Site C Clean Energy Project

Site C Total Dissolved Gas Monitoring Program (Mon-11)

Construction Year 8 (2022)

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23 August 2023

REPORT

Site C Total Dissolved Gas Monitoring Program (Mon-11)

2022 Feasibility Study

Submitted to:

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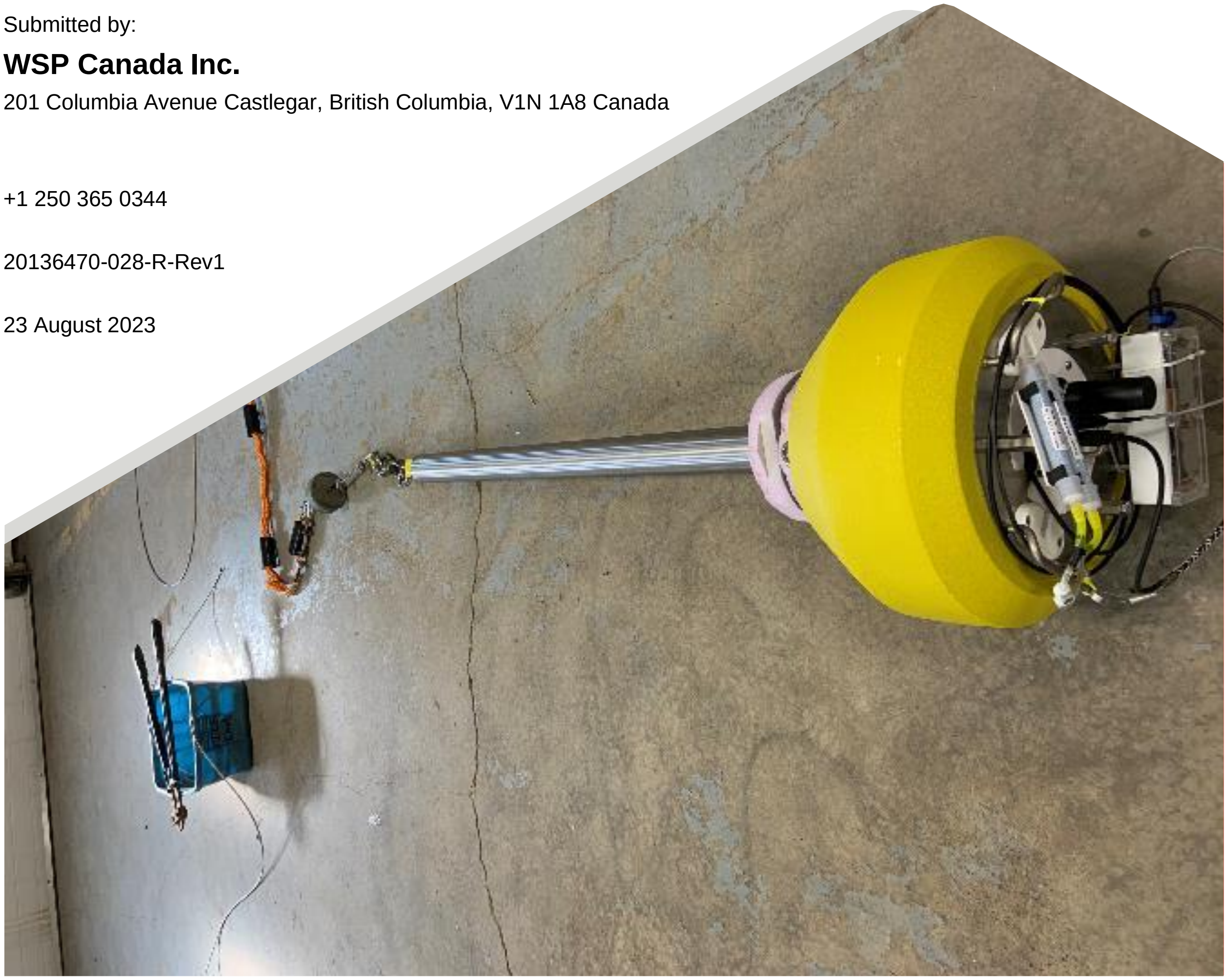

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Description
DCP	Data Collection Platform
EAC	Environmental Assessment Certificate
EIS	Environmental Impact Statement
FAHMFP	Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program
GBD	Gas Bubble Disease / Gas Bubble Trauma
Mon-11	Site C TDG Monitoring Program
PCD	Peace Canyon Dam
Project	Site C Clean Energy Project
TDG	Total Dissolved Gas

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1.0 INTRODUCTION

Monitoring of total dissolved gas (TDG) at the Site C Clean Energy Project (the Project) is described in the Site C TDG Monitoring Program (Mon-11), a component of BC Hydro's Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program (FAHMFP; BC Hydro 2015). TDG is air dissolved in water and is commonly expressed as a percentage of the amount of air that water will hold when it is in equilibrium (100%) with the atmosphere at ambient water surface conditions (BC Hydro 2014, 2022). When air bubbles are entrained in water and the air-water mixture is carried to a substantial depth, entrained air dissolves into solution due to hydrostatic pressure, resulting in water that is supersaturated with gas relative to equilibrium at surface (atmospheric) pressure. Discharge from the Project may result in increased TDG and supersaturated conditions downstream of the Project with potentially negative effects on fish due to gas bubble disease (GBD). GBD can occur in fish that have been exposed to TDG supersaturation and is a condition where dissolved gas comes out of solution and forms bubbles in the fish's blood or tissues. GBD can range from mild cases with a few visible bubbles, to severe cases with numerous bubbles, hemorrhaging, exophthalmia (bulging eye), and possibly death. The occurrence and severity of GBD in fish exposed to supersaturated TDG levels depends on several variables, the most important of which include the level of TDG, water depth, and duration of exposure (Weitkamp 2008). Symptoms of GBD can be mitigated by hydrostatic pressure if fish reside at a water depth where hydrostatic pressure equals or exceeds the total dissolved gas pressure, referred to as the "compensation depth". The hydrostatic pressure provided by one metre of water depth compensates for an approximately 10% incremental increase in TDG above ambient pressure (e.g., 1 m of depth compensates for 110 TDG%; 2 m of depth compensates for 120 TDG%, and so on). Fidler and Miller (1994) defined the risk to aquatic life from GBD as low when TDG is below 110 TDG% and defined the risk as high when TDG is 120 TDG% or higher, especially for fish and aquatic life that are constrained to shallow water habitat (e.g., a small side channel).

Under Mon-11, TDG monitoring will focus on two phases of the Project's development: 1) reservoir filling; and 2) opportunistically during spill periods or unusually low flow periods during Project operation. During reservoir filling, continuous TDG monitoring stations will be deployed on the left and right banks of the Project's tailrace, and downstream of the Project at locations where complete mixing of the Project's generation and spill discharge can be verified. During Project operation, monitoring TDG levels will be done through the temporary deployment of continuous TDG monitoring station meters and portable TDG meters (to record instantaneous TDG at specific locations).

BC Hydro consulted TDG specialists with the U.S. Geological Survey (USGS) and U.S. Army Corps of Engineers (USACE) to review the approach used by these organizations to collect, process, and analyze TDG data using remote data telemetry systems. Based on the results of these consultations, BC Hydro established both data collection objectives and TDG monitoring equipment specifications for the Project. TDG monitoring systems that met the Project requirements based on those design specifications were reviewed by both BC Hydro and WSP Canada Inc. (WSP) (Golder 2022a), and a conceptual system was developed for a feasibility assessment. Feasibility testing for TDG monitoring in 2022 consisted of the installation of a single station to test proof-of-concept of the station's design in terms of reliability and service requirements. The results of this feasibility study and lessons learned during the study will be used to support the selection of equipment to be used for long-term TDG monitoring under Mon-11.

1.1 TDG Feasibility Study Objectives

The objectives of the 2022 feasibility study were as follows:

- Identify a suitable location downstream of the Project where all-season TDG monitoring would be feasible.
  - In addition to having physical attributes that facilitate successful all-season monitoring (e.g., sufficient depth, protection from floating debris, low water velocities during periods of higher flow)
- Based on a review of TDG equipment available from select manufacturers, purchase TDG monitoring equipment that meets BC Hydro's data collection and quality assurance criteria.
- Design and deploy a TDG station at the selected monitoring location and conduct all-season TDG monitoring.
- Monitor the functionality of the TDG station during deployment and determine the effect of environmental variables on TDG sensor data, power consumption, and remote data download success to identify a typical station maintenance frequency and potential improvements to station design.

The following sections provide the rationale and the approach implemented to meet the objectives detailed above and summarize the results and lessons learned during the 2022 feasibility study.

1.2 TDG Monitoring Approach

A review of candidate TDG monitoring equipment was conducted in April 2022 to identify TDG monitoring equipment that met BC Hydro's TDG data collection objectives for the Project (Golder 2022a). The TDG monitoring station consists of two main components; the TDG probe, which is deployed in the water and contains the TDG sensor, and the Data Collection Platform (DCP), which is connected to the TDG probe to record data and allow remote download and user access to query the station status. Based on Golder (2022a), the follow components were selected for the feasibility study:

TDG Probe: Pro-Oceanus Solu-Blu™ TDG probe (Pro-Oceanus Systems Inc., Bridgewater, Nova Scotia)

- The Pro-Oceanus Solu-Blu™ TDG probe uses a semipermeable membrane called Enduraflux™, which was developed by Pro-Oceanus specifically to measure TDG.
- The Solu-Blu™ TDG sensor's primary strengths include a rapid equilibrium time and low maintenance and calibration requirements for the sensor.
- The probe contains a vented internal barometer used to record barometric pressure, which allows the calculation of percent saturation as an output parameter.
- Data outputs of the Solu-Blu™ TDG probe include water temperature, barometric pressure, total gas pressure, and percent TDG.
- All parameters are output as a single data stream, which simplifies data capture and transmission.

- Advertised calibration stability of the TDG sensor, factory calibration and maintenance are recommended every three years.

Data Collection Platform (DCP): The GolderWatch™/GoldConnect DCP (GolderWatch Telemetry Solutions, Denver, Colorado)

- The DCP consists of a GolderWatch™ remote monitoring unit (RMU) with hardwire connections to the TDG probe, a satellite modem and antenna, and an onboard battery power supply.
- The RMU powers and records data from the TDG probe.
- Data stored within the RMU memory buffer are transmitted over a satellite connection to the GoldConnect cloud-based server.
- Through GoldConnect, data can be queried, plotted for review, and algorithms and equations can be applied and exported by users. Station status and functionality can be monitored and automated email or text message alerts can be sent to users based on user-defined criteria (e.g., loss of connection, low battery voltage, high TDG).
- If required, administrators can conduct over-the-air programming of the RMU to change data recording and transmission time intervals.

The 2022 TDG monitoring approach and overall configuration of the TDG probe and DCP components are outlined in Figure 1.

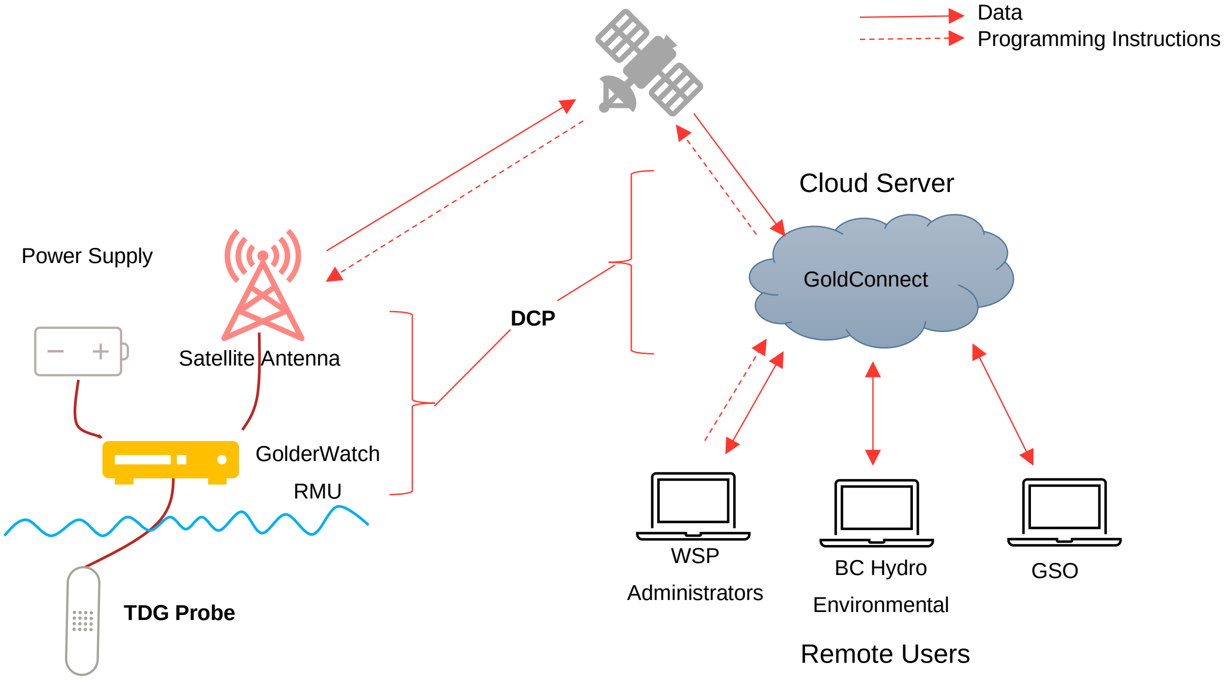

Figure 1: Summary of the configuration of TDG monitoring equipment deployed during the 2022 feasibility study associated with the Site C TDG Monitoring Program (Mon-11).

2.0 METHODS

2.1 Site Reconnaissance - 11 May 2022

Several factors were considered while identifying potential sites for deploying the TDG monitoring equipment. High water depths were required to ensure the TDG probe remained wetted and below compensation depth through a range of Peace River discharge levels. Low water velocities were required to reduce strain on the TDG probe and facilitate the safe deployment and retrieval of equipment. High bank stability was required to reduce the likelihood of equipment loss due to bank failures. Safe and authorized shoreline access was required to allow equipment to be mounted or attached to objects on shore and above the anticipated high watermark. The site also had to be sheltered from the main thalweg of the river, to reduce the likelihood of floating debris, such as logs, getting entangled in float lines, while not being located in areas expected to be more prone to the formation of surface ice (e.g., smaller side channels). The main channel of the Peace River between the Project and the confluence of the Peace River with the Pine River has an average width of approximately 270 m (Golder 2022b), is fast flowing (up to 2.3 m/s; WSP 2023), and was anticipated to have few locations where all of the above mentioned parameters would be conducive to the installation of TDG monitoring equipment.

Several back eddies adjacent to the thalweg were identified as candidate sites for deployment of the TDG monitoring equipment based on a review of recent Google Earth imagery and input from WSP personnel with recent experience working in this portion of the Peace River. A reconnaissance survey of the candidate sites was conducted on 11 May 2022 and results of that survey confirmed that most of the candidate sites were not suitable.

Of the candidate sites inspected, two were considered potentially suitable and the candidate site that was ultimately selected was located approximately 7 km downstream of the Project near RKm 112.5, as measured downstream from W.A.C. Bennett Dam, on the left downstream bank. The location consisted of a large back eddy with low water velocity and a water depth of approximately 6 m at the time of the reconnaissance survey. The site was also far enough downstream of the Project that it was assumed that, during potential future monitoring efforts, Project generation and spill discharge flows would be fully mixed and that TDG data recorded at the site would be representative of combined flows from the Project. The TDG monitoring station at this site was designated Stn_112.5L (Figure 2).

2.2 TDG Probe and DCP Configuration and Testing

Two TDG probes were purchased for the 2022 study. One was configured for use in a buoy station (SN380084; equipped with a 3 m long cable) and one was configured for use as a portable monitor (SN380083; equipped with a 15 m long cable). Prior to deployment, both probes were tested for functionality and responsiveness. The station and portable probes were connected to a Bluetooth portable monitor and tested for responsiveness in air at ambient barometric pressure and at elevated TDG conditions using soda water. The station probe and the portable probe reported nearly identical TDG, barometric pressure, and temperature readings during the test.

In consultation with the manufacturer, the DCP was configured to record probe sensor readings at 15-minute intervals and then the most recent four readings were transmitted to by satellite each hour. Prior to station deployment, the station probe was connected and powered, and DCP and satellite connectivity were tested by placing the station outside for a two-hour period. After two hours, the cloud server was queried to confirm that the sensor data successfully uploaded.

If a satellite data transfer was not successful, the DCP was programmed to continually attempt the data transfer until it was successful. If data were not received for more than two consecutive hours, the DCP was configured to automatically send an email alert to the database managers. If data transfers continued to fail, the internal onsite storage capacity of the DCP allowed for up to seven days of storage for data recorded in 15-minute intervals.

LEGEND

- ● TOTAL DISSOLVED GAS MONITORING LOCATION, 2022
- ○ RIVER KILOMETRE AS MEASURED DOWNSTREAM FROM W.A.C. BENNETT DAM
- — ROAD
- ➡ FLOW DIRECTION

0 1 2

1:55,000 KILOMETRES

REFERENCES

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3. DATUM: NAD83 PROJECTION UTM10

CLIENT
BC HYDRO

PROJECT
SITE C CLEAN ENERGY PROJECT

TITLE
TOTAL DISSOLVED GAS MONITORING LOCATIONS 2022

CONSULTANT

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PREPARED	CD
REVIEWED	PG
APPROVED	DF

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2.3 TDG Station Design

Two different station setups were considered for the 2022 feasibility study: a shore-based station and a buoy-based station. A shore-based station was expected to require the construction of a long sloping standpipe to ensure the TDG probe was at a suitable depth. Given the high angle of the banks in the study area, coupled with the relatively flat river bottom, a large span of a standpipe would likely be unsupported and suspended in air. A standpipe would also require extensive ballasting and would need to be deployed in a location with minimal current to reduce leverage on the standpipe during periods of high flow. Similar to a buoy system, a standpipe would be at risk of damage and displacement from floating debris and ice and be susceptible to debris accumulation on the standpipe itself. A shore-based station would also be prone to damage in the event of flooding and bank slope failures. Due to the length of standpipe that would be required, it would be visible to the public and accessible by both boat and land, increasing the risk of vandalism and tampering. Time required to construct and install a standpipe was estimated to be considerably more than was required to construct and deploy a buoy-based system. Based on the above rationale, a buoy-based TDG monitoring station was selected for the 2022 study.

The design of the TDG station deployed during the 2022 study was based on marine buoy stations that use a custom-designed buoy to house station components. This design allowed the station to operate autonomously without a shore-based component. The advantages of a buoy station design included the following:

- Simplicity of design – Stations can be easily constructed, deployed, and serviced by a small boat-based field crew.
- Self-adjusts to changing water levels – A buoy floats on the water surface, keeping the sensor at a constant depth below the surface, at or below compensation depth, to prevent TDG readings from being affected by changes in hydrostatic pressure or by air bubbles forming on the sensor.
- Lower risk of damage – A buoy is less susceptible to vandalism, tampering, or damage from animals because it is situated offshore. A buoy can also be deployed at locations where ownership of the adjacent shore will not allow the installation of a shore-based station.
- Temperature management – A buoy station’s electronic components remain in the water, and thus are subject to less extreme air temperatures compared to a shore-based station.

Disadvantages of a buoy-based system are as follows:

- The station could potentially be damaged by floating debris, including ice, that may contact or accumulate on the station’s float or anchor lines over time.
- The station could be displaced by current due to increased drag associated with debris accumulation on the float or anchor lines and/or changes in flow conditions.
- The station could potentially be submerged if water level elevation increased substantially.
- The station could potentially be damaged if water level elevation decreased substantially and the station contacted the river bottom.
- The station could potentially be inundated by waves created by wind or adjacent boat traffic.

- Accessing the station requires a boat, which might not be possible at all water levels or at all stages of Project development.

The buoy-based TDG monitoring station and mooring system that were designed and deployed for the 2022 study is described below and detailed in Figure 3.

Mooring System

- The mooring system consisted of a 45 kg steel pyramid anchor to which a shoreline retrieval cable and the TDG station tether were attached.
- The shoreline retrieval cable consisted of 20 m of ¼” diameter stainless steel cable, which served as both a safety line to prevent downstream displacement of the anchor and as a backup retrieval method for the pyramid anchor and station.
- The TDG station tether consisted of a 2 m long 5/16” galvanized steel chain (Transport 70 gauge) connected to a 5 m long steel cable and bungee tether. The tether attached to the bottom of the TDG station and kept it positioned approximately over top of the pyramid anchor.
    - The stainless-steel cable component of the tether consisted of a 5 m length of ¼” diameter stainless steel cable.
    - The bungee component of the tether was an Airhead™ AHAB-2 Anchor Bungee Lite (Aqua-Leisure Recreation, LLC, Denver, CO), which had a stretch range from 2 to 7 m and provided retractive force to re-center the station over the pyramid anchor when current conditions fluctuated.
    - Four ABS cylindrical bungee guides were attached to the upper 2 m of the stainless-steel cable to reduce wear on the bungee and prevent twisting of the bungee and tether cable.
- Where possible, stainless-steel hardware and connectors were used to reduce wear and increase longevity.

TDG Station Design

A custom-designed NexSens CB-25 Data Buoy (NexSens Technology, Inc., Fairborn, OH) was used to house the DCP and TDG probe components attached to either the top of the buoy, within the interior of the buoy’s central canister, or attached to the bottom of the buoy:

TDG probe:

- A 1.5 m long stainless-steal instrument tube secured to the bottom of the buoy was used to house the TDG probe. The instrument tube was attached in the center canister base plate of the buoy with three bolts. A hole in the center of the base plate allowed access to the instrument tube to deploy the TDG probe.

- The length of the TDG instrument tube (1.5 m) was selected to keep the TDG probe sensor below the compensation depth, below which air bubbles would not be expected to form on the TDG probe sensor, based on the levels of TDG expected during Project construction and operation.
- The station TDG probe cable was 3 m long; extra cable was coiled within the buoy canister and the probe was connected to the DCP by a probe connector located on the top plate of the DCP.
  The DCP provided power to the TDG probe.
- A strain relief was used to protect the TDG probe cable connection to the DCP.
- The TDG probe's barometric pressure sensor's air reference line was connected to in-line desiccant tubes to control condensation and reduce the risk of water blockages in the air reference line.
  The desiccant tubes were mounted on the top of the buoy to fixed metal mounts that allowed the tubes to be replaced easily during station servicing.
- The TDG sensor accuracy was ±0.1TDG%; TDG sensor's resolution was 0.1TDG% saturation level; and the TDG sensor's measurement range was 75 to 150 TDG%

DCP:

- The DCP electronics were housed in a clear acrylic cylinder and secured within the interior of the buoy canister with a top plate. The DCP housing was sealed with two double O-ring end caps. The end cap affixed to the top plate contained the TDG probe connector, power connector, and an Iridium satellite antenna (Iridium Communications Inc., McLean, VA). Desiccant and a moisture indicator strip were added to the RMU in the DCP housing and the housing was sealed with a double O-ring end cap.
- The DCP power supply was mounted on the top of the buoy on a friction-fit PVC mounting bracket designed to allow the power supply to be easily removed and replaced with a new power supply during station servicing. The power supply consisted of a water-proof PVC container with 24 AA 1.5 V lithium ion batteries configured in 4 parallel banks of 6 cells, linked in series in each bank, to produce 9.0 V and an approximate battery capacity of 12,000 mAh. The power supply was equipped with desiccant packs and sealed with a water-tight lid with an O-ring gasket that was secured to the container body with 8 machine screws. A battery cable connected the power supply to the DCP.

Other station components:

- An active radio telemetry tag was affixed to the buoy to allow the station to be located by radio telemetry if needed. Should the station detach from its anchor and drift downstream, telemetry data from shore stations deployed as part of the Site C Fish Movement Assessment would be reviewed to indicate its potential location, and then mobile tracking (fixed-wing, helicopter, boat) could be conducted to locate and retrieve the station.
- Components on the top of the buoy were protected from weathering and UV damage by a fabric cover, and later, with a hard acrylic cover.

- Around the instrument tube, at the base of the buoy, up to five 2” thick closed-cell foam floats were used to provide additional buoyancy to keep station components on the top of the buoy (i.e., the power supply and desiccant tubes) higher above the water surface and to counter the bottom ballast.
- A bottom ballast consisting of a 5-kg lead weight and heavy swivel were attached to the eye-bolt integrated into the bottom of the instrument tube. The bottom ballast helped keep the station vertical in the water column.

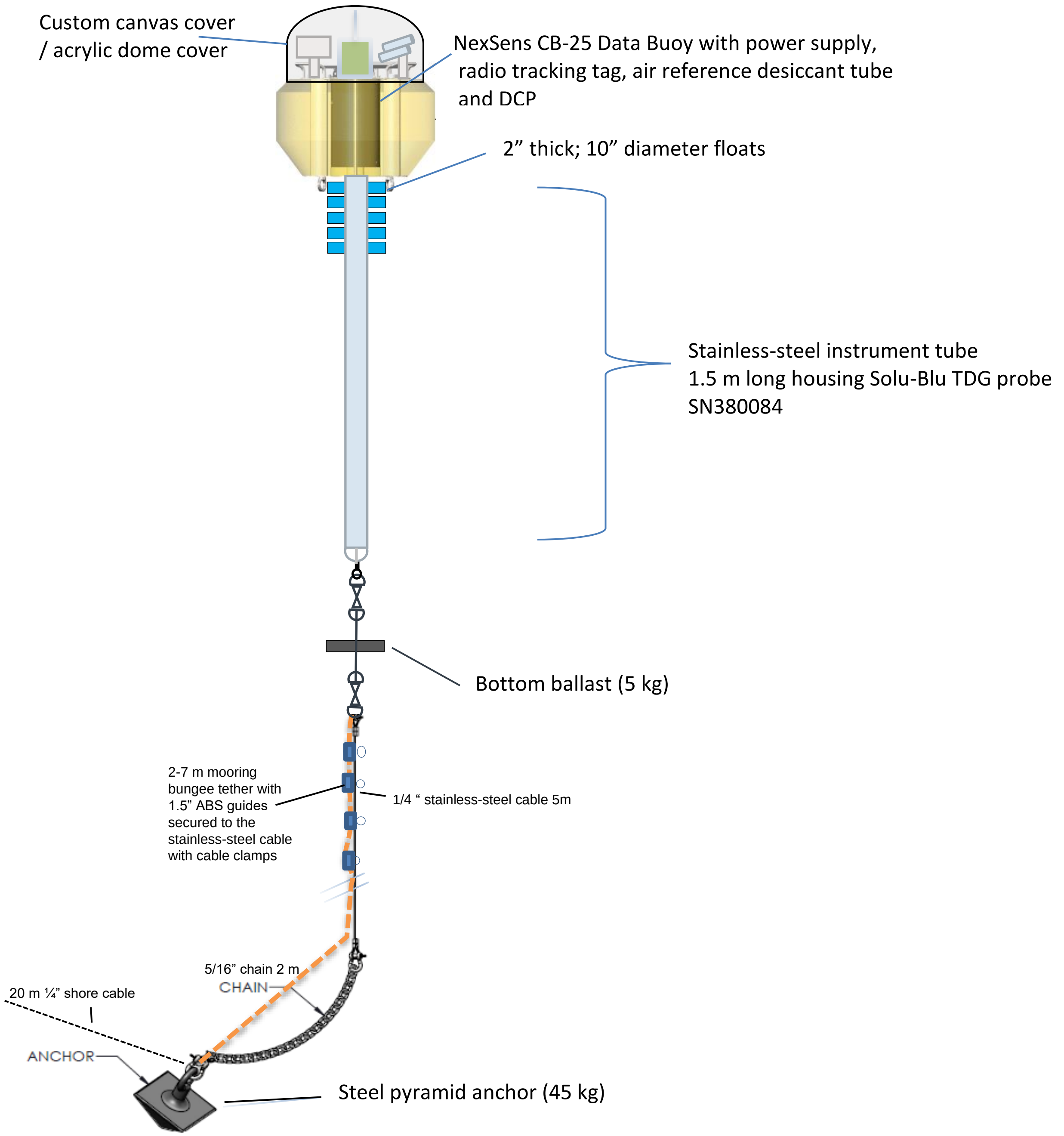

Figure 3: The TDG monitoring station design deployed at Stn_112.5L during the 2022 TDG feasibility study.

2.4 TDG Station Deployment

Once the TDG station was assembled and functionality testing of the TDG monitoring equipment was complete, the station was deployed at the selected candidate site (Stn_112.5L; Figure 2). The station was deployed by a boat-based 2-person crew on 17 August 2022. On site, the mooring system, equipped with a shoreline retrieval cable and a LD-2 float (Polyform U.S., Kent, WA) attached to the station tether, was arranged along the river bank in a sequential manner to facilitate deployment of the mooring. A rope was looped through the eyelet of the pyramid anchor and the anchor was suspended from the bow of the boat. As the boat backed away from shore, the shoreline and station tether and float were left to trail in the water. Once the boat was in position over the candidate site, the rope loop was used to lower the pyramid anchor to the river bottom and then the rope was recovered by pulling it back through the anchor's eyelet. After confirming that the mooring was secure, the TDG station was positioned along the side of the boat and the float on the mooring tether was retrieved. Once retrieved, the float was removed and the tether was shackled to the ballast weight at the bottom end of the instrument tube. Shackle pins were tightened and secured with cable ties, to prevent them from coming loose, and the station was lowered over the side of the boat into the water.

2.5 TDG Station Site Visits and Station Servicing

Boat-based site visits were conducted opportunistically over the station deployment period by crews that were working in the general vicinity of the station. Dedicated site visits were conducted when staff received email notifications from the station or when data recorded by the DCP displayed changes in parameters that were indicative of structural integrity issues. Site visits generally consisted of a visual inspection of the station to photo-document and assess its integrity and provide information needed to plan station service visits.

A battery-operated trail camera was used to monitor the TDG station and flow conditions at the site over the winter. The camera was deployed on 15 December, affixed to a tree adjacent to the station, and was programmed to record a digital photograph each hour. Camera imagery was reviewed to assess changes in station integrity and the presence of floating debris and ice in the site.

2.6 Spot TDG Measurements

Spot TDG measurements were conducted using the portable Solu-Blu probe (SN380083) and with a BC Hydro-owned Point Four™ Tracker Portable TDP Meter (Probe SNPT4TGPSM084; Tracker SN Unit 4; Point Four Systems Inc., Coquitlam, BC) to provide comparisons between the two different meters and manufacturers. The two portable TDG meters differed from each other in that the Solu-Blu meter used an Enduraflux™ TDG sensor and the Point Four™ Tracker meter used a silastic membrane-style TDG sensor. Both units were factory calibrated prior to use. When deployed from either a boat or from shore, both probes were deployed together and at the same depth. Deployed depths were approximately 1 m or greater.

During deployment of the TDG station on 17 August, spot TDG measurements were conducted at the TDG monitoring station (Stn_112.5L) and upstream of the station, immediately below the Project (Prt_DS1; Figure 2). On 29 November and 15 December, spot TDG measurements were conducted at sites upstream (Prt_US1) and downstream (Prt_DS1) of the Project to document TDG differences associated with discharge through the diversion tunnels and to verify concurrent TDG recordings at the TDG station. To compare TDG at Prt_DS1 to measurements recorded at Stn_112.5L, a mean water velocity of 1 m/s and a 2-hour water transit time was assumed between the 7 km separating the two locations.

2.7 Data Analysis

TDG data were routinely inspected during the monitoring period using the graphing tools integrated into the GoldConnect cloud database interface. Inspection of the data was conducted opportunistically over the monitoring period in response to client questions, substantial changes in Peace River discharge, changes in weather, and in response to email notifications from the DCP that indicated a change in the station’s status (i.e., a loss of satellite connectivity). All TDG data were downloaded and initially inspected in Microsoft Excel™ to identify erroneous data and potential data outliers.

Hourly Peace River discharge and water level elevation data were downloaded from the Water Survey of Canada “Peace above Pine” gauge station (Station 07FA004; Water Survey of Canada 2022). All discharge data were downloaded and inspected in Microsoft Excel™ for initial comparisons to TDG data.

Barometric pressure data recorded at the North Peace Regional Airport (Fort St John, BC) were used to compare and cross-check barometric pressure data recorded by the TDG station. For these comparisons, the following correction formula was used to address the 287 m difference in elevation between the TDG station and the airport, as measured in Google Earth™ (Omnicalculator 2022):

$$P=P_0 \exp (-gM(h-ho)/RT))$$

where

h is the altitude at which to calculate the barometric pressure (m),

P is the barometric pressure at altitude h,

P_0 is the barometric pressure at the airport at reference elevation h_0,

T is the temperature at altitude h, expressed in Kelvins (assumed 15°C or 288.5 K),

g is the acceleration due to gravity (9.80665 m/s^2),

M is the molar mass of air (0.0289644 kg/mol),

and R is the universal gas constant (8.31432 N·m(mol·K)).

After the initial data inspection, the subsequent cleaning, analysis, and plotting of the data were conducted in R (R Core Team 2021) and ggplot2 (Wickham 2016) within the RStudio interface (RStudio 2022).

3.0 RESULTS

3.1 Site Visits and Station Servicing

The TDG station was initially deployed on 17 August 2022. Station service visits were conducted on 18 and 19 November to restore the station to optimal operating condition. These service visits required the crew to remove the station from the water to inspect station components. On 18 November, the desiccant filter for the barometric pressure sensor and the system's battery power supply were replaced. The station mooring was also repositioned during this site visit. The station was moved to a shallower location within the site to reduce the risk of submersion during periods of higher water. On 19 November, the station appeared to be floating low in the water and at risk of submersion; additional floatation disks were added to the instrument tube to provide additional buoyancy.

On 27 December 2022, contact with the TDG station was lost during a period of extreme cold weather (i.e., -40°C) and could not be restored. Air temperature and river conditions improved enough by 6 January 2023 that a field crew were able to reach the site and inspect the station. The TDG station was removed from its mooring and brought to the WSP office. The station's mooring was left in place with an LD2 float attached to the tether.
The TDG station was inspected after its removal and was deemed too damaged to be redeployed and was sent to the manufacturer for repairs on 1 February 2023.

3.2 Total Dissolved Gas

The analyses presented in the following sections include data from 17 August to 27 December. Inspection of the station data noted more variability in TDG data recorded after 12 December compared to data collected prior to 12 December. However, after removal of outliers, the general trend in TDG corresponded with discharge levels and was consistent with data recorded prior to 12 December. As such, the entire dataset was considered in analyses and potential causes of spurious data were identified.

The average mean daily TDG over the monitoring period was 106.9 TDG% and ranged between a low of 98.8 TDG% on 31 October and 111.7 TDG% on 7 October. Mean hourly TDG ranged between a minimum of 97.5 TDG%, which was recorded on 31 October at 09:00, and a maximum of 113.9 TDG%, which was recorded on 19 August at 03:00 (Figure 4). From 30 to 31 October, TDG briefly decreased below 100 TDG%. These low values corresponded with a substantial reduction in total river discharge.

When Peace River discharge was between 300 and 1,600 m³/s, there was a linear relationship between discharge and TDG, with higher TDG corresponding to higher discharge (Figure 5). When discharge exceeded 1,600 m³/s, TDG decreased as discharge increased, resulting in TDG that was similar to TDG produced at lower discharges between 600 and 1,300 m³/s.

The station service completed on 18 and 19 November involved replacing the desiccant filter for the probe's barometric pressure air reference, installation of a new power supply, and relocation of the station to a shallower and more secure location within the site. TDG data recorded by the station before and after this service were consistent with each other (i.e., no large changes), which was considered as evidence that the TDG station calibration had not drifted since deployment on 17 August.

Over the duration of the monitoring period, the TDG produced at a given discharge decreased over time, with the highest TDG recorded in August, followed by incrementally lower TDG recorded from September to December for the same discharge (Figure 5). Over this time, water temperature also gradually decreased; however, cumulative bio-fouling of the TDG membrane and other changes in the TDG station functionality also occurred over the same time period.

Figure 4: A hourly time-series comparison of percent TDG and water temperature recorded at Stn_112.5L in relation to Peace River total discharge, 17 August to 27 December 2022. The dash lines in the top panel correspond with BC Hydro TDG guidelines in British Columbia (BC Hydro 2014, 2022) in relation to the risk for gas bubble trauma in fish. The green vertical bar indicates the timing of the service visit to the station.

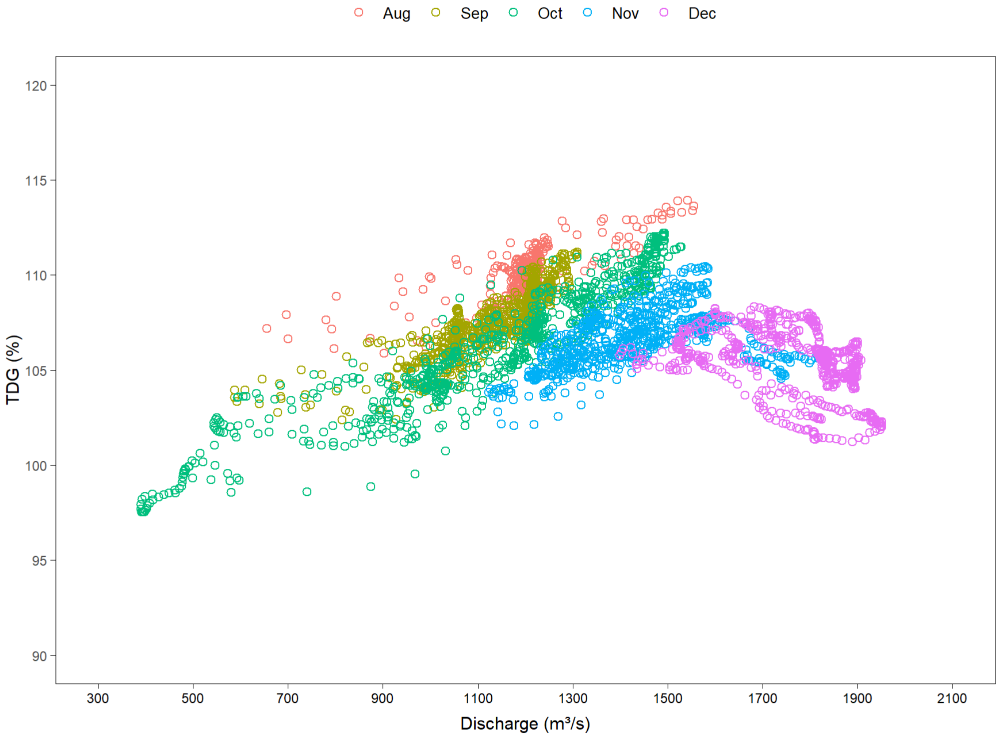

Figure 5: A comparison of TDG recorded at Stn_112.5L and Peace River total discharge recorded at the Water Survey of Canada's "Peace above Pine" gauge station (Station 07FA004) from 17 August to 27 December 2022. Colour indicates the month the data were recorded.

3.3 Discharge

Peace River discharge fluctuated during the 17 August to 27 December deployment period of the TDG station. These fluctuations in discharge occurred over short-term (i.e., daily) and long-term (i.e., monthly) time frames, and were interspersed with periods of relatively stable flows (Figure 4). The largest and most rapid change in river discharge was recorded on 19 August, when mean hourly discharge decreased from 1,555 m^3/s at 04:00 to 655 m^3/s at 16:00, a change of 900 m^3/s over a 12-hour period. Other changes in discharge >500 m^3/s were recorded during the monitoring period over relatively short time frames (e.g., from 389 m^3/s at 11:00 on 31 October to 1,322 m^3/s at 21:00 on 1 November, a 933 m^3/s change over a 34-hour period). Over the entire monitoring period, the minimum mean hourly total river discharge was 389 m^3/s on 31 October at 11:00 and the maximum mean hourly total river discharge was 1,950 m^3/s, which occurred over a 6-hour period from 21:00 on 20 December to 03:00 on 21 December.

3.4 Temperature

Mean daily water temperature during the monitoring period ranged between a maximum of 15.1°C on 13 September and a minimum 0.0°C on 25 December. The highest mean hourly water temperature was 15.3°C recorded on 13 September; the lowest mean hourly water temperature was 0.0°C recorded during the night for extended durations from 24 to 26 December (Figure 4). From 17 August to 20 October, mean daily water temperature was generally uniform and ranged between 11.9°C and 15.1 °C. After 20 October, Peace River water temperatures rapidly cooled and mean daily water temperature remained below 1°C from 19 December onward until the station failed on 27 December.

3.5 Comparison Between Station and Spot TDG Measurements

As a quality assurance check of the TDG station calibration, spot TDG measurements were taken on the day of station deployment (17 August) and during site visits conducted on 18 and 19 November. Spot measurements were taken with portable TDG meters (Solu-Blu SN 3800083 and/or the Point Four Unit 4) and compared with concurrent TDG station data. Both the TDG station and the portable meters were factory calibrated and produced similar TDG readings when tested prior to the station’s deployment. As such, identical or near identical TDG measurements between the station and portable meters were expected in the field.

On 17 August, spot TDG measurements with a portable meter (Solu-Blu SN 3800083) at the TDG station were notably lower (i.e., 965 mbar or 99.5 TDG%) than concurrent TDG measurements recorded by the station (i.e., 1046 mbar or 107.6 TDG%). Similarly low TDG measurements were also recorded by the portable meter upstream of the station in the tailwater area of the Project at Prt_DS1 (Figure 2) on 17 August (971 mbar or 100 TDG%; Table 1). Reasons for this discrepancy in values between the station and the portable TDG meter were not known at the time when the portable measurements were recorded; however, reasons for the discrepancy were identified during subsequent communications with the manufacturer. These reasons are discussed in detail in Section 4.1.

Substantial differences in TDG were recorded between the Solu-Blu portable meter and the TDG station on both 18 and 19 November (Table 1). TDG reported by the Solu-Blu portable meter (SN 3800083) were unrealistically high on both days (i.e., 112.6 TDG% and 117.3 TDG%, respectively) and did not correspond with either the TDG station or the Point Four meter when they were deployed at the same location and depth. The Point Four meter was similar to the TDG station on both service days, albeit slightly higher. A plot of TDG recorded during the 18 November site visit indicates that TDG was equal to barometric pressure at 14:00, when the station’s probe was removed from the water and exposed to atmospheric pressure (Figure 6). These data provide evidence that the calibration of both the station’s TDG probe and the station’s barometric pressure sensor did not drift between station deployment and the site visit, and confirmed that both sensors were still responsive at the time of the visit. When the station was redeployed at approximately 14:45, TDG was initially elevated, but slowly approached a lower equilibrium over the 45 to 60 minutes immediately following redeployment. Reasons for the slow response time of the probe were not known at the time when the portable measurements were recorded, but were identified later (see Section 4.1).

After servicing on 19 November, the station reported higher battery voltage due to the new power supply. Although TDG readings from the station and the portable Solu-Blu probe differed, barometric pressure and temperature measurements aligned.

Table 1: Comparison of Station Stn_112.5L data and spot measurement data collected during deployment of the station on 17 August and during site visits conducted on 18 and 19 November. For the TDG station, data from immediately before and immediately after each site visit are provided.

Date	Time	Location	Portable or Station	Meter Serial Number	TDG (mbar)	BP (mbar)	TDG%	Water Temperature (°C)
17-Aug-22	14:18	Stn_112.5L	Portable	Solu-Blu 380083	965	972	99.3	14.4
17-Aug-22	15:00	Prt_DS1	Portable	Solu-Blu 380083	971	971	99.9	14.4
17-Aug-22	15:00	Stn_112.5L	Station	Solu-Blu 380084	1046	972	107.6	13.8
18-Nov-22	13:00	Stn_112.5L	Station	Solu-Blu 380084	1037	978	106.1	5.3
18-Nov-22	16:19	Stn_112.5L	Portable	Solu-Blu 380083	1102	979	112.6	5.4
18-Nov-22	16:06	Stn_112.5L	Portable	Point Four Tracker Unit 4	1045	975	107.2	-[a]
18-Nov-22	16:00	Stn_112.5L	Station	Solu-Blu 380084	1032	975	105.9	5.2
19-Nov-22	8:45	Stn_112.5L	Station	Solu-Blu 380084	1046	972	107.6	5.1
19-Nov-22	10:07	Stn_112.5L	Portable	Solu-Blu 380083	1139	972	117.3	5.2
19-Nov-22	10:07	Stn_112.5L	Portable	Point Four Tracker Unit 4	1064	965	110.2	-[a]
19-Nov-22	11:00	Stn_112.5L	Station	Solu-Blu 380084	1043	972	107.4	5.1

[a] Point Four Tracker temperature sensor was not functioning.

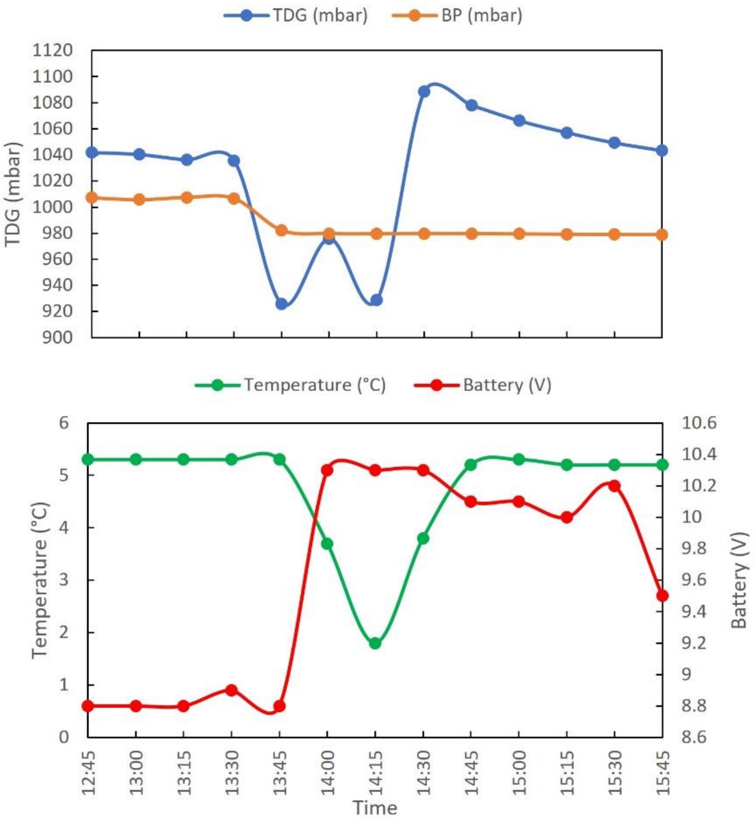

Figure 6: Station Stn_112.5L TDG, barometric pressure (BP), temperature, and battery voltage during a station service visit conducted on 18 November 2022.

3.6 TDG Comparison Upstream and Downstream of Project

Spot measurements of TDG were recorded at locations upstream (Prt_US1) and downstream (Prt_DS1) of the Project on 29 November and 15 December and compared to TDG station data on those days to determine the contribution of the diversion tunnels to Peace River TDG downstream of the Project (Table 2).

On 29 November, with the probes of the two portable meters deployed together at the same depth and location, the TDG recorded at Prt_US1 by the Solu-Blu portable meter (SN 3800083) was notably higher (103.3 TDG%) than the value recorded by the Point Four portable meter (PT4_Unit_4; 99.2 TDG%). Downstream of the Project, slightly higher TDG was recorded at Prt_DS1 (105.6 TDG%), with similar TDG recorded by both portable meters and by the TDG station (105.5 TDG%). Mean hourly total river discharge at the time of the measurements was approximately 1,687 m^3/s.

On 15 December, TDG upstream (106.5 TDG%) and downstream (106.8 TDG%) of the Project were nearly identical. At the same time, TDG measured at the TDG station was slightly higher (107.8 TDG%); however, the difference between the reading taken downstream of the Project and the reading taken by the station was less than 1 TDG% and within the range of instrument error. Mean hourly total river discharge at the time of these measurements was approximately 1,657 m^3/s.

Table 2: Spot measurements of TDG taken upstream (Prt_US1) and downstream (Prt_DS1) of the Project in relation to TDG values recorded at the Stn_112.5L TDG station, 29 November and 15 December. For a valid comparison, a flow transit time of two hours was assumed between Prt_DS1 and the TDG station.

Date	Time	Location	Portable or Station	Meter Serial Number	TDG (mbar)	BP (mbar)	TDG%	Water Temperature (°C)
29-Nov-22	15:16	Prt_US1	Portable	Solu-Blu 380083	1011	979	103.2	3.6
29-Nov-22	15:16	Prt_US1	Portable	Point Four Tracker Unit 4	971	979	99.2	-[a]
29-Nov-22	15:41	Prt_DS1	Portable	Solu-Blu 380083	1036	981	105.6	3.4
29-Nov-22	15:41	Prt_DS1	Portable	Point Four Tracker Unit 4	1033	977	105.7	-[a]
29-Nov-22	18:00	Stn_112.5L	Station	Solu-Blu 380084	1030	976	105.5	3.4
15-Dec-22	17:25	Prt_US1	Portable	Solu-Blu 380083	1037	974	106.5	2.7
15-Dec-22	16:22	Prt_DS1	Portable	Solu-Blu 380083	1042	975	106.8	2.9
15-Dec-22	18:00	Stn_112.5L	Station	Solu-Blu 380084	1046	971	107.8	2.7

[a] Point Four Tracker temperature sensor was not functioning.

4.0 DISCUSSION

4.1 Total Dissolved Gas Sensor Performance

The performance of the Pro-Oceanus Solu-Blu TDG probe as a continuous TDG monitor met study expectations both in terms of responsiveness and low maintenance requirements over the duration of the feasibility study. A review of the 15-minute raw sensor data confirmed that the TDG sensor was highly responsive and that it reported small incremental changes in TDG in response to similarly small incremental changes in total river discharge over the same time period. The responsive performance of the TDG sensor during the study aligned with positive comments about the sensor's performance provided by other researchers with experience using the Pro-Oceanus equipment (R. Izett, personal communication; Golder 2022a). Over the duration of deployment, the sensor's responsiveness did not notably attenuate over time, in that changes in TDG data generally tracked with changes in discharge over the same time period; however, over short-duration time frames (1-2 hours), some variability or noise was evident in the data, where one reading in the series would deviate from the overall trend in the data over that duration.

Where the Pro-Oceanus equipment did not meet expectations was in the use of the Solu-Blu probe as a portable monitor to record spot TDG readings in a timely manner as a quality assurance check of the TDG station readings. Pro-Oceanus literature and operating instructions did not provide a clear indication of the time required for the TDG sensor to reach equilibrium and report accurate readings. What information Pro-Oceanus did provide in company literature regarding equilibrium time requirements was specific to a Mini-TDGP sonde, which uses a TDG sensor similar to the Solu-Blu probe; however, this information consisted of only a high-level review of the factors that may affect equilibrium time requirements. During concurrent TDG investigations conducted for BC Hydro and Hydro Quebec in 2023, inquiries about TDG probe equilibrium time requirements were directed to Pro-Oceanus technical staff. Answers to these inquiries revealed that Pro-Oceanus TDG sensors, upon initial deployment to depth, require approximately two hours to reach a functional operational state, during which time the sensor's semipermeable membrane is positioned on the sensor by hydrostatic pressure (E. Hachey, Application Scientist, Pro-Oceanus System Inc., personal communication). Pro-Oceanus confirmed that after the membrane is in the correct position, the TDG sensor are highly responsive to changes in TDG and unaffected by further changes in hydrostatic pressure; data recorded during the feasibility study supported this claim. Considering the above information, the portable spot monitoring data recorded during the feasibility study should be considered less reliable than the continuous TDG monitoring data recorded by the station. The interpretation of the study's TDG data that is provided below is based solely on the TDG monitoring data recorded at the station.

4.1.1 Pilot Study TDG Data

Over the 2022 study period, mean TDG was 106.9 TDG%, which was below the 110 TDG% guideline limit in British Columbia, above which, risk to aquatic life from gas bubble trauma increases (Fidler and Miller 1994). Fluctuations in TDG corresponded to changes in total river discharge, with changes in total river discharge as minor as 50 m³/s resulting in detectable changes in TDG. In late August and early September, a proportion of the diel fluctuation in TDG recorded was attributed to diel changes in photosynthesis and water temperature that resulted in slightly higher TDG during the day compared to night (see Figure 4). During the day, TDG was generally higher due to an increase the partial pressure of dissolved oxygen due to photosynthesis and lower solubility of dissolved gas as water temperature increased due to solar heating. At night, TDG generally decreased due reduced partial pressure of oxygen due to respiration and higher solubility of dissolved gas in water due to lower water temperatures (Fidler and Miller 1994). Similar diel fluctuations in TDG of up to 10 TDG%

have been recorded in Winston Reservoir, and in 2021, TDG in the reservoir varied between 103 TDG% and 117 TDG% solely as a result of photosynthesis and solar heating (Diversified 2022). Downstream of the Project, the baseline TDG levels decreased over time from August to December. This decrease was attributed to seasonal reduction in photosynthesis and reduced water temperature due to reduced solar radiation based on the processes described above (see Figure 4).

Fluctuations in total river discharge resulted in the most notable changes in TDG. The highest TDG was associated with flows between 1,500 and 1,600 m^3/s (see Figure 5). During high flow conditions in August, when flows approached 1,600 m^3/s, a maximum TDG of 113.9 TGP% was recorded. At discharge levels above 1,600 m^3/s, gas entrainment plateaued and then incrementally decreased as discharge approached 1,950 m^3/s. When total river discharge was between 1,900 and 1,950 m^3/s, the TDG recorded (i.e., approximately 102 TGP%) was similar to the TDG recorded when flows were between 600 and 800 m^3/s. A decrease in TDG in response to increased discharge is atypical, and likely indicates some aspect of the diversion tunnels entraining more air under certain conditions. Due to the absence of TDG measurements upstream of the Project, the specific causes of these changes in TDG could not be identified.

4.2 TDG Station Integrity and Performance

Deployment of the TDG station at RKm 112.5 was conducted by boat on 17 August 2022 at approximately 14:00. Mean hourly river discharge was approximately 854 m^3/s during deployment. The station deployment went as planned and the TDG station was successfully positioned within the center of the eddy that was located at the site. After deployment, flows varied substantially from 17 to 19 August from a low of 779 m^3/s to a high of 1,555 m^3/s; this change in flow (i.e., discharge levels were twice as high as during deployment) tested the ability of the station design early on in the study to accommodate substantial flow changes and continue to function (Figure 7). During deployment, and from 17 August to 6 October, opportunistic observations of the station by field crews verified its integrity (i.e., above the surface of the water, protective cover in place) and that it was holding stationary within the center of the eddy where it had been originally deployed.

Figure 7: Deployment of the TDG station at Site Rkm112.5L, 17 August 2022.

From 17 August to 6 October, elevation-corrected airport barometric pressure readings estimated at the station were nearly identical to the barometric pressure readings recorded by the station's probe barometer (Figure 8). On 6 October, the barometric pressure recorded by the TDG station substantially deviated from the estimated barometric pressure, which indicated a problem with the station and possible damage to the air reference line used by the probe to measure barometric pressure. The change in barometric pressure corresponded to a rapid increase in total river discharge on 5 October from 1,110 m^3/s to approximately 1,450 m^3/s on 6 October. A visual inspection of the station conducted on 14 October confirmed that the station's fabric cover was missing and that the desiccant filter for the air reference line were dislodged and saturated with water. The station also appeared to have been displaced out towards the mainstem of the river and was in a location with higher velocities compared to the original deployment location in the eddy. Voltage readings from the station indicated that the batteries still had power and the TDG meter was still functioning. As such, a decision was made not to replace the desiccant filter until a full service of the station was conducted later in the year. Corrected airport barometric pressure data were used in the interim to calculate percent saturation.

The station functionality remained unchanged from 6 October to the first required service on 18 and 19 November; however, increased variability in TDG data was evident when total river discharge exceeded 1,500 m^3/s. Although the station had previously experienced flows of similar magnitude and higher and was not affected, the change in the TDG data suggest that the station had been displaced into deeper water or by higher current and was getting submerged. This assumption was later confirmed during the November service when field crews observed the station periodically becoming submerge by up to 0.5 m during their site visit. Periodic submersion, and possible entanglement of the station with floating woody debris, was assumed to be the cause for the loss of the fabric station cover and saturation of the desiccant filter on the barometer air reference line (Figure 9; Panel A). Even though the station was still functioning at the time of the service, inspection of the battery compartment determined that the single O-ring waterproof seal had not been sufficient to prevent moisture from entering the case when submerged (Figure 9; Panel B). The DCP canister had a double O-ring seal and, as it was still transmitting, was assumed water-tight and was not removed or opened. Removal of the station from the water allowed direct inspection of the mooring connections, buoy, instrument tube, and the probe's TDG membrane. The inspection revealed that, despite the high turbidity of the water and the deployment of the probe to approximately 1.5 m depth, a small amount of bio-fouling (algae) covered most surfaces (Figure 9; Panels C and D). The extent of biofouling on the probe's TDG membrane was not substantial and subsequent comparisons between the station's barometric pressure and total pressure readings indicated that the TDG sensor was still responsive. Upon completion of the final service on 19 November, and in preparation to monitor over the winter, the field crew relocated the station mooring to a shallower location (~4.5 m deep) and installed a new battery pack, a new air reference desiccant filter, added additional flotation to the station, and installed a hard dome cover to protect the instrumentation from ice and snow build-up (Figure 9; Panels E and F). On re-deployment, crews confirmed that the station and mooring were shallow enough to have sufficient scope to self-adjust to future changes in water level.

Figure 8: Barometric pressure measured by the TDG station in relation to calculated barometric pressure at the station and total river discharge (Station 07FA004) from 17 August to 12 December 2022. Green vertical bar indicated the dates that service visits were conducted at the station.

Figure 9: TDG station at Stn_112.5L without its fabric cover (A), water-damaged power supply (B), biofouling of station buoy, instrument tube, and TDG probe (C and D), new acrylic dome cover (E), and the deployed station after servicing (F).

From 19 to 25 November, the station functioned with no apparent issues. On 26 November, the probe's barometric pressure deviated from the estimated barometric pressure, which was assumed to be due to submersion of the station and saturation of the probe's air reference desiccant filter (see Figure 8). As the increase in total river discharge on 26 November was only 200 m^3/s, from approximately 1,300 to 1,500 m^3/s, water level elevation at the station did not change substantially and it was suspected that debris accumulation on the station contributed to the sensor failure.

During an opportunistic site visit on 15 December to inspect the station and deploy a trail camera to monitor the station, crews noted a substantial amount of ice formation on the station's acrylic dome (Figure 10; Panel A). The field crew was not equipped to retrieve the station and decided against attempting to remove the ice and risk damage to the dome. By 21 December, extreme cold resulted in the continued build-up of ice, which added weight and drag to the station. The additional weight, combined with increased total river discharge that approached 2,000 m^3/s, likely resulted in more frequent submersions of the station. Subsequent review of the trail camera imagery recorded on 21 December confirmed the presence of large chunks of ice floating through the TDG monitoring site (Figure 10; Panel B). From 21 to 26 December, the station experienced several periods of poor satellite connectivity when the station failed to upload hourly data. During this time, demand on the power supply increased and battery voltage dropped due to the continual reconnection attempts by the DCP, combined with the extreme cold. On 27 December, satellite connectivity was intermittent and all communication with the station was lost.

On 6 January 2023, air temperatures increased enough to facilitate recovery of the station. When the crew arrived on site, they noted that the acrylic dome cover was missing and that the station was covered in a layer of ice that had to be removed before the station could be lifted into the boat (Figure 10; Panel C). Once recovered, the crew noted that the air reference desiccant was saturated, and that the power supply had snapped free of its base and was missing (Figure 10; Panel D). The base of the stainless-steel instrument tube was bent at an approximately 15° angle and the stainless-steel mounting plate on the buoy was bent and had a slight buckle. The TDG probe itself was undamaged (Figure 10; Panel E and F). Moisture was evident inside the water-proof canister that housed the GolderWatch™ and satellite modem of the DCP. This moisture likely seeped into the cannister through a damaged electronic connector (Figure 10; Panel G). Based on the above evidence, the eventual failure of the station was attributed to a combination of frequent submersion to depth due to ice build-up and physical damage to station components due to floating ice that collided with the station.

Figure 10: TDG station at Stn_112.5L with ice build-up on its dome cover (A), ice floating through the monitoring site on 21 December (B), the station without its dome cover and encased in ice on 6 January (C), damage to the topside station components (D and E), the TDG probe with biofouling (F), and moisture inside the DCP cannister (G).

4.3 Lessons Learned

The 2022 feasibility study successfully collected a continuous record of TDG downstream of the Project from 17 August to 27 December. Throughout the monitoring period, the TDG station required only one maintenance service and the Solu-Blu TDG probe remained responsive and reported credible TDG data over the entire monitoring period without requiring calibration. The DCP reliably recorded and remotely transmitted all data to a cloud-based server, effectively eliminating the risk of onboard data loss. The DCP through GoldConnect provided real-time access to the data, diagnosed station performance, and sent email alerts if certain critical thresholds were exceeded. Due to the low maintenance requirement of the station design, substantial cost savings were realized compared to systems that require more maintenance (e.g., more power requiring more frequent battery replacements), more frequent calibrations (e.g., silastic membrane-style TDG monitors), or onsite data downloads.

Despite these successes, the study results indicated that a surface-buoy style station was not appropriate for all-season TDG monitoring in the Peace River. Use of the Pro-Oceanus TDG probe as a portable meter for spot measurements was complicated by the two-hour acclimation period required for the probe to achieve equilibrium when first deployed. Another possible factor that potentially affected TDG measurements, if only temporarily, was when the Solu-Blu TDG probe was deployed in a vertical-orientation, in either a station or portable configuration, air bubbles potentially can accumulation on the TDG sensor. Based on a review of data collected, and issues that arose during the study, the following “lessons learned” were identified:

- The TDG station buoy used in 2022 was undersized and had insufficient flotation when the station was fully assembled. Additional flotation was added to keep the TDG station electronic components above the water surface.
    - Selection of a larger buoy offered by the manufacturer would have provided more flotation, potentially preventing submersion, provided more “free-board” to better protect water-sensitive components, and eliminated the need to install additional flotation around the instrument tube.
- Single O-ring containers and double O-ring containers did not adequately protect the electronic components from water damage during submersion.
    - All electronic components should be housed in double O-ring waterproof containers that meet IPX8[1] standards (i.e., fully waterproof) for immersion. Although submersion of the station is ideally avoided, should it occur, electronic components that are deployed in IPX8 housings would be less likely to be damaged.
- The substantial daily and seasonal fluctuations in Peace River discharge were anticipated; however, designing and deploying a self-adjusting mooring system that kept the TDG station centered in a dynamic eddy was challenging, given the limited number of suitable candidate sites. Although the mooring and station initially performed well, performance declined when substantial flow changes occurred later in the study. The mooring was deployed and adjusted based on hydraulic conditions present at the time of deployment. As the full range of fluvial dynamics at the site were not known, more frequent adjustments of the mooring were required to keep the station positioned at an optimal location within the site.

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[1] International Electrotechnical Commission (IEC) https://www.audioreputation.com/ipx8/

  - The buoy-based TDG station is best suited for locations with low water velocity or deep-water sites (e.g., the Site C forebay) where deployment of a TDG probe on the river bottom is not an option.
  - If deployed at riverine locations with moderate to high water velocity, a buoy-based TDG station should be equipped with additional flotation and the station will initially require more frequent site service visits to assess station function over a range of flow levels.
- The amount of floating woody debris and ice on the Peace River, and the associated risk of displacement and damage to the station due to their presence, was underestimated.
  - A buoy-based TDG station is not appropriate at locations with high debris loading.
  - A buoy-based TDG station should be removed prior to winter flow conditions to avoid damage from river ice.
- Minor bio-fouling of the station's TDG membrane was evident during servicing and when the probe was inspected after the station was removed. The risk that bio-fouling affected TDG readings was considered low given turbidity levels of the Peace River, the depth that the station probe was deployed, and the enclosure of the probe in an instrument tube (which provided shading). The effect of biofouling on TDG readings was assumed minimal but this assumption should be confirmed.
  - Stations should be inspected monthly and readings from the station should be compared to portable TDG meters. If the readings between meters differ, and the station's probe has biofouling, it should be cleaned and additional measurements should be taken to determine if the difference in TDG was due to bio-fouling.
  - In future monitoring efforts, spare TDG membranes should be obtained and field crews should replace membranes in the event excessive bio-fouling or a damaged TDG membrane is noted during servicing.
  - Installation of a shade cover to limit light and algal growth could be explored.
- Discrepancies in readings between the station and portable TDG meters were subsequently attributed to the extended time required for the Pro-Oceanus TDG sensor to reach equilibrium after being deployed. A failure to allow a sufficient amount of time (i.e., approximately 2 hours) for the portable TDG meters to equalize before recording TDG values resulted in spurious readings.
  - Use of the Pro-Oceanus Solu-Blu TDG probe as portable units to conduct quality assurance checks will require portables be deployed for at least two hours prior to recording data. This could be accomplished through the temporary deployment of portable probes in conjunction with other task to efficiently make use of the time between deployment and when the reading is taken.
- When the Solu-Blu probe is deployed vertically with the sensor oriented downward, either in the station instrument tube or portable probes deployed vertically from the side of a boat, the manufacturer identifies a potential risk that air bubbles may accumulate on the TDG membrane's surface. Although bubbles forming or becoming trapped on the Solu-Blu TDG membrane was not observed, and the issue was considered unlikely, probe orientation was identified as a possible source of measurement uncertainty. The following quality assurance recommendations were identified for future study years:

- Pro-Oceanus probes deployed in stations or used as portable meters should be deployed with the sensor oriented upward, or at an angle, to eliminate the risk of bubbles accumulating on the TDG sensor's membrane.

Due to winter conditions, all-season TDG monitoring on the Peace River will require TDG stations with a more robust design than the buoy-based station deployed in 2022. One option is to deploy the station TDG probe on the river bottom in a weighted housing, with the probe cable protected by a length of armored conduit connected to a shore-based topside box that contains the station DCP and power supply. Due to upstream disturbance of river sediments by Project construction activities, sediment movement and the amount of sediment load carried by the Peace River will likely be high in the years immediately after Project commissioning as the river adjusts to a new hydraulic regime. Consequently, a bottom-deployed TDG station will have to be designed to not accumulate sediment and keep the TDG probe above the river bottom to avoid abrasion by suspended sediment and river ice.

5.0 CLOSURE

The 2022 feasibility study provided substantial insight into the challenges of all-season monitoring of TDG on the Peace River. Lessons learned can be used for the design, deployment, and servicing of stations as part of a long-term TDG monitoring program for the Peace River upstream and downstream of the Project. We trust that this report meets BC Hydro's expectations. Please contact the undersigned with any questions.

WSP Canada Inc.

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Dustin Ford
Senior Fisheries Biologist

PG/DF/jts/cmc

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