from normality and sample size occur (Blanca et *al.* 2017). If among-month variability was statistically significant ($p < 0.05$), a one-way ANOVA was completed comparing each month in the baseline/test dataset. To reduce Type 1 error (false positive) during this process, the Bonferroni correlation was implemented to interpret results: The critical value (0.05) was divided by the number of variables (12 months) to achieve a more robust significance level (0.004); reducing the chance of Type 1 errors (Simas et *al*. 2014).

To test overall differences SC frequency, the residual datasets were uploaded to R Project and a Welch t-test was conducted, because the assumption of equal variance is not required. Results were deemed significant if the $p < 0.05$ (95% confidence).
The assumptions of a Welch t-test are as follows:

1. The populations from which the samples are obtained are normally distributed.
2. Observations for within and between groups must be independent.

iii) Addressing Changes of Total Dissolved Gas Exposure for Downstream Aquatic Environments from Changes in Synchronous Condense Operations

To assess potential changes of TGP exposure in downstream aquatic environments from changes of SC operations due to the installation of Unit 5 and 6 (if any), results from analyses for $H_02_{x1\text{-}3}$ were compared to results from Appendix 1.

9.3 Results

SC usage at MGS appeared to have increased after the installation of Unit 5 and 6 in 2015, and has remained consistent after Units 5 and 6 were capable of SC in 2018 and 2021 respectively (Figure 9-2). SxGx use increased by 11 – 13% over 2010 – 2014, while SxG0 use increased by 4%. Specific SxG0 operations included 1 – 4 units in SC concurrently (5 – 6 units in SC concurrently was not recorded). When comparing the proportion of use for the number of units in SxG0 between 2010 – 2014 and 2018 – 2021, S1G0 use increased from 0.11 – 3%, S2G0 use decreased from 87 – 84%, S3G0 use remained constant at 13%, and S4G0 use was similar at 0.28 – 0.20% respectively.

A significant difference in SC duration and frequency was detected under certain conditions. A summary of results is provided in Table 9-1, while detailed results are presented in the following sections.

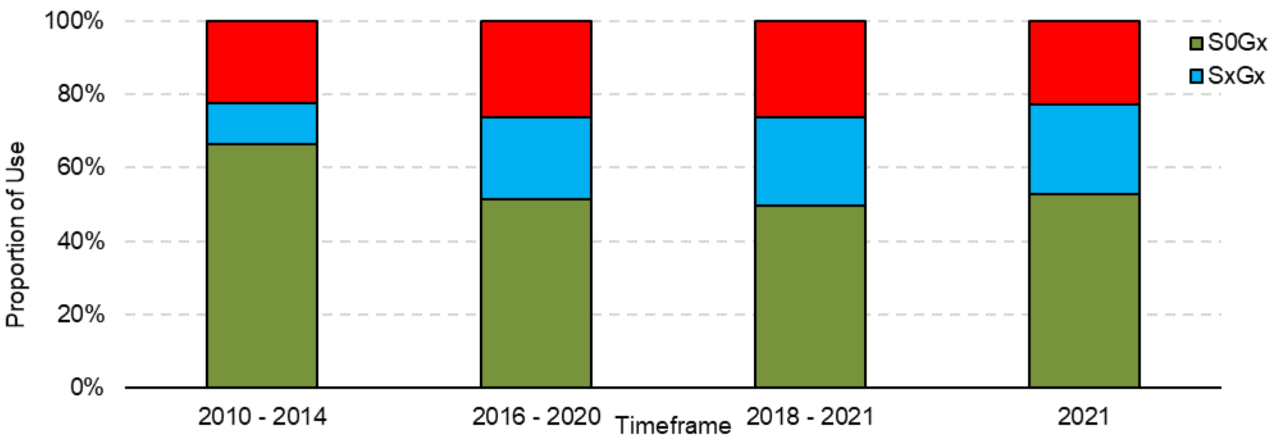


Figure 9-2. Proportion (%) of Mica Generating Station operation hours (S0Gx = generation without synchronous condense, SxGx = synchronous condense with generation, and SxG0 = synchronous condense without generation) by timeframe (2010 – 2014 = baseline, n = 43,814; 2016 – 2020 = post Unit 6/5 installation, n = 43,613; 2018 – 2021 = post Unit 5 synchronous condense operation, n = 34,817; and 2021 = post Unit 6 synchronous condense operation, n = 8,727).

Table 9-1. Summary of SC duration, frequency and intensity results, including a comparison of baseline and test averages for duration (h = hours) and frequency (e/m = events per month) and associated p-value (significance = < 0.05) by variable and test, where: Test 1 = 2010-2014 (baseline) vs 2016-2020 (post Unit 5/6 installation), Test 2 = 2010-2014 (baseline) vs 2018-2021 (post Unit 5 synchronous condense operation), and Test 3 = 2010-2014 (baseline) vs 2021 (post Unit 6 synchronous condense operation). Green underlined rows have data sets with significant differences.

Variable	Baseline Average	Test Average	p-value	Significant
Duration$_{\text{Test1}}$	12.3 h ± 2.09 h, n = 1,098	12.1 h ± 2.13 h, n = 1,609	0.102	FALSE
Duration$_{\text{Test2}}$	12.3 h ± 2.09 h, n = 1,098	13.4 h ± 3.00 h, n = 1,251	0.001	TRUE
Duration$_{\text{Test3}}$	12.3 h ± 2.09 h, n = 1,098	16.3 h ± 6.41 h, n = 274	0.003	TRUE
Frequency$_{\text{Test1}}$	21 e/m ± 4 e/m, n = 60	30 e/m ± 3 e/m, n = 60	< 0.001	TRUE
Frequency$_{\text{Test2}}$	21 e/m ± 4 e/m, n = 60	28 e/m ± 4 e/m, n = 48	0.002	TRUE
Frequency$_{\text{Test3}}$	21 e/m ± 4 e/m, n = 60	26 e/m ± 7 e/m, n = 12	0.284	FALSE
*Intensity$_{\text{Test1a}}$	4.7 h ± 0.20 h, n = 1,351	4.7 h ± 0.18 h, n = 1,546	0.290	FALSE
Intensity$_{\text{Test2a}}$	4.7 h ± 0.20 h, n = 1,351	4.8 h ± 0.21 h, n = 1,178	0.378	FALSE
Intensity$_{\text{Test3a}}$	4.7 h ± 0.20 h, n = 1,351	5.1 h ± 0.51 h, n = 243	0.194	FALSE
Intensity$_{\text{Test1b}}$	31 e/m ± 9 e/m, n = 60	35 e/m ± 8 e/m, n = 60	0.349	FALSE
Intensity$_{\text{Test2b}}$	31 e/m ± 9 e/m, n = 60	32 e/m ± 8 e/m, n = 60	0.545	FALSE
Intensity$_{\text{Test3b}}$	31 e/m ± 9 e/m, n = 60	29 e/m ± 17 e/m, n = 12	0.883	FALSE
Intensity$_{\text{Test1c}}$	7 e/m ± 3 e/m, n = 60	12 e/m ± 4 e/m, n = 60	0.009	TRUE
Intensity$_{\text{Test2c}}$	7 e/m ± 3 e/m, n = 60	13 e/m ± 5 e/m, n = 48	< 0.001	TRUE
Intensity$_{\text{Test3c}}$	7 e/m ± 3 e/m, n = 60	12 e/m ± 10 e/m, n = 12	0.150	FALSE

* Intensity tests were separated into “a” (average duration of SxG0), “b” (average frequency of SxG0 per month), and “c” (average frequency of SxG0 events ≥ 8h duration).

9.3.1 Synchronous Condense Duration 2010 – 2021

The annual pattern of SC duration remained consistent after the installation of Units 5 and 6 with longer (> 25 h) events occurring in May and June, to a lesser extent in April and July, and with shorter SC durations (< 25 h) in January to March and August to December (Figure 9-4 in Appendix 2-1). Sample size (n) for each respective month-year is shown in Table 9-2 (Appendix 2-1). The length of duration was highly variable (1 h – 1,450 h). The twelve-year (2010 – 2021) average SC duration was 12.3 h (± 1.4 h with 95% CI; n = 3,337). The most common SC duration between 2010 and 2021 was 7 h.

There was no significant difference in the average duration of SC operations after the installation of Unit 5/6, but average SC duration increased by ~ 1 h following Unit 5/6 SC operation ($\text{Duration}_{\text{Test1-3}}$ in Table 9-1). Among-month variability significantly influenced the comparison of duration between pre/post Unit 5/6 installation and all test scenarios (p = < 0.01). Average SC duration was ~ 3 h longer in January and ~ 70 h longer in May following SC operation of Unit 5/6; average SC duration in all other months were similar (Figure 9-5 and Table 9-3 in Appendix 2-1).

9.3.2 Synchronous Condense Frequency 2010 – 2021

The annual frequency of SC operations was above average 2016 – 2018, but returned to within the average 2019 – 2021. Frequency of SC events was higher post Unit 5/6 installation (2016 – 2021) than pre Unit 5/6 installation (2010 – 2014; p = < 0.001; Figure 9-3). Monthly SC frequency tended to be near the average between 2015 – 2021, though higher in January and February (Figure 9-6 in Appendix 2-2).

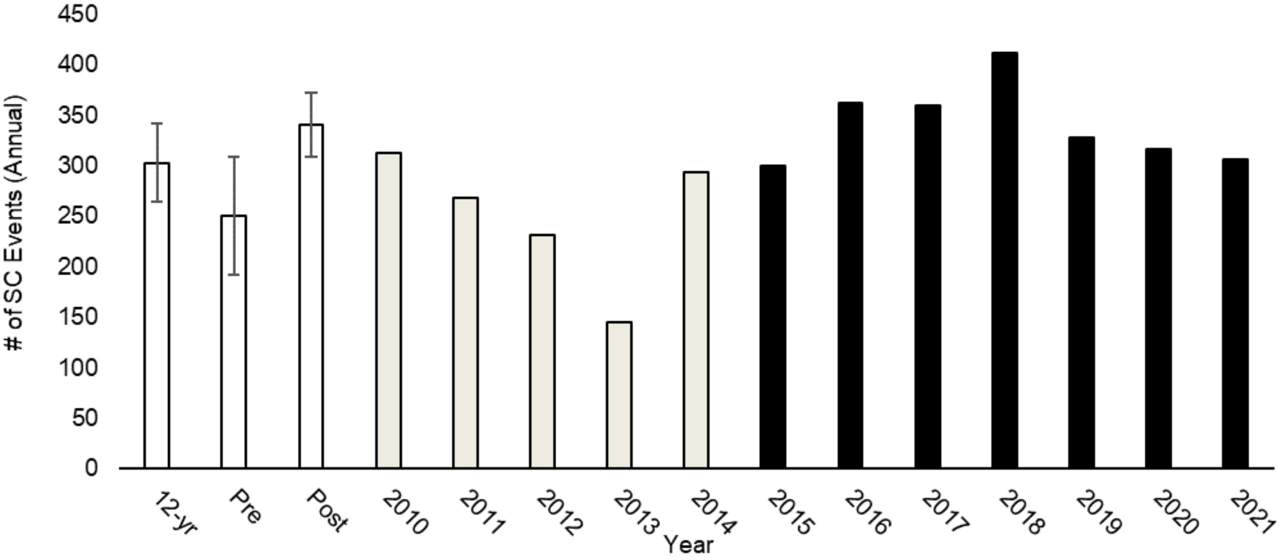


Figure 9-3. Annual frequency of SC events by year (grey; 2010 – 2021) compared to the 12-year average (12-yr; n = 12), pre Unit 5 and 6 installation average (2010 – 2014, “Pre”, n = 5), and post Unit 5 and 6 installation average (2016 – 2021, “Post”, n = 6) with 95% confidence intervals.

The frequency of SC events increased by 7 – 9 events/month on average following the installation and SC operation of Unit 5/6; though there was no significant difference in the frequency of SC events in 2021 when compared to 2010 – 2014 ($\text{Frequency}_{\text{Test1-3}}$ in Table 9-1). Among-month variability was only significant when comparing pre Unit 5/6 installation and post Unit 5 SC operation (p = 0.013). Frequency of SC operations in January increased by 27 events on average after Unit 5 began SC operations, SC frequency in other months did not change (Figure 9-7 and Table 9-4 in Appendix 2-2).

9.3.3 Synchronous Condense Intensity 2010 – 2021

The annual pattern of SxG0[4] duration was consistent between years, though appeared to be longer in January and February following 2015 (Figure 9-8 in Appendix 2-3). Sample size (n) for each respective month-year is available in Table 9-5 (Appendix 2-3). The length of SxG0 duration was variable (1 h - 41 h) and the twelve-year (2010 – 2021) average duration of SxG0 was 4.8 h (+/- 0.12 h with 95% CI; n = 3,309). The most common duration of SxG0 between 2010 and 2021 was 1 h.

Average duration and frequency of SxG0 operations did not change following the installation or SC operation of Units 5/6 ($\text{Intensity}_{\text{Test1a-3b}}$ in Table 9-1). However, the frequency of SxG0 operations ≥ 8-h in duration increased by 5 – 6 events/month on average following the installation and operation of Units 5/6; though there was no significant increase in the frequency of SxG0 ≥ 8-h duration in 2021 when compared to 2010 – 2014 ($\text{Intensity}_{\text{Test1c-3c}}$ in Table 9-1). This is significant because TGP (%) was shown to increase following ≥ 8 h of SxG0 operations (Appendix 1).

Among-month variability of overall SxG0 operations (frequency and duration) was not significant when comparing baseline operations to all test scenarios. However, frequency of SxG0 events ≥ 8 h in duration increased by 23 events on average in May (p = 0.002; Figure 9-11 and Table 9-6 in Appendix 2-3).

9.4 Discussion

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

$H_0 2$ *There is no significant change in the duration, frequency or intensity of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use*

$H_0 2$ is rejected under certain conditions. The average SC duration increased marginally (~ 1 h), as did SC frequency (~ 7 – 9 events per month). SC intensity (represented by the average duration and frequency of SxG0, and frequency of SxG0 ≥ 8 h duration) did not increase, but frequency of SxG0 ≥ 8 h duration increased (~ 5 – 6 events/month on average). This is significant because this operation has shown to increase TGP to levels harmful to fish (Appendix 1). However, the monitoring crew had to request specific operations in 2020 and 2021 in order to adequately address Management Question 1, due to the constricted monitoring window resulting from delays in Unit 6 SC operation capabilities. Some 2020 and 2021 data were similar to years under normal operating conditions, but were higher than the respective 12-year average; therefore, it is unclear whether data collected in 2020 and 2021 are typical of normal operations at MGS.

Rejecting $H_0 2$ and accepting there has been an increase in SC duration, frequency, and intensity does not necessarily indicate a greater TGP impact to downstream environments (compared to 2010 – 2014). Not all SC operations increase TGP; operations including states SxGx decreased TGP in longer durations (> 2 h with discharge > 200 cms; Appendix 1). Therefore, if the increased average duration and frequency of SC events is associated with SxGx operations (Figure 9-2), the impact of TGP exposure to downstream environments is likely minimal. Frequency of SxG0 ≥ 8 h in duration is likely the best indicator for increased TGP exposure for downstream aquatic environments from MGS operations. However, since the monitoring team requested specific operations of MGS in 2020 and 2021, the increased frequency of SxG0 ≥ 8 h in duration may not be representative of typical MGS operations.

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[4] SxG0 = Synchronous Condense without Generation; SxGx = Synchronous Condense with Generation; S0Gx = Generation without Synchronous Condense

In conclusion, SC duration, frequency, and intensity increased following the installation and SC operation of Unit 5/6. However, it is unclear whether data collected in 2020 and 2021 are typical of normal MGS operations. Therefore, rejection of H_02 is under the assumption that data collected were representative of normal MGS operations. The following sections provide a more in-depth discussion for each sub-null hypotheses.

9.4.1 Implications for Management Question 2a – Synchronous Condense Duration

H_02_a: *There is no significant change in the duration of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use.*

H_02_{a1}: *There is no significant change in the duration of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 installation/operation in 2015.*

H_02_{a2}: *There is no significant change in the duration of synchronous condense operations at the Mica Project resulting from Unit 5 commencing synchronous condense operations in 2018.*

H_02_{a3}: *There is no significant change in the duration of synchronous condense operations at the Mica Project resulting from Unit 6 commencing synchronous condense operations in 2021.*

H_02_a is rejected. For H_02_a to be accepted both H_02_{a1-2} were required to be accepted; sample size for H_02_{a3} was not comparable (ratio > 1.5) to baseline (2010 – 2014) data, and therefore was interpreted as an indication rather than a significant result. The average SC duration was statistically similar between Unit 5/6 installation (2016 – 2020) and baseline SC average durations (2010 – 2014).

The average SC duration post Unit 5 (2018 – 2021) and 6 (2021) SC operations were statistically longer than baseline operations (2010 – 2014). The average SC duration was approximately one hour longer post Unit 5 SC operation over the baseline average (Table 9-1); therefore these findings are statistically significant but likely not biologically significant when considering the entire timeframe, as longer periods (> 24 h) of SC are required to produce significant biological effects (see Appendix 3, section *10.3.3*).

Average SC duration post Unit 6 SC operations was consistently longer than baseline duration by about 4 h, however, sample size for 2021 data (n = 274) was not similar to 2010 – 2014 baseline data (n = 1,098) so this is considered an indication of increased SC average duration rather than a significant result. Sample sizes for average SC duration 2016 – 2020 and 2018 – 2021 were similar (ratio < 1.5) to 2010 – 2014.

May had the highest increase of average monthly SC duration (70 h longer on average) following Unit 5/6 SC operations; this was likely biologically significant due to the additional 3 days of SC operation (Figure 9-5 in Appendix 2-1). Specific operations were requested by the monitoring crew May – July 2020/2021 to collect data pertaining to Management Question 1; due to the delay of Unit 6 SC capability. May 2021 had the longest average duration recorded (148.8 h; Figure 9-4 in Appendix 2-1) and could have increased the overall post Unit 5/6 SC operation average. Therefore, operations in May 2021 my not be typical of the normal operating regime; as indicated by the 12-year average SC duration for May (32 h). Smaller increases in average monthly SC duration were identified in January and December following Unit 5/6 installation and operation (~ 2 h per month longer on average). This small increase in duration is not biologically significant. All other months had similar average durations post Unit 5/6 installation and SC operation). May and June consistently had the longest durations of SC (2010 – 2021) because this operation is used during periods of low energy demand; and May and June are typically between summer cooling and winter heating demands.

This section specifically looked at SC duration as a whole and did not account for the states of other units (whether they were idling or generating). The influence of specific SC states on TGP generation is addressed in Appendix 1 and the impacts of SC duration on fish is discussed in Appendix 3.

In conclusion, overall average SC duration was slightly longer (1 h) after Unit 5/6 were capable of SC operations. A greater increase of average SC duration was detected on a monthly scale, specifically in May. It is unclear whether these increases are attributed to normal MGS operating regimes, or a product of experimental operation in 2020 and 2021 at the request of the monitoring crew.

9.4.2 Implications for Management Question 2b – Synchronous Condense Frequency

H_02_b: *There is no significant change in the frequency of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use.*

H_02_{b1}: *There is no significant change in the frequency of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 installation/operation in 2015.*

H_02_{b2}: *There is no significant change in the frequency of synchronous condense operations at the Mica Project resulting from Unit 5 commencing synchronous condense operations in 2018.*

H_02_{b3}: *There is no significant change in the frequency of synchronous condense operations at the Mica Project resulting from Unit 6 commencing synchronous condense operations in 2021.*

H_02_b is rejected. For H_02_b to be accepted both H_02_{b1-2} were required to be accepted; sample size for H_02_{b3} was not comparable (ratio > 1.5) to baseline (2010 – 2014) data, and therefore was interpreted as an indication rather than a significant result. The frequency of SC events increased by 7 – 9 events per month following the installation of Units 5/6 (2016 – 2020) on average.

SC frequency increased by 25 events in January post Unit 5 SC operation, while all other months were statistically similar to baseline values. Frequency of SC events were fewer in April, May, June following Unit 5/6 installation and SC operations, likely due to an increase in SC duration (fewer events but longer durations).

Specific operations were requested by the monitoring crew May – July 2020/2021 to collect data pertaining to Management Question 1; due to the delay of Unit 6 SC capability. Therefore, frequency of SC operations in May 2020 (0 SC events) and 2021 (8 SC events) may not be typical of the normal operating regime as indicated by the 12-year average (21 events in May). Samples size in 2016 – 2020 and 2018 – 2021 were comparable (ratio < 1.5) to 2010 – 2014.

In conclusion, SC frequency increased following the installation of Unit 5/6 and Unit 5 SC operations, with the greatest increase in SC frequency occurring in January. SC frequency in May 2020/2021 may not have been typical of MGS operating regimes due to requests by the monitoring crew. However, the requests would have resulted in lower SC frequency rather then higher SC frequency (since individual events were requested to be longer and thus frequency was reduced), based on the number of SC events in 2020 and 2021, and the 12-year average.

9.4.3 Implications for Management Question 2c – Synchronous Condense Intensity

H_02_c: There is no significant change in the intensity of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use.

H_02_{c1}: There is no significant change in the intensity of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 installation/operation in 2015.

H_02_{c2}: There is no significant change in the intensity of synchronous condense operations at the Mica Project resulting from Unit 5 commencing synchronous condense operations in 2018.

H_02_{c3}: There is no significant change in the intensity of synchronous condense operations at the Mica Project resulting from Unit 6 commencing synchronous condense operations in 2021.

H_02_c is rejected. For H_02_c to be accepted, both H_02_{c1-2} were required to be accepted; sample size for H_02_{c3} was not comparable (ratio > 1.5) to baseline data, and therefore was interpreted as an indication rather than a significant result. There was no significant change in the overall average duration or frequency of SxG0 following the installation and operation of Units 5/6; however, the frequency of SxG0 ≥ 8-h duration increased by 5 – 6 events per month on average.

May experienced the highest increase in frequency of SxG0 ≥ 8 h (23 events more on average) following the installation and SC operation of Unit 5/6; changes in all other months were statistically insignificant (Figure 9-14 and Table 9-6 in Appendix 2-3). Specific operations were requested by the monitoring crew May – July 2020/2021 to collect data pertaining to Management Question 1; due to the delay of Unit 6 SC capability. Therefore, the frequency of SxG0 operations ≥ 8-h duration in May, June, and July in 2020/2021 may not be typical of the normal operating regime. However, frequencies of SxG0 with ≥ 8 h in 2020 and 2021 were similar to 2018 and 2019, years assumed to have operated within the normal regime (Figure 9-11 in Appendix 2-3).

In conclusion, although there was no change in overall SxG0 frequency or average duration, H_02_c cannot be accepted due to the increased frequency of SxG0 events ≥ 8 h; as this state is shown to increase TGP (Appendix 1). However, it is unclear whether the increased frequency of SxG0 ≥ 8 h is a result of regular MGS operations or a product of requests made by the monitoring team in 2020 and 2021 to collect data for Management Question 1.

9.4.4 Implications for Management Question 2d – Changes in Total Dissolved Gas Exposure for Downstream Aquatic Environments

H_02_d: There is no significant increase in TDG exposure for downstream aquatic environments from changes in synchronous condense operations at Mica Dam with the installation Unit 5 and 6 (if any).

It is inconclusive whether H_02_d should be accepted or rejected. To accept H_02_d the data would need to show there was no significant (both statistically and biologically) increase in SC frequency and duration that increase TGP to levels harmful to aquatic life (> 110%; Fiddler and Miller 1994; see also Appendix 1). There was an increase in overall SC duration once Unit 5 was capable of SC operation; particularly in May and to a lesser extent in January and December. SC frequency also increased after the installation of Unit 5/6 and Unit 5 SC operations. Most significantly, frequency of SxG0 operations ≥ 8 h in duration increased following Unit 5/6 installation and Unit 5 SC operations by approximately 5 – 6 events per month. Occurrences of SxG0 ≥ 8 h were associated with elevated TGP that produced levels deemed harmful to fish when only interrupted by 1 h of SxGx or S0Gx (110%; Appendix 1). Long-term TGP monitoring did not occur at MGS prior to the installation of Unit 5/6 (2010 – 2014), so baseline TGP values are not available. However, 30% of recorded TGP values exceeded 110% between 2015, 2016, and 2017 (post Unit 5/6 installation but pre Unit 5/6 SC operation; n = 9,701) compared to 66% in 2020 and 2021 (post Unit 5/6 SC operations; n = 5,446; Appendix 1). Therefore H_02_d cannot be accepted as SxG0 ≥ 8 h increased, and the frequency of > 110% TGP records doubled following Unit 5/6 SC operations.

However, in order to reject H_02_d the data would need to show there was a significant increase in SC operations that elevate TGP to levels harmful to aquatic life as a direct result of typical MGS operations. Not all SC operations increase TGP; operations including SxGx are shown to decrease TGP in longer durations (≥ 2 h; Appendix 1). Therefore, an increase in overall SC duration and frequency does not directly translate to increased TGP, and rejection of H_02_a and H_02_b does not automatically result in the rejection of H_02_d.

Frequency of SxG0 ≥ 8 h is likely the best indicator for increased TDG exposure for downstream aquatic environments from MGS operations. However, the increased frequency of SxG0 ≥ 8 h requested in 2020 and 2021 and resulting increased frequency of 110% may not be typical MGS operations, and H_02_d cannot be rejected.

9.5 Recommendations

9.5.1 Additional Analyses of MGS Operations

In order to confidently accept or reject H_02 (*There is no significant change in the duration, frequency or intensity of synchronous condense operations at the Mica Project resulting from Unit 5 and 6 use*) additional analysis is required. Because the management hypothesis was based on Unit 5/6 SC operations, and Units 5/6 were not operating in SC regularly (> 50 hours in a year) until 2018 and 2021 respectively, there was not a clear divide between pre and post Unit 5/6 SC operations. In addition, the monitoring crew had to request specific operations in 2020 and 2021 in order to adequately address Management Question 1, due to the constricted monitoring window resulting from delays in Unit 6 SC operation capabilities. Therefore, it is recommended that additional analyses occur after 5-years of normal MGS operations with both Units 5/6 operating in the typical regime. Assuming the 5-year period begins in 2022, 2022 – 2026 operational data should be compared to 2010 – 2014 operational data.

9.6 References

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9.7 Appendix 2-1 Figures and Tables for Synchronous Condense Duration Resulting from Unit 5 and 6

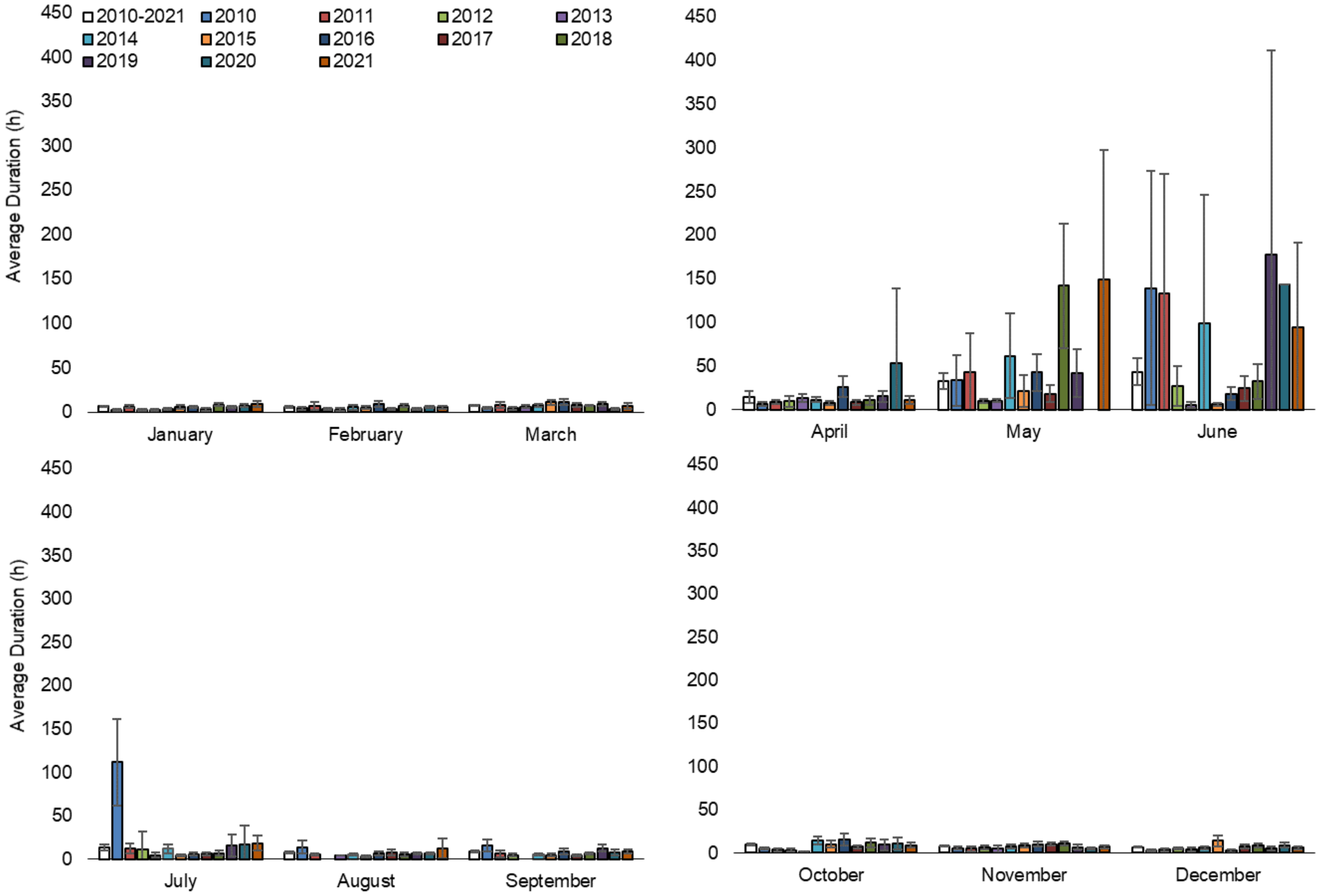

Figure 9-4. Monthly average duration (h) of synchronous condense operations at MGS between 2010 and 2021 with 95% confidence intervals.

Table 9-2. Monthly average duration (h) of synchronous condense operations by year (2010 – 2021) with sample size (n) used to assess durational monthly patterns in Figure 9-4.

Duration	**Month**		**2010**		**2011**		**2012**		**2013**		**2014**		**2015**	
			Average	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**
Graph 1	January		2.83	6	6.24	25	2.17	6	2.50	2	3.69	16	5.82	17
	February		4.22	18	7.00	6	3.80	5	2.86	7	5.40	5	5.10	39
	March		4.74	38	7.68	34	4.29	7	5.92	24	7.49	35	10.93	30
Graph 2	April		6.39	36	8.77	43	9.32	28	13.18	33	11.42	38	7.90	21
	May		33.30	23	43.38	16	9.79	42	10.21	43	61.50	12	21.47	15
	June		139.00	6	132.80	5	27.16	32	5.20	5	98.57	7	6.10	20
Graph 3	July		112.00	4	12.63	30	11.50	2	4.50	2	12.04	28	4.25	12
	August		13.73	30	5.60	20	0.00	0	4.00	1	5.44	16	3.08	13
	September		15.73	30	6.42	24	4.85	13	0.00	0	5.22	18	4.78	9
Graph 4	October		5.28	54	3.60	10	3.29	7	2.00	1	13.97	32	10.09	35
	November		5.33	21	4.88	8	6.60	20	4.67	3	7.46	24	8.95	22
	December		2.63	8	3.60	15	4.62	26	4.20	5	5.84	43	13.83	24

Duration	**Month**	**2016**		**2017**		**2018**		**2019**		**2020**		**2021**		**2010-2021**	
		Average	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**
Graph 1	January	5.65	17	3.55	11	8.49	41	6.37	240	0.62	39	8.76	25	6.37	240
	February	8.71	34	3.50	22	7.22	41	5.76	251	0.66	45	5.35	20	5.76	251
	March	11.69	42	7.95	39	7.43	53	7.72	378	0.73	25	6.45	11	7.72	378
Graph 2	April	26.38	24	8.29	48	10.59	41	14.54	415	6.94	33	11.00	39	14.54	415
	May	42.65	17	18.09	35	141.67	6	32.44	234	9.04	0	148.78	9	32.44	234
	June	18.35	23	24.25	20	32.41	17	43.30	149	15.53	1	94.63	8	43.30	149
Graph 3	July	5.60	25	6.13	16	7.00	24	13.13	199	3.35	14	18.45	22	13.13	199
	August	6.30	20	7.84	19	5.76	33	7.49	229	1.32	34	12.29	14	7.49	229
	September	8.93	28	4.30	20	6.37	35	8.46	253	1.27	26	8.57	21	8.46	253
Graph 4	October	15.32	31	6.95	38	11.79	29	9.45	322	1.38	21	9.08	36	9.45	322
	November	10.25	40	10.29	24	10.97	34	7.99	292	0.78	23	6.98	45	7.99	292
	December	2.80	5	7.29	34	8.76	29	6.82	276	0.87	28	6.08	24	6.82	276

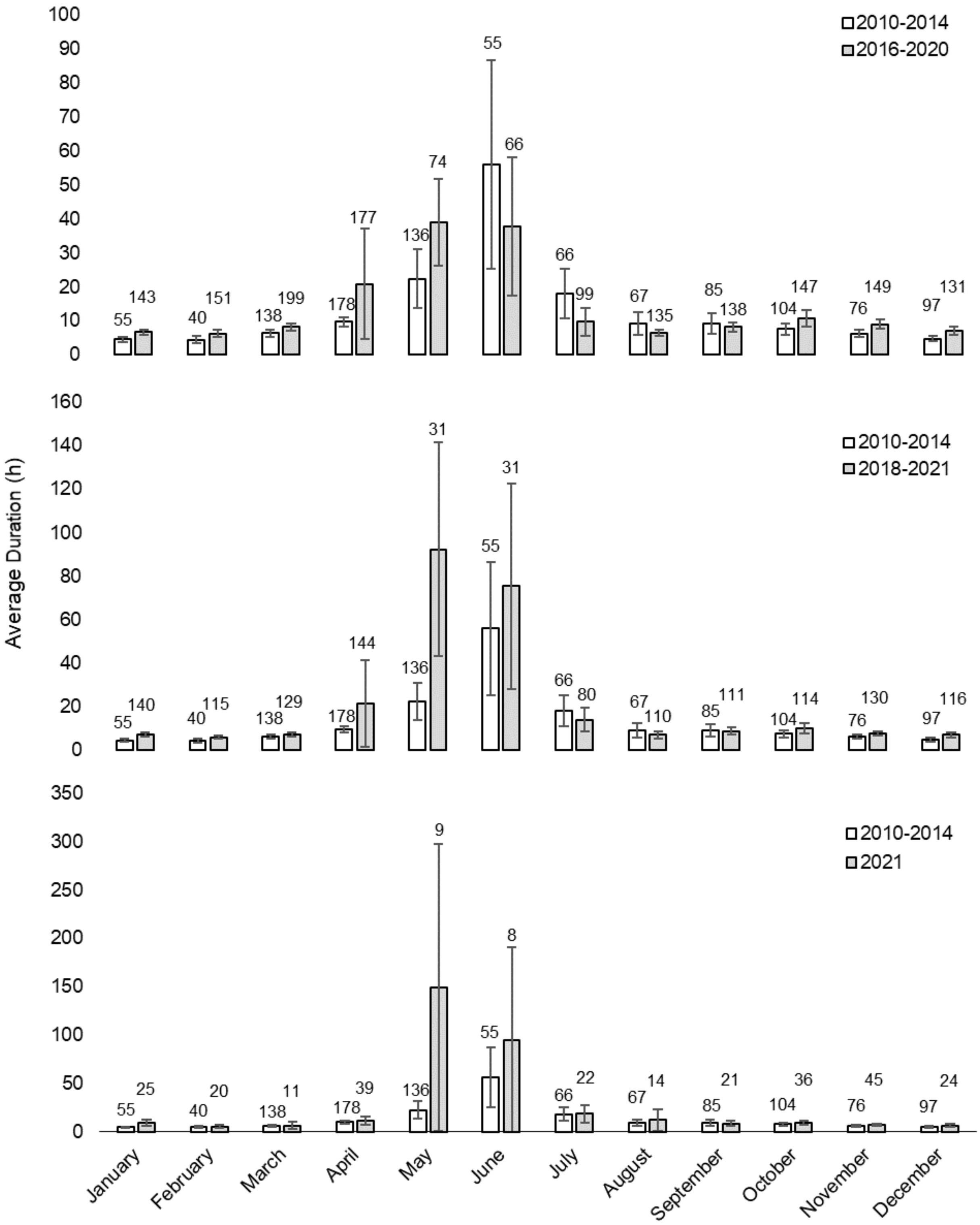

Figure 9-5. Average duration (h) of SC operations by month between 2010 – 2014 and 2016 – 2020 = post Unit 5/6 Installation (top panel), 2018 – 2021 = post Unit 5 SC operation (middle panel), and 2021 = post Unit 6 SC operation (bottom panel) with 95% confidence intervals; sample size (n) is identified above each dataset.

Table 9-3. Comparison of average synchronous condense (SC) duration (h) by month where: Test 1 = 2010 – 2014 (baseline) vs 2016 – 2020 (post Unit 5/6 installation), Test 2 = 2010 – 2014 (baseline) vs 2018 – 2021 (post Unit 5 SC operation), and Test 3 = 2010 – 2014 (baseline) vs 2021 (post Unit 6 SC operation). Green rows indicate statistical significance (analysis of variance; significance = $p < 0.004$) with regards to the respective test.

Test	Month	Baseline Average	Test Average	p-value	Significant
Test 1	January	4.6 h ± 0.81 h, n = 55	6.7 h ± 0.73 h, n = 143	0.0011	TRUE
	February	4.5 h ± 1.07 h, n = 40	6.3 h ± 0.98 h, n = 151	0.0663	FALSE
	March	6.3 h ± 1.08 h, n = 138	8.3 h ± 1.02 h, n = 199	0.0139	FALSE
	April	9.8 h ± 1.43 h, n = 178	20.9 h ± 16.13 h, n = 177	0.1772	FALSE
	May	22.4 h ± 8.70 h, n = 136	38.9 h ± 12.66 h, n = 74	0.0324	FALSE
	June	56.1 h ± 30.69 h, n = 55	37.7 h ± 20.34 h, n = 66	0.3172	FALSE
	July	18.1 h ± 7.24 h, n = 66	9.7 h ± 4.09 h, n = 99	0.0344	FALSE
	August	9.2 h ± 3.38 h, n = 67	6.6 h ± 0.86 h, n = 135	0.0579	FALSE
	September	9.2 h ± 2.91 h, n = 85	8.2 h ± 1.45 h, n = 138	0.5070	FALSE
	October	7.6 h ± 1.70 h, n = 104	10.7 h ± 2.48 h, n = 147	0.0631	FALSE
	November	6.3 h ± 1.10 h, n = 76	9.0 h ± 1.27 h, n = 149	0.0049	FALSE
	December	4.8 h ± 0.86 h, n = 97	7.2 h ± 1.18 h, n = 131	0.0019	TRUE
Test 2	January	4.6 h ± 0.81 h, n = 55	7.5 h ± 0.91 h, n = 140	0.0003	TRUE
	February	4.5 h ± 1.07 h, n = 40	6.0 h ± 0.77 h, n = 115	0.0385	FALSE
	March	6.3 h ± 1.08 h, n = 138	7.1 h ± 0.92 h, n = 129	0.3037	FALSE
	April	9.8 h ± 1.43 h, n = 178	21.5 h ± 19.73 h, n = 144	0.1968	FALSE
	May	22.4 h ± 8.70 h, n = 136	92.4 h ± 49.14 h, n = 31	< 0.0001	TRUE
	June	56.1 h ± 30.69 h, n = 55	75.5 h ± 47.17 h, n = 31	0.4838	FALSE
	July	18.1 h ± 7.24 h, n = 66	14.1 h ± 5.56 h, n = 80	0.3802	FALSE
	August	9.2 h ± 3.38 h, n = 67	7.1 h ± 1.66 h, n = 110	0.2386	FALSE
	September	9.2 h ± 2.91 h, n = 85	8.8 h ± 1.58 h, n = 111	0.8015	FALSE
	October	7.6 h ± 1.70 h, n = 104	10.2 h ± 2.56 h, n = 114	0.1152	FALSE
	November	6.3 h ± 1.10 h, n = 76	7.7 h ± 1.10 h, n = 130	0.0902	FALSE
	December	4.8 h ± 0.86 h, n = 97	7.1 h ± 1.24 h, n = 116	0.0052	FALSE
Test 3	January	4.6 h ± 0.81 h, n = 55	8.8 h ± 3.28 h, n = 25	0.0014	TRUE
	February	4.5 h ± 1.07 h, n = 40	5.4 h ± 1.24 h, n = 20	0.3322	FALSE
	March	6.3 h ± 1.08 h, n = 138	6.5 h ± 3.42 h, n = 11	0.9551	FALSE
	April	9.8 h ± 1.43 h, n = 178	11.0 h ± 4.39 h, n = 39	0.5479	FALSE
	May	22.4 h ± 8.70 h, n = 136	148.8 h ± 148.62 h, n = 9	< 0.0001	TRUE
	June	56.1 h ± 30.69 h, n = 55	94.6 h ± 96.08 h, n = 8	0.3948	FALSE
	July	18.1 h ± 7.24 h, n = 66	18.5 h ± 8.97 h, n = 22	0.9618	FALSE
	August	9.2 h ± 3.38 h, n = 67	12.3 h ± 11.20 h, n = 14	0.4985	FALSE
	September	9.2 h ± 2.91 h, n = 85	8.6 h ± 2.44 h, n = 21	0.8345	FALSE
	October	7.6 h ± 1.70 h, n = 104	9.1 h ± 2.58 h, n = 36	0.3845	FALSE
	November	6.3 h ± 1.10 h, n = 76	7.0 h ± 1.52 h, n = 45	0.4504	FALSE
	December	4.8 h ± 0.86 h, n = 97	6.1 h ± 1.63 h, n = 24	0.1964	FALSE

9.8 Appendix 2-2 Figures and Tables for Synchronous Condense Frequency Resulting from Unit 5 and 6

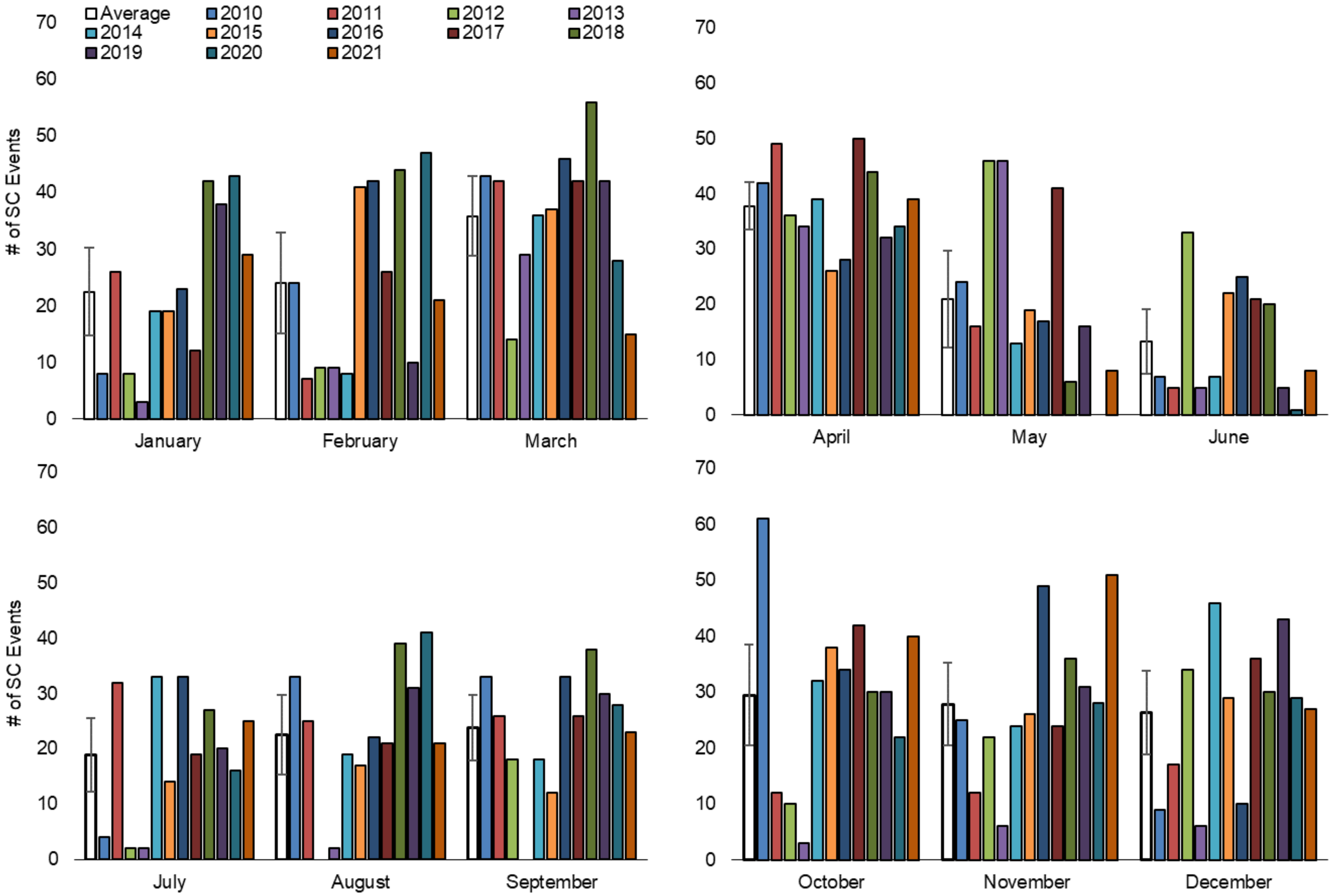

Figure 9-6. Monthly frequency (# of events) of synchronous condense (SC) operations at MGS between 2010 and 2021, and 12-year monthly averages with 95% confidence intervals (n = 12).

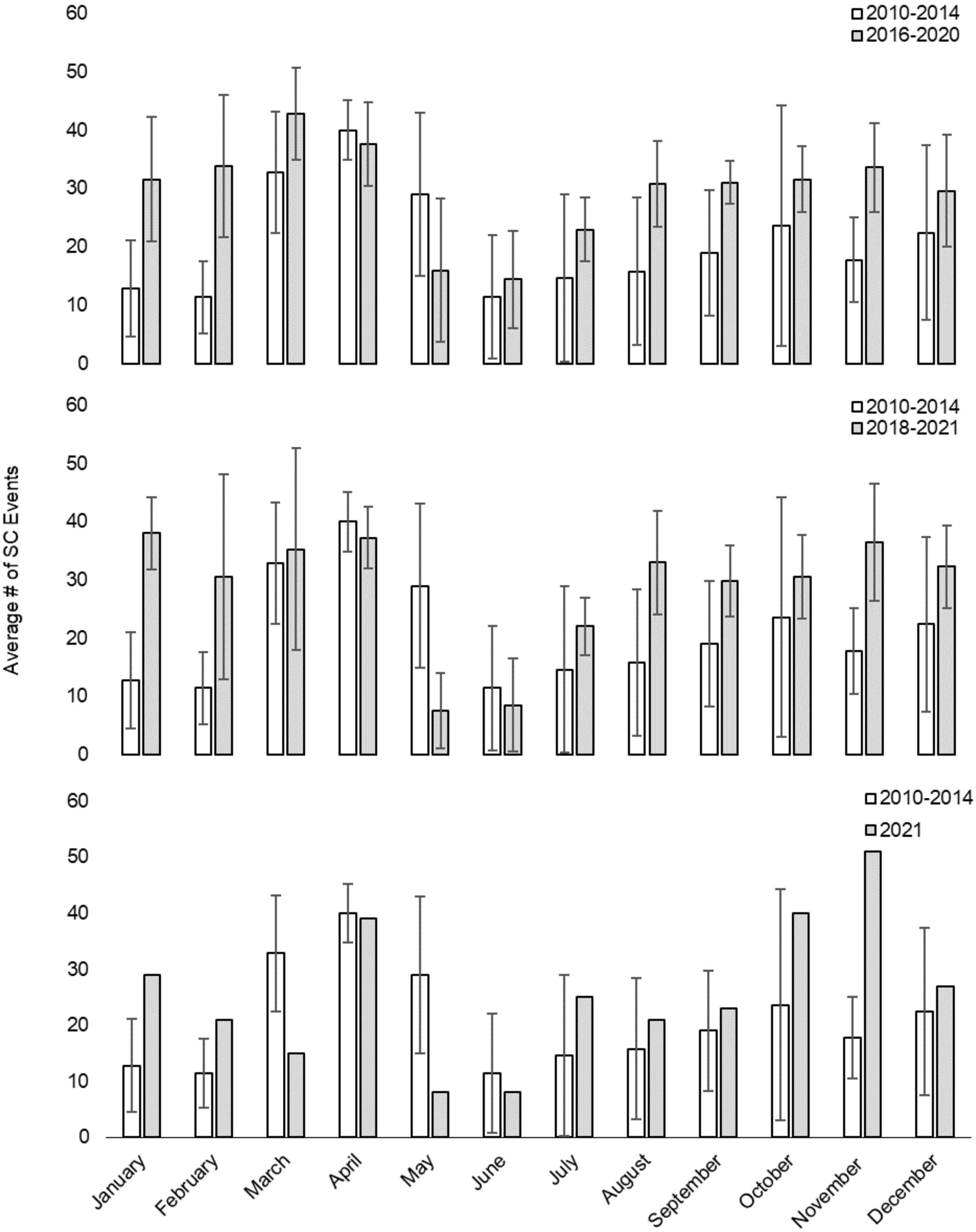

Figure 9-7. Average number of synchronous condense (SC) events by month compared between 2010 – 2014 (baseline; n = 5/month) and 2016 – 2020 = post Unit 5/6 Installation (n = 5/month; top panel), 2018 – 2021 = post Unit 5 SC operation (n = 4/month; middle panel), and 2021 = post Unit 6 SC operation (n = 1/month; bottom panel) with 95% confidence intervals.

Table 9-4. Comparison of synchronous condense (SC) frequency (# of events) by month for Test 2 (2010 – 2014 = baseline vs 2018 – 2021 = post Unit 5 SC operation). Green row indicates statistical significance (analysis of variance; significance = $p < 0.004$).

Month	Baseline Average	Test Average	p-value	Significant
January	13 events ± 8 events, n = 5	38 events ± 6 events, n = 4	0.0026	TRUE
February	11 events ± 6 events, n = 5	31 events ± 18 events, n = 4	0.0632	FALSE
March	33 events ± 10 events, n = 5	35 events ± 17 events, n = 4	0.8105	FALSE
April	40 events ± 5 events, n = 5	37 events ± 5 events, n = 4	0.4929	FALSE
May	29 events ± 14 events, n = 5	8 events ± 6 events, n = 4	0.0416	FALSE
June	11 events ± 11 events, n = 5	9 events ± 8 events, n = 4	0.6959	FALSE
July	15 events ± 14 events, n = 5	22 events ± 5 events, n = 4	0.4170	FALSE
August	16 events ± 13 events, n = 5	33 events ± 9 events, n = 4	0.0777	FALSE
September	19 events ± 11 events, n = 5	30 events ± 6 events, n = 4	0.1593	FALSE
October	24 events ± 21 events, n = 5	31 events ± 7 events, n = 4	0.5941	FALSE
November	18 events ± 7 events, n = 5	37 events ± 10 events, n = 4	0.0192	FALSE
December	22 events ± 15 events, n = 5	32 events ± 7 events, n = 4	0.3218	FALSE

9.9 Appendix 2-3 Figures and Tables for Synchronous Condense Intensity Resulting from Unit 5 and 6

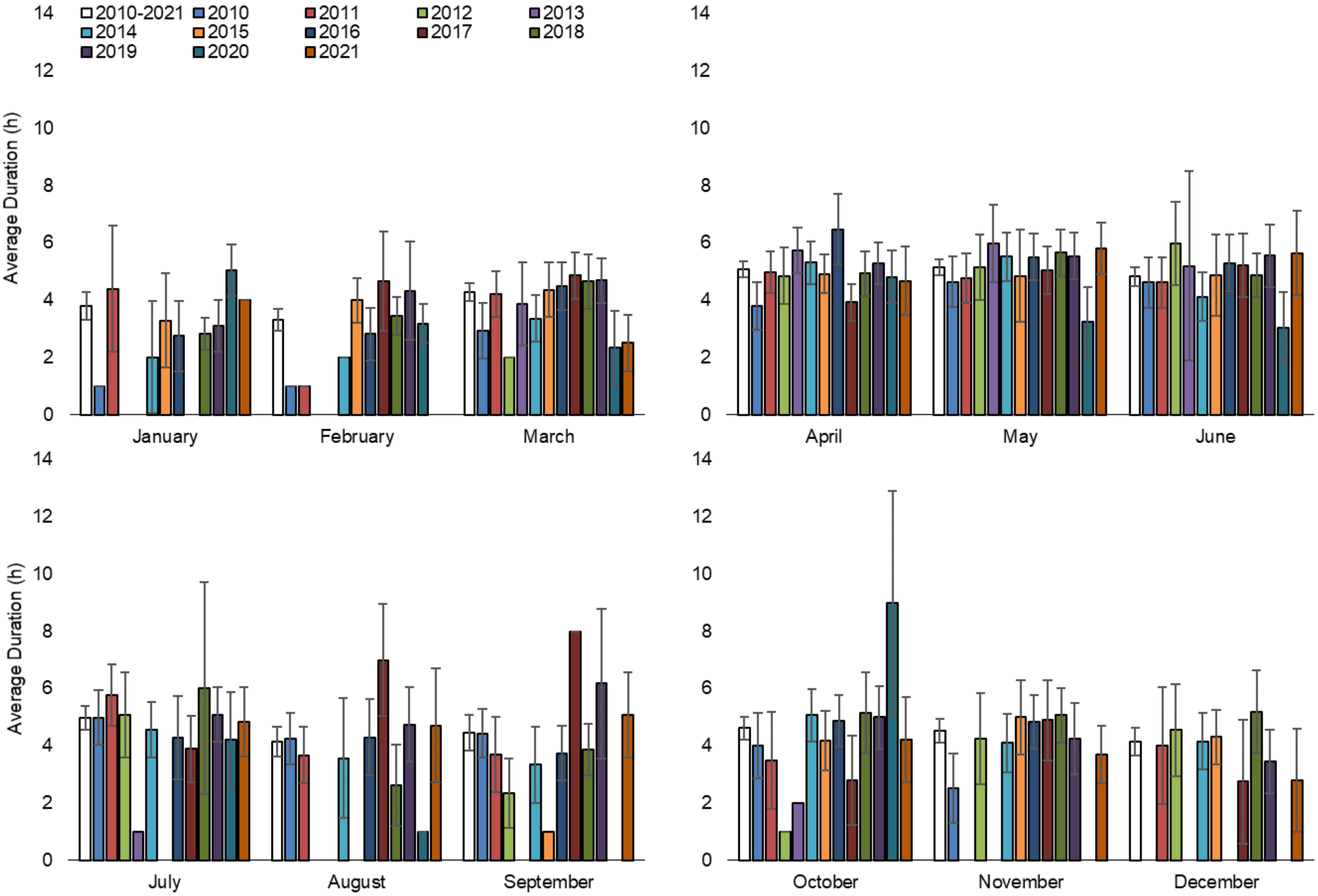

Figure 9-8. Monthly average duration (h) of synchronous condense without generation (SxG0) between 2010 and 2021 with 95% confidence intervals.

Table 9-5. Monthly average duration (h) of synchronous condense (SC) operations without generation by year (2010 – 2021) with sample size (n) used to assess SC intensity as it relates to potential high TGP events for Figure 9-8.

Duration	**Month**		**2010**		**2011**		**2012**		**2013**		**2014**		**2015**	
			Average	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**
Graph 1	January		1.00	1	4.40	5	0.00	0	0.00	0	2.00	2	3.29	7
	February		1.00	1	1.00	1	0.00	0	0.00	0	2.00	1	4.00	20
	March		2.93	14	4.23	22	2.00	1	3.88	8	3.36	22	4.37	30
Graph 2	April		3.80	25	4.97	36	4.85	33	5.73	41	5.31	36	4.92	13
	May		4.64	59	4.77	81	5.16	45	5.98	48	5.51	72	4.85	20
	June		4.62	82	4.62	78	5.97	58	5.20	5	4.13	88	4.88	16
Graph 3	July		4.99	91	5.78	49	5.09	46	1.00	1	4.56	43	0.00	0
	August		4.24	42	3.67	9	0.00	0	0.00	0	3.57	7	0.00	0
	September		4.43	53	3.69	13	2.33	6	0.00	0	3.33	9	1.00	1
Graph 4	October		4.00	15	3.50	4	1.00	1	2.00	1	5.06	31	4.18	28
	November		2.50	6	0.00	0	4.25	8	0.00	0	4.10	10	5.00	9
	December		0.00	0	4.00	5	4.55	11	0.00	0	4.16	25	4.30	30

Duration	**Month**	**2016**		**2017**		**2018**		**2019**		**2020**		**2021**		**2010-2021**	
		Average	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**	**Average**	**n**
Graph 1	January	2.75	4	0.00	0	2.82	17	3.10	10	5.04	28	4.00	2	3.80	76
	February	2.81	27	4.67	3	3.45	20	4.33	3	3.19	27	0.00	0	3.32	103
	March	4.48	54	4.86	37	4.65	20	4.69	35	2.33	3	2.50	2	4.29	248
Graph 2	April	6.47	62	3.92	50	4.94	47	5.30	40	4.81	31	4.68	25	5.08	439
	May	5.50	70	5.04	57	5.65	72	5.54	67	3.23	64	5.81	67	5.15	722
	June	5.30	43	5.22	55	4.88	74	5.56	59	3.05	60	5.64	59	4.83	677
Graph 3	July	4.29	7	3.89	9	6.00	10	5.09	46	4.21	24	4.83	29	4.98	355
	August	4.29	7	7.00	2	2.63	8	4.75	16	1.00	1	4.71	7	4.15	99
	September	3.74	19	8.00	1	3.88	16	6.17	29	0.00	0	5.08	12	4.46	159
Graph 4	October	4.86	44	2.80	5	5.15	13	5.00	24	9.00	2	4.21	19	4.62	187
	November	4.84	37	4.89	9	5.06	31	4.25	16	0.00	0	3.69	16	4.52	142
	December	0.00	0	2.75	4	5.18	11	3.45	11	0.00	0	2.80	5	4.15	102

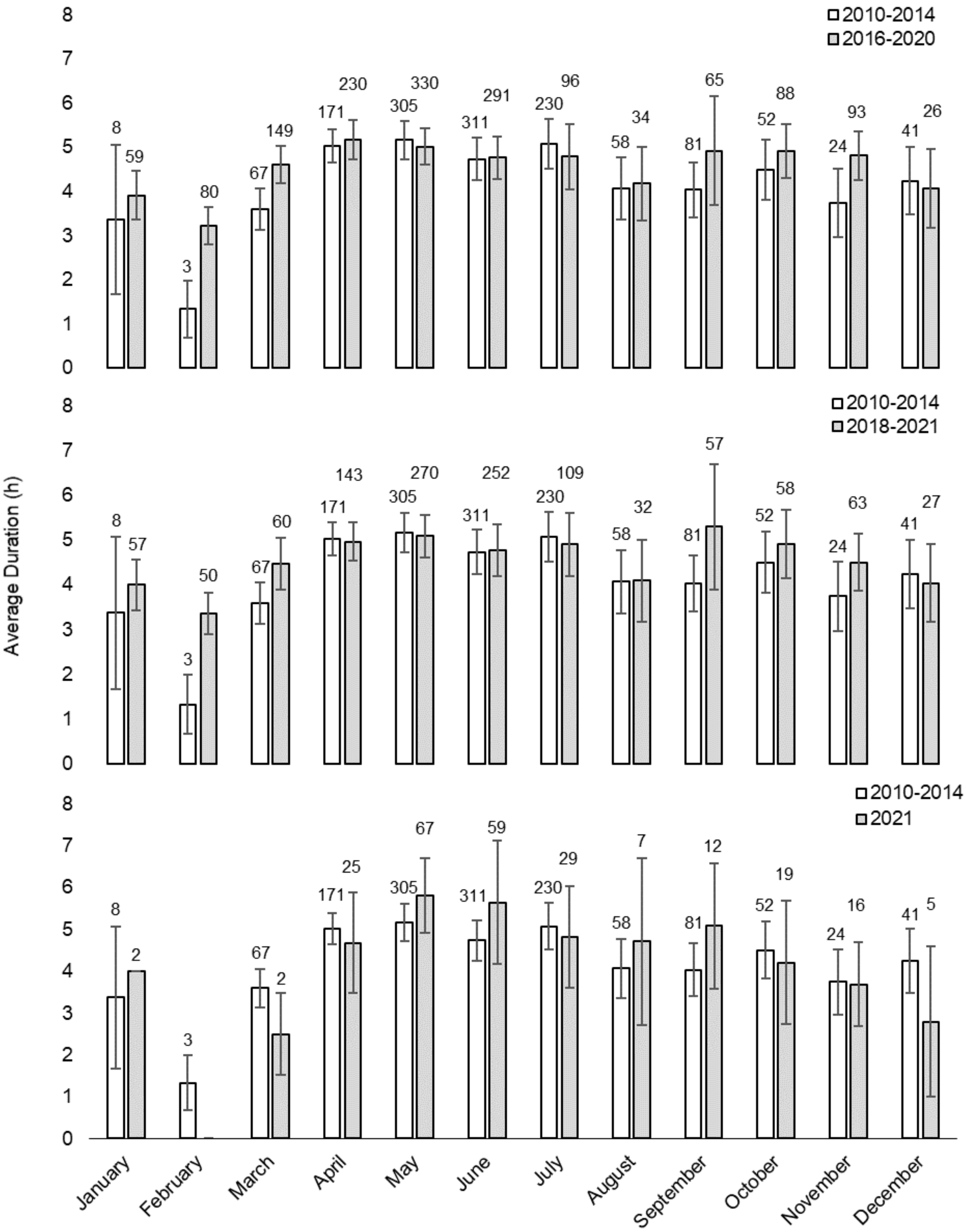

Figure 9-9. Average duration (h) of synchronous condense (SC) operations without generation (SxG0) by month between 2010 – 2014 and 2016 – 2020 = post Unit 5/6 Installation (top panel), 2018 – 2021 = post Unit 5 SC operation (middle panel), and 2021 = post Unit 6 SC operation (bottom panel) with 95% confidence intervals; sample size (n) is identified above each dataset.

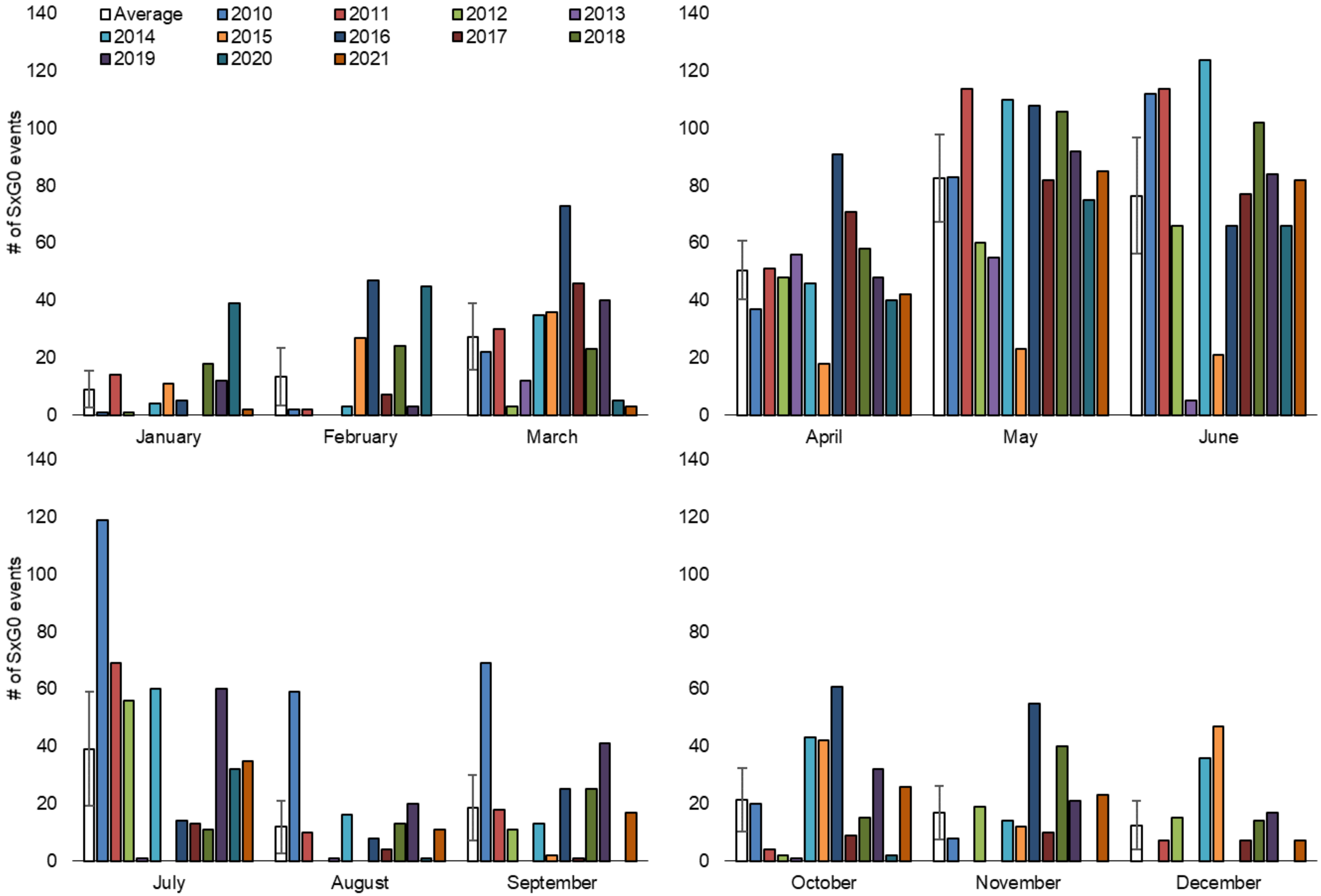

Figure 9-10. Monthly frequency (# of events) of synchronous condense operations without generation (SxG0) between 2010 and 2021 and 12-year monthly averages with 95% confidence intervals (n = 12).

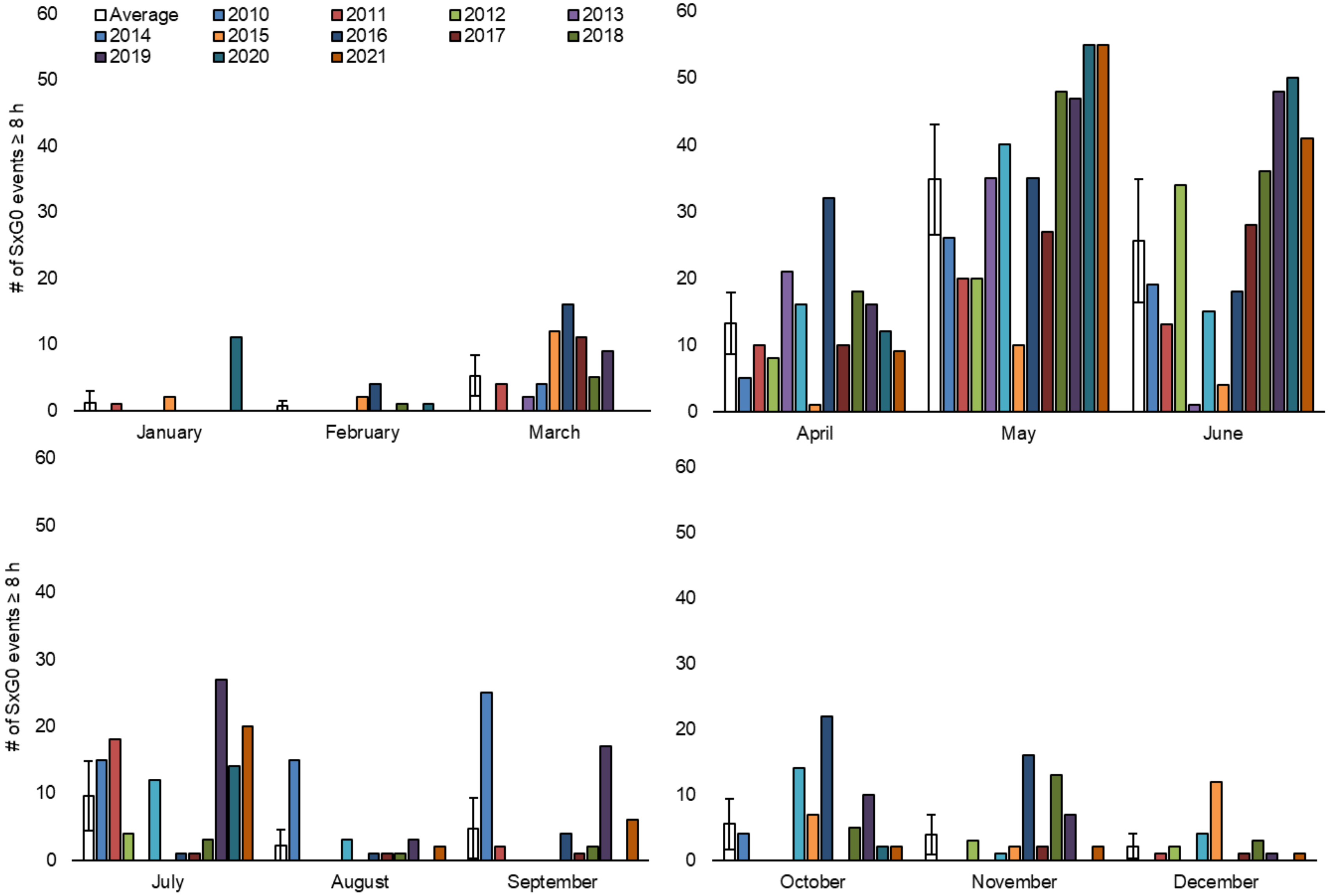

Figure 9-11. Monthly frequency (# of events) of synchronous condense operations without generation (SxG0) events with ≥ 8 h duration between 2010 and 2021, and 12-year monthly averages with 95% confidence intervals (n = 12).

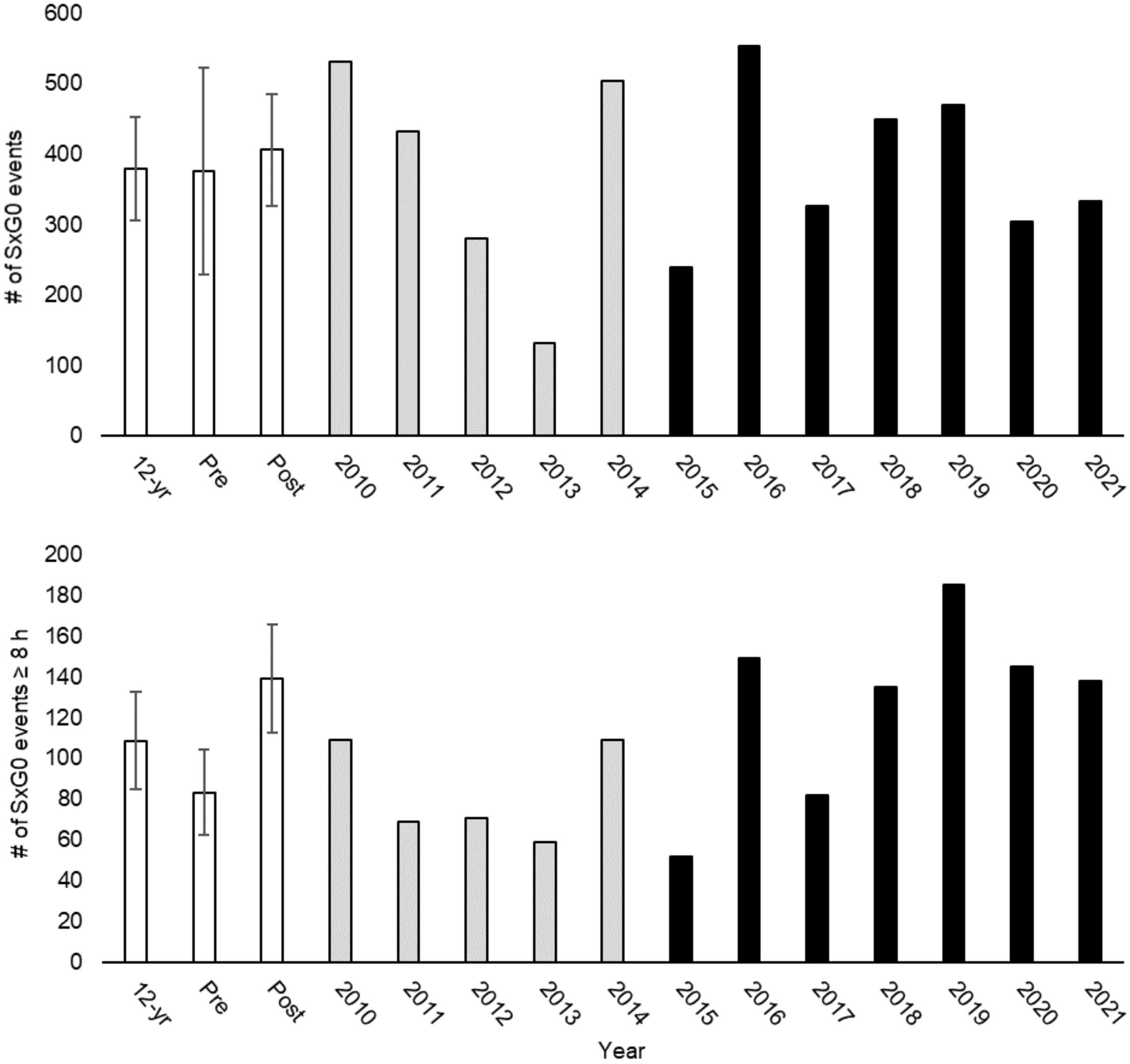

Figure 9-12. Annual frequency of synchronous condense events without generation (SxG0; top) and annual frequency SxG0 events ≥ 8 h in duration (bottom) compared to the 12-year averages (“12-yr”, n = 12), pre Unit 5/6 installation average (2010 – 2014, “Pre”, n = 5), and post Unit 5/6 installation average (2016 – 2021, “Post”, n = 6) with 95% confidence intervals.

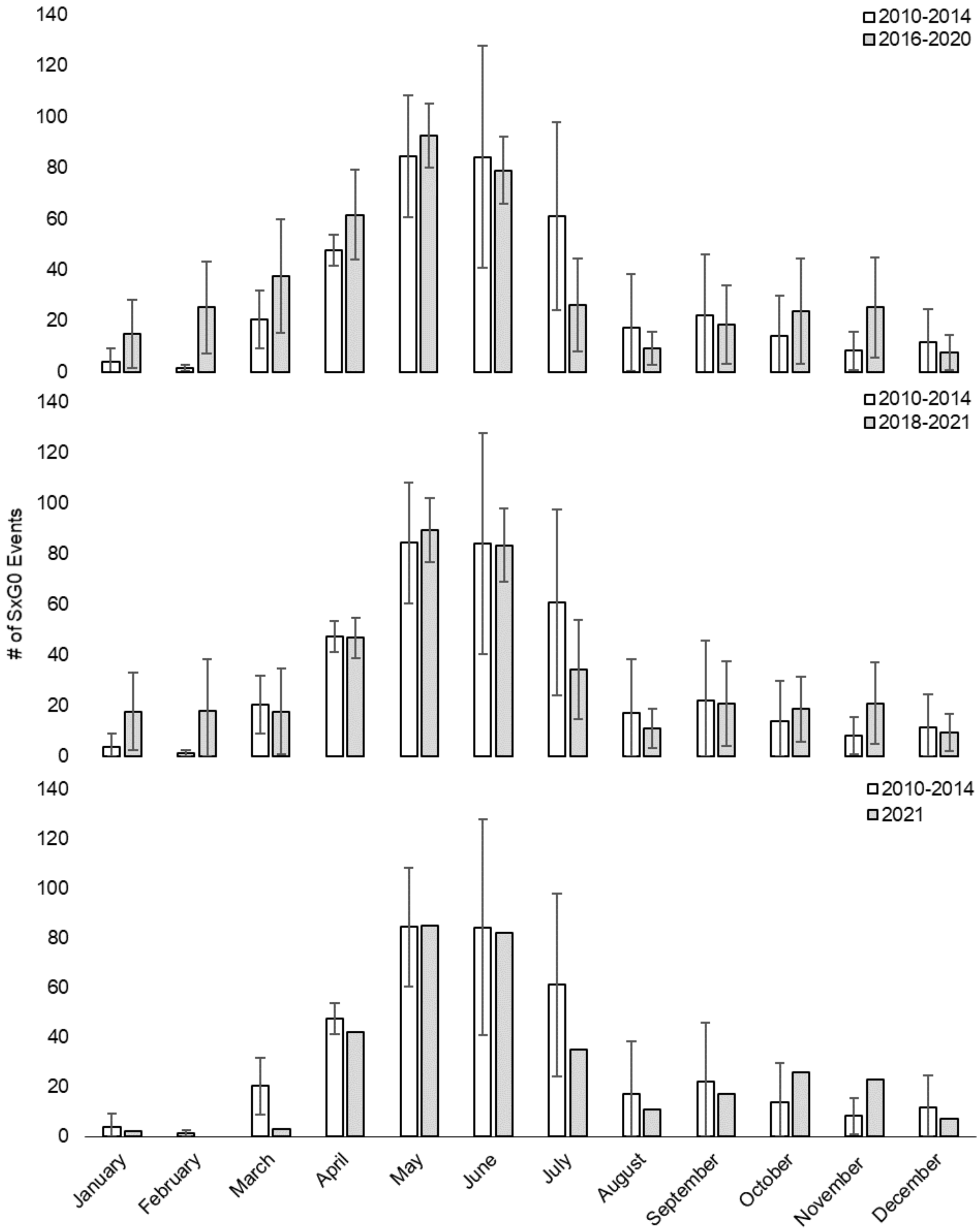

Figure 9-13. Average number of SC events without generation (SxG0) by month compared between 2010 – 2014 (baseline; n = 5/month) and 2016 – 2020 = post Unit 5/6 Installation (n = 5/month; top panel), 2018 – 2021 = post Unit 5 SC operation (n = 4/month; middle panel), and 2021 = post Unit 6 SC operation (n = 1/month; bottom panel) with 95% confidence intervals.

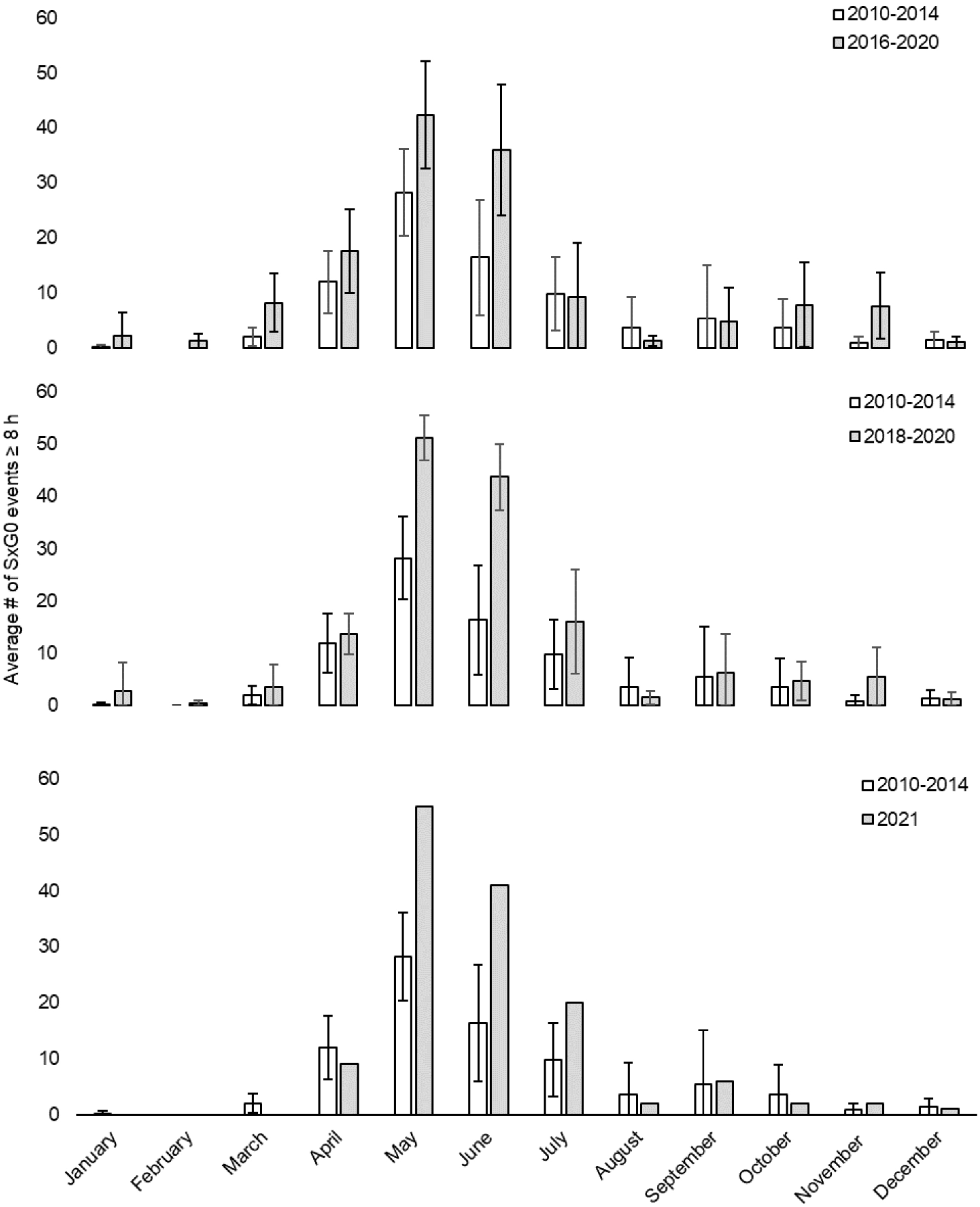

Figure 9-14. Average number of SC events without generation (SxG0) ≥ 8 h duration by month compared between 2010 – 2014 (baseline; n = 5/month) and 2016 – 2020 = post Unit 5/6 Installation (n = 5/month; top panel), 2018 – 2021 = post Unit 5 SC operation (n = 4/month; middle panel), and 2021 = post Unit 6 SC operation (n = 1/month; bottom panel) with 95% confidence intervals.

Table 9-6. Comparison of the frequency of synchronous condense without generation lasting longer than 8 hours (# of events) by month for Test 2 (2010 – 2014 = baseline vs 2018 – 2021 = post Unit 5 SC operation). Green row indicates statistical significance (analysis of variance; significance = $p < 0.004$).

Month	Baseline Average	Test Average	Pval	Pval_Sig
January	0 events	3 events ± 5 events, n = 4	-	-
February	0 events	1 event ± 1 event, n = 4	-	-
March	2 events ± 2 events, n = 5	4 events ± 4 events, n = 4	0.1230	FALSE
April	12 events ± 6 events, n = 5	14 events ± 4 events, n = 4	0.6520	FALSE
May	28 events ± 8 events, n = 5	51 events ± 4 events, n = 4	0.0023	TRUE
June	16 events ± 10 events, n = 5	44 events ± 6 events, n = 4	0.0046	FALSE
July	10 events ± 7 events, n = 5	16 events ± 10 events, n = 4	0.5490	FALSE
August	4 events ± 6 events, n = 5	2 events ± 1 event, n = 4	0.4068	FALSE
September	5 event ± 10 events, n = 5	6 events ± 7 events, n = 4	0.6518	FALSE
October	4 events ± 5 events, n = 5	5 events ± 4 events, n = 4	0.3658	FALSE
November	1 event ± 1 event, n = 5	6 events ± 6 events, n = 4	0.2911	FALSE
December	1 event ± 1 event, n = 5	1 event ± 1 event, n = 4	0.5790	FALSE

10.0 Appendix 3: Technical Report for Management Question # 3

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

10.1 Introduction

This analysis was used to assess whether high total gas pressure (TGP) events (including level of saturation, areal extent, and persistence) downstream of Mica Generating Station (MGS) are capable of impacting fish populations for a given duration and combination of units in synchronous condense (SC) operations. The null hypothesis in the Terms of Reference (TOR) is as follows (BC Hydro 2014):

$H_0$3: *Given what is known of Revelstoke fish ecology and the level of saturation, areal extent and persistence of the plume for a given duration and combination of units in S/C operation, there is no expected population impact.*

In 2012, high flows resulting from above average snow pack and rainfall caused BC Hydro to spill water over MGS from July to September, resulting in a likely period of total gas pressure supersaturation (TGPS). In response, a study was completed for BC Hydro in 2014 to assess the TGPS risk of resident fish in the Revelstoke Reservoir (Plate 2015). This study directly contributed to $H_0$3, as it consisted of a literature review of the effects of TGPS on fish and an inventory of resident fish species in the Revelstoke Reservoir. Therefore, this analysis includes a reiteration of Plate (2015), with emphasis on components that directly relate to $H_0$3.

10.2 Methods

To address $H_0$3, the results from Plate (2015) regarding Revelstoke Reservoir fish species composition and habitat usage, and the associated literature review on TGP affects on fish were compared to the Revelstoke Reservoir TGP environment (cf Appendix 1 and Appendix 2). The methods used by Plate (2015) between 2013 and 2014 to identify resident fishes and associated habitat included hydroacoustic surveys, DIDSON imagery sampling, and fish capture sampling; detailed methods were described in Plate (2015). Methods used to determine the Revelstoke Reservoir TGP environment are available in Appendix 1 and Appendix 2. References to the “Revelstoke Reservoir” in this section are primarily referring to the section of reservoir between the MGS tailrace and Birch/Big Mouth Creek, where all field data were collected (Figure 10-1).

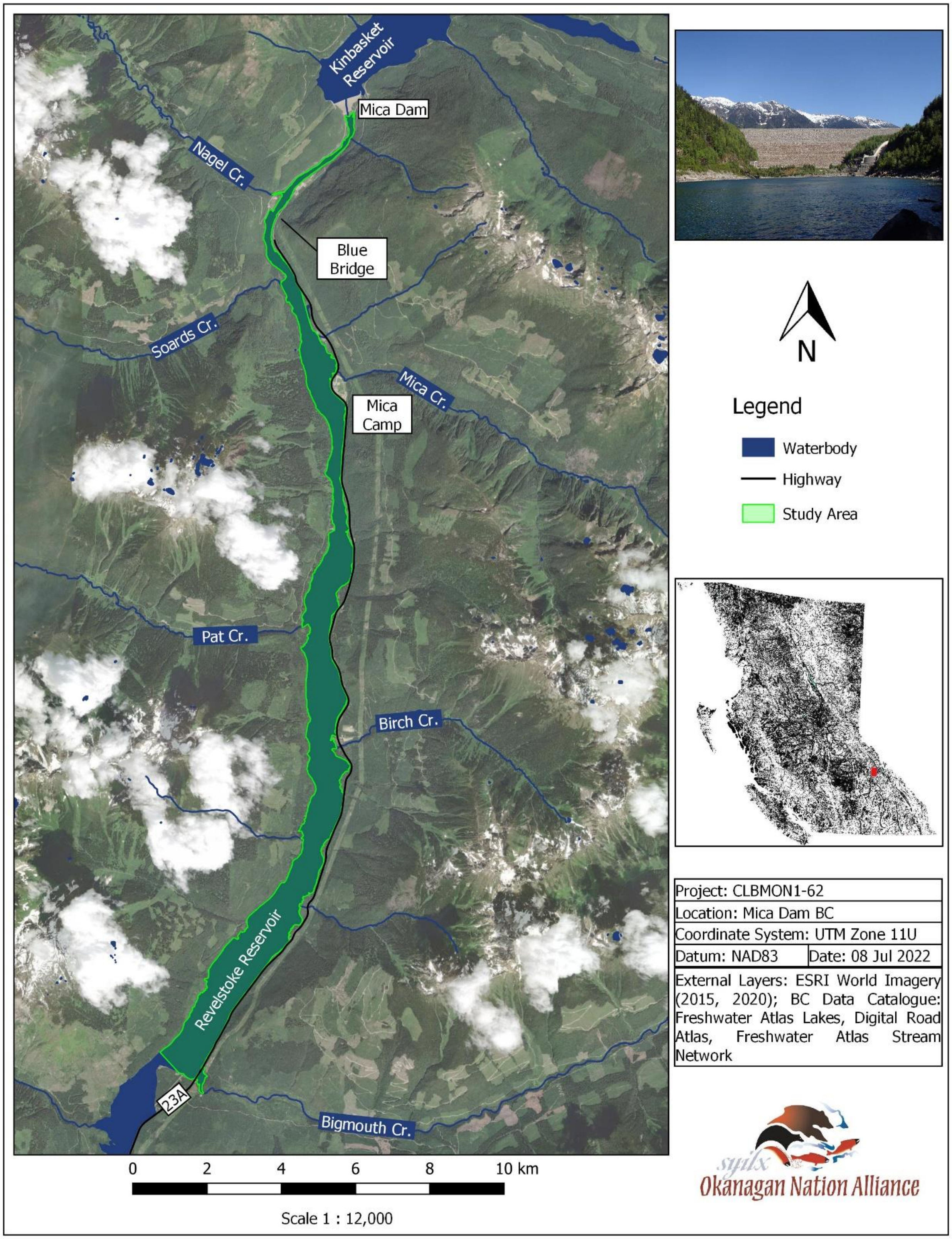

Figure 10-1. Management Question 3 study area between the MGS tailrace and Bigmouth Creek for fish presence, behavior, and TGP environment.

10.3 Literature Review on the Revelstoke Reservoir Fish Species Composition, Habitat Use, and General Impacts of Total Gas Pressure Supersaturation

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

The first 3 km of the reservoir between MGS and Nagle Creek are narrow (< 300 m), shallow (5 m – 10 m), slow flowing, and very clear nutrient poor water. With the contribution of nutrients from Nagle Creek, the water in the reservoir becomes more turbid. Approximately 3 km downstream of Nagle Creek, the valley and the reservoir widen to more than 1 km and to full width at Mica Camp, approximately 8 km downstream of MGS. 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 the main nutrients (Nitrogen and Phosphorus) follow freshets in tributary watersheds which transport nutrients into the reservoir. Accordingly, chlorophyll a concentrations (mean = 0.92 µg/L; 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 northern 20 km of Revelstoke Reservoir below MGS are characterized by hypolimnetic cold water (~ 9 – 11ºC in the summer) fed into the reservoir through MGS from Kinbasket Reservoir. In comparison to a natural lake, these water temperatures appear low for late summer or early fall but they will also be higher than in a natural lake in the winter. With regards to the incubation of Kokanee eggs, the higher winter temperatures will speed up development and likely lead to an early emergence timing of juvenile Kokanee in Revelstoke Reservoir when compared with a natural lake.

Conductivity values throughout the water column of Revelstoke Reservoir were close to 103 µS/cm (in 2013). This is higher than conductivity typically observed in ultra-oligotrophic reservoirs such as Coquitlam Reservoir or Powell Lake in southern BC, were conductivity ranged from 5 – 7 µS/cm (Plate et *al*. 2011; Plate et *al*. 2012^1) and 5 – 18 µS/cm (Plate et *al*. 2012^2). The higher conductivity values in Revelstoke Reservoir when compared to ultra-oligotrophic lakes are likely based on the influx of glacial run-off with increased mineral and turbidity load. For the same reason, total dissolved solid values in Revelstoke Reservoir (94 – 96 mg/L) were also higher than in the same ultra-oligotrophic reservoirs in 2010/11 (4 – 18 mg/L).

Absolute Oxygen values in 2013 in the Revelstoke Reservoir (10.5 – 11.2 mg/L) were in line with values measured in the two ultra-oligotrophic Coquitlam Reservoir (10.8 – 11.8 mg/L) and Powell Lake (10 – 12 mg/L) in late summer or early fall. These oxygen values also represent optimal growing conditions for fish. The temperature dependent Oxygen saturation levels for Revelstoke Reservoir (90 – 100%) in September 2013 were also in line with fall values measured in other reservoirs systems with a similar fish fauna, such as Coquitlam Reservoir and Powell Lake (85 – 100%), and are considered optimal for fish growth and well-being. The pH values measured in Revelstoke Reservoir in September 2013 (7.9 – 8.0) were slightly basic but well within the range of pH values typical for lakes in BC and that allows for good living conditions for aquatic fauna.

10.3.1 Revelstoke Reservoir Fish Community and General Habitat Use

Multiple fish species have been identified in the Revelstoke Reservoir and the MGS tailrace through capture programs (Table 10-1). Observations of non-native Lake Whitefish (*Coregonus clupeaformis*) and Yellow Perch (*Perca flavescens*) are also documented (Golder 2009).

Table 10-1. Identified fish species in the Revelstoke Reservoir and MGS Tailrace.

Species	**Scientific Name**	**Present in** **Reservoir**	 **Tailrace**	**Source**
Kokanee	*Oncorhynchus nerka*	X	X	Golder 2009 Irvine et *al*. 2013 Plate 2015 Caley et *al*. 2018
Bull Trout	*Salvelinus confluentus*	X	X	Golder 2009 Irvine et *al*. 2013 Plate 2015 Caley et *al*. 2018
Rainbow Trout	*Oncorhynchus mykiss*	X	X	Golder 2009 Irvine et *al*. 2013 Plate 2015 Caley et *al*. 2018
Mountain Whitefish	*Prosopium williamsoni*	X	X	Golder 2009 Irvine et *al*. 2013 Plate 2015 Caley et *al*. 2018
Burbot	*Lota lota*		X	Golder 2009
suckers*	Catostomidae	X	X	Golder 2009 Plate 2015 Caley et *al*. 2018
sculpin**	Cottoidea	X	X	Golder 2009 Plate 2015 Caley et *al*. 2018

* Longnose Sucker (*Catostomus catostomus*) identified (Caley et *al*. 2018)

** Prickly Sculpin (*Cottus asper*) and Slimy Sculpin (*Cottus cognatus*) identified (Golder 2009; Irvine et *al*. 2013; Caley et *al*. 2018)

Species diversity in the MGS tailrace appears to be low, consisting primarily of Mountain Whitefish (*Prosopium williamsoni*), Kokanee, and sculpin (Cottoidea); followed by Bull Trout (*Salvelinus confluentus*; Golder 2009; Irvine et *al*. 2013; Caley et *al.* 2018). This trend is also observed in the Revelstoke Reservoir (Plate 2015). Rainbow Trout (*Oncorhynchus mykiss*), Burbot (*Lota lota*), and suckers (Catostomidae) are present but are typically caught in lower numbers; though Burbot abundance may be higher than indicated as the methods used in previous capture programs (electrofishing, gillnetting, and beach seines) are not optimal for sampling Burbot (Golder 2009; Irvine et *al*. 2013; Plate 2015; Caley et *al*. 2018). Juvenile (< 200 mm) Kokanee, Bull Trout, and Mountain Whitefish were found in near-shore environments from the tailrace to the reservoir, though this habitat is typically dominated by sculpin (Golder 2009; Irvine et *al*. 2013; Plate 2015; Caley et *al*. 2018).

Based on estimates from 2008, abundance of most species in the tailrace appeared to be highest in the fall, with Kokanee abundance highest in spring (Golder 2009). Hydroacoustic data in 2013 estimated the population of pelagic fish in the Revelstoke Reservoir (1,600 ha) at 631,000 fish (± 258,000 fish with 95% CI) with 182,000 fish (± 52,000 fish with 95% CI) inhabiting the top two meters of water and 450,000 fish (± 271,000 fish with 95% CI) at two-meters depth and below (Plate 2015). Gillnet sampling indicated 94% of the fish detected through hydroacoustic surveys were Kokanee.

Plate (2015) found fish densities downstream of Blue Bridge tended to be lower during the daytime than during nighttime. The highest density (2,011 fish/ha) was recorded at night in the 3.8 km section between the Blue Bridge and the CMH ski lodge. Fish density distribution did not have a distinct pattern relating to water depth or distance from MGS during daylight; but at night, the majority of fish in the riverine section (closer to MGS) were found at depths greater than two meters, while fish in the lacustrine (reservoir) section were found primarily in the top two meters of the water column. Kokanee prey (insect) availability is suspected to influence this distribution pattern; where prey is relatively available throughout the water column in the shallow riverine section, but is limited to the reservoirs surface in the deep lacustrine section. Juveniles were the most abundant and were generally present at depths greater than two meters; while adult individuals were more frequently observed in the top two meters of water. However, fish of all length classes appeared to migrate to shallow littoral zones at night (Figure 10-3 in Appendix 3-1). Large (> 500 mm) Bull Trout were found to move from the reservoir to tributaries in late summer to spawn, and returned to the reservoir at the beginning of October (Bray 2001, 2003[1], and 2003[2]).

The shallow littoral zone of Revelstoke Reservoir closely resembles a natural lake, with shallow vegetated zones and mud-silt-sand shelves with large-woody debris. Since neither of these features are exposed above the water level for prolonged periods of time, due to the small range of water-level fluctuations typical of Revelstoke Reservoir, the shallow littoral zones appear to be extensively used by fish. This zone of Revelstoke Reservoir provides rearing habitat for all life stages of sculpin species, the juvenile stages of Mountain Whitefish and the odd Kokanee. In addition, this zone is used at night by spawning Kokanee, and large Bull Trout that potentially preying on Kokanee or sculpin species. In contrast, the pelagic zone of Revelstoke Reservoir appears to be the rearing environment for approximately a third of the fish population, mainly composed of juvenile and medium sized Kokanee.

10.3.2 Introduction to Total Gas Pressure Supersaturation

The recorded TGPS levels in Revelstoke Reservoir and in other similar systems are the result of an increase in partial gas pressure of one or more gases in water. The blood of fish that are exposed to TGPS will quickly attain TGP equilibrium with their environment via gas exchange at the gills and become supersaturated. In the supersaturated state, the dissolved gases in the blood have the tendency to come out of solution and form bubbles that can lead to embolism or blockage of blood vessels. Embolism in turn can lead to a lack of blood circulation to parts of the organism or to death. In fish, the state of gas bubbles in the organism is called Gas Bubble Trauma (GBT) and the same condition is known as “the bends” when human SCUBA divers encounter bubble formation in their body or blood. The symptoms of GBT 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 TGPS of less than 110% does not lead to damage in fish while TGPS 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; Fiddler 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 (Fiddler and Miller 1994).

TGPS will only lead to GBT in fish if they are in shallow water where the gases are not kept in solution by hydrostatic pressure. As a rule of thumb, for every meter of depth gained by a fish it can tolerate 10% more TGP (Figure 10-2). For example, most fish would die of GBT and embolism exposed to a multi-day TGPS of 130% near the surface. At a depth of three meters, the same fish would only experience a TGP of 100% and therefore not suffer injury or mortality from GBT. TGPSs ranging from of 120 – 140%, typically encountered below dams during water release over spill ways, will only lead to GBT in fish that are in the top 2 – 3 m of the water column.

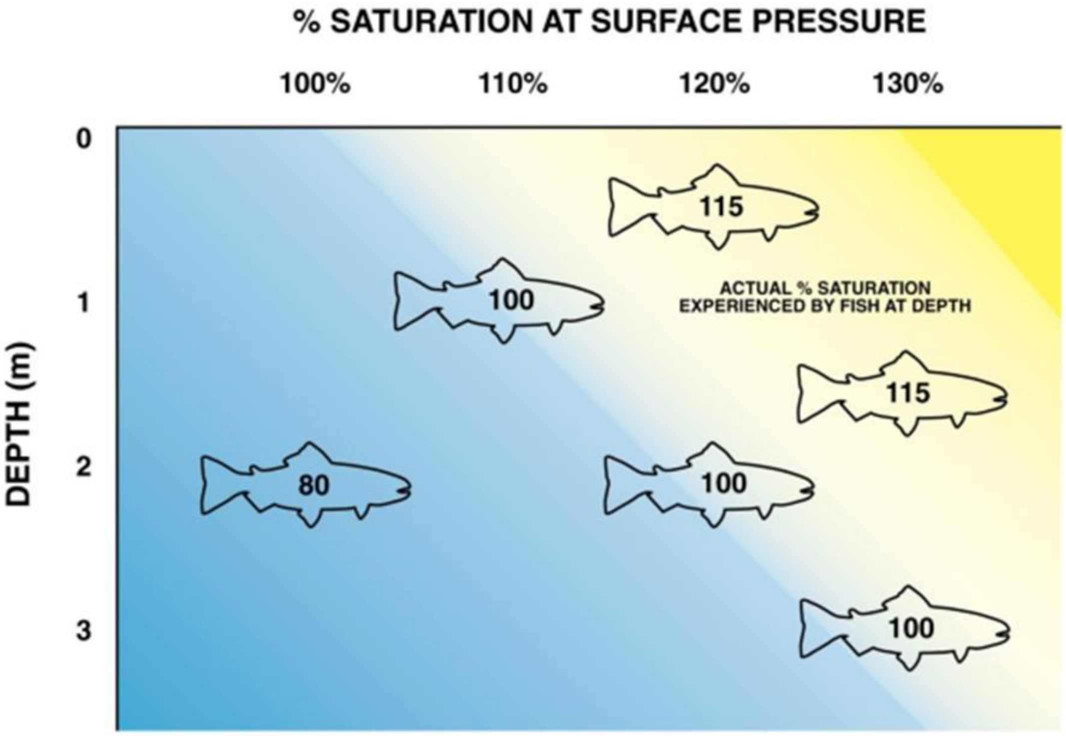

Figure 10-2. Relationship of measured and actual total dissolved gas levels experienced by fish at various depths in a river or lake (Weitkamp 2008).

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 (Fiddler 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 the majority of the water column the supersaturated state persists 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 Fiddler and Miller 1994; Weitkamp and Katz 1980; Hildebrand 1991; White et *al.* 1991).

2. Water is mixed with air bubbles in a suction scenario. In this case the air bubbles are suctioned 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 (Fiddler 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 (Fiddler and Miller 1994). This scenario can occur below dams when generating electricity without spilling especially when the water level at the intake 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% (Fiddler 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. Synchronous Condense (SC) operation of turbines in a generation facility can create TGPS. In this scenario, a turbine actively turns above the water level to keep overland lines charged while water supply to the turbine chamber is limited. The turning turbine supercharges the small amount of water running through the turbine chamber and can lead to TGPS values of > 130%. In addition to the surface spilling scenario, the SC operational mode for one or more turbines is the main reason for TGPS downstream MGS.

The TGPS exposure risk in Revelstoke Reservoir is dependent on the TGP values created by spilling or SC operations over or discharge through MGS. For example: TGP values of 110 – 117% would have a low risk of GBT occurring in fish, even if they are holding in the top two meters of the water column. The risk would only occur if fish were holding close to the surface in < 0.1 m of water depth for periods of hours or days. Fish migrating between the water surface and one-meter depth would be exposed to fluctuating TGP values between 100 – 110% and likely not be affected.

The recovery from high TGPS exposure is quite quick and ranges from 2 to 48 hours for juvenile salmonids, which are considered to be on the more sensitive end of the sensitivity spectrum to TGPS (Hans et *al*. 1999). It can therefore be assumed that fishes that are only exposed to TGPS for short periods of time and then descend to depths greater than one meter are not vulnerable to lasting damage.

Should TGPS values of > 125% be created at MGS over periods of more than two to three days, fish would likely be affected. Juvenile and adult sculpin species as well as juvenile Mountain Whitefish, juvenile Kokanee, Kokanee spawners and eggs, as well as large Bull Trout and Rainbow trout would likely suffer from GBT, or mortality depending on TGPS duration and intensity.

10.4 Species Specific Life Histories, Habitat Use, and Tolerances to Total Gas Pressure Supersaturation

Weitkamp and Katz (1980) and Fiddler and Miller (1994) reviewed the literature on the effects of TGPS in a variety of fish species with a focus on migratory and resident salmonids. They found that, although the species specific tolerance to TGPS was different, the range of tolerance was quite narrow. Most of the literature reviewed by Weitkamp and Katz (1980) determined TGPS caused GBT and mortalities in laboratory experiments. Mortality rates > 50% (LD 50) following exposure times of less than a week in shallow water without a deep-water hydrostatic pressure refuge occurred in most species above 130% TGP. TGP percentages of 120 – 130% could often be tolerated for more than a week without high mortalities but always led to the occurrence of GBT symptoms and significant mortalities at exposure times of more than 20 days. Below 120% TGP, mortality rates and GBT symptoms varied greatly across species and studies. Within this continuum of responses to TGP, percentages of < 120%, salmonids were classified as more sensitive to GBT than cyprinids and a general trend was observed for the developmental stages of salmonid species. The early developmental stages of salmonids (egg) were less sensitive or likely even not sensitive to TGPS at all, while the later juvenile stages became more sensitive. Then the trend reversed and adult salmonids were again found to be less sensitive to TGPS and GBT relative to juvenile salmonids.

Emboli (bubble formation) under the skin is a readily visible symptom of GBT and has often been used to monitor the onset and recovery from GBT. Based on visible emboli, the recovery from high TGPS exposure is quite quick and ranges from 2 h to 48 h for juvenile salmonids that are considered to be on the more sensitive end of the sensitivity spectrum to TGPS (Hans et *al*. 1999). It can therefore be assumed that fishes exposed to TGPS for short periods of time and then descend to depths that protect them from GBT, or that have daily migrations in and out of TGPS, may not suffer from GBT.

In a literature review by Weitkamp (2008), most responses to and effects of TGPS were reported to be derived from field studies and it was found that fishes often are not affected by TGPS values of 120% since they will hold deep enough in the water column to avoid GBT. In general, no TGPS based population effects have been demonstrated in the field according to Weitkamp (2008). In contrast, Marotz et *al*. (2006) found a very high occurrence of TGPS related mortalities in Mountain Whitefish, Rainbow Trout and Bull Trout in the Kootenay River.

It is not clear from the literature whether anatomical differences such as swim bladder structure or lateral line pore size affect TGPS tolerance in fishes (Weitkamp 2008). For example, it can be hypothesized that fish species that regulate their buoyancy through gas exchange with the blood system (physoclistous fishes) can tolerate TGPS better than fishes that can readily adjust their buoyancy through an air duct (physostomous fishes). Based on this theory, Bluegill (*Lepomis macrochirus*), a physoclistous species, should be less tolerant to TGPS than Rainbow Trout, a physostomous species. However the opposite has been shown as Abernethy et *al*. (2001) found Bluegill to be more tolerant of TGPS than Rainbow Trout. Results from other studies reviewed by Weitkamp (2008) with regards to anatomical differences that could ward off TGPS effects have been equally equivocal. These data suggest that it is likely that behavioural and life history differences and the resulting exposure to higher TGPS values play a more important role in the effects of TGPS than anatomical features.

Based on the reviews by Weitkamp and Katz (1980) and Weitkamp (2008) there is no clear indication of active behavioural avoidance of very high TGPS. Fishes were reported to continue on their typical behavioural patterns even when that meant to enter into zones of high TGPS. The following sections describe the general life history and habitat use of fish species observed in Revelstoke Reservoir. Table 10-3 in Appendix 3-1 provides a summary.

i) Mountain Whitefish

Mountain Whitefish are an endemic North American species and are widely distributed along the slope of the Rocky Mountains from the border to the U.S to the Stikine River system in British Columbia (BC; McPhail 2007). Mountain Whitefish life history patterns range from completely riverine to completely lacustrine in BC. They mainly spawn in rivers but are occasionally lake spawners and dependent on the latitude, spawn from fall to early winter when water temperatures drop below 10ºC. Eggs incubate over the winter and fry emerge from late March to early June depending on temperature.

Mountain Whitefish fry and juveniles in rivers and lakes typically inhabit the littoral zones and shallow water of less than one-meter depth were they feed on small invertebrates, plankton organisms and occasionally on terrestrial insects. In these habitats, Mountain Whitefish are commonly associated with silt to coarse gravel substrates. When reaching adulthood in rivers, they remain in shallow water all year round but in lakes Mountain Whitefish occupy shallow water only in the spring and fall while staying in deeper water (< 20 m) in the summer and winter.

Juvenile Mountain Whitefish are commonly found in the top one meter of the water column and are therefore susceptible to GBT in a TGPS situation. The potential exposure of juvenile Mountain Whitefish in Revelstoke Reservoir can be considered likely based on their general life history and results from previous studies (Golder 2009; Irvine et *al*. 2013) which reported that all Mountain Whitefish age classes were caught by electrofishing in the Mica tailrace area. In addition, many of the adult Mountain Whitefish caught in the same study displayed typical morphological signs of spawning which would lead to an annual rearing of fry in the shallow littoral habitat of the Mica tailrace area.

Antcliffe et *al*. (1997) monitored the health of Mountain Whitefish in the Columbia River system below Hugh Keenleyside Dam (Castlegar, BC) and found that TGP values of 115 – 125% did not lead to visible GBT. More subtle symptoms in response to TGPS such as changes in behaviour were not investigated in that study. Details of the exposure time to these elevated TGP values were not reported and therefore it is difficult to assess the detailed effects of TGPS. Nevertheless, it can be assumed that at least adult Mountain Whitefish are resilient to short exposure of TGPS values of 115 – 125%. For TGPS exposure from 125 – 131%, Marotz et *al*. (2006) found an 85% incidence of GBT in Mountain Whitefish after 14 days of exposure.

ii) Bull Trout

Bull Trout, native to western North America, are widely distributed throughout much of BC (McPhail 2007). They generally display three common life history patterns which consist of fluvial, adfluvial and resident populations distributed throughout their entire geographic range. Bull Trout spawn in the fall and depending on the life history, reach sexual maturity between five and six years of age. At this age, Bull Trout in the Revelstoke Reservoir are typically > 500 mm (Bray 2001). This char species is considered slow growing and long lived, often exceeding 10 years of age. As well, depending on the life history pattern, adfluvial forms In Revelstoke Reservoir can attain > 1,000 mm at maturity.

Adult Bull Trout do not appear to occupy the top three meters of the water column in most lakes and deeper rivers, and would therefore likely be less prone to TGPS caused GBT. In Revelstoke Reservoir nevertheless, large (> 500 mm) Bull Trout were found in the shallow littoral zone at night by Plate (2015). In contrast, juvenile Bull Trout are known to rear in shallow water of less than one meter, but would likely be found in tributary streams of Revelstoke Reservoir rather than in the reservoir or the tailrace area itself. Therefore it is important to know at which age Bull Trout migrate from their natal stream into Revelstoke Reservoir. If the migration occurs early in their first or second summer, juveniles would likely be exposed to TGPS, but if they migrate later in life Bull Trout would likely occupy deeper waters once reaching the reservoir and thus avoid TGPS exposure.

High TGPS values severely affect Bull Trout in rivers. As the result of an extended spill over Libby Dam, Bull Trout in the Kootenay River were exposed to TGPS values of 120 – 131% over a period of 21 days (Marotz et *al*. 2006). In response to this high TGPS, a 100% incidence of GBT in Bull Trout was found after eight days of exposure. In addition to GBT, Bull Trout also showed hemorrhaging on the ventral body surface which is frequently followed by secondary complications such as fungal infections (Weitkamp and Katz 1980). In the same study, other fish species such as Mountain Whitefish and Rainbow Trout had slightly lower occurrence of GBT at comparable exposure times. As a result Bull Trout can be categorized as particularly prone to GBT within the salmonid group.

iii) Rainbow Trout

Rainbow Trout are native to North America and northeastern Siberia but have been introduced to cold water environments around the world. In BC, Rainbow Trout are widely distributed, connected to coastal rivers and the middle ranges and headwaters of inland rivers (McPhail 2007). In many lakes Rainbow Trout have been introduced and are regularly stocked as is the case for Revelstoke Reservoir where Rainbow Trout were stocked from 1990 on (RL&L 1993).

Rainbow Trout spawn from late spring to early summer in rivers and only in very few instances lake spawning has been observed. Rainbow Trout fry emerge in late summer and inhabit the shallow margins of the riffles and runs of their natal streams with gravel or cobble substrate were they often become territorial and feed on drifting stages of aquatic insects, other invertebrates and small terrestrial insects. Usually fry of lacustrine populations migrate from the natal stream into the lake at the end of their first summer or in early fall where they remain in the shallow littoral zone associated with cover during daytime and leave their cover to forage at night. Typically, adults also inhabit the littoral zone in lakes but stay slightly deeper but often still within the top three meters of the water column. In warm lakes, adults prefer to stay below the 16 – 18ºC thermocline and can therefore be found in deeper water in the summer. In Powell Lake, a deep, oligotrophic lake on the BC Coast, Rainbow were found to occupy the top three meters of the water column, fed mostly on terrestrial insects and were never encountered in the pelagic zone of the lake (Plate et *al*. 2012[2]; LGL unpublished data). Rainbow Trout appear to mainly occupy the top three meters of the water column as juveniles, and use the surface zone throughout their life cycle and are therefore potentially affected by TGPS caused GBT.

Multiple age classes of Rainbow Trout were present in low densities in the shallow littoral area of the MGS tailrace in electrofishing surveys carried out in 2008 (Golder 2009) and 2012 (Irvine et *al*. 2013). There is no information about the daily behavioural patterns of Rainbow Trout in Revelstoke Reservoir but based on the general affinity for shallow water foraging (McPhail 2007), all free swimming life stages of Rainbow Trout could be exposed to TGPS if it should occur in Revelstoke Reservoir. Rainbow Trout experienced high mortality rates in response to TGPS values higher than 125 % and over periods longer than 8 days in a river (Marotz et *al*. 2006).

iv) Kokanee

Kokanee evolved post glacially from Sockeye Salmon (*Oncorhynchus nerka*) and are widely distributed within BC (McPhail 2007). From the anadromous life history patterns used by Sockeye, non-anadromous Kokanee generally have colonized lacustrine habitats of many large lakes, and have been introduced to numerous small lakes in the central BC interior. Although Kokanee can express variable life history traits, they remain in freshwater throughout their entire life history (McPhail 2007). Kokanee spawn in the fall and generally mature as 2+ or 3+ aged fish, depending on the population and lake productivity. For example, Kokanee in the Williston Reservoir typically spawn at age 3+ with an average length of 231 mm ± 11 mm Standard Deviation (SD; Sebastian et *al*. 2008). This small size at maturity is typical for Kokanee in ultra-oligotrophic lakes in BC, such as Powell Lake where age 3+ Kokanee spawned at an average length of 216 mm ± 9 mm SD and 231 mm ± 8 mm SD in 2011 and 2012, respectively (Plate et *al*. 2012[2] and LGL Limited unpublished data) and Coquitlam Lake where age 3+ Kokanee spawned at an average length of 244 mm ± 8 mm SD (Plate et *al*. 2011). Most of the time Kokanee are distributed throughout all water layers in lakes and often rear near the thermocline. In some areas such as Williston Reservoir, Kokanee were vulnerable to gillnetting above the thermocline in the top three meters of the water column (Plate et *al*. 2013; Sebastian et *al*. 2008; Pillipow and Langston 2002; Blackman 1992).

Kokanee can occupy waters shallower than three meters at all life stages starting from fry and may therefore be susceptible to TGPS and GBT. Historic hydroacoustic work in Revelstoke Reservoir focused on the pelagic fish community in water deeper than five meters. In addition, shallow gillnetting has never been carried out close to MGS (Triton 2011), but electrofishing revealed that all age classes of Kokanee occupied the shallow water littoral zone of the MGS tailrace area (Golder 2009; Irvine et *al.* 2013); but fish were only sampled at night so it is unknown whether Kokanee also occupy the top two meters of the water column during day time.

Weitkamp et *al*. (2003) found Kokanee to be hardly affected by TGPS values of 120 – 150% in the deep Lower Clark Fork River where Kokanee, for at least part of the day, would be able to hold in water depths that would reduce real TGPS levels at the fish holding depth to 100%. This example can be applied to the Revelstoke Reservoir situation where Kokanee would likely be holding in water deeper than three meters for at least part of the day, and high TGPS values could thus be avoided or recovery from GBT could occur. Aside from this low potential for GBT during most of the Kokanee life cycle in Revelstoke reservoir, Plate (2015) observed Kokanee spawning at depths of 2 m where exposure to TGPS for the spawning adults and the resulting eggs and juveniles would be higher. Literature on TGPS effects in Kokanee appears to be rare since the presence of Kokanee in rivers below dams is often the result of entrainment, and the

Kokanee are therefore not considered to be a resident fish species. In general, the TGPS tolerance of Kokanee should be similar to that of other salmonid species.

v) Burbot

Burbot are widely distributed throughout the world and the only representative of the Cod family (Gadidae) in freshwater in BC. Their local distribution ranges from the north to the south of BC, limited to the eastern part of the province. Occasionally, Burbot are also found in the lower reaches of the Fraser River (McPhail 2007). Burbot are cool-water fish and spawn in late winter and early spring. In reservoirs, Burbot can have a very specific migration pattern between summer feeding grounds and winter-spring spawning grounds within the reservoir itself, as found in the Arrow Lakes Reservoir (Glova et *al*. 2010; Robichaud et *al*. 2011, 2012, and 2013).

After spawning in a creek, a creek mouth, or a lake, the non-adhesive and almost neutrally buoyant eggs drift slowly to the bottom and the larvae quickly hatch to start their planktonic life stage. Details of this life stage are virtually unknown. Once the juveniles commence their benthic life style, and have the typical Burbot morphology, they start out with foraging on zooplankton and benthic organisms before becoming mainly piscivorous as adults. Also, benthic juveniles Burbot are often associated with shallow (< 2 m) boulder habitats for cover. As adults, Burbot stay below the thermocline in the summer and do not appear to enter the shallow littoral zone year-round other than to enter tributaries to spawn. Base on their general life history, the benthic-oriented juvenile Burbot are mainly occupying shallow water and would therefore likely be affected by TGPS if it should occur.

In Revelstoke Reservoir, Burbot were only caught once in the MGS tailrace area in shallow water during an electrofishing survey (Golder 2009), and two adult Burbot were caught on a long-line set for White Sturgeon (*Acipenser transmontanus*) in the same area. Overall, the Burbot abundance in the top two meters of the water column in Revelstoke Reservoir appears to be low for all age classes and therefore Burbot susceptibility to TGPS also would be likely low if it should occur. Specific assessments of Burbot TGPS tolerance were not found in the literature review carried out for this report and therefore no assumptions were made.

vi) Sculpin

Based on Irvine et *al.*'s (2013) review of the existing literature, Slimy, Torrent (*Cottus rhotheus*) as well as Prickly Sculpin can be found in Revelstoke Reservoir. Although morphologically different, all three species have a similar life history and occupy similar habitats at the same life stages. In this review, no distinctions are made in the descriptions for the three species and they are mostly referred to as sculpins.

The range for two of the three sculpin species overlaps for the inland form of the Prickly Sculpin and the Slimy Sculpin for southern BC. In the inland sections of northern BC, only the Slimy Sculpin can be found. Sculpin species spawn in the spring when a minimum temperature of 4 – 6 ºC is reached. The spawning ritual for both species involves the adhesion of the eggs to the underside of flat rock by the female and subsequent nest guarding and egg aeration by the male. Larvae are initially pelagic but quickly shift to a demersal stage. As the sculpins grow their forage base shifts from plankton to aquatic and terrestrial insect larvae and fish eggs and larger adults can become efficient predators of juvenile salmonids (McPhail 2007). During their first summer and when they have settled, sculpins often hide in shallow and weedy areas and in flooded vegetation (AMEC 2013). From their second summer on, sculpins can be found in all depths of a lake from the shallow littoral zone to 300 m.

Based on their general life history, juvenile sculpins use shallow water for rearing and could therefore easily be exposed to TGPS. In Revelstoke Reservoir, sculpin species were caught in high densities in the MGS tailrace area in 2008 (Golder 2009), 2012 (Irvine et *al*. 2013), and 2017/2018 (Caley et *al*. 2019) in the shallow water littoral zone at night. Similarly juvenile sculpin species were observed to be using the cover of plants in shallow water in the Lower Columbia River (AMEC 2013). Whether the high densities in these habitats change during daytime is unknown.

Sculpins are often reported to be on par with other non-salmonid species with regards to their TGPS tolerance but consistently more tolerant than salmonid species (Weitkamp 2008). Due to their frequent residence in the shallow littoral zones of large river and lakes, sculpins may be more affected by exposure to TGPS than other species that prefer deeper habitats.

vii) Longnose Sucker

The Longnose Sucker is widely distributed throughout the BC inland regions from the north to the south border and inhabits all freshwater environments from small headwaters of streams to large lakes (McPhail 2007). Longnose Suckers spawn mainly in shallow streams or shallow water on lakeshores over gravel substrate in the spring when the water temperature reaches 5ºC or when the freshet flows start. Spawners for most Longnose Sucker populations are longer than 300 mm. The eggs are demersal and adhesive and are laid without the site preparation that is typical for salmonids. Fry reach 50 mm – 60 mm at the end of their first summer and mainly feed on plankton and chironomid larvae before they start shifting to a mainly benthivore diet of chironomid larvae, ostracods (seed shrimp) and the larvae of many terrestrial insects at the end of their first summer. In cold water situations without a pronounced thermocline, juvenile Longnose Suckers can be found in shallow and quiet water in littoral zones of lakes and the margins of rivers. Longnose Suckers also migrate extensively between spawning habitat in the spring and feeding habitat in the summer and very few details are known about water depth or habitat use during these migrations.

Longnose Suckers are potentially susceptible to TGPS when they occupy shallow water as juveniles and during their migrations as adults. Sucker species were observed in the MGS tailrace area of Revelstoke Reservoir in very low densities during an electrofishing survey conducted in the fall of 2008 (Golder 2009). No sucker species were captured in a gillnet survey in the summer of 2010, approximately 7 km downstream of MGS (Triton 2011) but a small number of suckers were caught in a gillnet survey at the same location (Plate 2015). Based on these results, it can be assumed that sucker species densities in the MGS tailrace area, and the upper 7 km of Revelstoke Reservoir, are low and therefore the chance of TGPS exposure in the Upper Revelstoke Reservoir appears to be also low.

In general, the literature indicates that the tolerance of the Columbia River sucker species is comparable to the tolerance of Mountain Whitefish and higher than the TGPS tolerance of Rainbow Trout (Cochnauer 2000). Sucker species will therefore be tolerant to temporary TGPS values of < 120% and will likely show GBT and other symptoms in response to long-term TGPS levels of > 120%.

viii) Other Species (Potentially Present)

Peamouth Chub (*Mylocheilus caurinus*)

The Peamouth Chub is a member of the minnow family (Cyprinidae) and is widely distributed within the interior of BC; reaching between 250 mm – 300 mm in length (McPhail 2007). Based on general life history patterns, Peamouth Chub have colonized lacustrine habitats of most large lakes, including riverine habitats of many large rivers within BC. They are considered to be mainly insectivorous, feeding on a wide variety of aquatic insects and terrestrial insects, although, Scott and Crossman (1973) indicated that Peamouth Chub can selectively feed upon planktonic crustaceans. Peamouth Chub spawn in early summer and typically mature in their fourth summer in most areas. For example, in Williston Reservoir, Peamouth Chub appear to be maturing in their fifth summer and at an average length of 216 mm ± 16 mm SD (Plate et *al*. 2013). While some Peamouth Chub populations are known to spawn in shallow areas (beaches) of lakes, most lacustrine populations utilize inlet or outlet streams proximate to the lake or reservoir in which they reside. Juvenile Peamouth Chub typically school in shallow littoral areas (< 1 m) in the daytime and disperse into deeper water at night. Adult Peamouth in the summer have a diel migration which brings them near the surface and into shore in the evenings (McPhail 2007). After hatching, newly emerged fry are found in nearshore and littoral areas of most lakes and reservoirs, often associated in mixed-species schools with Redside Shiner (*Richardsonius balteatus*), and Northern Pike Minnow (*Ptychocheilus oregonensis*). Therefore, juvenile Peamouth Chub typically do not contribute to the pelagic community that is detected in hydroacoustic surveys. However, in some locations, such as Williston Reservoir, Peamouth > 120 mm are known to utilize the pelagic habitat and contributed to the fish fauna that can be detected in mobile and pelagic hydroacoustic studies (Blackman 1992; Pillipow and Langston 2002; Sebastian et *al.* 2008; Plate et *al*. 2013). The typical lack of Peamouth in midwater trawling compared with surface gillnetting suggests that they are vertically distributed within the upper few meters (< 5 m) of the water column (Sebastian et *al*. 2003 and 2008; Plate et *al*. 2013).

Peamouth Chub at all developmental stages, but particularly as juveniles due to their preference for shallow water of less than 1 m, are likely to be exposed to TGPS if it should occur. Peamouth Chub were not caught near MGS (within 7 km) in the Revelstoke Reservoir, but were detected halfway between MGS and Revelstoke Dam and closer to Revelstoke Dam (Triton 2011). Peamouth Chub in Revelstoke Reservoir would therefore likely only be exposed to TGPS if TGPS persists throughout all of Revelstoke Reservoir in a non-dissipated manner.

Weitkamp (2008) reports the TGPS tolerance of Peamouth Chub to be within the normal range of up to 120% and reported high mortalities at 130 – 138%. As described above, due to their affinity for shallow water, Peamouth Chub would likely be affected more by TGPS than other fish species that prefer deeper water.

Redside Shiner

This small (< 200 mm) Cyprinid has a British Columbia distribution range from the U.S. border in the south to the Peace River in the north. Redside Shiner live in riverine and lacustrine environments but almost always release their demersal and adhesive eggs in moving water over clean gravel when the water reaches approximately 10ºC in the spring (McPhail 2007). Juvenile Redside Shiner mainly use the shallow (< 1 m) littoral zone in lakes to forage mainly for large plankton organisms, chironomid larvae and pupae and for ostracods. Adults forage from the bottom, in mid-water and on the surface in depths < 4 m mainly for nymphs and pupae of aquatic and adults of terrestrial insects.

Based on their general life history, all age classes of Redside Shiner are likely affected by TGPS and young-of-the-year Redside Shiner will especially be prone to TGPS and GBT in the very shallow water they prefer. In Revelstoke Reservoir, Redside Shiner can only be found close to the Revelstoke Dam; no shiners were caught in the vicinity of MGS or halfway between Mica and Revelstoke Dam (Triton 2011). Therefore, as with Peamouth Chub, Redside Shiner in Revelstoke Reservoir would only be exposed to TGPS if TGPS affects all of Revelstoke Reservoir in an unabated manner.

Redside Shiner have been reported to be less tolerant to TGPS than Northern Pikeminnow by Bouck (1976 in Fickeisen and Schneider 1976) and more tolerant than Northern Pikeminnow by VanderKooi et *al*. (2003). Based on these contradictory results, the Redside Shiner tolerance to TGPS falls within the same range as most other indigenous species but the preference for shallow water habitat will make this species more prone to encounter TGPS conditions than many other species that prefer deeper water.

Northern Pikeminnow

The Northern Pikeminnow is the largest minnow in British Columbia and can reach lengths of > 400 mm. Northern Pikeminnow are widely distributed in British Columbia from the U.S. border in the south to the Skeena system in the north (McPhail 2007). Northern Pikeminnow spawn in late spring when water temperatures of ~ 12 ºC are reached. Spawning aggregations can be mainly found in shallow flowing water of large rivers and the demersal and adhesive eggs are released over clean gravel and cobble. Occasionally, Northern Pikeminnow have also been observed to be spawning in lakes over the same substrate and in shallow water. As young-of-the-year and as 1-year old juveniles, Northern Pikeminnow inhabit the very shallow (< 1 m) water of the littoral zone in lakes and large rivers close to weed beds or other forms of cover. Northern Pikeminnow consume a variety of prey items with a focus on plankton and chironomid larvae as juveniles and fish and other large prey as adults. Based on their general life history, juvenile Northern Pikeminnow throughout their first year are occupying very shallow water (< 1 m) and would therefore likely be exposed to TGPS if it should occur.

In Revelstoke Reservoir, Northern Pikeminnow are very rare and have only been caught in the forebay area of Revelstoke Dam, and halfway between MGS and Revelstoke Dams (Triton 2011). Northern Pikeminnow were not captured during two electrofishing surveys in the tailrace area of Mica Dam in 2008 (Golder 2009) and 2012 (Irvine et *al*. 2013). Overall, the likelihood of TGPS exposure for Northern Pikeminnow in Revelstoke Reservoir is therefore considered low.

Mortalities in Northern Pikeminnow were not observed following 20 – 35 day exposure to TGPS at 123% (Blahm et *al*. 1976 in Fickeisen and Schneider 1976) and Northern Pikeminnow appear to be more tolerant to TGPS than Steelhead at low TGPS values but equally or less tolerant at high TGPS values (Meekin and Turner 1974). One hundred percent of mortalities following 12 day exposure to TGPS at 126% were observed and within 1 day of exposure reduced feeding was observed at TGPS levels above 110% (Bentley et *al*. 1976 in Fickeisen and Schneider 1976). Northern Pikeminnow therefore have a similar TGPS tolerance as other non-salmonid species.

10.5 Revelstoke Reservoir Total Gas Pressure Environment and Impacts to Resident Fish Species

Appendix 1 provides methods and analysis for described TGP conditions, while Appendix 2 provides methods and analysis for MGS operations.

MGS operations that increase TGP above the BC Water Quality Guideline of 110% (SC without generation ≥ 8-h duration with intermittent occurrences of SC with generation for 1 h) typically occur in May and June. This period coincides with a period of low power demand, between winter heating and summer cooling. Therefore, spring (May/June) would be the period of most risk to fish. Limited data collected in the fall of 2016 indicated MGS operations outside of spring do not result in long-term periods of elevated TGP (based on TGP data collected in 2016 and comparing MGS operations during that time to other months).

MGS operations in the spring resulted in elevated TGP for up to ~ 504 h (21 days; June 2020). However, elevated TGP events were typically between 7 h and 45 h (averaging 40 h) with an average TGP usually between 110 – 113%. TGP plumes were estimated to be between 2.1 km and 10.5 km in size with travel rates between 26 m/h and 636 m/h (averaging 168 m/h), depending on the discharge from MGS. TGP dissipation appeared to be uniform between 0.3 km and 10.5 km from MGS at a reduction rate of ~ 1%/km (when TGP was > 110% at 0.3 km).

The most severe (longest occurrence with highest average) ocurred in June of 2020 when elevated TGP event was an average of 115% for 13 days, including 1.3 days of 120 – 130% TGP in the tailrace, and averaged 115% for 21 days at Blue Bridge (only 2 h was 120 – 130% TGP). By the time the plume reached downstream of Mica Camp, TGP decreased to values of ≤ 112%. 21 days of 115% TGP on average was the closest recorded TGP event to conditions that caused mortality in fish (Weitkamp and Katz 1980).

Observed elevated TGP events with values ≥ 130% and 120 – 130% downstream of MGS were not sufficiently long enough to cause mortality based on temporal thresholds observed by Weitkamp and Katz (1980; Table 10-2); however, it should be noted these events were part of longer periods of time when TGP was > 110%. Though the longest instance of TGP ranging between 120 – 130% TGP was 1.3 days, multiple events of elevated TGP were detected with averages of ≥ 120% lasting 1.4 – 4.2 days. Elevated TGP was higher in the tailrace than at Blue Bridge, but the exposure time at Blue Bridge was on average longer. Therefore, fishes in the tailrace are exposed to higher levels of TGP for a shorter periods of time, while fishes downstream of the tailrace are exposed to lower levels of TGP for longer periods of time. TGP plumes ≥ 110% detected downstream of Mica Camp were typically at, or slightly above (+2%), 110%.

Table 10-2. Total gas pressure (TGP) level and mortality threshold (Weitkamp and Katz 1980; Plate 2015) compared to the maximum observed duration for each TGP strata downstream of MGS in Revelstoke Reservoir (Appendix 1).

TGP Level	Threshold	Maximum Observed Duration
> 130%	> 7 days	1 h
120 – 130%	> 20 days	1.3 days
> 110%	variable	21.0 days

Considering high TGP occurs in the spring during daytime, the species most at risk of impacts from elevated TGP are juvenile and adult Mountain Whitefish, spawning Rainbow Trout, juvenile and adult Kokanee, and sculpin. During nighttime, adult Bull Trout moving into the shallow (< 1 m) littoral zone as observed by Plate (2015), could also be at risk of GBT but these fish likely retreated to deeper water during daytime. However, the fish density of other species in the riverine section closer to MGS was higher at night but the majority were detected in depths > 2 m. During daytime much fewer fish were in this section. (Plate et *al*. 2015). Therefore all species were likely at depths that would have been sufficient to act as refuge for part of elevated TGP saturation. The majority of fish (primarily Kokanee) in the reservoir section (Mica Camp and downstream) were in the top two meters of the water column, but TGP averaged < 112% and typically lasted less than a day in that area.

10.5.1 Mountain Whitefish

Mountain Whitefish were the most common species detected in the tailrace of MGS, though their abundance was lower in the spring than in the fall (Golder 2009; Irvine et *al*. 2013; Caley et *al*. 2018). In rivers, Mountain Whitefish inhabit shallow waters year round while Mountain Whitefish are found in shallow water in the spring and fall in lakes, retreating to deeper (> 20 m) water in the summer and winter. Juvenile Mountain Whitefish were found in near-shore and shallow (< 1 m) environments from the tailrace to the reservoir (Golder 2009; Irvine et *al*. 2013; Plate 2015; Caley et *al*. 2018). Therefore, Mountain Whitefish were considered to be at risk of exposure to high TGP values downstream of MGS.

The timing of high TGP events in Revelstoke Reservoir coincides with potential Mountain Whitefish egg emergence and fry rearing, when adults inhabit shallow waters in lacustrine environments. Mountain Whitefish have been found to be resilient to short durations of TGP levels of 115 – 125% (Antcliffe et *al*. 1997). However mortality has been observed at TGP levels of 125 – 131% over 14 days (Marotz et *al*. 2006), and GBT was observed in salmonids after a week of 120 – 130% TGP exposure (Weitkamp and Katz 1980). These TGP conditions were not observed during the monitoring period (the closest was 120% average peaking at 127% over 4 days). Juvenile salmonids were found to be the most sensitive to TGP (Weitkamp and Katz 1980) and reside in shallow habitats in the tailrace. Behavioural changes, and potentially GBT and mortality of juvenile Mountain Whitefish between the tailrace and Blue Bridge as a result of TGP exposure cannot be dismissed during the more severe elevated TGP events observed in the monitoring period.

Based on Mountain Whitefish population estimates by Golder (2009), Mountain Whitefish were least abundant between MGS and Blue Bridge in the spring when compared to summer, fall, and winter. This indicates Mountain Whitefish primarily reside in the reservoir in spring, where TGP is relatively low compared to the tailrace, and ≥ 110% for shorter durations. Therefore if an elevated TGP event should be severe enough to cause mortality in the tailrace to Blue Bridge stretch, the impact is unlikely to be population wide due to the seasonal distribution of these fish. In addition, refuge from high TGP is available within the tailrace and downstream, as depths can reach 3 – 5 m throughout the study area; though whether or not Mountain Whitefish seek out refuge during periods of high TGP is unknown.

10.5.2 Kokanee

Kokanee were detected in the MGS tailrace and were the most abundant species observed in the winter and spring (Golder 2009). Kokanee can occupy waters shallower than three meters at all life stages starting from fry and may therefore be susceptible to TGPS and GBT. However, the majority of Kokanee in the Revelstoke Reservoir (Mica Camp downstream) were observed at depths > 5 m.

The timing of high TGP events in Revelstoke Reservoir coincides with potential Kokanee egg emergence and rearing of fry, and both adult Kokanee and fry were found in shallow waters in the spring between MGS and Blue Bridge. Kokanee were observed to be minimally affected by 120 – 150% TGP in a river where they held at depths that reduced the effect of TGP for at least part of the day (Weitkamp et *al*. 2003). The MGS tailrace and downstream habitats possess sufficient depth to provide refuge for the TGP levels observed during the monitoring period. In addition, there appears to be a pelagic population of Kokanee in the Revelstoke Reservoir which would provide resiliency to the overall Kokanee population should a severe TGP event cause mortality between Mica Camp and MGS. If Kokanee fry are unable to retreat to depths suitable to provide relief from high TGP, then they would likely experience deleterious impacts and possibly mortality from some of the more significant events observed in the monitoring period.

10.5.3 Bull Trout

Bull Trout were detected in the MGS tailrace, though they were less abundant than Mountain Whitefish, and appeared to be more abundant in the fall than the spring (Golder 2009). Adult Bull Trout prefer deeper habitats and therefore would likely be less prone to TGPS caused GBT. In contrast, juvenile Bull Trout are known to rear in shallow water (< 1 m), but likely use the tributaries of Revelstoke Reservoir rather than the tailrace. The timing of juvenile Bull Trout migration to the Revelstoke Reservoir is unknown, but if emergence is in spring, they would likely miss the period of high TGP.

Bull Trout have experienced severe impacts (GBT, hemorrhaging, fungal infections) from 21 days of 120 – 131% TGP downstream of Libby Dam (Marotz et *al*. 2006; Weitkamp and Katz 1980). During the same event, Mountain Whitefish and Rainbow Trout had fewer occurrences of GBT at comparable exposure times. These conditions were not observed during the monitoring period at MGS (the closest were 120% average peaking at 127% over 4 days, and 115% average peaking at 120% over 21 days). Adult Bull Trout were likely the most impacted by these events based on their susceptibility and their tendency to occupy shallow waters at night to forage (Plate et *al.* 2015), and could have potentially experienced behavioural changes among other ill effects during the more severe elevated TGP events observed in the monitoring period.

The Bull Trout population within the MGS tailrace is lower in the spring than the fall (approximately half), and Bull Trout likely migrate to the Revelstoke Reservoir where the effects of TGP are less significant. In addition, the larger Bull Trout population in the Revelstoke Reservoir could provide resiliency if a severe TGP event resulted in mortality between Blue Bridge and MGS. The MGS tailrace also contains deeper habitat for refuge. Though Bull Trout appear to occupy shallow water at night they likely retreat to deeper habitats during the day, limiting their exposure and providing opportunity to recover.

10.5.4 Rainbow Trout

Rainbow Trout were detected in the MGS tailrace, but were not as prevalent as Mountain Whitefish, Bull Trout, and Kokanee (Golder 2009; Irvine et *al*. 2013; Caley et *al.* 2018). Typically, adults inhabit the littoral zone in lakes (within the top three meters of the water column) and spawn from late spring to early summer in rivers.

Rainbow Trout experienced high mortality rates in response to TGPS values higher than 125% and over periods longer than 8 days downstream of Libby Dam (Marotz et *al*. 2006), and GBT was observed in salmonids after a week of 120 – 130% TGP (Weitkamp and Katz 1980). These TGP conditions were not observed during the monitoring period (the closest was 120% average peaking at 127% over 4 days). However other severe events observed during the monitoring period could have potentially caused behavioural changes and/or other impacts.

Rainbow Trout appear to be more abundant in the MGS tailrace in the fall than in the winter, spring, and summer (Golder 2009). Rainbow Trout in the Revelstoke Reservoir likely spawn in tributaries which would remove them from TGPS resulting from MGS. Rainbow Trout holding to enter tributaries and those that do spawn in the MGS tailrace would be the most at risk. Salmonid eggs were observed to be more resilient to high TGP (Weitkamp and Katz 1980), and the most sensitive stage (juveniles) emerge in late summer, when operations that create TGP are less likely. Therefore, if an elevated TGP event severe enough to cause mortality in the tailrace to Blue Bridge area were to occur, its impact would be unlikely to be population wide. In addition, refuge from high TGP is available within the tailrace and downstream, as depths can reach 3 – 5 m throughout the study area.

10.6 Discussion

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

$H_0$3: *Given what is known of Revelstoke fish ecology and the level of saturation, areal extent and persistence of the plume for a given duration and combination of units in S/C operation, there is no expected population impact.*

$H_0$3 is accepted. While many fish species are temporarily holding in shallow water (< 1 m) within the first 10 km downstream of MGS, and would therefore be exposed to TGPS > 110% caused by SC operations, the TGP values and exposure durations are likely not high enough to cause population impact in any species based on the literature.

10.7 References

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10.8 Appendix 3-1 Figures and Tables for Management Question # 3 Technical Report

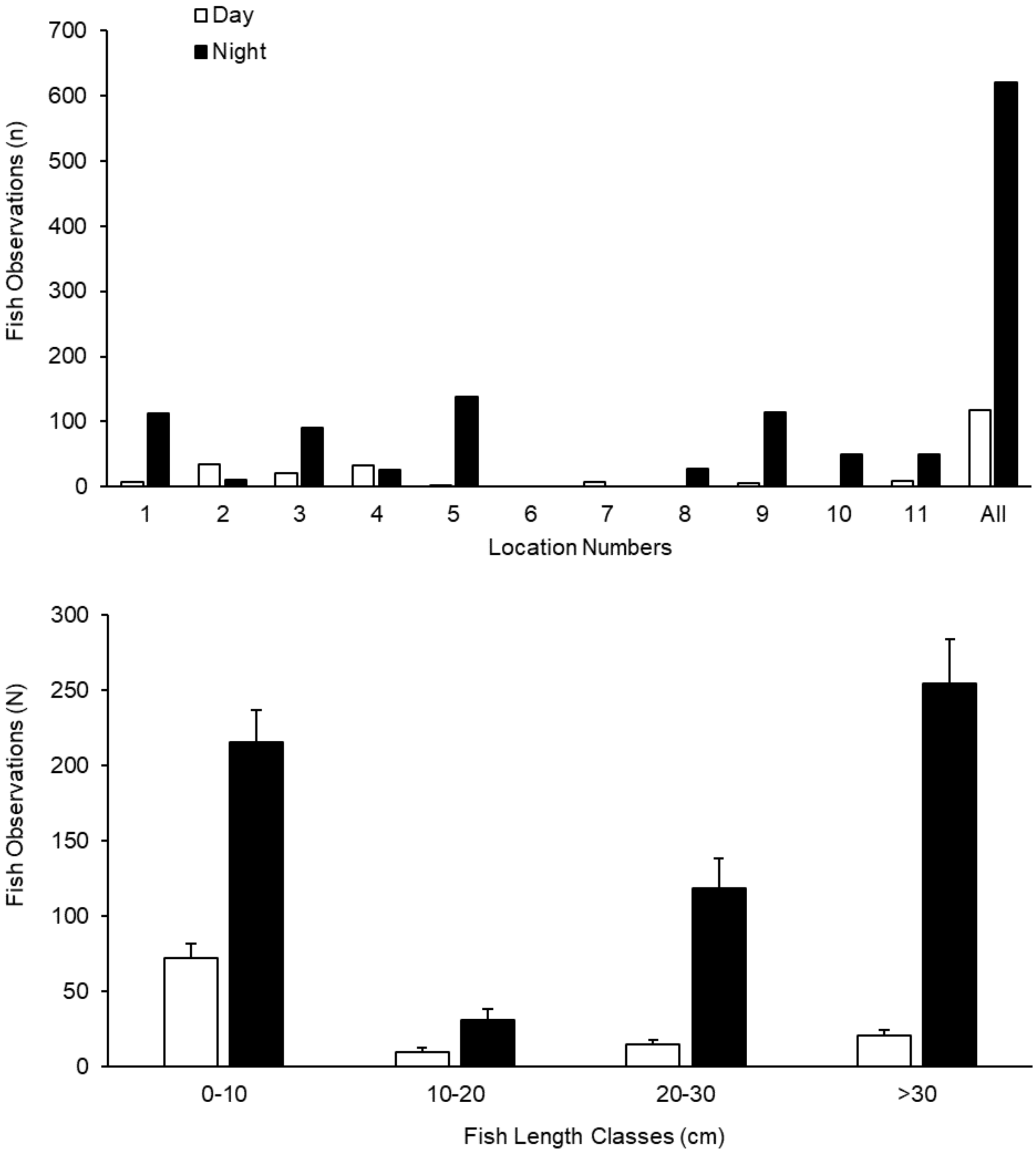

Figure 10-3. (Top) total standardized number of fish observations made with a DIDSON system at eleven shallow littoral locations (see Figure 10-4 for map), daytime (white) and nighttime (black). All fish observation numbers were standardized to observation made per hour; (bottom) average standardized number of fish observations made with a DIDSON system in the shallow littoral zone at all locations for different fish length classes (cm) compared between daytime (white) and nighttime (grey; error bars = SD). Figures from Plate (2015).

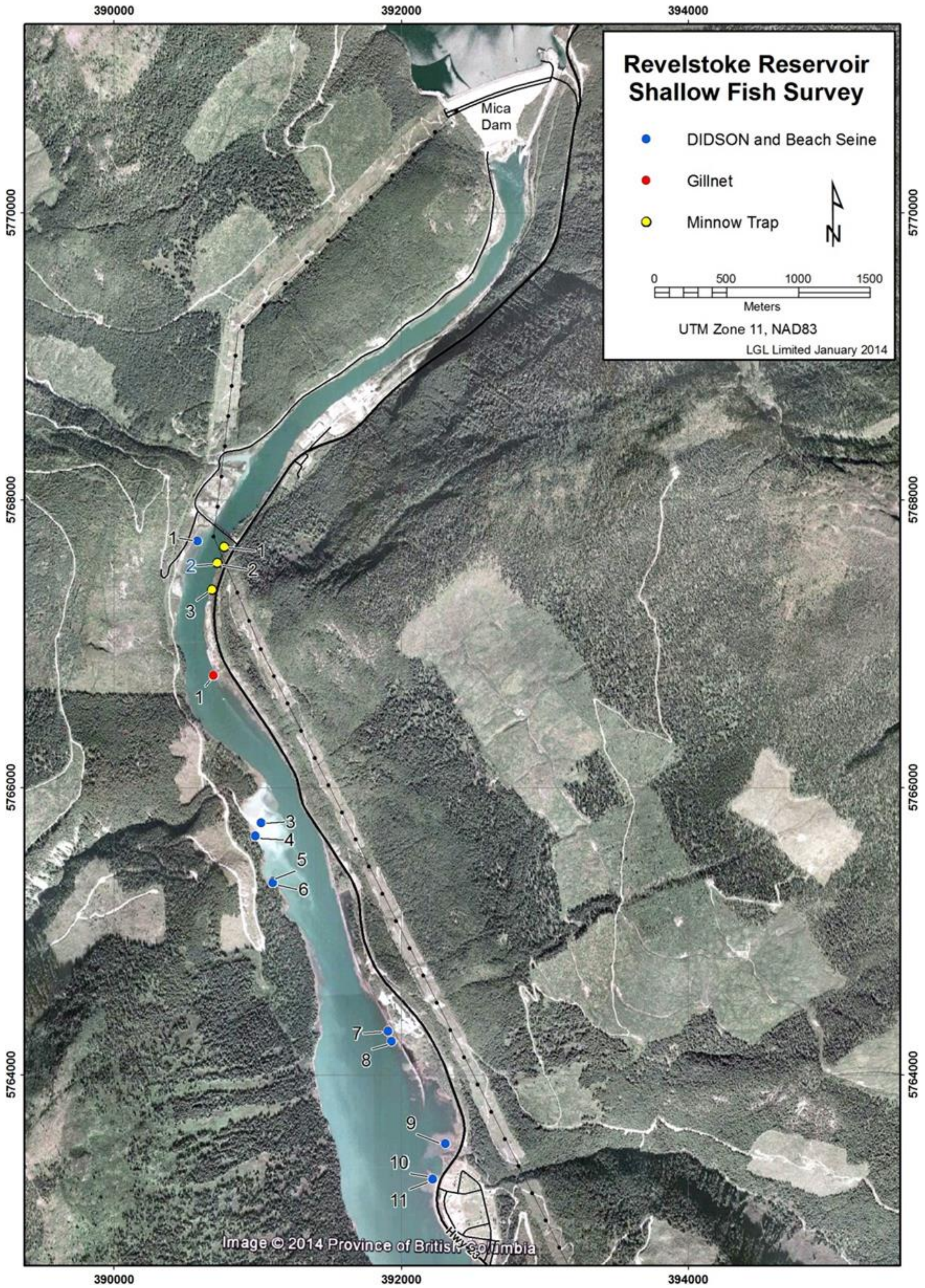

Figure 10-4. Map of DIDSON, beach seine, and minnow trapping locations used in September 2013 (Plate 2015).

Table 10-3. Summary table of TGPS exposure risk for fish species at different developmental stages in Revelstoke Reservoir downstream of Mica Dam (modified from Plate 2015).

Species	**Developmental Stage**	**Season**	**Revelstoke Reservoir Knowledge**	**Inferred potential TGP exposure risk below Mica**	**Inferred risk of injury or mortality**	**Rationale for inferred risk of injury or mortality**
Mountain Whitefish	All	Year-round	Present in shallow water in Mica Dam area in all age classes	High	Medium	Lower seasonal abundance in the tailrace of MGS in spring (when compared to summer, fall, winter). Deep water refuge is available within the MGS tailrace where TGP is highest.
Rainbow Trout	All	Year-round	Present in shallow water in Mica Dam area in multiple age classes	High	Medium	High TGP conditions occur around spawning season when at least part of the population are in tributaries. Eggs are shown to be resilient to high TGPS, so those spawned in the tailrace would be at low risk and juvenile emergence is in the summer when TGP levels are lower. Deep water refuge is available within the MGS tailrace where TGP is highest.
Kokanee	All	Spring-Fall-Winter	Present in shallow water in Mica Dam area in multiple age classes	High	Medium	Kokanee appear to be resilient to high TGPS when deep water refuge is available for part of the dat. Deep water refuge is available within the MGS tailrace where TGP is highest. There appears to be a population of pelagic dwelling in the Revelstoke Reservoir which would provide resiliency if a large mortality event were to occur.
Bull Trout	All	Year-round	Present in shallow water in Mica Dam area in multiple age classes	High	Medium	Bull Trout population within the MGS tailrace is lower (approximately half) in the spring than the fall, it is likely Bull Trout migrate to the Revelstoke Reservoir where the effects of TGP are less significant. Deep water refuge is available within the MGS tailrace where TGP is highest.
Longnose Sucker	Juvenile	Summer	Low density throughout reservoir and no observations in shallow water in Mica Dam area	Low	Low	Deep water refuge is available within the MGS tailrace where TGP is highest.
Peamouth Chub	All	Year-round	No observations in shallow water in Mica Dam area, medium densities in lower	Medium	Low	Deep water refuge is available within the MGS tailrace where TGP is highest.

			and central reservoir			
Redside Shiner	All	Year-round	No observations in shallow water in Mica Dam area, medium densities in lower reservoir	Medium	Low	Deep water refuge is available within the MGS tailrace where TGP is highest.
Sculpins	Juveniles	Year-round	Present in shallow water in Mica Dam area in all age classes	High	Medium	Deep water refuge is available within the MGS tailrace where TGP is highest.
Northern Pikeminnow	Juveniles	Year-round	No observations in shallow water in Mica Dam area, low densities in lower and central reservoir	Low	Low	Deep water refuge is available within the MGS tailrace where TGP is highest.
Burbot	Juveniles	Year-round	Low densities in shallow water throughout the reservoir	Medium	Low	Deep water refuge is available within the MGS tailrace where TGP is highest.