Peace River Water Use Plan

Peace River Spill Total Gas Pressure/Temperature Monitoring Program – July/August 2020

Reference: GMSMON-11

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PEACE RIVER WATER USE PLAN

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EXECUTIVE SUMMARY

Long-term monitoring of baseline water temperature and total dissolved gas pressure (TDGP) in the vicinity of the WAC Bennett and Peace Canyon dams has been identified as an essential component of the Peace Spill Protocol (PSP) and the Peace River Flood Pulse Plan as set out by the Peace River Water Use Plan Consultative Committee and the Peace River Water Use Plan (WUP). The Plan provides for the collection of TDGP and water temperature data under the GMSMON-11 monitoring program, during spill events which exceed spill discharge and duration thresholds. The objectives of the GMSMON-11 monitoring program are to record TDGP levels during and immediately after a qualifying spill event and assess TDGP levels in terms of impact on fish populations in Dinosaur Reservoir and the Peace River downstream of the Peace Canyon Dam.

In July 2020, BC Hydro determined it was necessary to release water from the WAC Bennett and Peace Canyon dam spillways in order to arrest the rising elevation of Williston Reservoir. A spill was initiated on the morning of July 17, 2020 and ran continuously, at both dams, for 32 days. All spill operations then ceased for 7 days, after which, the Peace Canyon spillway was re-opened for 8 days.

TDGP monitoring efforts were hampered by a lack of ready access to reliable TDGP monitoring equipment. Six used Point Four Systems Inc. Model PT4 TGP meters were secured on loan and deployed immediately prior to the spill at monitoring sites upstream and downstream of both facilities. Due to previously-reported reliability problems with the Model PT4 meters, BC Hydro staff also arranged for the rental of six new HydroLab Model MS5 TGP meters to be deployed in tandem with the PT4 meters midway through the spill as a back-up and data quality check.

Monitoring results indicated slightly supersaturated background TDGP levels in Williston Reservoir near the entrance gates to the WAC Bennett Dam spillway (103-106%), likely due to rapid mid-summer surface warming. Consistent with previous monitoring events, it was observed that atmospheric gases were easily introduced into Dinosaur Reservoir inflow at relatively low spill rates due to a combination spillway design and plunge pool depth. The incremental increase in TDGP associated with the Bennett Dam spillway was approximately 13% (at 560-670 cms), resulting in air saturation levels of 116-119% throughout Dinosaur Reservoir within 36 hours.

Interpretation of TDGP monitoring results downstream of the Peace Canyon Dam spillway was limited by insufficient data due to meter failures and poorly-defined mixing patterns. However, recovered data

suggested that operation of the Peace Canyon Spillway may result in a relatively small incremental increase in air saturation levels (2%) when Dinosaur Reservoir TDGP is low and a potential reduction in downstream saturation levels when TDGP levels in Dinosaur Reservoir are high (i.e., during simultaneous operation of the WAC Bennett Dam spillway). Limited data recovered from the Peace River downstream near Hudson's Hope indicated saturation levels of approximately 115%.

Outright spillway entrainment mortality was monitored through boat-based mortality patrols on the upper portion of Dinosaur Reservoir during the first 6 days of the spill. Low numbers of dead fish were observed relative to past spill events. Recovered mortalities were exclusively juvenile Kokanee.

Potential effects of air superstaturation on downstream fish populations (gas bubble trauma) was monitored through the concurrent Peace River Fish Community Indexing Program. Thirty boat electro-fisher transects were conducted within 60 km downstream of the Peace Canyon Dam between August 22 and September 14, 2020. During this period, 2,841 fish were visually assessed using the DELT classifications system and key symptoms indicative of gas bubble trauma. No symptoms consistent with gas bubble trauma were recorded.

Based on the results of the 2020 GMSMON-11 monitoring program, no definite determination could be made as to the potential impacts of air supersaturation on downstream fish populations in the Peace River, although no symptoms were observed during 2020 indexing program activities. Based on limited data from the Peace Canyon tailrace and Hudson's Hope TDGP monitoring sites, it appears that fish residing in water deeper than 1 m could have avoided the effects of incremental air supersaturation through depth compensation.

It is recommended that ready access to reliable TDGP monitoring equipment be improved in the event that future spills become likely.

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1.0 INTRODUCTION

Long-term monitoring of baseline water temperature and total dissolved gas pressure (TDGP) in the vicinity of the WAC Bennett and Peace Canyon dams has been identified as an essential component of the Peace Spill Protocol (PSP) and the Peace River Flood Pulse Plan as set out by the Peace River Water Use Plan Consultative Committee and the Peace River Water Use Plan (WUP).

The Plan provided for the collection of TDGP and water temperature data, during spill events from Peace River generating stations, under the GMSMON-11 monitoring program for a 10-years period between 2008 and 2019. Monitoring stations included the WAC Bennett Dam forebay, WAC Bennett Dam tailrace, Peace Canyon Dam forebay, Peace Canyon Dam tailrace, Peace River at Hudson's Hope, Peace River downstream of the Halfway River, and Peace River downstream of the Pine River.

In June 2019, the Peace River Water Use Plan Monitoring Program Terms of Reference Addendum 2 extended the GMSMON-11 spill monitoring program beyond 2019 and discontinued the use of monitoring sites within and below the proposed Site C inundation zone, limiting spill monitoring sites to the forebays and tailraces of the WAC Bennett and Peace Canyon dams (Fig.1).

Triggering of the GMSMON-11 spill monitoring program is conditional on the occurrence of a spill where discharge from:

- the WAC Bennett Dam spillway exceeds a daily average of 205 cms for 2 days or more,
- the Peace Canyon Dam spillway exceeds a daily average of 1,500 cms for 2 days or more,
- the Peace Canyon Dam spillway exceeds a daily average of 500 cms for 7 days or more, or
- the total discharge from the Peace Canyon Spillway and generating station exceeds 2,000 cms for 2 days or more.

TDGP monitoring is to begin immediately prior to a triggering spill event and continue for up to 2 weeks after the spill.

The objectives of the GMSMON-11 monitoring program are to record TDGP levels during and immediately after a qualifying spill event and assess TDGP levels in terms of impact on fish populations in Dinosaur Reservoir and the Peace River downstream of the Peace Canyon Dam.

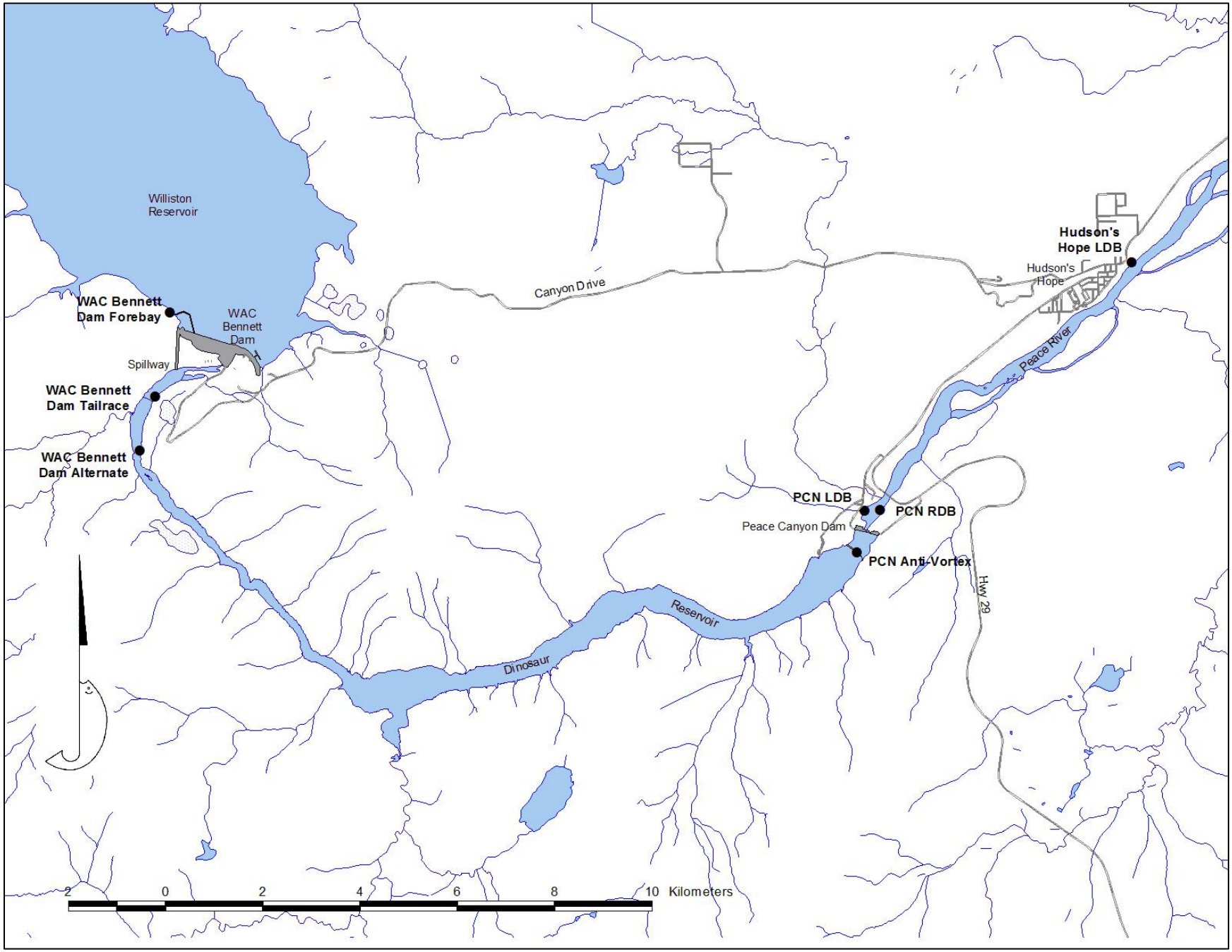

Figure 1. Location of 2020 TDGP monitoring sites.

Background

Total dissolved gas (TDG) supersaturation is a condition where the cumulative partial pressures of atmospheric gases dissolved in water exceed atmospheric pressure. Total dissolved gas pressure in a body of water is often quantified as the difference between the TDG pressure of the water and the ambient barometric pressure and can be expressed as a percentage of the barometric pressure. Thus, TDG pressures that exceed equilibrium with barometric pressure are expressed as values greater than 100% and denote supersaturation.

Excessive levels of TDGP are known to have adverse effects on aquatic organisms, including fish. When excess dissolved gas in supersaturated water escapes from solution in the tissues or circulatory systems of fish, physiological impairment, or death may occur. Common visible indications may include the presence of gas bubbles under the skin, along the lateral line, within fin membranes, behind the eyes, and in the gills. These symptoms are suggestive of a condition referred to as Gas Bubble Trauma (GBT) or Gas Bubble Disease (GBD).

In order for gas to escape solution and form bubbles in the tissues or body fluids of fish, the TDG pressure in the fish must overcome the combined effects of both barometric pressure and hydrostatic pressure. Since hydrostatic pressure increases by 0.1 atmosphere (10% saturation) for each metre of water depth, fish living in deeper water require a higher level of supersaturation before feeling the effects of GBT. For example, a fish at 2 m depth will experience gas equilibrium in a water body with a TDGP of 120% at surface. As a result, reservoir-dwelling fish populations are generally believed to be less susceptible to GBT than those living in shallow rivers.

The air supersaturation of water generally occurs when the pressure gradient between the air and the water exceeds the equilibrium of normal atmospheric conditions. This situation is most commonly created when air bubbles are suddenly forced deep into the water column and subjected to rapidly increased hydrostatic pressure. The resulting pressure gradient forces air from each compressed bubble to dissolve into the surrounding water. This mechanism occurs naturally in waterfall plunge pools, a situation often mimicked at manmade dam spillways. The degree of supersaturation is typically dependent on the density of air bubbles within the water, the depth to which the air bubbles are carried, and the amount of time the bubbles are forced to remain at depth.

A second mechanism by which water can become naturally supersaturated involves the surface warming of thermally stratified reservoirs and lakes by solar radiation. Since the gas solubility of

water decreases with rising temperature, and dissolved gas dissipates from water at a relatively slow rate, excess dissolved gas can become trapped near the surface of a water body when the temperature of the epilimnion increases rapidly in mid-summer, resulting in supersaturated conditions.

The design of the WAC Bennett spillway appears to be particularly conducive to the entrainment of air bubbles within the spillway discharge stream after it leaves the deflection bucket and prior to its contact with the plunge pool below (Fig. 2). Additionally, a prominent scour hole has developed below the spillway over the 50-year life of the facility. During an assessment of Lake Trout spawning habitat in the WAC Bennett Dam tailrace, Euchner (2006) characterized the spillway plunge pool as resembling a "blast crater" approximately 100 m by 150 m across, with sides plummeting sharply to 65 m depth. The outer rim of the crater was surrounded with unconsolidated bedrock rubble displaced from the scour hole by the force of the spillway discharge falling vertically into the channel.

Figure 2. WAC Bennett Dam Spillway, July 17, 2020; 570 cms.

In contrast, the Peace Canyon Dam spillway discharge descends the downstream face of the dam in a more laminar fashion before being directed horizontally at tailrace elevation. This design allows the spillway discharge to enter the tail waters parallel to the surface of the river channel with the aim of preventing the formation of a significant plunge pool.

2.0 METHODS

2.1 Total Dissolved Gas Pressure Monitoring

During the 2012 spill event, TDGP monitoring was conducted using six Common Sensing Model DL6 TGP meters owned by BC Hydro and maintained in field-ready condition under the GMSWORKS-2 water temperature monitoring program. In March 2020, the GMSWORKS-2 contractor notified BC Hydro that the aging Model DL6 meters could no longer be relied on for monitoring of future spills due to the requirement for factory calibration by the manufacturer or its successor, which no longer existed, and the fact that communication with the meters required the use of antiquated hardware capable of running the obsolete Windows 98™ operating system. Once informed, BC Hydro staff started work to procure replacement TGP meters but had been unable to acquire replacements prior to the start of the 2020 spill. The COVID-19 pandemic further complicated the acquisition of TGP monitoring equipment, which is very specialized with limited suppliers.

When the July 2020 spill was confirmed, BC Hydro staff scrambled to source alternate monitoring equipment on short notice and were able to secure the loan of six Point Four Systems Inc. Model PT4 TGP meters in the process of being pulled from a monitoring program in the Columbia basin.

The Point Four Systems Model PT4 TGP meters were shipped to Fort St. John and immediately deployed at 5 monitoring sites on July 14, three days prior to the anticipated spills at the G.M Shrum (GMS) and Peace Canyon (PCN) generating stations. These locations included:

1. WAC Bennett Dam Forebay – near the south shoreline anchor point of the spillway log boom approximately 500 m upstream of the spillway entrance gates (UTM 10.548579.6208989);
2. WAC Bennett Dam Tailrace - rock island adjacent to east shoreline approximately 500 m downstream of spillway plunge pool (UTM 10.548271.6207278);
3. Peace Canyon Dam Forebay – anti-vortex dam log boom approximately 450 m upstream of spillway entrance gates (UTM 10.562692.6204070);
4. Peace Canyon Tailrace LDB – north shoreline approximately 270 m downstream of dam face (turbine outlet side) (UTM 10.562834.6204935)
5. Peace Canyon Tailrace RDB – south shoreline approximately 450 m downstream of dam face (spillway side) (UTM 10.563164.6204945).

The Model PT4 meters were programmed to record ambient barometric pressure (mmHg), water temperature (°C), and total dissolved gas pressure (mmHg), and automatically calculate per cent air

saturation at 15 minute intervals. The meters were launched and downloaded using the communications software HyperTerminal® loaded onto a laptop computer.

The Point Four Model PT4 meters consisted of a cylindrical probe connected by a waterproof electrical cable to a meter unit enclosed in a plastic Pelican Case™. The probe contained temperature and TDGP sensors and was fastened inside the lower end of a 3.65 m length of 50.8 mm plastic pipe (ABS) which extended from the shoreline to approximately 1 m depth. The lower end of the pipe assembly was held in place with a metal anchor and the upper end was secured to the shoreline with nylon rope or stainless steel cable. The onshore meter unit, which included data storage hardware, battery pack, LCD display, and barometric pressure sensor, was secured to a tree or rock well above the waterline.

During the launching and deployment process it was learned from a consultant involved in the Columbia monitoring program that the PT4 meters had performed with a low level of reliability and had exhibited a relatively high failure rate. For this reason, BC Hydro staff began arranging for the short term rental of much newer HydroLab Model MS5 TGP meters to be deployed in tandem with the PT4 meters midway through the spill as a back-up and data quality check.

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The HydroLab Model MS5 units consisted of temperature and TDGP sensors, data storage hardware, and battery pack, integrated into a single submersible sonde which was similarly secured into the lower end of a 50.8 mm ABS pipe at approximately 1 m depth. Since no components of the Model MS5 units were above water, they were not equipped to record real time barometric pressure and were instead factory programmed with a standard sea level atmosphere value of 760 mmHg. The Model MS5 sondes were launched and downloaded using HydroLab's Hydras3LT communication software loaded onto a laptop computer. Unlike the Model PT4 meters, the integrated submersible MS5 sondes had to be removed from the water and their protective pipes during each field download.

A HydroLab Model MS5 sonde was deployed next to the Model PT4 unit at the Bennett Dam forebay site and the Peace Canyon tailrace LDB and RDB sites on August 6 and at the Bennett Dam tailrace and Peace Canyon forebay on August 7. The Bennett Dam tailrace deployment was made at an alternate site 1,000 m downstream of the original PT4 deployment site, due to difficulty accessing the original site by boat during high flows (UTM 10.547953.6206169). On August 12, the Model PT4 meter was moved from the original tailrace site to the alternate MS5 site.

A sixth Model MS5 sonde was deployed alone on the Peace River at Hudson's Hope (LDB), approximately 7.8 km downstream of the Peace Canyon Dam on August 12, 2020 (UTM 10.568332.6210027). All Model PT4 and Model MS5 loggers were removed on August 29.

After deployment of the Model PT4 meters on July 14, test downloads were performed on July 16, one day prior to the commencement of spilling. Additional downloads were conducted on July 21, August 12, and August 29. Model MS5 recorders were downloaded on August 12 and August 29.

At the end of the monitoring period, downloaded data for each recorder model were assembled into continuous data sets for each monitoring site in Microsoft Excel™. Fifteen minute interval readings were converted to hourly average values to be consistent with spillway and turbine output hourly average values. Default barometric pressure values of one standard atmosphere (760 mmHg) for the Model MS5 sondes were replaced with corrected local barometric pressure values using the following method. Hourly station pressure readings recorded at the Environment Canada Fort St. John weather station were downloaded in Excel (https://climate.weather.gc.ca/climate_data) and corrected for elevation at each monitoring site by adding 0.0847 mmHg per metre elevation drop (Table 1).

Table 1. Barometric pressure correction values for 2020 spill monitoring site elevations.

	Elevation (ASL)	Elevation change	BP correction
EnvCan FSJ weather station	695 m	-	-
Williston Reservoir	670 m	-25 m	+2.1 mmHg
Dinosaur Reservoir	502 m	-193 m	+16.3 mmHg
Peace Canyon tailrace	460 m	-235 m	+19.9 mmHg

Data sets were then reviewed for obvious corrupted or unreasonable values and these were removed.

2.2 Fish Mortality Monitoring

Two types of potential fish impacts are associated with the operation of spillways at the WAC Bennett and Peace Canyon dams. These include 1) outright mortality or severe physical trauma unrelated to GBT, as a result of entrainment over the spillway, and 2) the chronic and acute effects of GBT on fish inhabiting receiving waters downstream of the spillways. Low level mortality monitoring was conducted concurrently with TDGP monitoring for each potential impact type. In addition, spillway entrainment at the WAC Bennett Dam was monitored using hydro-acoustics (GMSMON-4) and reported under separate cover (Golder 2021).

During past spill events, significant outright mortality has been observed in relation to entrainment of fish from Williston Reservoir into the WAC Bennett Dam spillway discharge, particularly in the opening hours and days of a spill (B. Culling, per obs. 1983, 1996, 2012). For this reason, the majority of monitoring effort was concentrated in the area of the Bennett Dam tailrace and the upper half of Dinosaur Reservoir. Monitoring consisted of daily 4-hour boat patrols on the upper 7.5 km of Dinosaur Reservoir, between the bottom of the former Peace River Canyon, near Moosebar Creek, and a point approximately 500 m downstream of the spillway plunge pool. Patrols involved a 2-pass reconnaissance (upstream and downstream) in which the surface of the channel was visually scanned for dead and injured fish, with particular attention given to eddies and other shoreline features that tended to accumulate and retain passing debris. Approximately one hour of each patrol was spent observing the behavior of 12-15 bald eagles that perched on both banks of the channel along the first kilometre downstream of the spillway plunge pool. These birds were assumed to be members of the year-round resident population that forage in the turbine output flow upstream of the spillway during normal operations.

Daily mortality monitoring patrols below the WAC Bennett Dam spillway were conducted on the first 6 days of the spill (July 17- 22) with additional patrols on August 7 and 12. One mortality monitoring patrol was conducted on the Peace River downstream of the Peace Canyon Dam on July 28, immediately following an 8-hour long, 4-fold spike in Peace Canyon spillway discharge. This patrol consisted of a similar 2-pass reconnaissance along a 14 km section of the Peace River from Lynx Creek to the Peace Canyon Dam tailrace. Dead fish encountered during these monitoring patrols were collected from the surface with a dip net, identified to species, and measured (Fork Length in mm).

Due to relatively low 2020 spill rates, targeted fish sampling and physical examination for symptoms of GBT was not conducted specific to the spill monitoring program. Instead, an assessment of GBT symptoms was incorporated into the annual Peace River Fish Community Indexing Program conducted by Golder Associates through the Site C monitoring program. Fish sampling was conducted between August 22 and October 5 during standardized boat electro-fisher transects within 2 sections of the Peace River within 60 km downstream of the Peace Canyon Dam. Section 1 consisted of an 8.2 km segment of the Peace River between Lynx Creek and the Peace Canyon Dam and Section 3 consisted of a 9.4 km segment of the river between the mouths of the Cache Creek and the Halfway River. All captured fish were measured, weighed, and assessed for physical abnormalities using the DELT (Deformities, Erosions, Lesions, and Tumors) classification system. In addition, field staff visually inspected fish for symptoms suggestive of GBT including bulging eyes and blistering beneath the skin.

3.0 RESULTS AND DISCUSSION

3.1 Operational Parameters/Spill Characteristics

In July 2020, BC Hydro determined it was necessary to release water from the WAC Bennett and Peace Canyon dam spillways in order to arrest the rising elevation of Williston Reservoir at approximately 670.5 m (ASL). The spill was initiated on the morning of July 17, 2020 and ran continuously, at both dams, for 32 days until the afternoon of August 18. All spill operations then ceased for 7 days, after which, the Peace Canyon spillway was re-opened for 8 days from August 25 to September 2. During this 8 day period, a corresponding volume was released from the WAC Bennett Dam spillway through a series of seven once-daily pulse spills each lasting 6-7 hours (Fig. 3).

Turbine output volumes from both generating stations remained relatively stable throughout the spill period (Fig. 3). Between July 17 and September 01, mean turbine output rate from GMS varied between 1,365 cms and 1,924 cms with a mean rate of 1,745 cms. With the exception of a 7-hour period on July 28, turbine output from PCN was slightly greater and more stable than GMS output, fluctuating between 1,715 cms and 1,969 cms (mean 1,884 cms). On July 28, PCN turbine output was decreased from 1,900 cms to 985 cms between 0800-1500 hrs.

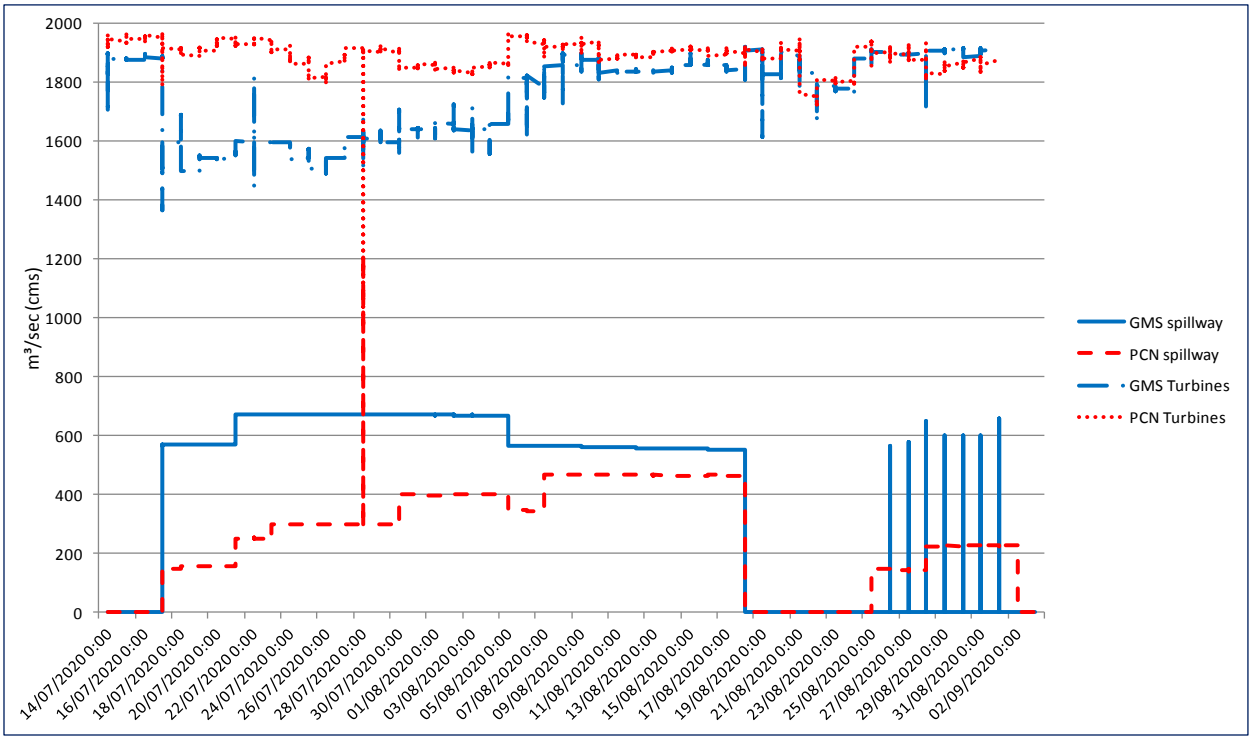

Figure 3. Spillway and turbine discharge from GMS and PCN generating station during the 2020 spill event, July 17 – September 2, 2020.

The spill rate at the WAC Bennett Dam spillway remained within 2 relatively tight ranges (Fig. 3). The spill was initiated on July 17 at approximately 570 cms and remained at that rate for 4 days before being increased to 674 cms on July 21. This rate was maintained for 15 days until reduced to the original rate for the remaining 18 days of the continuous spill period. The 7 once-daily pulse spills occurring in the second phase of the spill period were conducted at a rate of approximately 600 cms.

With the exception of July 28, spill rate at the Peace Canyon Dam increased in a series of steps over the spill period, starting at 150 cms on July 17 and ending at 470 cms on August 18 (Fig. 3). A 7-hour spike on July 28 saw the spill rate increase from 300 cms to 1,217 cms and coincided with the previously mentioned reduction in PCN turbine output. The second phase of the Peace Canyon spill was similarly stepped, flowing at 145 cms for the first 3 days and 230 cms for the remaining 5 days until September 2.

The GMSMON-11 monitoring protocol was triggered at the WAC Bennett Dam spillway when the opening spill rate of the July 17-Aug 18 continuous spill exceeded 205 cms. Although the seven once-daily spill events during the second spill phase exceeded 205 cms, they did not exceed the 48-hour criteria.

Although the Peace Canyon spillway discharge rate threshold of 500 cms was never exceeded, the combined spillway and turbine discharge threshold of 2,000 cms was narrowly surpassed during both the July 17-Aug 18 and the Aug 25-Sept 2 continuous spill phases.

Spill discharge rates during the July-August 2020 spill event were relatively low from a historical perspective. The last GMSMON-11 triggering spill occurred in 2012 and saw median spillway discharge rates of 1,490 and 1,160 cms at the WAC Bennett and Peace Canyon dams, respectively, between June 26 and July 13, 2012 (McArthur 2014), representing a 2.2 fold increase over 2020 levels. During the 1996 “Sink Hole” spill, discharge rates over the WAC Bennett Dam spillway exceeded 3,000 cms for 7 weeks.

3.2 Total Dissolved Gas Pressure Monitoring

3.2.1 Data Quality

During the initial stages of monitoring, percent saturation values recorded from the LCD displays of the Model PT4 meters at all locations indicated relatively low air saturation levels (<110%). The meters displayed pre-spill values and background values in the Bennett Dam forebay in the order of 95-99% saturation and during-spill values of 106-109% in Dinosaur Reservoir. These comparatively low values were initially assumed to be a function of the low spill rate relative to previous events.

An examination of the raw PT4 data at the end of the spill event revealed that the Model PT4 meters had consistently recorded on-site barometric pressure values much higher than would be expected for their respective elevations, resulting in downwardly biased air saturation values. Barometric pressure values measured by the Model PT4 meters at all sites averaged 58-74 mmHg higher than altitude-adjusted values recorded by Environment Canada at the Fort St. John weather station, and were consistently representative of pressures expected below sea level (up to 801 mmHg).

In order to correct this problem, the biased barometric pressure values in the PT4 data sets were replaced with the hourly, altitude-adjusted values (derived from the Fort St. John weather station), which had been calculated for insertion into the Model MS5 data sets.

The following procedure was undertaken to gauge confidence in the hourly altitude-adjusted, barometric pressure values derived from the Environment Canada data. Hourly Fort St. John station pressure values were downloaded for a period coinciding with the 2012 spill event and adjusted for monitoring site elevation as described in Section 2.1. The altitude-adjusted values were then compared with hourly site barometric pressure values recorded by 5 TGP meters during a 13-day period immediately after they were returned from recalibration by the manufacturer (Point Four Systems Inc.). The altitude-adjusted Environment Canada values were within 0.2% of the freshly calibrated TGP meter values for all sites (Table 2).

Table 2. Comparison of altitude-adjusted Fort St. John station pressure values with newly-calibrated DL6 meter values at 5 sites, July 26 to August 8, 2012.

Site	Alt-adjusted EnvCan Station Pressure (mean/range)	DL6 Meter BP (mean and range)	Difference
Bennett Dam Forebay	702 mmHg / 700-705	702 mmHg / 698-704	0 mmHg
PCN Forebay	716 mmHg / 714-719	717 mmHg / 714-721	1 mmHg
PCN Tailrace LDB	720 mmHg / 718-723	720 mmHg / 716-724	0 mmHg
PCN Tailrace RDB	720 mmHg / 718-723	719 mmHg/715-723	1 mmHg
Hudson's Hope LDB	720 mmHg / 718-723	720 mmHg / 171-723	0 mmHg

Several blocks of data were either missing from the Model PT4 data sets or removed during the data quality review due to various hardware and software failures including, premature low voltage, unexplained power downs, locking of data logger functions (repeated identical values), scrambled internal clocks, intermittent failure to communicate with probes, and dislodging of probes due to high flows.

The six HydroLab Model MS5 units operated reliably from their deployment dates on August 6-7 to their removal on August 29, with the exception of the GMS tailrace unit which stopped logging on August 15 due to a potential battery issue.

3.2.2 WAC Bennett Dam Forebay

Total dissolved gas pressure was recorded in the WAC Bennett Dam forebay approximately 500 m upstream of the spillway gates between July 14 and August 29, using a Model PT4 TPG meter, and from August 6 to 29 using a Model MS5 meter. Data recorded by both meters suggested supersaturation of forebay surface waters prior to entry into the spillway (Fig. 4). Saturation levels recorded by the MS5 sonde during its shorter monitoring period, closely tracked those simultaneously logged by the PT4 meter (approximately one percent saturation lower). A review of forebay water temperature data recorded by the GMSWORK-2 temperature monitoring program suggests the possibility of supersaturated conditions resulting from the rapid warming of the surface layer of the epilimnion (Fig. 5). Highest levels of saturation were recorded during the last half of July (averaging 107%), peaking on July 31, then declining in early August to stabilize around 103% (Fig. 4). This pattern corresponds to a period of rapidly increasing surface water temperature (Fig. 5), which also peaked on July 31, at over 20°C. It is also evident that the disparity in temperature between the 1 m and 10 m depths widened during the period of high saturation and then closed after August 1 as temperatures fell and saturation levels declined and stabilized. It can be noted that Williston Reservoir typically becomes strongly thermally stratified in the summer; temperature profiles recorded in the Peace Reach during unrelated work in 2017 and 2018 indicated significant thermoclines at between 20 m and 26 m (B. Culling, pers. obs.).

3.2.3 WAC Bennett Dam Tailrace

TDG pressure was monitored in the WAC Bennett Dam tailrace, approximately 500 m downstream of the spillway plunge pool between July 14 and August 29, using a Model PT4 TPG meter, and from August 7 to 29 using a Model MS5 meter. This was the only site where the Model MS5 recorder appears to have malfunctioned; the unit died after 8 days of operation. As illustrated in Figure 6, TDGP levels immediately before and after the spill matched those recorded above the spillway in the Bennett Dam forebay, including the 3-4% decrease in background saturation levels documented in the forebay during early August. Commencement of the spill on July 17 resulted in a 13% incremental increase in TDGP from approximately 106% to 119% saturation. A corresponding 13% decrease was recorded at the end of phase 1 of the spill, as TDPG declined sharply from 116% to 103%.

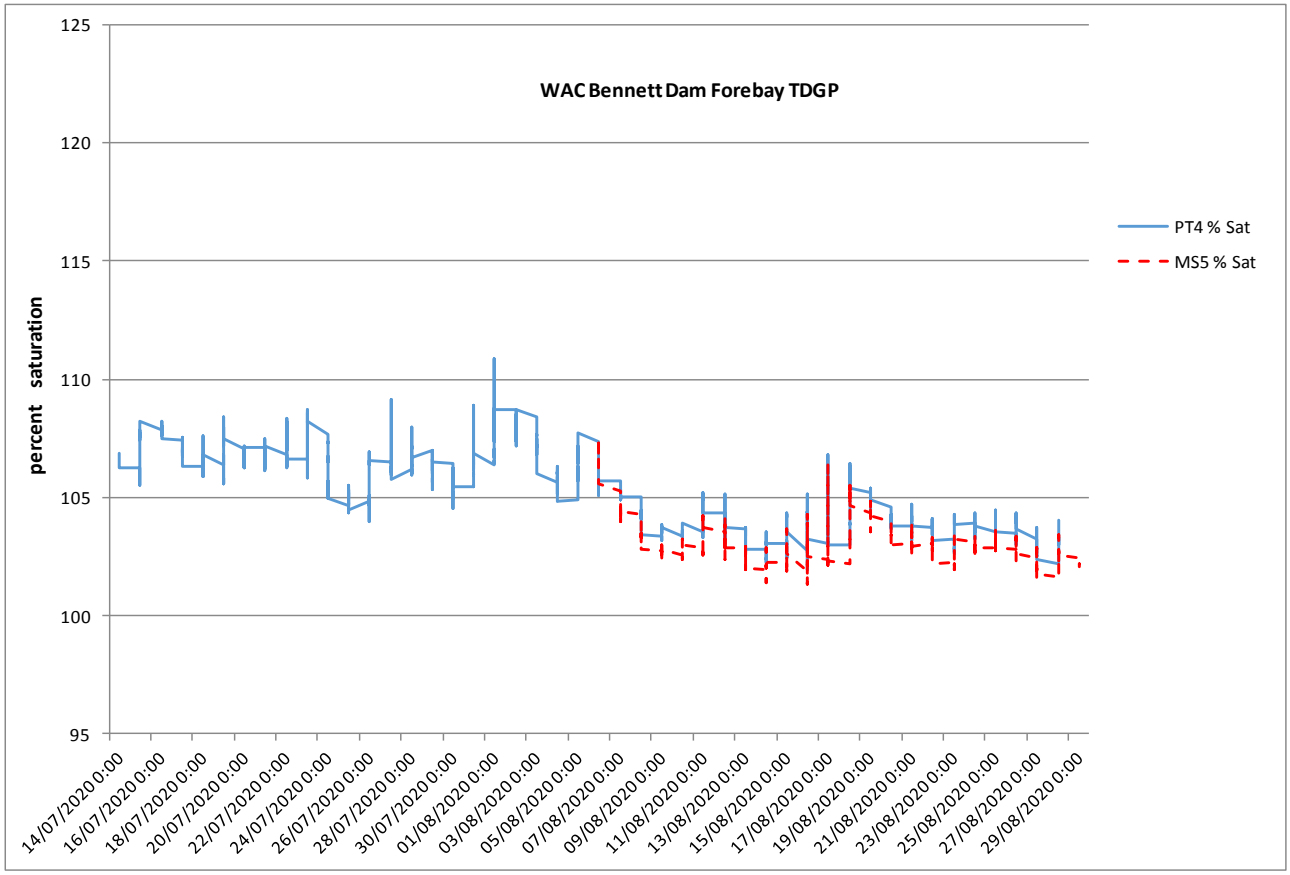

Figure 4. Percent air saturation levels recorded in the WAC Bennett Dam forebay, July 14 – August 28, 2020.

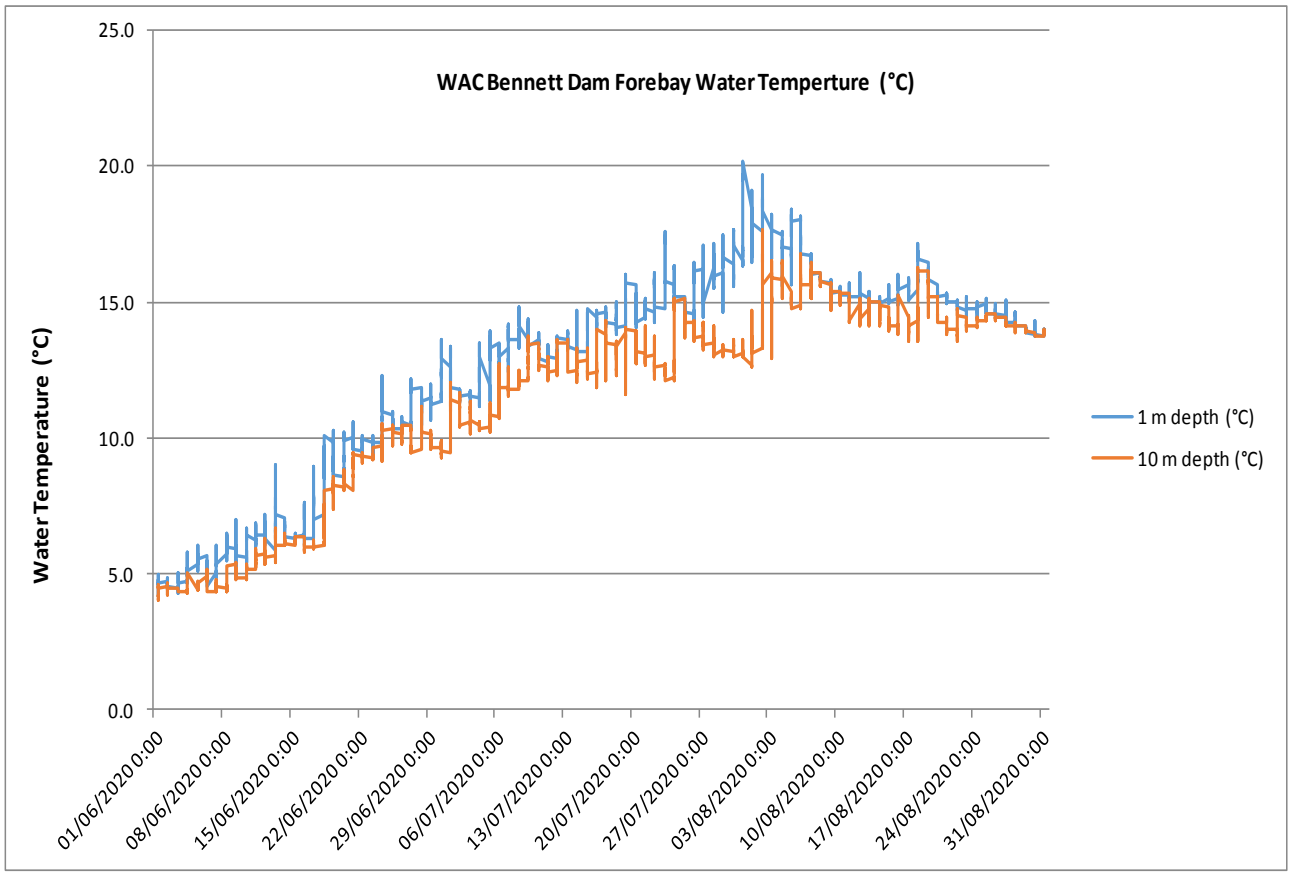

Figure 5. Water temperature recorded in the Bennett Dam forebay, June 1 – August 31, 2020 (1m and 10 m depth)

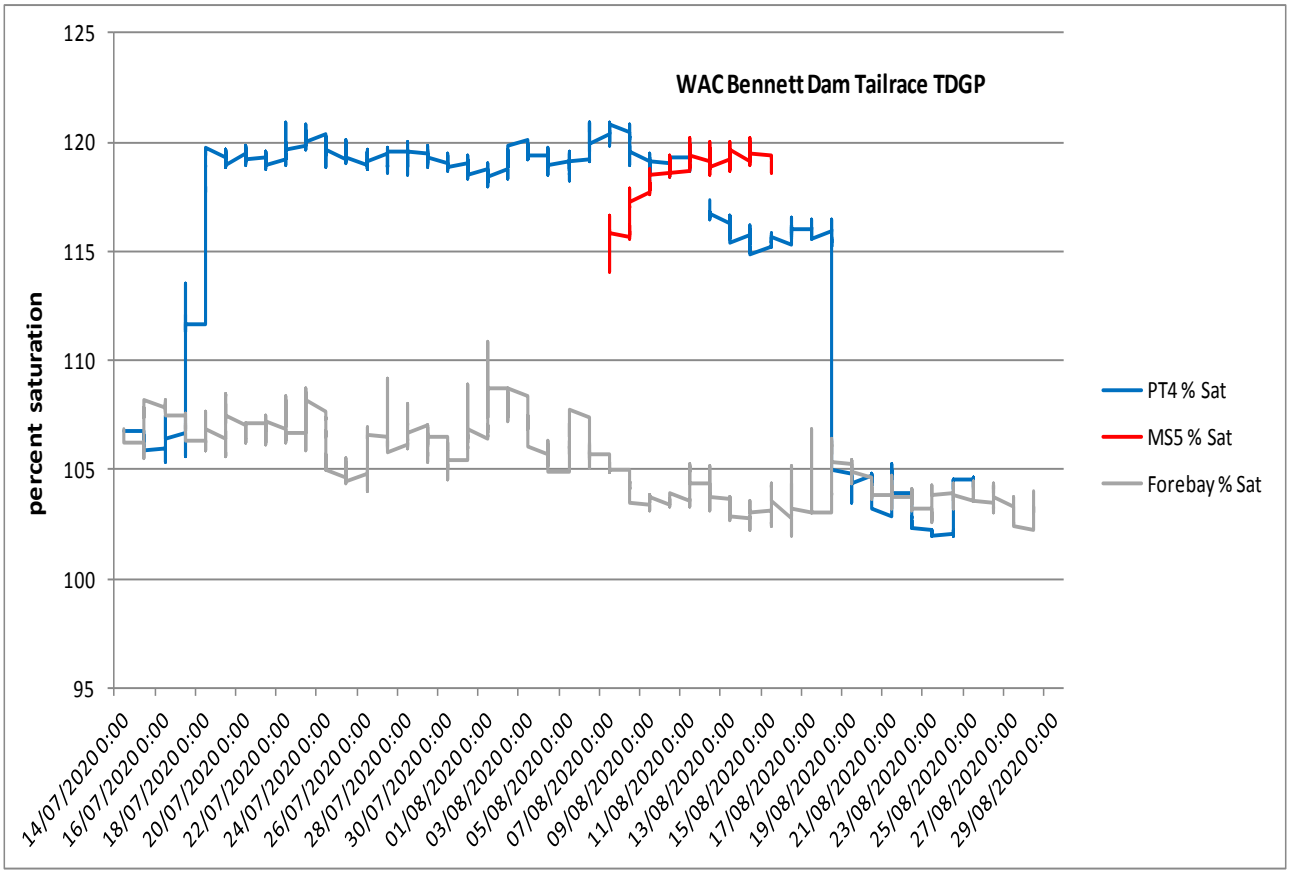

Figure 6. Percent air saturation levels recorded in the WAC Bennett Dam tailrace 500 m downstream of spillway plunge pool, July 14 – August 28, 2020; (Williston Forebay TDGP added for reference).

The Model PT4 meter ceased logging data on Aug 25, one day before the start of the phase 2 once-daily pulse spills.

No corresponding change in TDGP was detected when the spill rate was increased from 570 to 673 cms (18%) on July 21 or decreased from 673 to 560 cms (20%) on August 5. This is consistent with findings during the 2012 spill where only a modest increase in TDGP was recorded in Dinosaur Reservoir when Bennett Dam spillway discharge was increased from 581 cms to 1,491 cms (McArthur 2014).

3.2.4 Peace Canyon Dam Forebay

TDG pressure was monitored in the Peace Canyon Dam forebay, at the anti-vortex dam log boom, approximately 450 m upstream of the spillway gates, between July 14 and August 29 using a Model PT4 TPG meter, and from August 7 to 29 using a Model MS5 meter. The PT4 meter collected continuous data through its monitoring period but appeared to log suspect TGP values for a 5-day period immediately after a battery change on August 7. When the meter was downloaded and the

probe re-positioned on August 12, saturation readings dropped instantly by 4%, indicating the clearing of a temporary glitch. Suspect data recorded between August 7 and 12 was discarded.

As with the Bennett Dam tailrace, pre- and post-spill air saturation levels in the Peace Canyon forebay mirrored natural background levels in the Bennett Dam forebay and reflect a 3-5% decline in background saturation between mid July and mid August (Fig. 7). Elevated TDGP values were detected at the Peace Canyon forebay within 36 hours of commencement of the Bennett Dam spill on July 17. Saturation levels rose to 119% within 48 hours then stabilized at an average level of 117% until declining slightly, in line with declining background levels in Williston Reservoir. During spillway operations, mean saturation levels tracked 2% lower than those recorded immediately below the Bennett Dam spillway. Within 3-4 days after the end of the continuous phase of the Bennett Dam spill, Peace Canyon forebay saturation levels had recovered to baseline values of 103-104% (Fig. 7). Figure 7 also illustrates the Peace Canyon forebay response to the first 2 of the 7 once-daily pulse spills conducted at the Bennett Dam spillway starting Aug 25. Monitoring was discontinued August 29, just before the August 28 pulse spike arrived at Peace Canyon. Although the Model PT4 and MS5 records for the period after the closing of the Bennett Dam spillway on August 18 match closely, no explanation for the divergence in values prior to August 18 was evident.

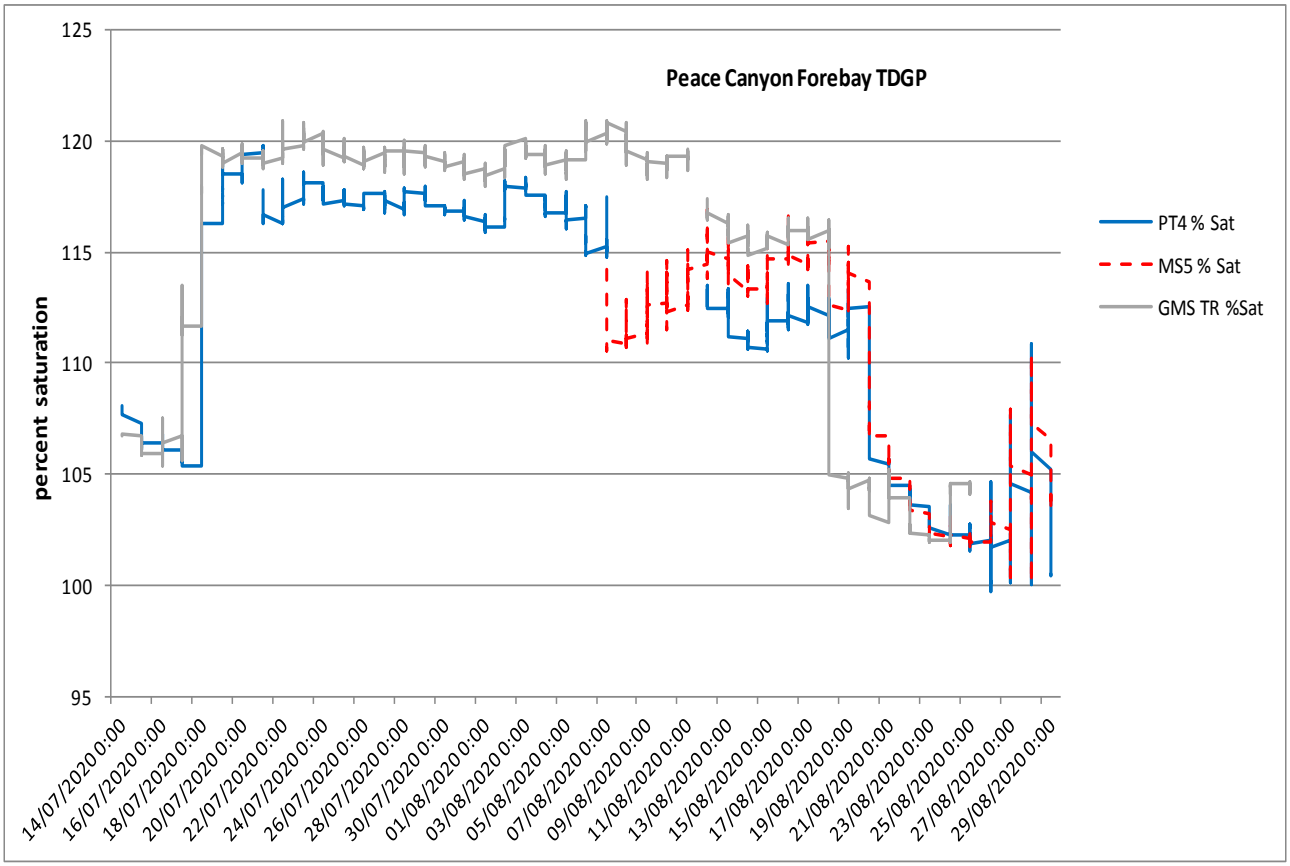

Figure 7. Percent air saturation levels recorded at the Peace Canyon forebay, July 14 – August 29, 2020; (GMS tailrace TDGP added for reference).

3.2.5 Peace Canyon Dam Tailrace

TDG pressure in the Peace Canyon Dam tailrace was measured on both the left and right banks. Model PT4 meters were installed on both banks on July 14 and Model MS5 meters were installed on August 6.

Data from the left bank PT4 became corrupted by a scrambled internal clock after July 28 and the unit was removed permanently on August 12 due to an unrepairable probe communication failure. A Model MS5 sonde was installed at this location on August 6 but may not have logged representative data during the first 6 days. During the August 12 download, the unit was found dislodged; once re-positioned it indicated TDGP values 74 mmHg higher (8% saturation) than before re-positioning. The suspect data was excluded from the data set, leaving continuous records from August 12 to August 29. The Model PT4 meter on the left bank appeared to log valid data continuously from July 14 to August 29 and the Model MS5 meter likewise recorded TGDP throughout its monitoring period from August 6 to 29. Figures 8 and 9 represent salvageable data from the Peace Canyon tailrace LDB and RDB, respectively.

Although no longer a requirement under GMSMON-11 protocols, TDG pressure was also recorded in the Peace River, approximately 7.8 km downstream at Hudson's Hope, between August 12 and August 29 using a Model MS5 meter, in order to better interpret values recorded at the Peace Canyon Dam tailrace. Percent saturation values from the Hudson's Hope LDB are included for reference in the Peace Canyon Tailrace figures (Fig. 8 and 9).

The Peace Canyon Tailrace LDB theoretically received output flow from the turbines and the RDB site from spillway discharge. However, it was observed that these flows were not necessarily laminar and that back circulation currents, which changed through various discharge levels, may confound this assumption. As during the 2012 spill monitoring program, TDGP patterns for the Peace Canyon Tailrace in 2020 remain somewhat uncertain, partially due to monitoring equipment failures.

Although somewhat contradictory, the 2020 data appears to support the 2012 assertion that while operation of the Peace Canyon Spillway may result in a relatively small incremental increase in air saturation levels (2%) when Dinosaur Reservoir TDGP is low (i.e., comparable to Williston background levels), the Peace Canyon spillway may partially attenuate high TDGP levels received from Dinosaur Reservoir during simultaneous operation of the WAC Bennett Dam spillway. For example, the MS5 meter on the Peace Canyon tailrace RDB recorded a sudden spike from 111% to 115% when the Peace Canyon spillway was closed on August 18 (Fig. 9).

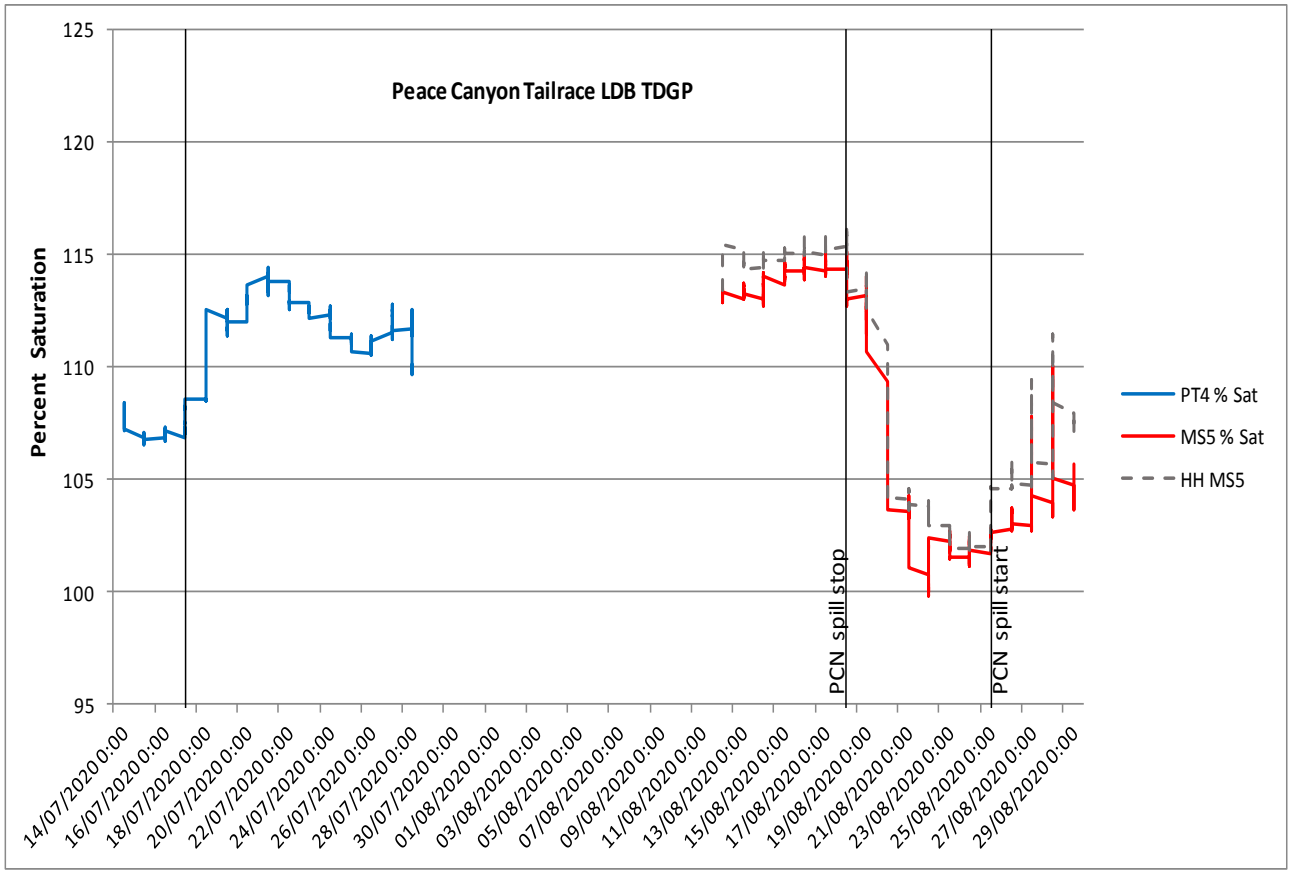

Figure 8. Percent air saturation levels recorded at the Peace Canyon tailrace LDB, July 14 – August 29, 2020.

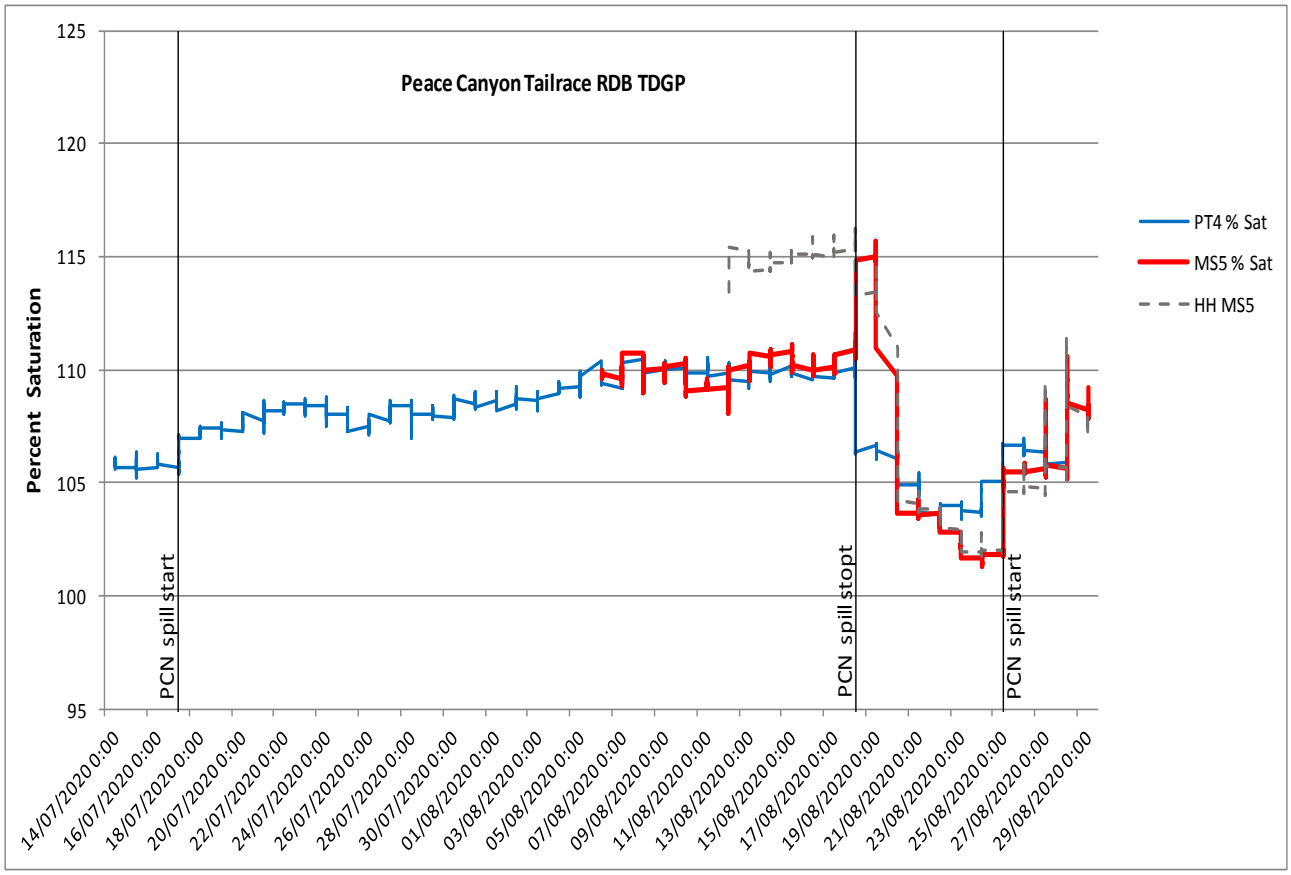

Figure 9. Percent air saturation levels recorded at the Peace Canyon tailrace RDB, July 14 – August 29, 2020.

In contrast, limited data from the Hudson's Hope site indicted TDGP levels slightly higher than the Peace Canyon forebay for the same period (115% vs 113%; Fig 7). Unfortunately, data from the Hudson's Hope site in 2020 was inadequate to establish a robust relationship between saturation levels downstream of the Peace Canyon tailrace and those in the Peace Canyon forebay.

3.3 Spill Effects on Water Temperature

Figure 10 represents daily mean water temperatures for the Bennett Dam Forebay surface, GMS Units 1-5 outflow (upstream of spillway), GMS Units 6-10 outflow (upstream of spillway), and Dinosaur Reservoir at the Peace Canyon Forebay. Flow from the WAC Bennett Dam into Dinosaur Reservoir originates from 3 depth ranges within Williston Reservoir. Spillway discharge is withdrawn from the surface of the forebay, while generation units 1-5 withdraw water from a lower mean penstock depth than units 6-10. During summer thermal stratification of the reservoir, the temperature of the 3 input streams can vary significantly (Fig. 10). During the July 17 to August 18 continuous spill period at the WAC Bennett Dam, mean daily water temperature varied from a high of 19°C in the spillway on August 2 to a low of 7°C in the Units 1-5 outflow for the same day. Consequently, the temperature of flow through Dinosaur Reservoir is primarily dependent on the volume proportions contributed from each of the 3 withdrawal points. These proportions can change frequently with adjustments in operating regime. For example, when the Bennett Dam spillway was opened on July 17, Dinosaur Reservoir temperature remained stable or declining despite increasing forebay temperatures (Fig. 10), due to a corresponding decrease in output volume from generation units 6-10. Conversely, when forebay and spillway temperatures declined significantly in early August, Dinosaur Reservoir temperature increased due to a decrease in the relative volume contribution from generation units 1-5.

Although weak thermal stratification can develop in Dinosaur Reservoir due to surface warming during the peak of summer (DES 2019), it is assumed that elevated flow rates associated with spill events likely break down any thermal stratification. Water temperatures between the Peace Canyon forebay and the left and right banks of the Peace Canyon tailrace remained within 0.5°C of each other during the 2020 spill, suggesting no temperature difference between Dinosaur forebay surface and generation withdrawal depth.

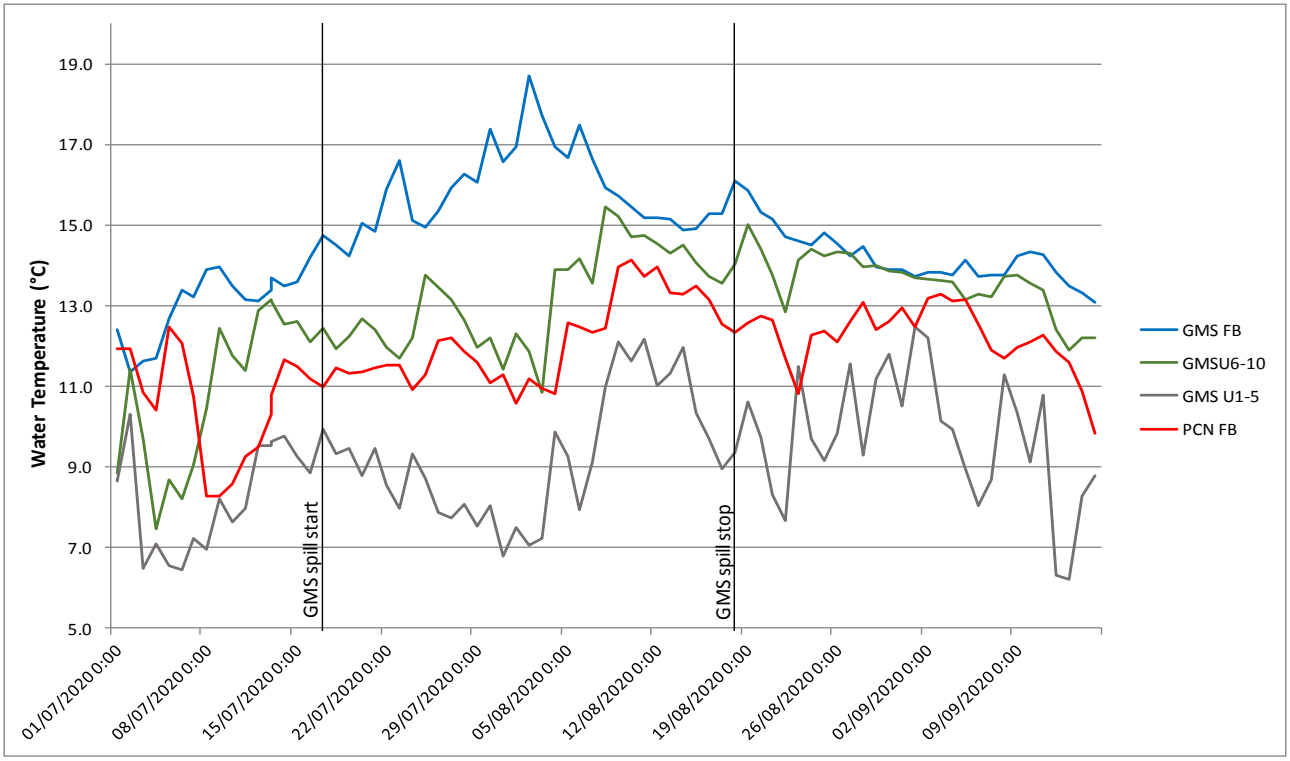

Figure 10. Comparison of water temperature in the GMS forebay (surface), GMS turbine outflow manifolds, and Dinosaur Reservoir, saturation levels recorded at the Peace Canyon tailrace RDB, July 01 – September 15, 2020.

3.4 Fish Mortality Monitoring

Fish mortality monitoring patrols below the WAC Bennett Dam spillway were conducted on the first 6 days of the spill and on days 21 and 26. These patrols were intended to document the relative level of outright spillway mortality unrelated to gas supersaturation. No dead or injured fish were recovered or observed during the opening hours of the spill on July 17. Up to 15 bald eagles were perched along the outflow immediately downstream of the spillway plunge pool, with some making occasional aerial patrols over the channel. In a one-hour period, 1 eagle made an attempt to retrieve an unidentified item from the surface of the water. Although no recent mortalities were observed, several decaying fragments of fish skin and tissue were recovered from turbulent, upwelling current in the vicinity of the Gething Creek alluvial fan, approximately 900 m downstream of the spillway plunge pool. These were assumed to be the remains of earlier turbine entrainment mortalities that had settled into the spillway plunge pool then been recently dislodged by spillway discharge. The day 2 mortality patrol recorded similar results with no fish recovered and decreased eagle activity.

During the day 3 patrol (July 19), a cluster of 32 dead juvenile Kokanee were collected along a 500 m segment of the reservoir near the bottom of the narrows, approximately 6.5 km downstream of the spillway. Fork lengths ranged from 87-191 mm (mean 130 mm). Most had sustained injuries

suggesting outright spillway mortality, including severe scale loss, dislocated eyes, ripped operculums, and disarticulated heads (Fig. 11). Based on estimated mean surface velocity and the spatial distribution of the carcasses, the fish had likely been entrained as a school of mixed-age juveniles approximately 2 hours earlier. No other fish were observed during the remainder of the day 3 patrol.

Figure 11. Subsample of 32 juvenile Kokanee recovered below the Bennett Dam spillway, July 19, 2020.

No mortalities were recorded on days 4 through 6, although an eagle was observed unsuccessfully attempting to recover an item from turbulent water immediately downstream of the spillway plunge pool on day 6. One 110 mm dead Kokanee was observed during the day 21 patrol (Aug 7) and none were detected on the day 26 patrol.

Levels of observed outright spillway mortality below the WAC Bennett Dam spillway were lower than expected based on previous spill events. In contrast, mortality monitoring during spill events in 1983 and 1996 recorded large numbers of dead Lake Whitefish in the first hours of each spill and subsequent pulses of mortality for several days (B Culling, pers. obs.). The apparent trend in decreasing observed mortality is consistent with documented changes in the composition of the fish species assemblage in Williston Reservoir. In recent decades, Kokanee populations have increased dramatically to overtake Lake Whitefish as the dominant species, while at the same time Lake Whitefish abundance has declined (Langston 2012, Plate et al. 2012).

On July 28, mortality monitoring was conducted on the Peace River between Lynx Creek and the Peace Canyon Dam spillway, during the final hours of an 8-hour long, 4-fold increase in Peace Canyon spillway discharge. No mortalities were observed.

As part of the Peace River Fish Community Indexing Program, 30 boat electro-fisher transects were conducted within indexing sample Sections 1 and 3 between August 22 and September 14, 2020, including 15 transects in Section 1 and 15 in Section 3. The index sampling spanned a period beginning 4 days after the end of the first phase of the 2020 spill (32 days long) and ended 12 days after the completion of the second phase (8 days long). During this period, 2,841 fish were visually assessed using the DELT classifications system and key symptoms indicative of gas bubble trauma. Of these, 51 physical abnormalities were recorded, however, none were considered to be consistent with GBT (D. Ford, pers. comm.). During the same program, an adult Mountain Whitefish with one bulging eye was captured approximately 130 km downstream, however, this injury was likewise not considered to be related to GBT.

Based on the results of the 2020 GMSMON-11 monitoring program, no definite determination can be made as to the impacts of potential GBT on downstream fish populations in the Peace River, although no symptoms were observed during 2020 indexing program activities. Based on limited data from the Peace Canyon tailrace and Hudson's Hope TDGP monitoring sites, it appears that fish residing in water deeper than 1 m could have avoided the effects of air supersaturation greater than pre-spill background levels.

4.0 RECOMMENDATIONS

The GMSMON-11 spill monitoring program was hampered by lack of access to reliable TDGP monitoring equipment when the intent to spill was issued on relatively short notice in July 2020. In the event that future spills become likely, a minimum of 5 dedicated new generation TDGP meters should be secured well in advance.

The role of Peace Canyon spillway operations on the incremental increase or potential attenuation of air saturation levels in water exiting Dinosaur Reservoir into the Peace River is still not fully understood. In the event that dedicated TDGP meters are acquired for future Peace spill monitoring, opportunities should be taken to gather further information on Peace Canyon tailrace TDGP patterns regardless of whether or not future spills trigger GMSMON-11 thresholds.

In addition, the location of monitoring sites in the Peace Canyon tailrace should be re-assessed in terms of spillway and generation discharge flow patterns, with the possible re-establishment of a monitoring site further downstream after bank to bank mixing has occurred. This measure would be conditional on the timing of inundation of the proposed Site C reservoir.

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