KOOTENAY RIVER
TOTAL GAS PRESSURE MONITORING

1999 INVESTIGATIONS

- DATA REPORT -

Prepared for

COLUMBIA RIVER INTEGRATED ENVIRONMENTAL MONITORING PROGRAM
Nelson, B.C.

by

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1.0 INTRODUCTION

Hydroelectric development on the lower Kootenay River, between Kootenay Lake and the confluence with the Columbia River, has been an ongoing process for over 100 years. The first dam on the Kootenay River, the Lower Bonnington Dam, was constructed in 1897 at Bonnington Falls. In 1908, the Upper Bonnington Dam and Nelson powerplant were constructed at the upstream end of Bonnington Falls to provide power to the city of Nelson and other developing communities. Three more dams were constructed between WW I and WW II: the South Slocan Plant in 1928, Corra Linn Dam in 1932, and Brilliant Dam in 1944. The most recent largescale hydroelectric project was the construction of the Kootenay Canal powerplant in 1975, where a canal was excavated between the Corra Linn Dam forebay and the Kootenay Canal powerplant, located approximately 4.5 km downstream near the tailrace of the South Slocan Plant.

The amount of total discharge through the hydroelectric facilities on the lower Kootenay River is hydraulically constrained by the Grohman Narrows and dependent on inflows regulated primarily from the Duncan and Libby dams. Kootenay Lake elevations fluctuate between a minimum of 1739.32 ft and a maximum of 1745.32 ft in accordance to an elevation rule curve established in 1938 by the International Joint Commission. Total discharge of the Kootenay Lake is typically lowest in April and peaks near mid-July. Average maximum seasonal discharge is approximately 3000 m^3/s (BC Hydro 1998).

From Grohman Narrows, water enters the Corra Linn Dam forebay and either flows through Corra Linn Dam or the Kootenay Canal powerplant via the intake canal located on the south side of the forebay. Maximum turbine capacity of the Corra Linn Dam powerplant and the Kootenay Canal powerplant are 354 and 821 m^3/s, respectively. When discharge levels in the river exceed the turbine capacity of both powerplants, all excess water is released over Corra Linn Dam via spillways. This discharge then flows downstream through Upper Bonnington, Lower Bonnington, and the South Slocan Plant. All three of these dams have incorporated parts of the original Bonnington Falls as auxillary spillways to handle excess discharge. Maximum turbine capacity of Upper Bonnington, Lower Bonnington, and the South Slocan Plant is 363, 269, and 306 m^3/s, respectively. When discharge exceeds maximum turbine capacity, additional discharge is released either through spillways, as unregulated flow over the falls, or both. The City of Nelson powerplant, located near Upper Bonnington Dam, does not have spillways and has a maximum turbine capacity of 84 m^3/s. The Slocan River enters the lower Kootenay River below South Slocan Dam and upstream of Brilliant Dam, the lowermost dam on the Kootenay River. At Brilliant Dam, eight spillways are available to release water when total discharge of the Kootenay River exceeds the 510 m^3/s turbine capacity of Brilliant powerplant.

When spillways are used to release excess flow, the total dissolved gas pressure of the water may be increased through the entrainment of air into the water. Total dissolved gas pressure (TGP) is defined as the sum of the partial pressures of all dissolved gas in solution. As water plunges to depth in the stilling basin below a dam, air carried within the water column is compressed and forced into solution. The amount of gas entrained will depend primarily on the design of the spillway. Spillways constructed with flip buckets, that tend to dissipate water energy, produce less TGP than spillways that allow water to directly plunge into the stilling basin. When the TGP of the water exceeds that of atmosphere, the dissolved gas content of the water is defined as supersaturated.

The absolute difference between dissolved gas and atmospheric pressure will determine the degree to which aquatic life will be adversely affected. Fish that are subjected to high levels of supersaturation may develop gas bubble trauma (GBT). Gas bubble trauma is typically characterized by the formation of air bubbles within tissues and body fluids that can result in a blockage of the circulatory system, overinflation of the swim bladder, sub-dermal lesions, and extracorporeal bubble formation. Secondary consequences of elevated TGP levels may include impaired locomotion, increased predation, and an increased susceptibility to bacterial, viral, and fungal infection (Fidler and Miller 1997).

The Columbia River Integrated Environmental Monitoring Program (CRIEMP) committee decided during the winter of 1998-1999 to undertake TGP monitoring in selected areas of the Columbia River basin in Canada. R.L. & L. Environmental Services Ltd. was contracted to conduct a monitoring program on the lower Kootenay River. The objective of this program was to identify the sources of TGP by continuous monitoring below all suspected TGP producing sites on the lower Kootenay River during low, medium, and high flow periods. Additional sites were spot monitored to include some extra sites of interest and provide QA/QC checks on the continuous monitoring sites.

2.0 METHODS

2.1 STUDY SITE LOCATIONS

Prior to commencement of monitoring, a reconnaissance survey was performed on 31 March 1999, to locate sample sites that would accurately represent TGP production at each facility. A combination of visual assessments of flow patterns and spot TGP measurements was used to select the sample site locations. To ensure TGP uniformity within the Corra Linn Dam forebay, spot TGP measurements were obtained near the left bank, mid-channel, and right upstream banks. During low discharge conditions, identical levels of dissolved gas were measured throughout the Corra Linn forebay. A similar test conducted in the tailrace of Brilliant Dam also confirmed that spill and generation discharge were completely mixed at the proposed monitoring location. These measurements were reconfirmed at both moderate and high discharge conditions.

The Kootenay River monitoring program consisted of temporary and permanent monitoring stations as well as spot TGP measurements. TGP production from all of the hydroelectric facilities located on the lower Kootenay River was continuously monitored over three sessions (13 to 16 April, 14 to 22 June, and 5 to 9 July 1999), selected to represent periods of low, high, and moderate discharge regimes. For each monitoring session, up to five temporary TGP monitoring stations were installed between the Upper Bonnington Dam forebay and the confluence of the Kootenay and Slocan rivers at the following locations (Figure 2.1):

- Slocan - Kootenay confluence (April);
- Slocan Pool (June and July);
- Kootenay Canal tailrace;
- South Slocan Plant forebay;
- Lower Bonnington forebay; and
- Upper Bonnington forebay.

During the first monitoring session (13 to 16 April), temporary stations were installed 100 m upstream of the Slocan-Kootenay confluence, and at the Kootenay Canal tailrace, South Slocan Plant forebay, and Lower Bonnington forebay. Due to a lack of monitoring equipment during the first monitoring session, TGP data was collected from a fifth station, located in the forebay of Upper Bonnington Dam, only during the June and July monitoring sessions. During subsequent monitoring sessions, elevated water levels required the relocation of the Slocan-Kootenay confluence station to a new location 3.0 km upstream in an area locally known as Slocan Pool. All other temporary monitoring locations remained constant throughout the survey.

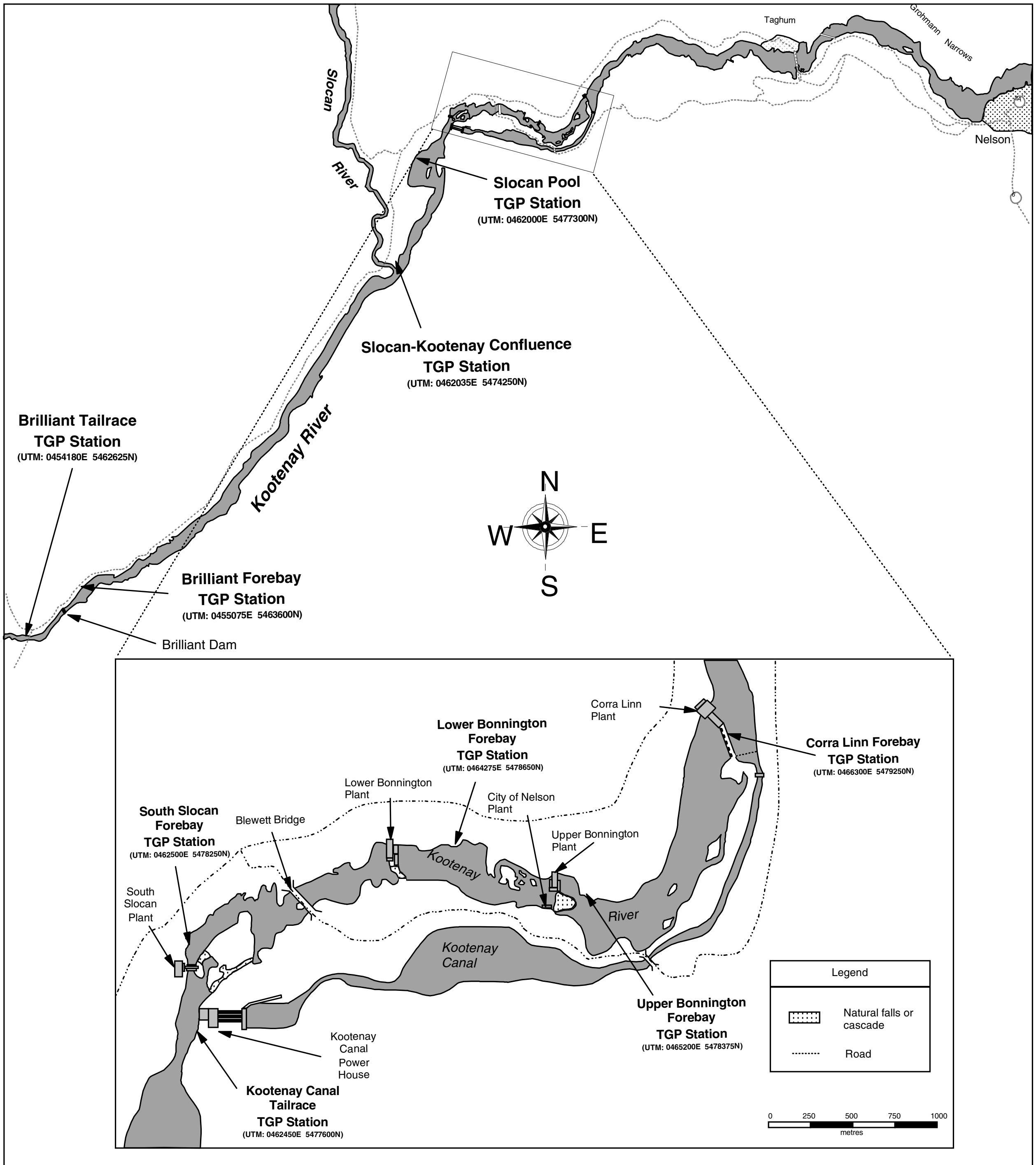

Figure 2.1

Location of the Lower Kootenay River TGP Monitoring Stations, 1999

R.L. & L. Environmental Services Ltd.

Kootenay River TGP levels were also continuously monitored at permanent stations established at the Brilliant Dam forebay and tailrace from early April to mid-September. An additional permanent station was established at the outlet of Kootenay Lake in the Corra Linn forebay in early April and was continuously operated until 10 November 1999. UTM coordinates of all monitoring locations on the Kootenay River used in the 1999 investigations are provided in Table 2.1.

Table 2.1 The UTM coordinates of permanent, temporary, and spot measurement TGP monitoring locations on the Kootenay River, 8 April to 10 November 1999.

Monitoring Location	UTM Coordinate	
	Easting	Northing
Permanent Stations		
Brilliant Dam tailrace	454180	5462625
Brilliant Dam forebay	455075	5463600
Corra Linn forebay	466300	5479250
Temporary Stations		
Slocan Pool	462000	5477300
Slocan-Kootenay Confluence	462035	5474250
Kootenay Canal tailrace (d/s)	462450	5477600
South Slocan Plant forebay	462500	5478250
Lower Bonnington forebay	464275	5478650
Spot Measurement Stations		
Slocan River	461600	5474075
Kootenay Canal tailrace (u/s)	462550	5477875
South Slocan Plant tailrace	462400	5477880
Blewett Bridge (right upstream bank)	463300	5478400
Upper Bonnington tailrace	464900	5478450
Nelson plant tailrace	464825	5478300
Upper Bonnington forebay	465200	5478375
Kootenay Canal Intake	466475	5479025
Corra Linn forebay (left upstream bank)	466150	5479575

All permanent monitoring stations were housed in weather resistant metal cabinets. At locations where security was a concern, a lockable heavy duty galvanized steel or aluminum box was used to house the monitoring equipment. Both the Corra Linn and Brilliant forebay stations were located within locked compounds and required minimal additional protection. At the Brilliant tailrace station, which was located in a high traffic area frequented by anglers and the general public, the monitoring equipment was housed in a galvanized metal, weatherproof box. The probe cable ran from the weatherproof box to a metal standpipe protected by a 4 m length of armoured flex conduit. The standpipe consisted of a 11 m length of heavy steel pipe (1/4 inch wall thickness) anchored to the bedrock bank with 1/2 inch diameter rock bolts. A lockable breakout box constructed of ¼ inch steel plate was attached to the top of the standpipe allowed the probe to be removed for servicing. Unfortunately, high flows during the month of May damaged the standpipe and rendered it unusable. A second Brilliant tailrace station was constructed approximately 50 m downstream in a more sheltered location. The new station, however, was prone to vandalism (i.e., the standpipe and breakout box were constructed from ABS pipe and fiberglass). Spot TGP measurements were used to confirm that TGP levels at the new station were identical to measurements recorded at the old station.

Temporary stations were located in isolated locations and required minimal protection. When a temporary station was established, monitoring equipment was double wrapped in plastic bags and positioned so that the monitoring station would be hidden from sight. Where security was a concern, an aluminum weatherproof box was used to house the monitoring equipment. In monitoring locations with high water velocities, a wire cage was used to protect the probe.

2.2 MONITORING EQUIPMENT

Due to the large amount of equipment required to perform a TGP monitoring program of this intensity, a variety of TGP meters and loggers were supplied by the CRIEMP participants. This resulted in the use of four different types of TGP meters and download protocols in order to successfully collect data over each monitoring session. The monitoring equipment used included two Common Sensing Inc. TBO-F units with external Onset DL3 data loggers, three Common Sensing TBO-F(DL) units with internal Onset DL3 data loggers, three TBO-DL units manufactured by collaboration between Point Four Systems Inc and Common Sensing, one Hydrolab Minisonde, and one Novatek portable meter. With the exception of the Novatek and Minisonde unit, all monitoring equipment are capable of measuring and recording the following parameters:

- barometric pressure or BAR (mm Hg);
- water temperature or T (°C);
- total gas pressure or Pt (mm Hg); and
- dissolved oxygen partial pressure or pO_2 (mm Hg).

During initial meter deployment and point TGP measurements, probes were placed below compensation depth (i.e., approximately 3 to 5 m) to prevent air bubble formation on the silastic membrane and allowed to equilibrate for a minimum of 20 minutes prior to recording a measurement. All continuous data were logged at 10 minute intervals.

The TBO-F style monitoring equipment consisted of a rotary dial to switch between parameters, an LED display, and manual trim pots to allow for calibration. The two TBO-F monitors were older models and used a probe with a different pin connector than the TBO-F(DL) units. The older style probes were not used because they had a shorter cable length (i.e., less than 5 m) and questionable measurement accuracy when compared to the newer probes. The TBO-F units had a secondary probe connector that allowed the use of the newer probes. An external Onset DL3 was used in conjunction with the TBO-F units when logging continuous data. The three TBO-F(DL) units used were similar in design to the

TBO-F units, with the exception that the meter and DL3 logger were combined into a single aluminum case. As with all DL3 loggers, a laptop computer was required to initialize logging and download data from the Onset DL3 logger. All TBO-F and TBO-F(DL) units, when working properly and equiped with a single external battery, could log continuous data at 10 minute intervals for up to 30 days. Two of the TBO-F(DL) units used the logging and download protocol Tattletools Version 1.23; the remaining units used a different protocol called Tattletools Version 2.06b.

The newer TBO-DL monitoring equipment consisted of a waterproof Pelican case that contained the monitor, data logger, and the battery power supply. A digital display and keypad was used to operate and calibrate the meter and activate the data logger. Due to electronic calibration within the probe, data collected with the TBO-DL were highly accurate and less subject to voltage fluctuations associated with older analog probes. As a result, TBO-DL probes were not interchangeable with probes from older TBO-F and TBO-F(DL) units. A digital interface allowed initiation of data logging without the use of a laptop; however, a laptop using the Hyperterminal communication protocol was required to download data. The small memory capacity of the logger limited the maximum logging capacity to approximately 11 days when logging data at 10 minute intervals. The TBO-DL unit also had high rate of power consumption that required external batteries be replaced on a frequent basis and periodic recharge of internal batteries using a 120V AC power supply.

The Minisonde, manufactured by HydroLab Ltd, was a self-contained unit that could monitor a variety of parameters, including dissolved oxygen, temperature, and total dissolved gas. When deployed, the entire unit was submerged beneath the water, which prevented the recording and logging of barometric pressure. As a result, barometric pressure values recorded at stations deployed upstream and downstream were use to estimate barometric pressure at the MiniSonde site. The unit used 4 AA cells that provided power for up to one month. A laptop computer, using the communication protocol Hyperterminal, was required to initiate logging and download data via a 200 ft serial cable attached to the end of the probe. This cable was also used to deploy and retrieve the unit.

A Novatek tensiometer was used as a backup portable meter. The lack of an internal barometer required that the probe sensor be re-calibrated prior to each use to compensate for changes in elevation and barometric pressure. The main drawback with this unit was that the standard 10 foot probe cable supplied with the meter was not long enough to allow the probe to be deployed below compensation depth at the majority of monitoring locations.

2.3 QUALITY CONTROL MEASURES

Spot measurements were conducted during each monitoring session to determine the TGP production of a specific facility or tributary to the Kootenay River. Portable meters were used to investigate mixing assumptions and for cross checking permanent and temporary monitoring stations as a measure of quality control. The following spot measurement locations were sampled during each monitoring session:

- Slocan River;
- South Slocan Plant tailrace;
- Upstream of the Kootenay Canal tailrace;
- Blewett Bridge on the right upstream bank;
- Nelson powerplant tailrace;
- Upper Bonnington tailrace;
- Upper Bonnington forebay (April session only); and
- Kootenay Canal intake.

Typically, TGP measurements at the Blewett Bridge and Kootenay Canal intake station were obtained only on the first day of a session as a measure of quality control to ensure that the temporary and permanent monitoring stations in the vicinity of these spot sample locations accurately represented the TGP production from upstream sources. Another quality control effort involved calibrating the station meters in air prior to deployment. During high flow conditions, all temporary station meters were calibrated in air and at elevated TGP levels in the tailrace of Brilliant Dam as part of a two-point calibration. During sessions in April and July, spot measurements were taken at each station with a portable meter and compared to the permanent or temporary station meter reading prior to removal of the station. The number of spot measurements obtained in June was limited due to the failure of the portable meter.

Permanent stations, located at Corra Linn forebay, Brilliant forebay, and Brilliant tailrace, were serviced bi-weekly. Servicing included downloading data and completing standardized meter calibration and maintenance protocols. After comparing the station meter barometer and total pressure readings against a second calibrated instrument, the station meter was then calibrated to current atmospheric pressure by removing the silastic membrane and exposing the probe to the atmosphere. To ensure accurate TGP readings, the silastic membrane on the station probe was exchanged with a new membrane in order to limit the amount of algal growth on the membrane and to prevent condensation within the membrane. The oxygen sensor of each probe was tested for responsiveness and calibrated and serviced when required. External batteries that powered both Brilliant forebay and tailrace station were changed during each calibration period.

2.4 MONITORING LOGISTICS

The majority of data was successfully collected during the three short-term monitoring sessions. A loss of fours days of Lower Bonnington forebay data during the June session was attributed to a power loss of the Hydrolab MiniSonde data logger because of discharged batteries. Data loss from the Brilliant Dam forebay and tailrace permanent stations also occurred on several occasions and was attributed to either power loss or damage to the station from high flow conditions. The TBO-DL meters used in both stations were unable to operate for sustained periods on external 12 V power supply without periodic recharging of the internal batteries with a 120 V power source. This resulted in the unplanned interruption of data logging even though new external 12 V batteries were installed on a regular basis.

3.0 RESULTS

The acronym TGP (total gas pressure) is equivalent to TDG (total dissolved gas) commonly used in the United States. In this report, TGP is used as a generic descriptive term encompassing all expressions of supersaturated total dissolved gas, including TGP%, TGP% corrected to Sea Level, ΔP, and total dissolved gas pressure in water. The data are plotted and presented as ΔP unless otherwise indicated.

The 1999 summer hydrograph at Brilliant Dam and the time period of the sampling sessions conducted during low, medium, and high discharge periods are illustrated in Figure 3.1. Spill discharge at Brilliant Dam from 1 April to 11 August averaged 946 m^3/s, and varied from a minimum of zero to a maximum of 2361 m^3/s. Generation discharge from Brilliant Dam for the same period averaged 462 m^3/s, with a minimum and maximum discharge of 233 and 546 m^3/s, respectively. Fluctuation in forebay elevation was minimal and maintained an average elevation of 450.1 m. Tailrace elevation was subject to greater fluctuation and averaged 419.3 m, between a minimum of 418.0 m and a maximum of 420.8 m.

3.1 LOW FLOW PERIOD

During the initial sampling period from 13 to 16 April, the only spills in the lower Kootenay River occurred at Brilliant Dam (Figure 3.2). Typically, the amount of discharge from generation was maximized whenever possible during the low flow period; however, the Kootenay Canal powerplant was restricted to less than half (i.e., less than 400 m^3/s) of the maximum discharge capacity.

The lowest TGP readings were recorded at the outlet of Kootenay Lake (Corra Linn forebay), with an average ΔP of 5 mm Hg, and a minimum and maximum of –4 mm Hg and 12 mm Hg, respectively. The shortage of one TGP meter meant that the forebay of Upper Bonnington was not continuously monitored; however, spot measurements of 53, 62, and 68 mm Hg were recorded from the Upper Bonnington forebay over the three day monitoring period. In addition, spot measurements conducted on 5 April recorded elevated TGP levels of 55 mm Hg in the tailrace of Corra Linn Dam. Data from the Lower Bonnington forebay monitoring station also recorded TGP levels of about 50 mm Hg for waters that passed through Upper Bonnington powerplants. This suggests that the Upper Bonnington powerplant does not incrementally increase the TGP of water that passes through the Corra Linn powerplant. The TGP values remained virtually unchanged between the Lower Bonnington forebay and the South Slocan forebay. This indicated that Lower Bonnington powerplant discharge does not increase TGP levels above background TGP levels produced by Corra Linn Dam. Spot TGP readings of 60 and 62 mm Hg measured at the Blewett Bridge on 14 and 15 April corresponded to Lower Bonnington and the South Slocan plant forebay station data for that period. Similarly, spot measurements from the Nelson powerplant tailrace (57 and 63 mm Hg) were nearly identical to measurements from the Upper Bonnington forebay, which indicated minimal effect of the Nelson powerplant turbines on downstream TGP levels.

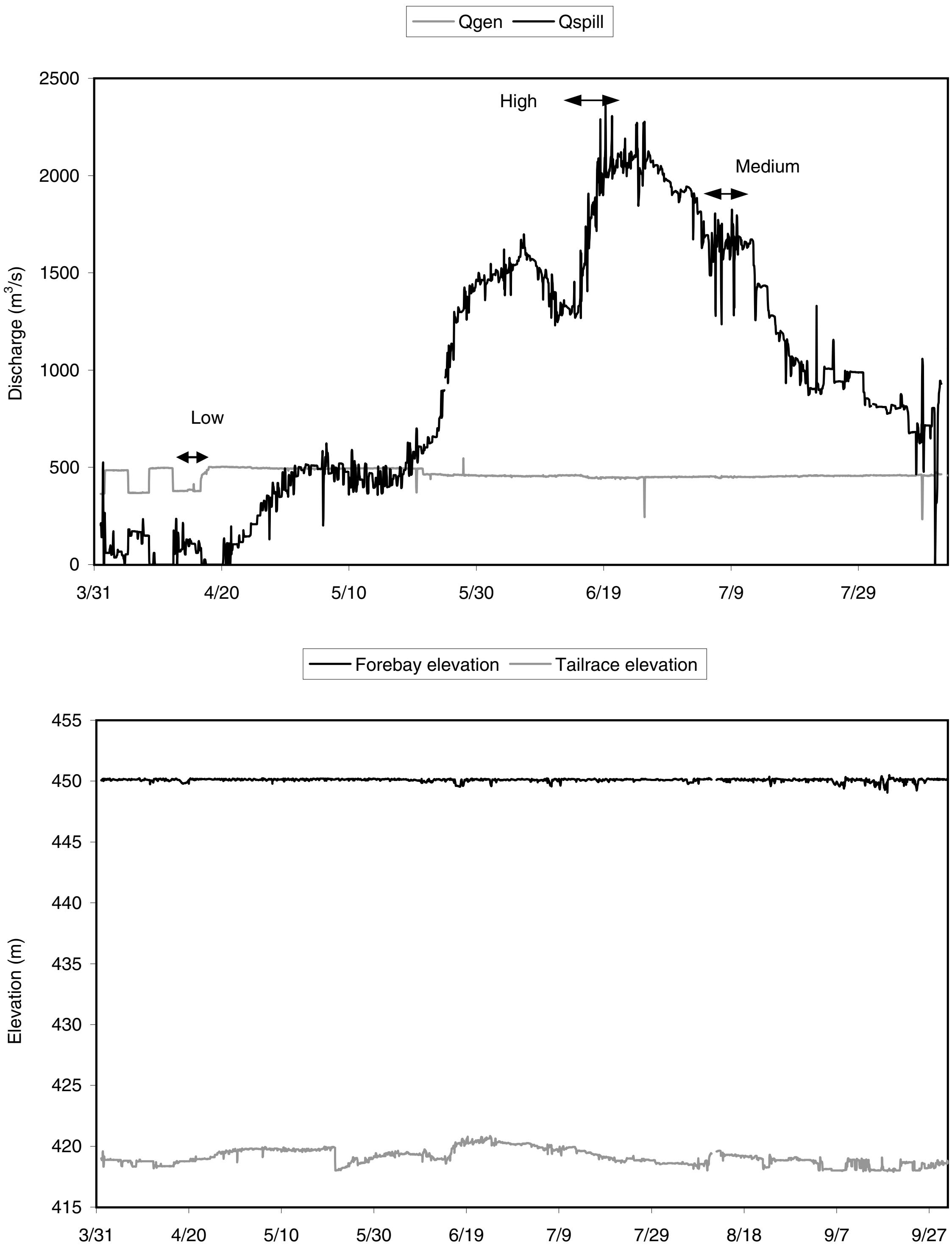

Figure 3.1 A comparison of generation (Qgen), spill (Qspill), forebay elevation, and tailrace elevation from Brilliant Dam, 1 April to 1 October 1999. The timing of low, medium, and high flow monitoring periods is presented in context with the seasonal changes in the hydrograph.

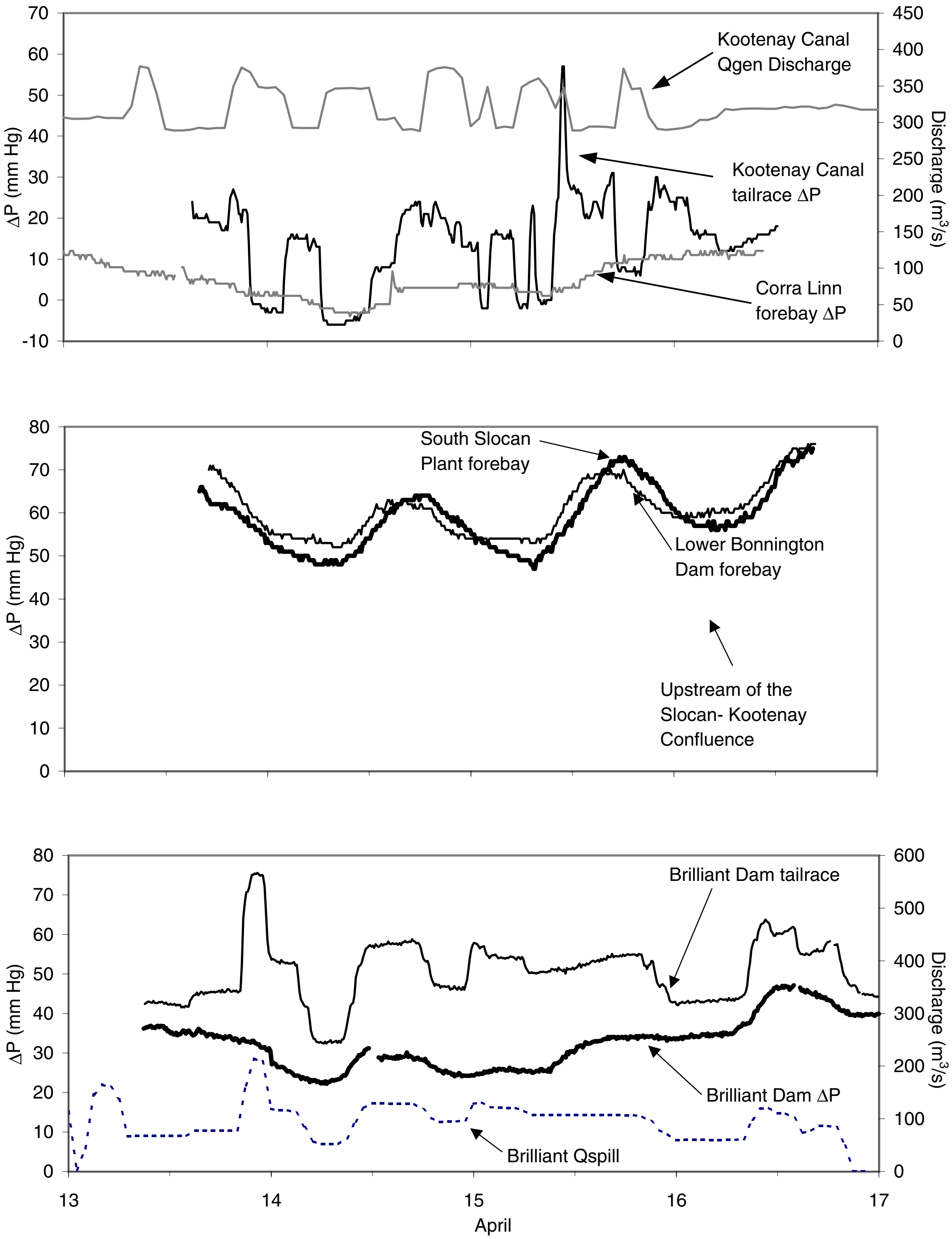

Figure 3.2 The amount of total dissolved gas, expressed as ΔP (ΔP=total gas pressure (Pt) - barometric pressure (BAR)), measured upstream and downstream of hydroelectric facilities located on the Kootenay River, 14 to 17 April 1999. Spill discharge (Qspill) from Brilliant Dam and generation discharge (Qgen) from Kootenay Canal are also presented over this time period.

TGP production from the operation of Kootenay Canal powerplant are indicated by comparison of the Corra Linn forebay data with the Kootenay Canal tailrace. Depending upon the number of units operating, TGP increases were either negligible or were elevated up to about 50 mm Hg. Discharge from Kootenay Canal fluctuated between 300 and 400 m^3/s. Further operational data concerning which units were active during the monitoring period will be required to identify the specific units that increased tailrace TGP. The average ΔP in the Kootenay Canal tailrace was 14 mm Hg, with a minimum of –6 mm Hg and a maximum of 57 mm Hg. On 14, 15, and 16 April, spot measurements obtained from the South Slocan Plant (76, 77 and 95 mm Hg, respectively) generally match concurrent TGP measurements recorded at the South Slocan Plant forebay station.

The next downstream station was located approximately 100 m upstream of the Kootenay-Slocan confluence. The average ΔP value recorded at this station was 35 mm Hg, with a minimum and maximum of 20 and 49 mm Hg, respectively. The TGP values from this site were intermediate between the South Slocan forebay and the Kootenay Canal tailrace which indicated a mixture of these two sources of TGP. Brilliant Dam forebay TGP was similar to the Kootenay-Slocan confluence but was slightly reduced, which reflected dilution from the Slocan River as well as dissipation during downstream transport. Over the three day monitoring period, spot ΔP values of 26, 17, and 33 mm Hg were recorded within the Slocan River. Average ΔP in the Brilliant Dam forebay was 33 mm Hg, with a minimum of 22 mm Hg and a maximum of 47 mm Hg.

Brilliant tailrace TGP readings indicated a highly variable pattern caused by minor spills that resulted from Kootenay Canal operations. Over the monitoring period, spill from Brilliant Dam averaged 94 m^3/s and ranged from 0 to 214 m^3/s. Average ΔP during the monitoring period was 50 mm Hg, with minimum and maximum values of 32 and 76 mm Hg, respectively. During periods without spill, tailrace TGP was essentially identical to the forebay values.

During the low flow monitoring session, tailrace TGP values were usually below the 76 mm Hg ΔP guideline (approximately 110%). This suggested that TGP formation in the lower Kootenay River was not a problem when flows were passed through the various powerplants under the operational conditions present during this monitoring period.

3.2 HIGH FLOW PERIOD

The monitoring of the high flow period occurred between 14 and 22 June. During this sampling period, the Upper Bonnington forebay was also monitored. Powerplants were operating continuously and at or near maximum output during this period. Variations in TGP were related to increased levels of spill that occurred as total Kootenay River discharge increased over the monitoring period (Figure 3.3).

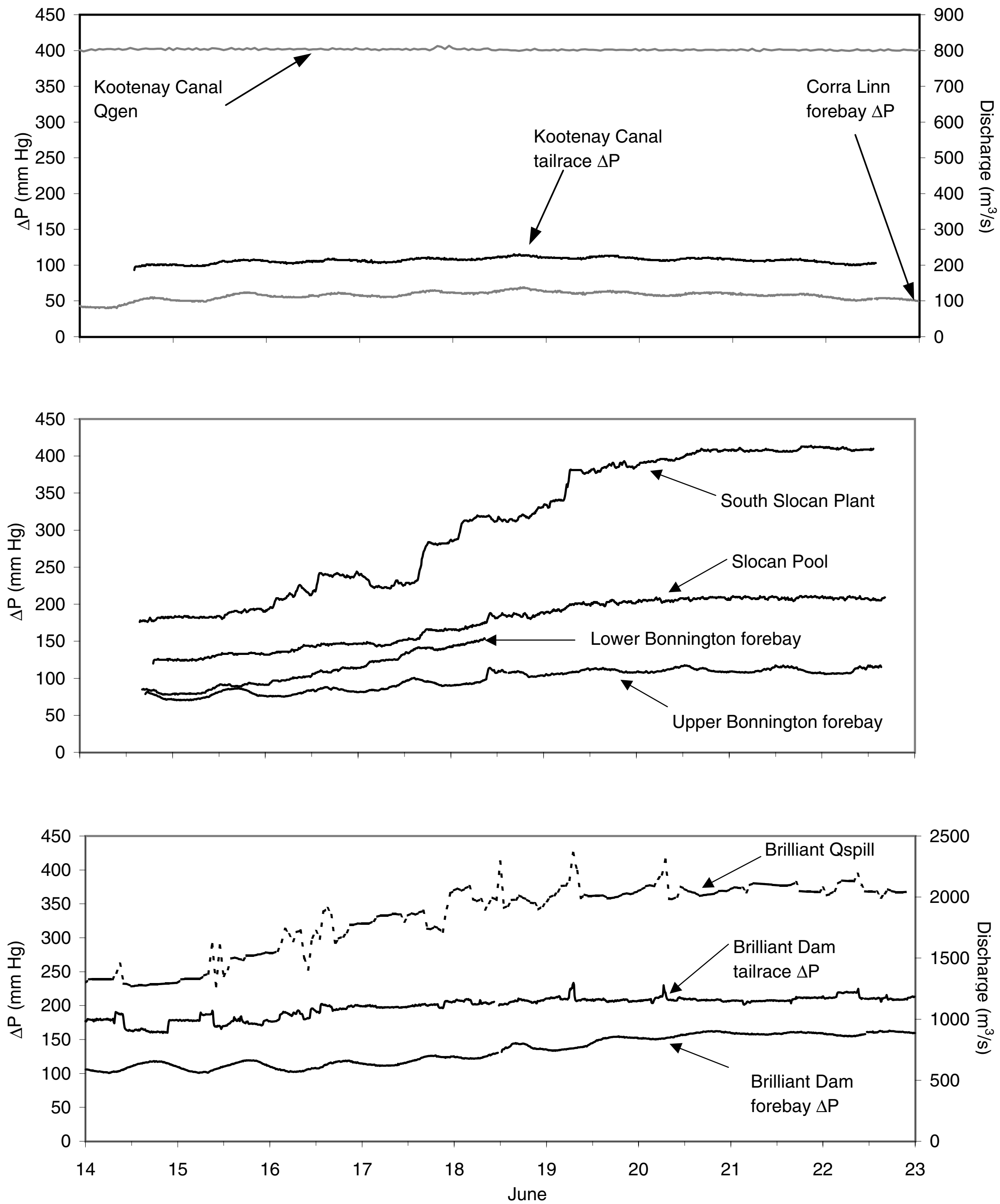

Figure 3.3 The amount of total dissolved gas, expressed as ΔP (ΔP=total gas pressure (Pt) - barometric pressure (BAR)), measured upstream and downstream of hydroelectric facilities located on the Kootenay River, 13 to 22 June 1999. Spill discharge (Qspill) from Brilliant Dam and generation discharge (Qgen) from Kootenay Canal are also presented over this time period.

The Corra Linn forebay exhibited small daily variations of TGP (Figure 3.3). Average Corra Linn forebay ΔP was 57 mm Hg and ranged between 40 and 69 mm Hg. Discharge from Kootenay Canal was maintained at an average output of 803 m^3/s and increased TGP by about 60 mm Hg above Corra Linn forebay TGP levels. Increases in TGP between the Corra Linn Dam forebay and the Upper Bonnington forebay stations were relatively small and ranged between 20 and 60 mm Hg as flow in the Kootenay River increased. Average ΔP in the Upper Bonnington forebay was 98 mm Hg with a minimum of 70 mm Hg and a maximum of 118 mm Hg. Spot measurements from the Nelson powerplant tailrace of 87, 97, and 123 mm Hg were similar to ΔP values recorded in the Upper Bonnington forebay for the same time period.

Due to the failure of the Lower Bonnington forebay meter, an incomplete record was obtained at that site. However, the rate of increase in TGP at that site over time suggested spills at Upper Bonnington resulted in more rapid increases in TGP than spills at Corra Linn, producing an average Lower Bonnington forebay ΔP of 109 mm Hg with a minimum and maximum of 78 and 154 mm Hg, respectively. The most significant source of TGP in the system was created by the spillways at Lower Bonnington Dam, with downstream South Slocan forebay TGP levels approximately 200 mm Hg greater than TGP levels measured in the Lower Bonnington forebay. South Slocan forebay TGP averaged 309 mm Hg and increased from a minimum of 176 mm Hg on 14 June to a maximum of 414 mm Hg (greater than 150%) on 22 June, the highest value recorded during this study. At the Blewett Bridge, spot measurement ΔP readings of 169 mm Hg on 14 June and 234 mm Hg on 17 June confirmed the rapid increase observed in the South Slocan forebay. These high TGP levels were dependent upon spill volume and dropped off quickly when discharge decreased. Previous studies also confirmed that out of all the dams located on the lower Kootenay River, spill discharge over Lower Bonnington Dam produced the highest downstream TGP levels (Clark 1977; Millar et. al. 1996).

During the June monitoring period, the Kootenay-Slocan confluence station was moved further upstream to a new location designated as Slocan Pool. Both of these sites represented a mixture of water (and associated TGP levels) from the Kootenay Canal tailrace, South Slocan tailrace, and the overflow spillways and natural cascades adjacent to the South Slocan and Kootenay Canal power stations (see Figure 2.1). On 15, 16, and 17 June, spot TGP measurements from the South Slocan tailrace (176, 200, and 220 mm Hg, respectively) were identical to South Slocan forebay measurements for the same time period.

The average ΔP value recorded at the Slocan Pool station was 176 mm Hg, with minimum and maximum values of 120 and 211 mm Hg, respectively. Reduced TGP levels at this station were attributed to the dilution of elevated TGP water from the South Slocan Plant and the natural cascade with the less saturated water from the Kootenay Canal tailrace. Brilliant Dam forebay TGP paralleled the values observed at Slocan Pool, but were apparently somewhat reduced through natural dissipation and from dilution with the Slocan River. On 15, 16, and 17 June, spot ΔP values of the Slocan River were 34, 26, and 24 mm Hg, respectively. Over this monitoring period, average Brilliant forebay TGP was 133 mm Hg, with a minimum of 101 mm Hg and maximum of 163 mm Hg. Brilliant tailrace TGP did not show the same increases in TGP at the higher spill rates recorded from 20 to 22 June as would be expected if a constant rate of entrainment of gas by the spillways had occurred. Average Brilliant tailrace TGP was 198 mm Hg, with minimum and maximum values of 160 and 234 mm Hg, respectively. Operations of spillway gates were quite variable during this period of time, and most likely variable gate selection likely resulted in the decreased entrainment rates. Spill from Brilliant Dam averaged 1833 m^3/s with a minimum of 1268 m^3/s and maximum of 2361 m^3/s. Ongoing modelling of individual spillway gas entrainment characteristics by Aspen Applied Sciences Ltd. will provide a clearer explanation of this effect (Aspen Applied Sciences Ltd. 1998).

3.3 MEDIUM FLOW PERIOD

Kootenay River TGP investigations during medium flow conditions were conducted at the beginning of the descending limb of the 1999 hydrograph from 5 to 10 July. Flow was sufficient to allow the majority of power facilities to operate at full capacity during this time. Both controlled and unregulated spill occurred during the monitoring session (Figure 3.4).

During the medium flow monitoring period, an average ΔP of 30 mm Hg was measured within the Corra Linn forebay, with minimum and maximum values of 26 and 50 mm Hg, respectively (Figure 3.4). Spot measurements taken near the Kootenay Canal intake confirmed that the forebay station data was representative of water flowing through both Corra Linn Dam and Kootenay Canal. Within the Kootenay Canal tailrace, ΔP ranged between 39 and 104 mm Hg with an average of 90 mm Hg. During the monitoring session, one of the four turbines at Kootenay Canal was temporarily shut down and this reduced tailrace ΔP by almost 50 mm Hg. Based on the data from the Kootenay Canal tailrace station, the amount of dissolved gas entrained by the Kootenay Canal turbines was approximately 100 mm Hg when all turbine units were operational.

Figure 3.4 illustrates incremental increases in TGP as spill water passes through the system, with Corra Linn Dam, having the smallest incremental affect, followed by somewhat higher increases in TGP as water is spilled at Upper Bonnington Dam. Average ΔP values within the Upper Bonnington forebay were 89 mm Hg, with a minimum of 68 mm Hg and a maximum of 112 mm Hg. Spot ΔP measurements values of 124, 106, and 108 mm Hg from the Nelson powerplant tailrace were higher than expected and may indicate partial mixing of supersaturated water from the Upper Bonnington falls and Nelson powerplant outfall at the sampling site. Lower Bonnington forebay TGP levels averaged 131 mm Hg, with a range of 106 to 197 mm Hg.

The very large increases in ΔP were still apparent from Lower Bonnington spillway operations as illustrated by the high continuously measured TGP levels observed in the South Slocan plant forebay and from spot measurements at Blewett Bridge. Average South Slocan forebay ΔP was 291 mm Hg, with a minimum of 223 mm Hg and maximum of 358 mm Hg, while spot readings at Blewett Bridge on 6 ,7, and 8 July were 296, 254, and 268 mm Hg, respectively. Spot measurements over the same time period from the South Slocan tailrace (246, 264, and 258 mm Hg), again confirmed the elevated TGP levels observed in the South Slocan forebay.

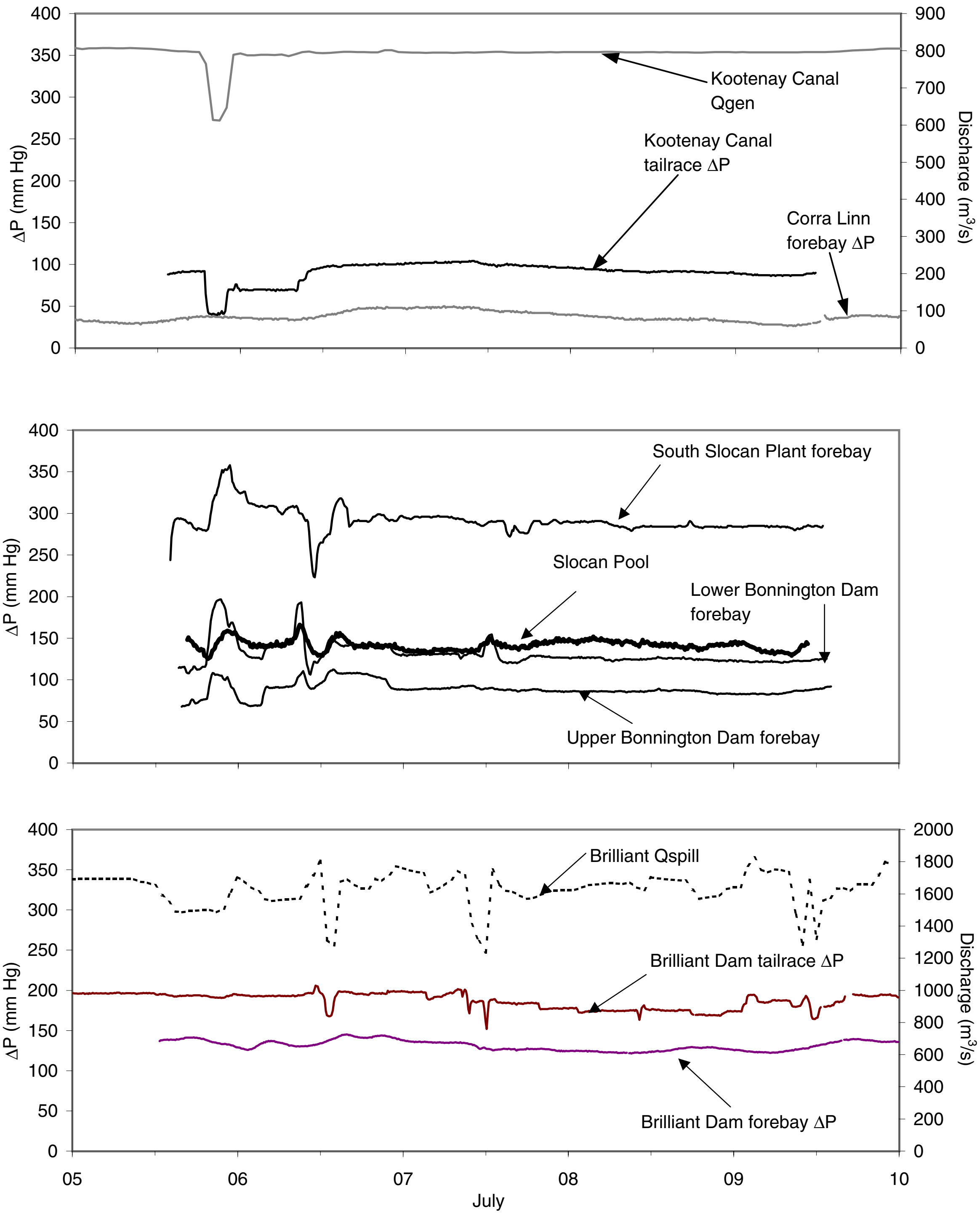

Figure 3.4 The amount of total dissolved gas, expressed as ΔP (ΔP=total gas pressure (Pt) - barometric pressure (BAR)), measured upstream and downstream of hydroelectric facilities located on the Kootenay River, 5 to 10 July 1999. Spill discharge (Qspill) from Brilliant Dam and generation discharge (Qgen) are also presented over this time period.

Data from the Slocan Pool site had an average ΔP of 142 mm Hg, a minimum value of 125 mm Hg, and a maximum of 166 mm Hg. Mixing of discharge from the Kootenay Canal tailrace and discharge and spill from the South Slocan powerplant, resulted in an intermediate value, closer to what would be expected by dilution of the two water sources.

Brilliant Dam forebay TGP again paralleled the TGP values observed at Slocan Pool with similar levels of dissipation and Slocan River dilution as was observed during the high flow sampling period. Spot ΔP measurements from the Slocan River (i.e.,18, 12, and 18 mm Hg) were relatively low compared to the Kootenay River. Dilution of Kootenay River water by the Slocan River and dissipation resulted in an average Brilliant forebay ΔP reading of 131 mm Hg that ranged between 121 and 145 mm Hg. Incremental increases in TGP from spill at Brilliant Dam followed a similar pattern as observed during the high flow sampling period, with Brilliant Dam tailrace ΔP averaging 187 mm Hg. The differences between minimum and maximum ΔP (i.e., 152 and 206 mm Hg, respectively) were likely dependent on the specific spillways used to discharge water from Brilliant Dam. Over the July monitoring period, average spill volume from Brilliant Dam was 1629 m^3/s, with minimum and maximum values of 1235 and 1825 m^3/s.

3.4 LOWER BONNINGTON SPILLWAY ASSESSMENT

In response to the high TGP values measured below Lower Bonnington, a short-term experiment was conducted on 13 July to estimate TGP entrainment through discharge over the natural falls located adjacent to Lower Bonnington powerplant. Tailwater TGP levels prior to closing the spillway gates were 188 mm Hg with a forebay level of 78 mm Hg (i.e., a 110 mm Hg difference). After closure of the spillgates, spill solely over the falls resulted in tailwater TGP values of 133 mm Hg (i.e., 55 mm Hg difference relative to forebay levels). The 133 mm Hg (118.5%) TGP level provides some insight as to TGP levels produced by the natural cascade, and likely reflects the magnitude of TGP concentrations that were present in the lower Kootenay system prior to the development of hydro-power facilities and associated spillways.

3.5 CONTINUOUS MONITORING AT BRILLIANT AND CORRA LINN

The ΔP data from the Brilliant forebay and tailrace, between 1 April and 11 August, are summarized in Figures 3.5 to 3.7. The spillway cumulative gate heights are also depicted to illustrate the large variation in operations of Brilliant Dam that occurred during this sampling period. These data will be used in the development of a spill management plan as part of the Brilliant Upgrade Project. The number of operational days and average weighted gate opening of individual spillways from 1 April to 11 August is summarized in Figure 3.8. Spillways 1 and 7 were used for the longest duration, a total of 114.3 and 63.8 days, respectively. Spillways at Brilliant Dam are raised and lowered with two mobile gantries that can be operated remotely (if dedicated to a single spillway) or manually by the dam operator. During high flows, Spillway gate 1 would be hung in the open position, thus allowing the gantry to be detached and moved into position over Spillway 2, the third most commonly used spillway. In years with average discharge, the combined discharge capacity of Spillways 1, 2 and 7 is usually sufficient to handle the maximum discharge during the spring freshet.

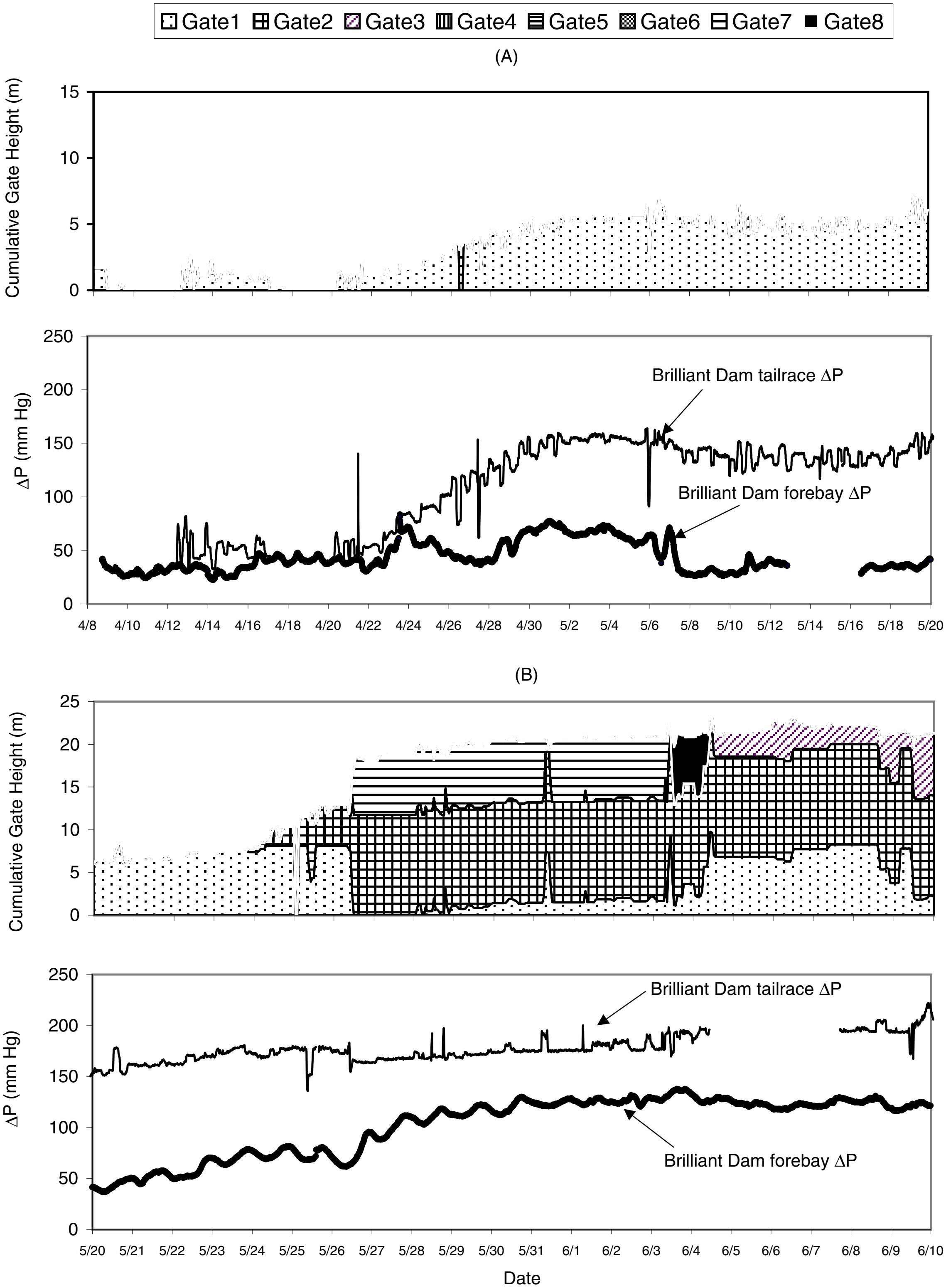

Figure 3.5 The amount of total dissolved gas, expressed as ΔP (ΔP=total gas pressure (Pt) - barometric pressure BAR)), in the forebay and tailrace of Brilliant Dam in relation to total cumulative gate height, 8 April to 20 May 1999 (A) and 20 May to 10 June 1999 (B).

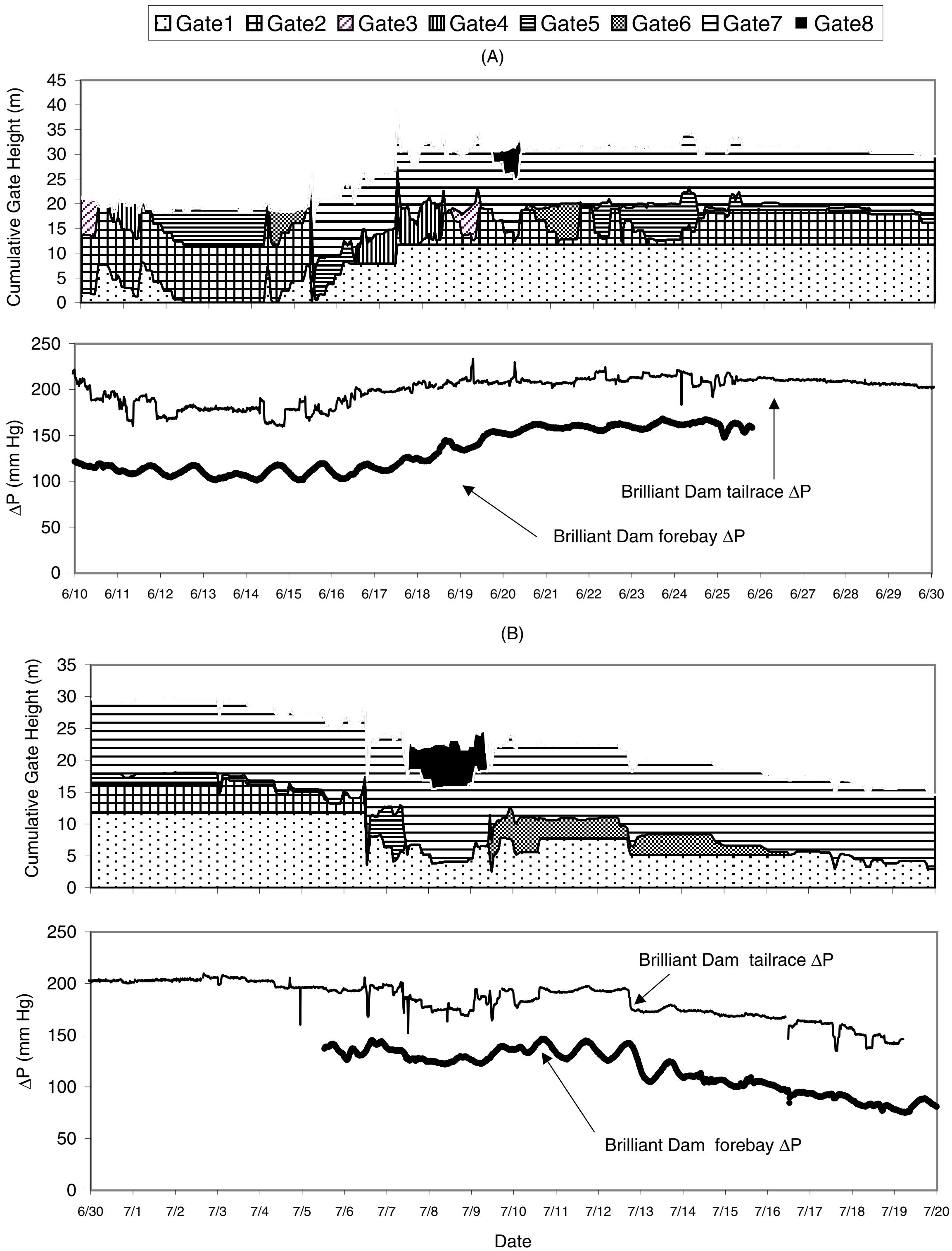

Figure 3.6 The amount of total dissolved gas, expressed as ΔP (ΔP=total gas pressure (Pt) - barometric pressure (BAR)), in the forebay and tailrace of Brilliant Dam in relation to total cumulative gate height, 10 to 30 June 1999 (A) and 30 June to 20 July 1999 (B).

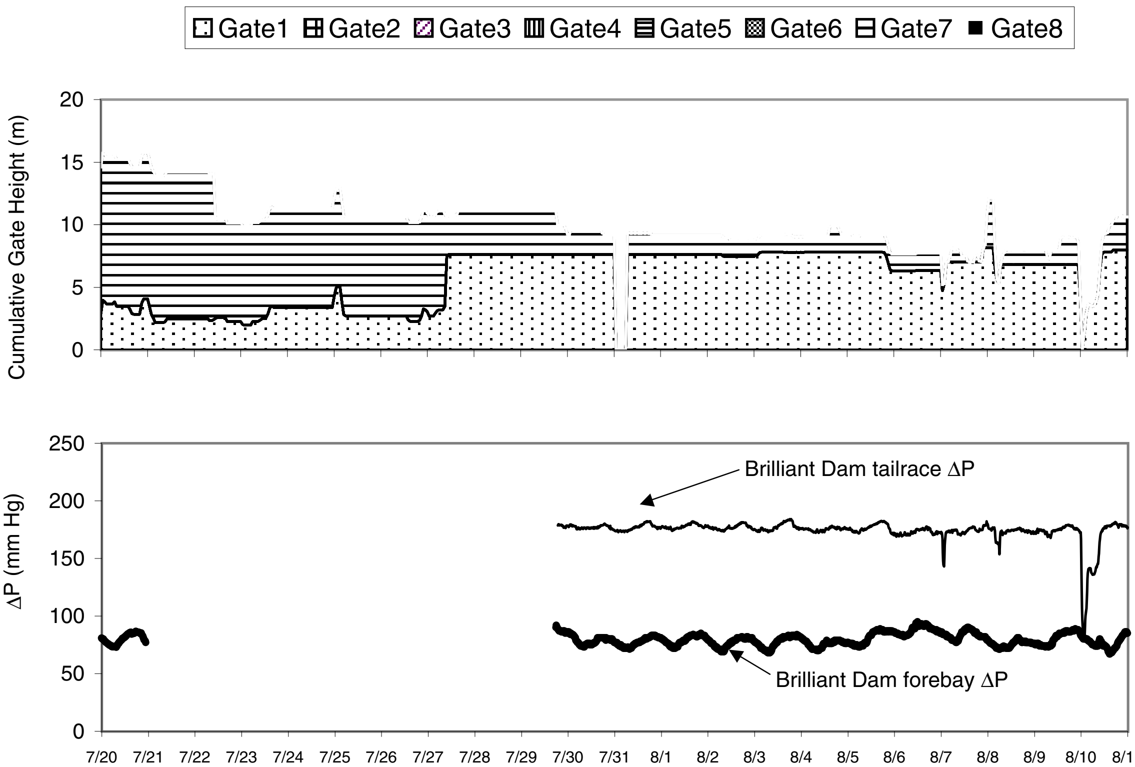

Figure 3.7 The amount of total dissolved gas, expressed as ΔP (ΔP=total gas pressure (Pt) barometric pressure (BAR)), in the forebay and tailrace of Brilliant Dam in relation to total cumulative gate height, 20 July to 11 August 1999.

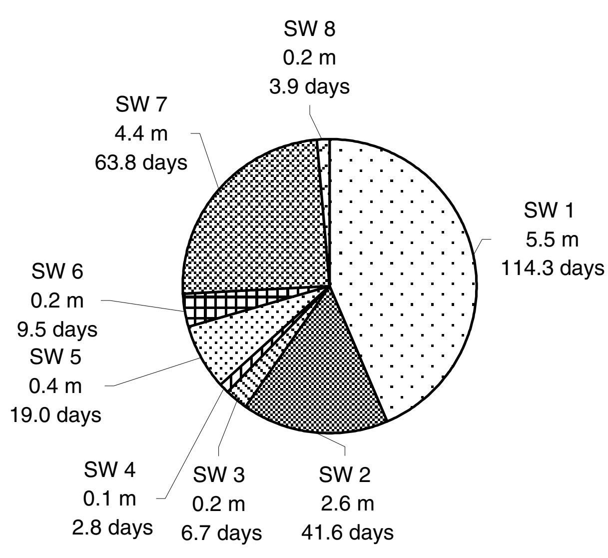

Figure 3.8 The number of operational days and average weighted gate opening of individual spillways (SW) at Brilliant Dam, 1 April to 11 August 1999.

Continuous TGP data from the Corra Linn forebay, Brilliant forebay, and Brilliant tailace from 8 April to 10 November are presented in Figure 3.9. Data were collected from the forebay and tailrace of Brilliant Dam from 8 April to 16 September. After 16 September, spill from Brilliant Dam decreased substantially and, thereafter, only occurred during heavy precipitation events. Monitoring within the Corra Linn forebay continued until 10 November. Average Brilliant forebay and tailrace ΔP levels were 79 and 148 mm Hg, respectively, while Corra Linn forebay ΔP averaged 29 mm Hg.

The measured dissolved oxygen (pO_2) associated with the forebay and tailrace of Brilliant Dam and the forebay of Corra Linn Dam was highly variable and dependent on sufficient water flow (i.e., 5 cm/s) across the oxygen sensor membrane. The velocity of flow within both the Corra Linn and Brilliant forebays was not always sufficient to obtain an accurate pO_2 measurement. Typically, pO_2 levels in the Corra Linn forebay ranged between 119 and 179 mm Hg. Brilliant forebay pO_2 ranged between 140 and 194 mm Hg and Brilliant tailrace pO_2 ranged between 147 and 211 mm Hg. The water temperature for all three stations ranged between a minimum of 5.0°C and a maximum of 18.0°C.

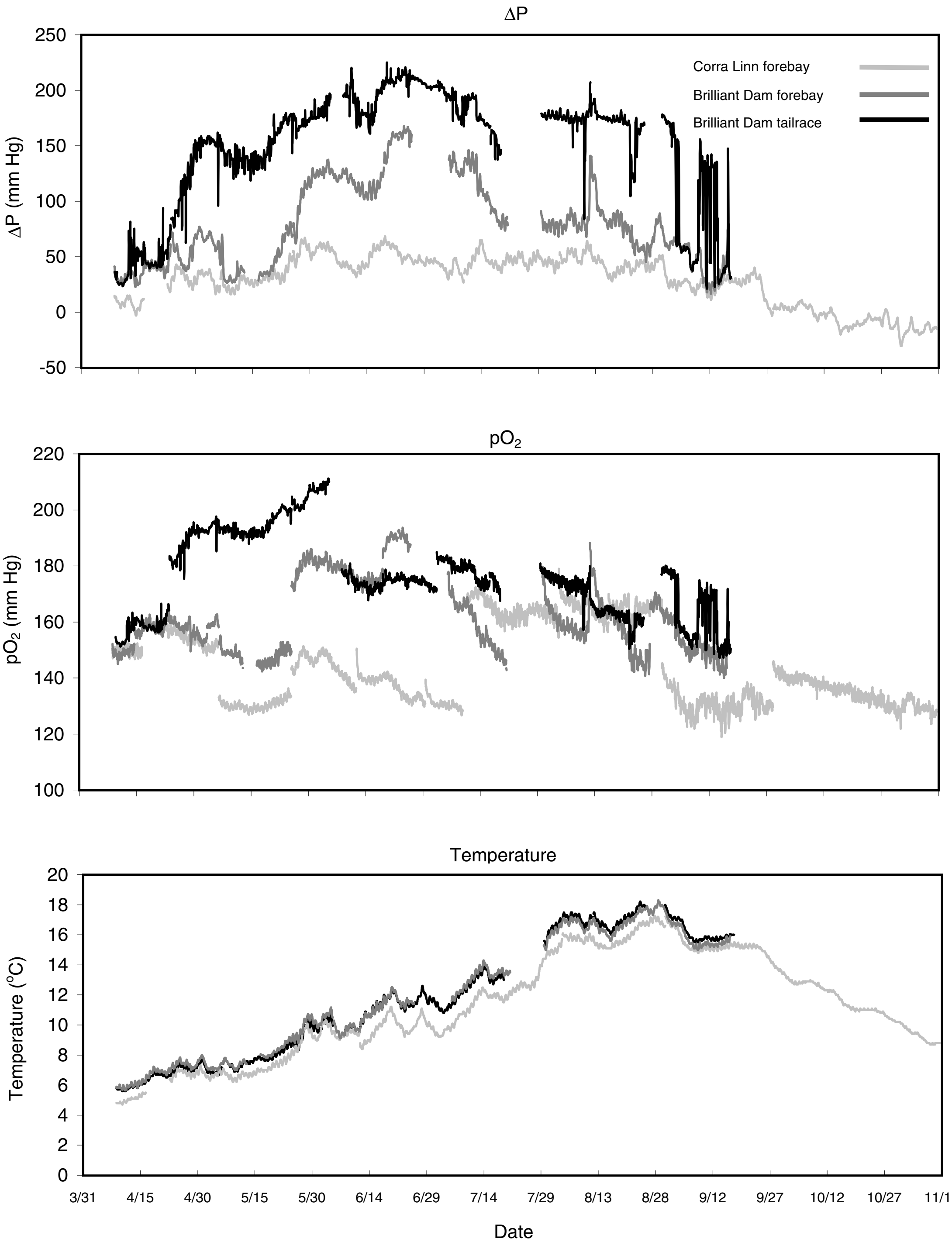

Figure 3.9 A summary of ΔP (ΔP=total gas pressure (Pt) - barometric pressure (BAR)), pO_2 (partial pressure of oxygen), and temperature data from the Corra Linn forebay, Brilliant Dam forebay, and Brilliant Dam tailrace stations, 8 April to 10 November 1999.

4.0 SUMMARY

From this presentation of the time series of the 1999 spring and summer TGP monitoring data, some conclusions can be drawn. TGP levels entering the Kootenay River from Kootenay Lake are generally below the provincial water quality guidelines and provide minimal contribution to the basin TGP load. During low flow periods in April, the majority of discharge from Kootenay Lake is diverted into Kootenay Canal to supply the Kootenay Canal powerplant. A minimum of 142 m^3/s (5000 cfs) must be released through Corra Linn to provide water to downstream hydroelectric facilities on the mainstem Kootenay River and prevent dewatering of the river channel. Generation discharge from Corra Linn Dam in April ranged between 140 and 170 m^3/s. Spill was minimized during the low flow period; however, the combined discharge of Kootenay Canal, Corra Linn Dam, and the Slocan River frequently exceeded the generation discharge capacity of Brilliant Dam which forced spills of excess water at this site. Increases in TGP levels upstream of Brilliant during low flow (non-spill) periods were attributed to minor gas entrainment during power generation at upstream facilities.

During medium and high discharge periods, when total discharge from Kootenay Lake exceeded maximum Kootenay Canal discharge (581 m^3/s), spillways at Corra Linn Dam were used to release excess discharge. Use of spillways at this dam and at all downstream facilities increased TGP, but the major contributions were from the Lower Bonnington Dam and Brilliant Dam spillways. The test at Lower Bonnington between flows over the dam spillways and the natural cascade showed that discharge over the natural falls reduced TGP levels. This spillway operational change reduced TGP, but at the expense of reduced energy generation at the City of Nelson and Upper Bonnington plants because of increased tailwater elevation. Dilution of Lower Bonnington spill by low TGP discharge from Kootenay Canal and the Slocan River reduced the amount TGP measured downstream and reduced the possibility of detrimental effects on fish (i.e., gas bubble trauma). The amount of TGP generated by Kootenay Canal was relatively low when compared to Lower Bonnington; however, based on data from the medium flow monitoring session, all TGP produced by generation at Kootenay Canal appeared to be associated with only one of the four turbines. On 5 July, the suspect turbine was temporarily disengaged, reducing total discharge from approximately 800 to 600 m^3/s. This resulted in a reduction of Kootenay Canal tailrace TGP by approximately 50 mm Hg to a level identical to the Corra Linn forebay. Subsequent re-activation of the turbine, Kootenay Canal tailrace TGP increased to the pre-deactivation level as reservoir head and power production approached maximum capacity on 6 July. The reason for increased production of TGP by this unit is unknown.

A cursory examination of the cumulative gate setting at Brilliant Dam indicated that altering Spillway 1 gate settings produced acute changes in downstream TGP levels. In the absence of discharge from Spillway 1, the effects of manipulating other spillways on the downstream TGP data were more pronounced. Overall, Spillways 6, 7, and 8 appeared to produce less TGP, and when run in conjunction with other spillways, reduced downstream TGP levels through dilution. Spills at Brilliant Dam under the operational characteristics that existed during this study, apparently do not result in TGP increases in the tailrace above a threshold level of about 128% of saturation, even though the volume of spillwater increased. This suggests that at Brilliant Dam, spill management by selective use of spillways will be beneficial in obtaining lower TGP levels.

Further analysis of the monitoring data by Aspen Applied Sciences Ltd. and R.L. & L. as part of the Brilliant Expansion Project should provide a more quantitative analysis as to the contribution of each facility to the TGP burden in the overall system. However, this initial examination of the data provides some insights as to where most gain in TGP abatement is likely to be obtained through either structural or operational changes.

5.0 LITERATURE CITED

Aspen Applied Sciences Ltd. 1998. Analysis of Brilliant Dam 1997 dissolved gas data and recommendations for the 1998 TGP monitoring program. Report prepared for West Kootenay Power, South Slocan, B.C.

BC Hydro. 1998. Brilliant generating station: Brilliant upgrade memorandum on operational impacts. Report prepared for Columbia Power Corporation. Report No. PSE56: 46 p + 9 app.

Clark, M.J.R. 1977. Environmental protection dissolved gas study: data summary–1977. B.C. Ministry of Environment, Pollution Control. Report No. 77-10. 246 p.

Fidler, L.E., and S.B. Miller. 1997. British Columbia water quality guidelines for the protection of aquatic biota from dissolved gas supersaturation - Summary Report. Prepared by Aspen Applied Sciences Limited for the B.C. Ministry of Environment, Lands and Parks, Environment Canada, and Department of Fisheries and Oceans. Vancouver, B.C. 53 pp.

Millar, S.A., G.R. Ash, and C.J. Powell. 1996. Seasonal and operational surveys of total gas pressure production in the Columbia River Basin, 1995. Prepared for BC Hydro, Burnaby, B.C. by R.L. & L. Environmental Services Ltd., Castlegar, B.C. BC Hydro Strategic Fisheries Report No. SFP96-COL-02:108 p. + 6 app.