TOTAL GAS PRESSURE MONITORING AT HUGH L. KEENLEYSIDE DAM

1999 INVESTIGATIONS

- DATA REPORT -

Prepared for

COLUMBIA RIVER INTEGRATED ENVIRONMENTAL MONITORING PROGRAM
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by

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1.0 INTRODUCTION

Hugh L. Keenleyside Dam (HLK) was constructed in 1968 as part of the Columbia River Treaty and is located on the Columbia River 8 km upstream from Castlegar, B.C. The primary role of the dam is to control flooding and regulate flow for downstream hydroelectric facilities located in the United States. The dam is constructed of earth and concrete and contains a navigational lock, four spillways, and eight low level ports. The water held back by the dam forms Arrow Lake Reservoir, which has total storage capacity of 8.8 x 109 m^3 (Millar et al. 1996). Due to the design of discharge structures, water discharged from the dam can become supersaturated with dissolved gas. Potentially, high levels of total gas pressure (TGP) can produce gas bubble trauma (GBT), a disease in fish caused by the formation of nitrogen bubbles in the vascular system (Fidler and Miller 1997). The downstream TGP levels are often elevated when discharge is from the spillways, with lower TGP resulting when discharge is from the dam's low level ports.

Total dissolved gas monitoring on the Columbia River was conducted at the HLK forebay and at the Robson station, located approximately 5.4 km downstream from HLK. Both sites have been used during previous TGP investigations on the lower Columbia River since 1992 (Millar et al. 1996). As part of the 1999 investigations, continuous TGP data were collected from 7 April to 1 November 1999 at the HLK forebay and from 12 May to 1 November 1999 at the Robson station. Monitoring data were also obtained from 3 May to 4 August 1999 at the Department of Environment (DOE) monitoring station on the Columbia River, located 1.4 km upstream of the Columbia and Pend d'Oreille rivers confluence, and from the U.S. Bureau of Reclamation station (CIBW) on the mainstem of the Columbia River, located immediately downstream of the Canada-U.S. border.

Data from this study will be used to further refine existing computer models that are used to predict downstream TGP levels during different operational regimes at HLK (Aspen Applied Sciences Ltd. 1995). The long-term objective of the study is provide information to dam operators, using predictive models based on real time TGP data, so that discharge regimes can be modified in order to minimize downstream TGP levels to the extent possible.

2.0 METHODS

2.1 MONITORING LOCATIONS AND STATION DESIGN

Continuous TGP data were collected in the Columbia River in the HLK forebay and downstream at the Robson station. All Robson TGP data were collected at 10 minute intervals and later summarized at hourly intervals. Data from the HLK forebay, however, were only available in hourly interval format. This difference in resolution did not affect the interpretation of the data to determine the effects of different operational regimes on downstream TGP levels. The location of HLK and Robson monitoring station are shown in Figure 2.1.

The HLK forebay TGP monitoring station was first established in 1991 to measure forebay dissolved gas levels. Subsequent cross-sectional profiles determined that TGP levels were homogenous throughout the forebay and that the forebay monitoring location accurately represented forebay TGP levels. During the 1999 study, the location and design of the forebay monitoring station were identical to previous studies. The probe was mounted in a 4 m long ABS conduit that was fastened on the forebay guide wall approximately 10 m west of the dam face (UTM 444008E 5465751N). The conduit was fitted with a porous end cap that protected the probe within and allowed water to freely exchange across the probe surface. A Common Sensing TBO-F monitor was placed inside the dam control room and connected to the probe by an extension cable. All data collected was downloaded to BC Hydro's Data Collection Platform (DCP) system that transmitted the data on a daily basis to a server in Burnaby. Remote data download by the DCP system reduced the amount of service time required by eliminating the need to have a technician download data on-site with a laptop computer.

The Robson station was located at UTM 448886E 5465017N. The TGP sensor probe entered the water through an entrenched 35 m long standpipe (100 mm diameter ABS pipe) that extended from the shore into the Columbia River. On the distal end of the pipe, a perforated T-end piece was used to seal the end of the pipe, while still allowing water to flow freely across the probe. A breakout box was used to secure the shore end of the standpipe was designed to permit access to the standpipe for sensor probe servicing. A series of 15 mm PVC push rods were used to slide the probe up and down the pipe. Improvements in station security in 1999 included replacing the fibreglass breakout box with a custom metal breakout box. A length of armoured flex-conduit was installed to protect the probe cable connection between the breakout box and the weatherproof cabinet that housed the logger. These improvements reduced the incidence of vandalism and the down time associated with station repair. In 1999, the Robson station was upgraded with a modem, a phone line, and a custom designed data logger to enable instantaneous TGP readings on demand and to remotely download data on a daily basis. Installation of the new custom configured data logger (Campbell Scientific Inc.) and phone line at the Robson station resulted in data being successfully collected over the entire monitoring period. A solar panel was also installed to keep the station power supply fully charged, eliminating the need for external battery power source.

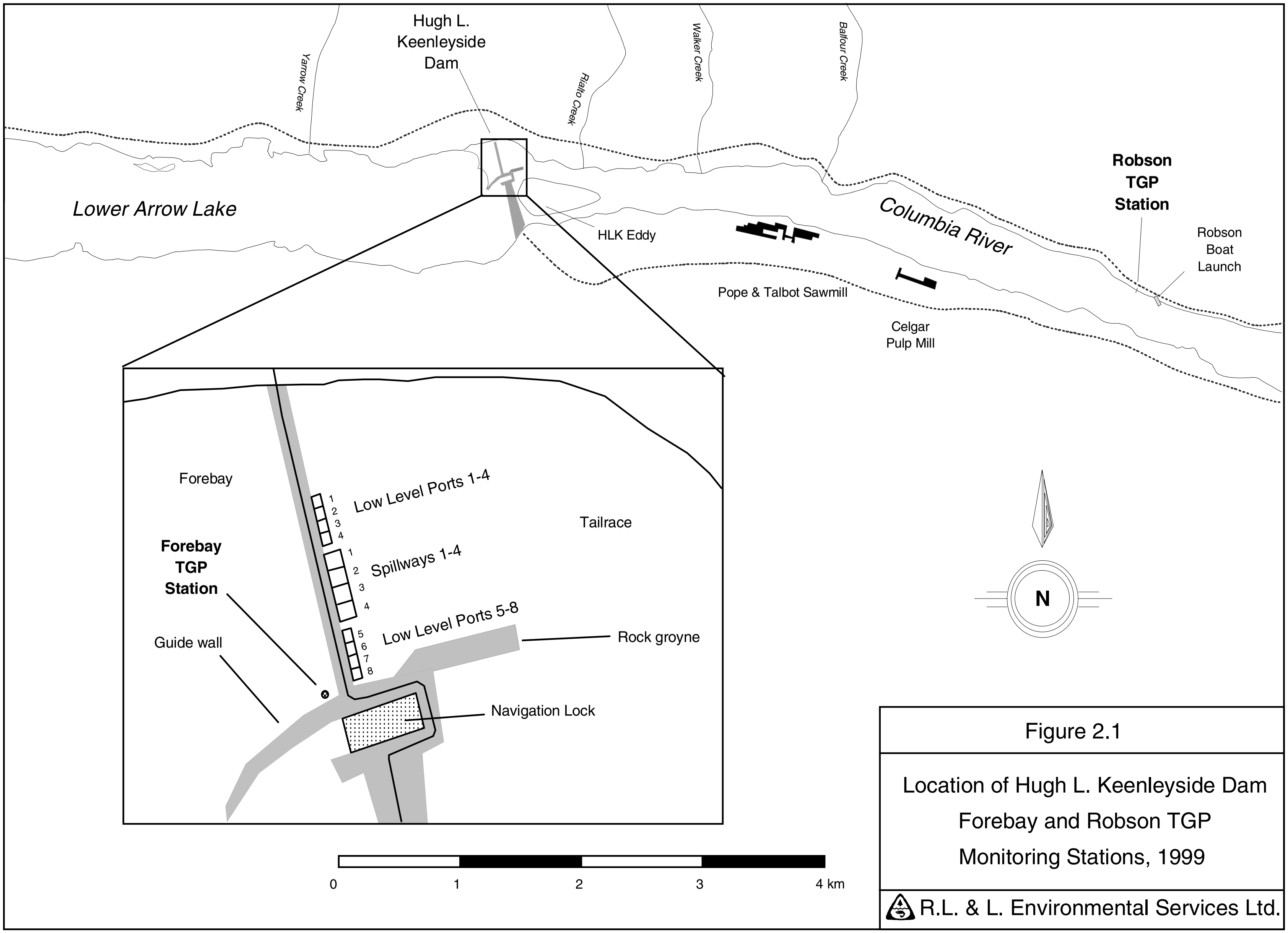

Figure 2.1

Location of Hugh L. Keenleyside Dam Forebay and Robson TGP Monitoring Stations, 1999

R.L. & L. Environmental Services Ltd.

The DOE monitoring station was located approximately 1.4 km upstream of the Pend d'Oreille-Columbia confluence on the right bank (upstream orientation) of the Columbia River This location, being downstream of the Columbia River and Kootenay River confluence, reflected the combined seasonal water quality attributes from each system. The station was operated by DOE but was housed in the Cominco Ltd. water monitoring station facility. Department of Environment technicians were responsible for the calibration of monitoring equipment, data download, and quality control measures.

The CIBW station, maintained by the U.S. Bureau of Reclamation, was located on the mainstem Columbia River just south of the Canada-U.S. border. This station monitored the combined flows from the Columbia, Kootenay, and Pend d'Oreille rivers.

Both the Robson and HLK stations were serviced on a bi-weekly basis from April to November 1999. A typical service visit involved an inspection for damage and the calibration and maintenance of the station probe. 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 from forming within the membrane. Dissolved oxygen partial pressure was measured with a Oxyguard™ galvanic oxygen sensor, that required a minimum water velocity of 5 cm/s across the sensor. The oxygen sensor was regularly tested for responsiveness and serviced when required during each calibration session. A laboratory grade thermometer was used to calibrate the temperature sensor at each station. As water temperature and daylight decreased from September to November, station calibration frequency was reduced to once a month due to decreased algal growth and reduced risk of condensation within the membrane. The following parameters were measured during the monitoring session:

- 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).

From the above measurements, the following parameters were derived:

- $\Delta P = Pt - BAR$ (mm Hg);
- saturation or $\%TGP = Pt/BAR \times 100$ (%); and
- saturation at sea level or $\%TGPsea = (\Delta P + 760)/760 \times 100$ (%).

The TGP probes were placed below compensation depth (i.e., approximately 3-4 m) to prevent air bubble formation on the silastic membrane. Point TGP measurements conducted during calibration periods required that probes remain in the water for a minimum of 20 minutes to allow the probe to reach equilibrium. Winkler titrations were conducted each calibration session to assess the accuracy of the oxygen sensor.

2.2 MONITORING LOGISTICS

The majority of TGP data was collected successfully at both the HLK and Robson monitoring locations; however, some data loss did occur at the HLK station between 11 July and 9 August due to a combination of mechanical and electronic equipment failure. Water temperature data was not recorded by the DCP system from 7 April to 9 June and from 1 July to 13 August. As identified during the 1998 gate testing survey (R.L. & L. 1999a), the 1999 ΔP and temperature data from the forebay monitoring site were prone to some variation when compared to other measured parameters and to data from the portable monitoring equipment. The variation in data may have resulted from an induced voltage potential on the probe extension cable from an adjacent high voltage cable. Alternatively, an intermittent break in the cable or electrical ground also are potential causes. As with previous TGP monitoring efforts in the HLK forebay, insufficient water flow across the oxygen sensor often resulted in low oxygen partial pressure relative to the values obtained from the Winkler tests conducted during each calibration period.

3.0 RESULTS

3.1 DISCHARGE AND OPERATIONAL SETTINGS

3.1.1 Discharge and Reservoir/Tailrace Elevations

All TGP, dissolved oxygen, temperature, spillway and low level port discharge, and gate setting data are provided in electronic format (CD-ROM) under separate cover to CRIEMP participants. Discharge from low level outlet (LLO) ports ranged from zero discharge to a maximum of 2331 m^3/s (82 317 cfs) with an average of 1086 m^3/s (38 351 cfs). Spillway discharge facilities were used primarily from 8 July to 22 October and ranged from zero discharge to a maximum of 2511 m^3/s (88 674 cfs). Average spill discharge over the monitoring period was 330 m^3/s (11 654 cfs) Spill maximums occurred from 20 July to 9 August when spillways were the sole discharge method (Figure 3.1).

Forebay and tailrace elevations were highest during July and August, with a seasonal maximum difference of 18.97 m during normal operating conditions. The observed minimum difference between forebay and tailrace elevations was 7.51 m. The decrease in tailrace elevation on 2 October resulted from a temporary discharge reduction as part of a whitefish habitat compensation (scarification) program approved by the provincial and federal agencies (Figure 3.1).

3.1.2 Spillways and Low Level Outlet Operational Settings

Of the eight low level ports, LLO 4 was used most frequently to discharge water during the monitoring period. When the need to discharge water was high, LLO 2 and 3 were used in combination with LLO 4, for prolonged periods in August and September. During this time, both LLO 3 and 4 were operated at full capacity. Low level ports LLO 5 and 6 were only used sporadically in September and October, while LLO 1, 7, and 8 were not used (Figure 3.2). Typically, Spillway 4 was the primary spillway discharge structure used. The remaining spillways were operated in decreasing order of preference (Spillway 3, 2, and then 1) when additional discharge capacity was required. When multiple spillways were used, the entire discharge volume was partitioned evenly among all four spillways (Figure 3.3).

Dam spillway operations were summarized by the number of operational days (out of a maximum of 185 days) and weighted average gate height from 1 May to 1 November (Figure 3.4). Spillways 3 and 4 were used most frequently, for a total of 50.8 and 53.9 days, respectively. Average gate height of Spillway 4 (0.81 m), however, exceeded that of Spillway 3 (0.70 m), indicating that Spillway 4 was the primary structure used for spill discharge. Spillway 2 was operational for 44.1 days, with an average weighted gate height of 0.40 m. Spillway 1 was used least of all and was operational for only 25.8 days at an average gate height of 0.09 m. Of the eight low level ports, LLO 4 was used the most (144.7 days) and maintained the highest average gate height (5.13 m). Low level ports 2 and 3 were used for 115.5 and 118.2 days at an average gate height of 2.44 and 3.19 m, respectively. Of the remaining low level ports used, LLO 5 was operational for 8.2 days at an average gate height of 0.12 m, while LLO 6 was active for 37.8 days at an average gate height of 0.52 m. Low level ports 1, 7, and 8 were not used during the study period.

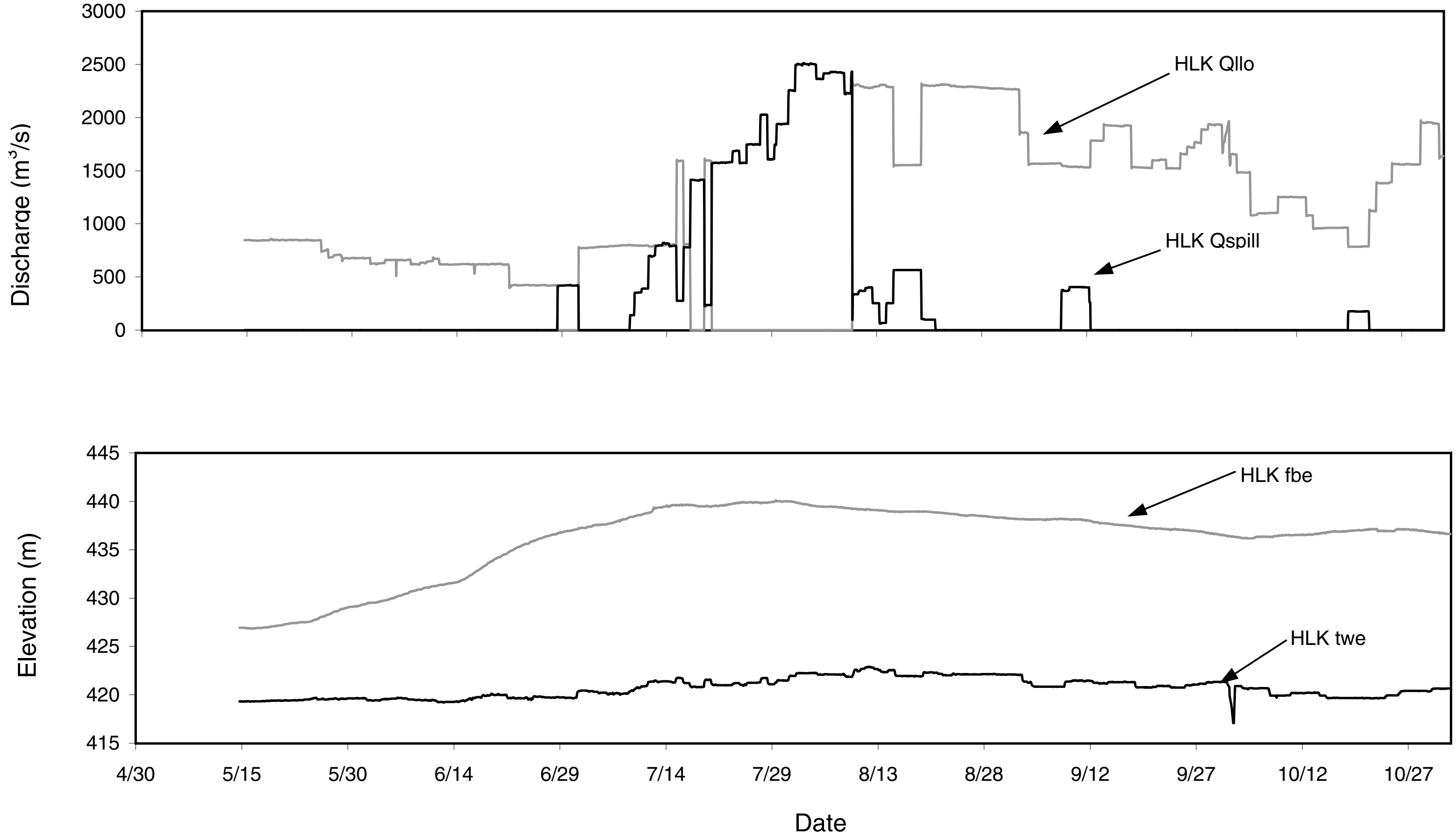

Figure 3.1 Discharge from low level ports (HLK Qllo) and spillways (HLK Qspill) at Hugh L. Keenleyside Dam, 14 May to 1 November 1999 (top) and plot of forebay (HLK fbe) and tailrace (HLK twe) elevations at Hugh L. Keenleyside Dam, 14 May to 1 November 1999 (bottom).

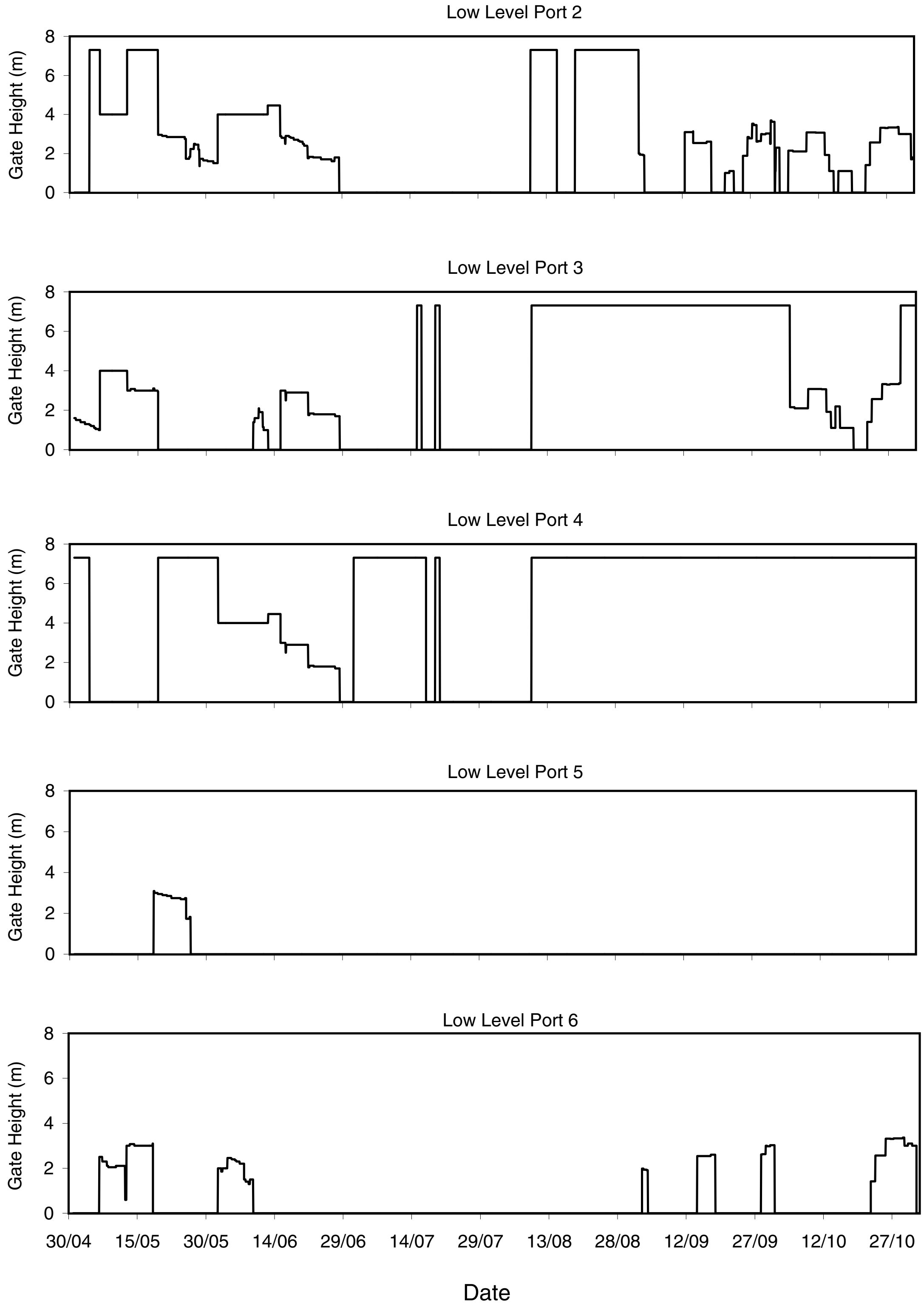

Figure 3.2 Gate heights for Low Level Ports 2 through 6 at Hugh L. Keenleyside Dam, 1 May to 1 November 1999. Low Level Ports 1, 7, and 8 were not used during this period.

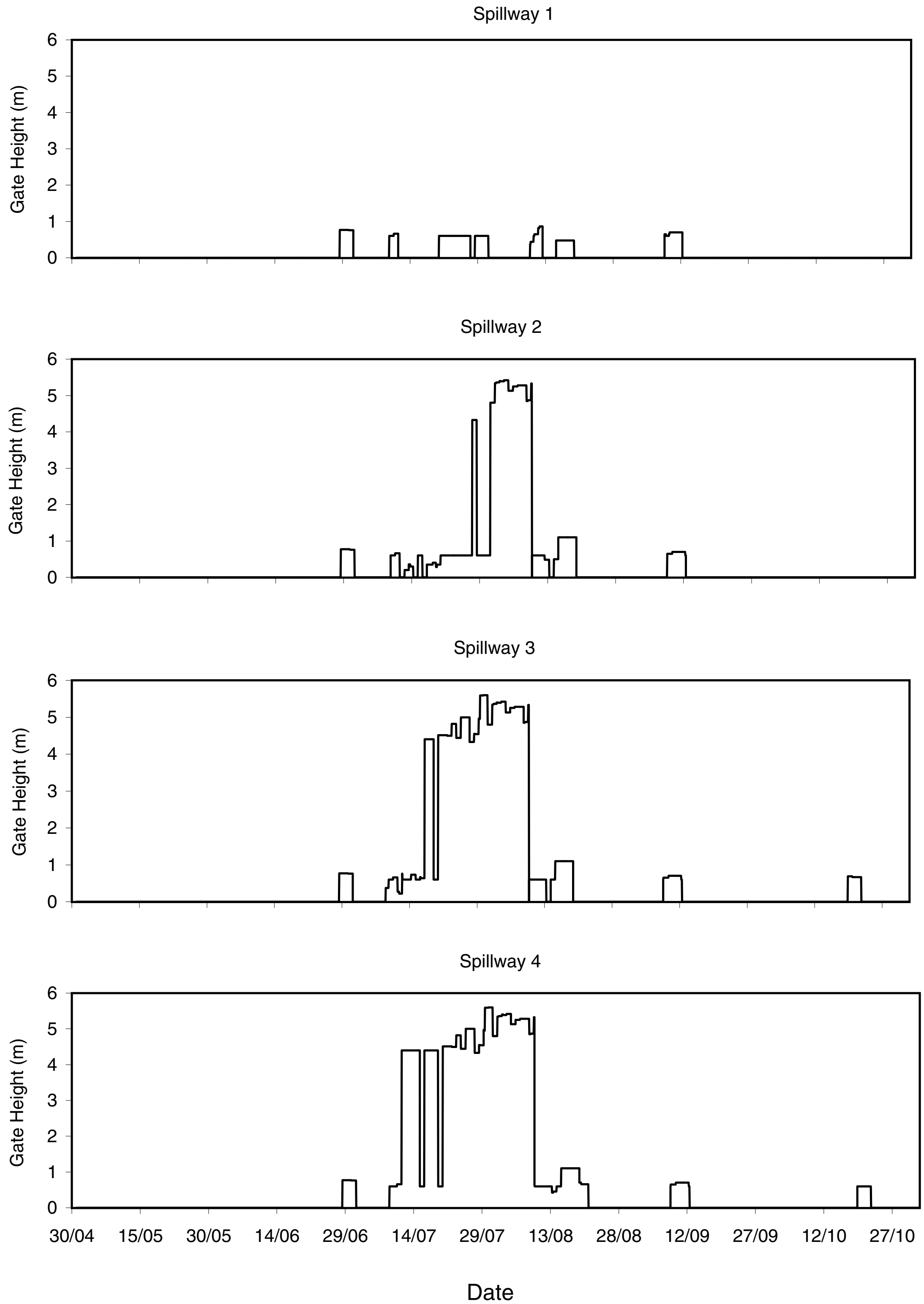

Figure 3.3 Gate heights for Spillways 1 through 4 at Hugh L. Keenleyside Dam, 1 May to 1 November 1999.

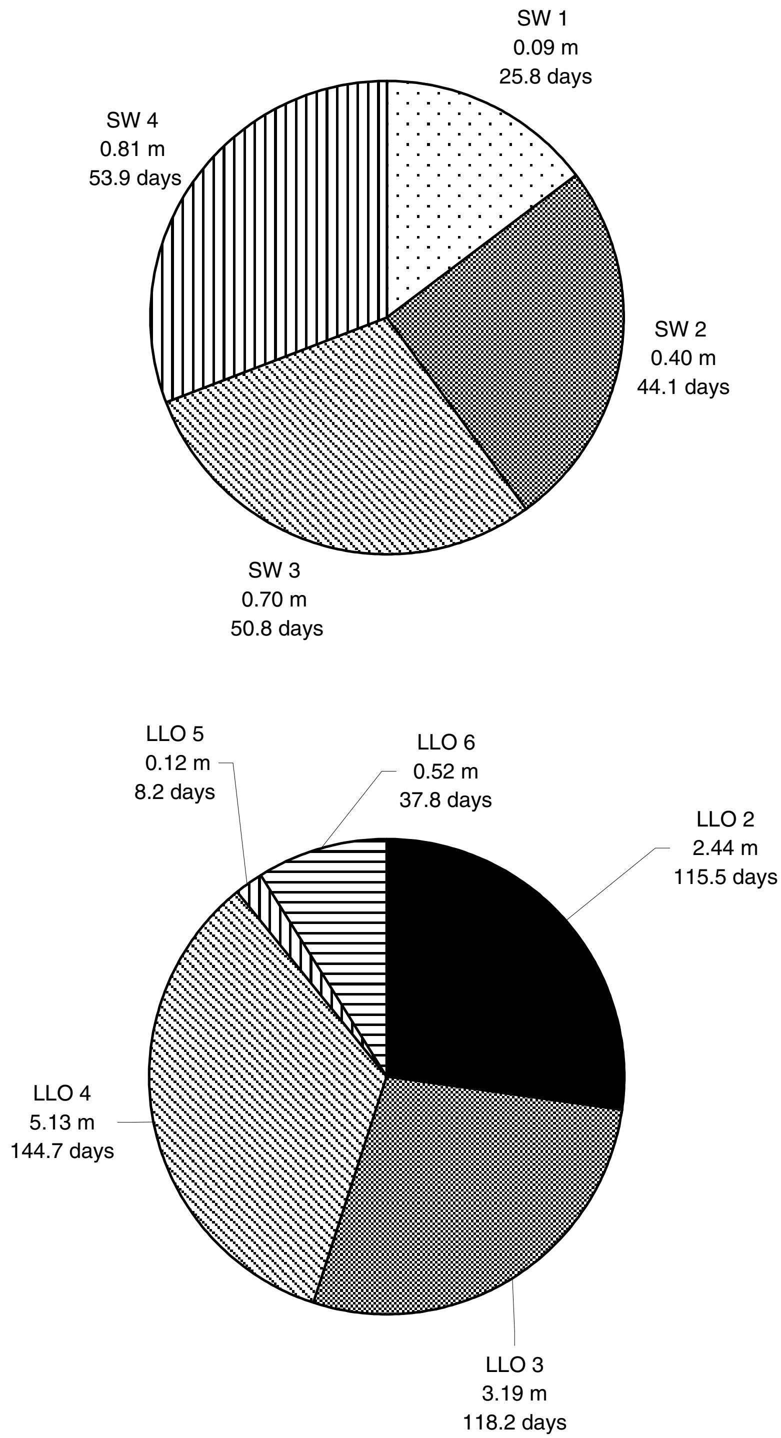

Figure 3.4 The number of operational days and average weighted gate opening of individual spillways (SW; top) and low level ports (LLO; bottom) at Hugh L. Keenleyside Dam, 1 May to 1 November 1999.

3.2 TOTAL GAS PRESSURE DATA

Average HLK forebay ΔP over the duration of the monitoring period was 34 mm Hg (104.6%), with a minimum of 13 mm Hg (98.2%) and a maximum of 88 mm Hg (111.5%; Figure 3.5). Water temperature in the forebay averaged 15.5°C and ranged between a minimum of 10.0°C and a maximum of 19.2°C. Dissolved oxygen averaged 147 mm Hg, with a minimum of 101 mm Hg and a maximum of 167 mm Hg. Forebay ΔP and pO_2 values were highly variable and did not track one another, in that an increase or decrease in ΔP did not result in a corresponding change in pO_2. This lack of agreement may be attributed to inadequate water velocity across the oxygen sensor or passive electronic interference with the data logger.

Dam operations produced large variations in TGP measurements downstream at the Robson station (Figure 3.6). Average ΔP at the Robson station for the duration of the monitoring period was 127 mm Hg (117.5%), with a minimum of 29 mm Hg (104.0%) and a maximum of 340 mm Hg (147.3%). In contrast to the data collected in the HLK forebay, changes in pO_2 data measured at the Robson station directly corresponded to changes in ΔP. Tailrace water temperature averaged 13.4°C over the monitoring period, within a range minimum and maximum of 5.6 and 17.1°C, respectively.

A comparison of spill and total discharge (Figure 3.3) against ΔP data from the Robson station (Figure 3.6) indicates that high levels of TGP observed downstream occurred during spill events at HLK. Based on the data in relation to spillway gate settings, the highest levels of TGP were produced when spillways were the sole method of discharge from HLK and the spill volume was partitioned evenly between all four spillways (e.g., 28 June to 1 July). Previous studies have determined that for a given discharge volume, Spillway 1 entrains the greatest amount of dissolved gas relative to the other spillways and low level ports (Aspen Applied Science Ltd. 1995; R.L. & L 1999a, 1999b). During other periods when Spillway 1 is active, higher rates of discharge from either the remaining spillways or the low level ports results in dilution of Spillway 1 discharge and reduced ΔP values relative to the peak value. The lowest ΔP levels were observed between 12 May and 11 June when total discharge from HLK was less that 1000 m^3/s and low level ports were the sole method of discharge.

As observed in previous studies, up to 13 hours was required for TGP readings at the Robson station to stabilize for a given change in operation at HLK (R.L. & L. 1999a, 1999b). Gradual turnover of water within Keenleyside eddy, a large eddy immediately downstream of the dam, was believed to be the likely cause that resulted in delayed TGP equilibrium at the Robson station. This time lag was again confirmed during the 1999 investigations on 1 July, when discharge from HLK was changed from split spillways (i.e., equal discharge through Spillway 1 to 4) to LLO 4. Initial ΔP levels, that averaged 333 mm Hg, gradually decreased to approximately 80 mm Hg over a 13 hour period.

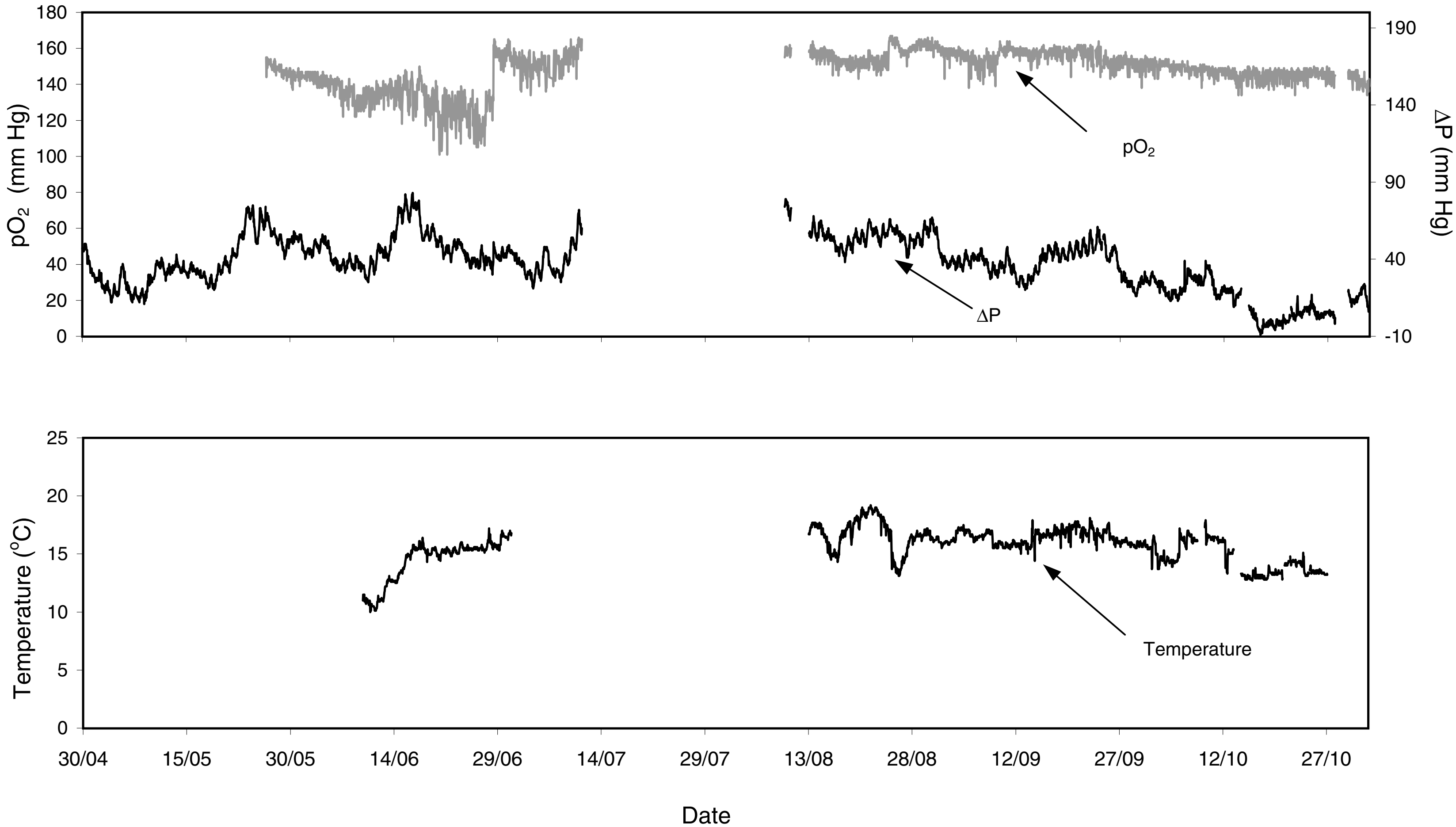

Figure 3.5 The amount of total dissolved gas, expressed as ΔP (ΔP=total gas pressure - barometric pressure) and pO_2 (partial pressure of oxygen; top), and temperature (bottom) in the forebay of Hugh L. Keenleyside Dam, 1 May to 1 November 1999.

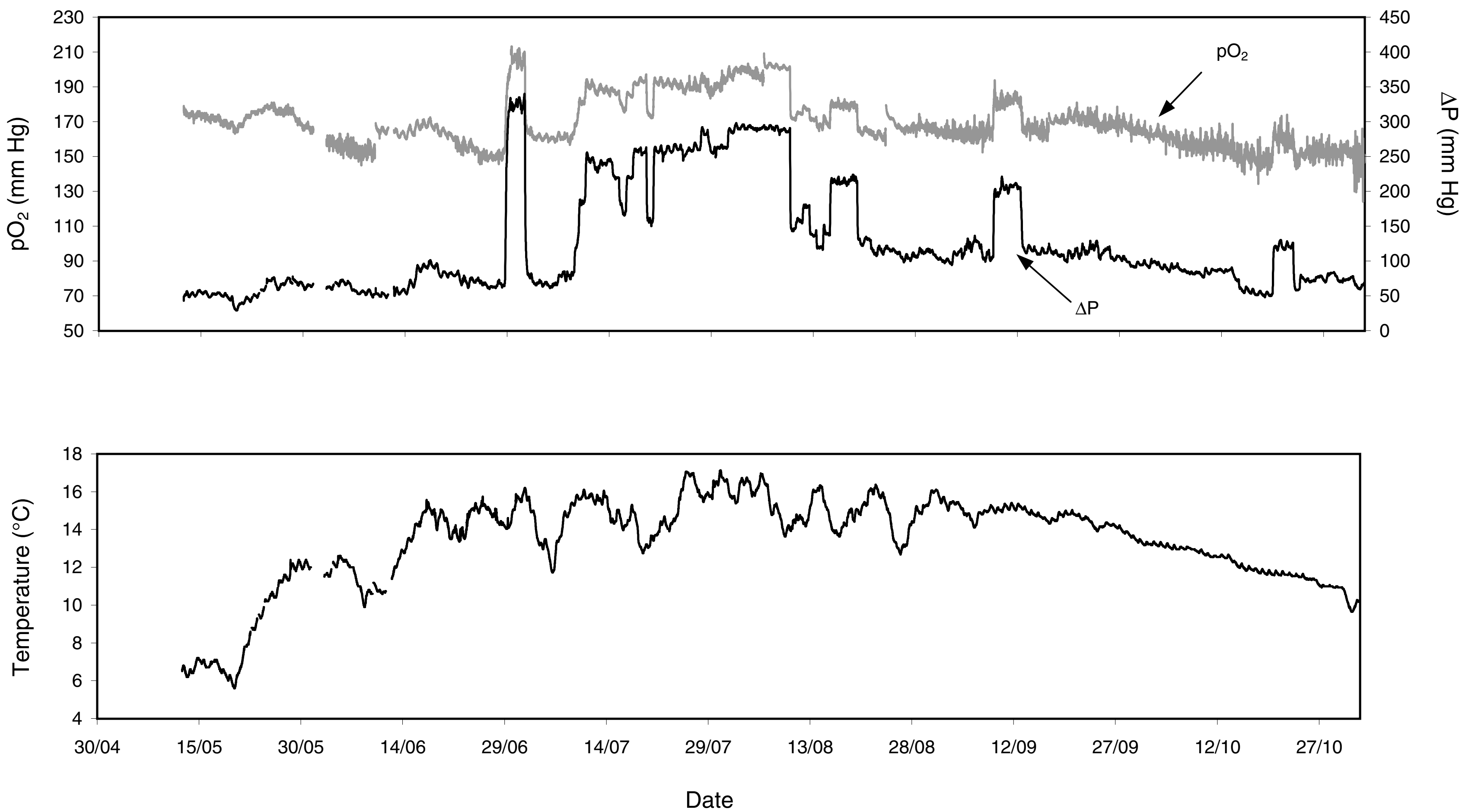

Figure 3.6 Total gas pressure data, consisting of ΔP (total pressure - barometeric pressure) and pO_2 (partial pressure of oxygen; top), and temperature (bottom) measured at the Robson station, 12 May to 1 November 1999.

Individual spillways and lower level ports have been tested in previous studies to determine the amount of gas entrainment at a given rate of discharge (R.L. & L. 1999a). To obtain a representative equilibrium TGP reading at the Robson station, a discharge structure must be used in isolation at a constant discharge rate for a minimum of 13 hours, when total discharge is below 1000 m^3/s. A review of HLK operations during the 1999 study indicated that this criteria was only met on one occasion when LLO 4 was operated exclusively from 1 to 8 July. The operational gate setting of LLO 4 and average discharge volume were maintained at 7.31 m and approximately 785 m^3/s, respectively, and resulted in an average ΔP of approximately 73 mm Hg. In 1998, the gate setting of LLO 4 was held constant at 7.31 m and at a average discharge of 798 m^3/s from 3 to 10 October. Average ΔP for this period was approximately 62 mm Hg.

Dissolved gas and temperature data recorded downstream at the DOE and CIBW stations were compared against each other, and the Robson and HLK stations. Both the DOE and CIBW monitoring stations represented a mixture of Columbia and Kootenay River water; however, the CIBW station was also influenced by the Pend d'Oreille River. Typically, peak flows in both the Kootenay and Pend d'Oreille rivers occur between mid-June to early July, while peak flows on the Columbia River do not occur until mid-July to early August. Over the monitoring session from 1 June to 1 November, average ΔP at the DOE station was 103 mm Hg (114.2%), with a minimum of 26 mm Hg (103.5%) and a maximum of 218 mm Hg (130.1%). Average ΔP at the CIBW station from 1 May to 1 November was 103 mm Hg (114.8%), with a minimum of 19 mm Hg (102.5%) and a maximum of 200 mm Hg (127.5%). In the absence of spill from HLK, ΔP at both the DOE and CIBW stations exceeded ΔP levels at the HLK forebay and Robson station because of spill from the Kootenay and Pend d'Oreille rivers from May to late June. During this period, TGP levels at the CIBW station were higher than the DOE station due to high discharge from the Pend d'Oreille. With the commencement of spill at HLK, fluctuations in ΔP observed at the Robson station were also observed at the DOE and CIBW stations (Figure 3.7).

During low flows from the Kootenay and Pend d'Oreille Rivers, water temperatures at the HLK, Robson, DOE, and CIBW stations closely followed each other. Changes in upstream water temperature were observed at downstream monitoring stations. High flows from the Kootenay River in June reduced water temperature at the DOE station relative to the upstream Robson station, which only measured water from HLK. Average water temperature at the DOE station averaged 14.3°C over the monitoring period, within a range minimum and maximum of 9.9 and 18.5°C, respectively. Warm water from the Pend d'Oreille River resulted in an increase in the average water temperature measured at the CIBW station relative to the upstream DOE station. Water temperature at the CIBW station averaged 13.5°C over the monitoring period, within a range minimum and maximum of 7.7 and 20.1°C, respectively. Large fluctuations observed in HLK forebay water temperature after August were not observed downstream and might be attributed to data transfer problems (Figure 3.7).

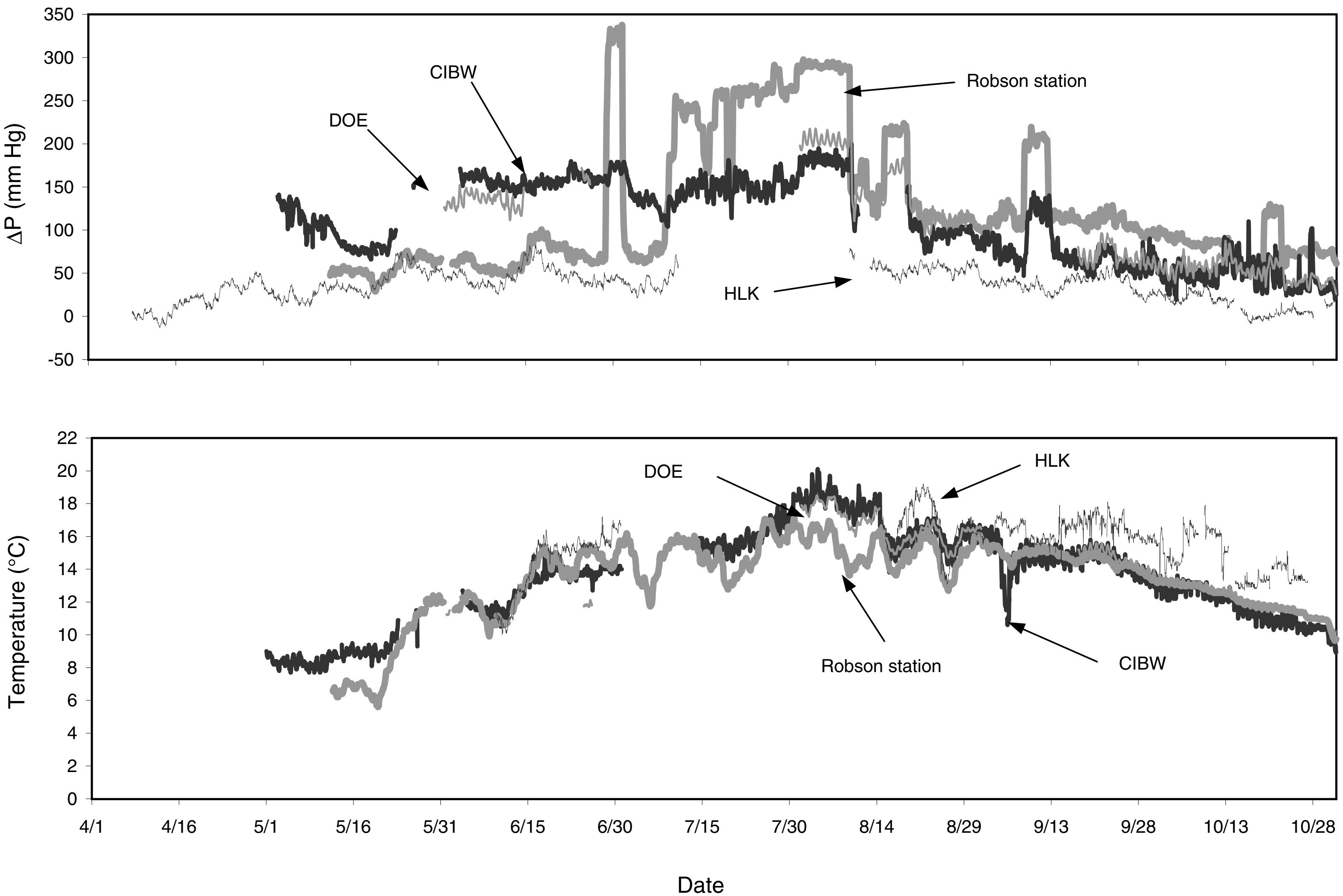

Figure 3.7 A comparison of ΔP (total pressure - barometric pressure; top) and temperature (bottom) measured at Hugh L. Keenleyside Dam (HLK), Robson, Department of Environment (DOE), and U.S. Bureau of Reclamation (CIBW) dissolved gas monitoring stations, 7 April to 1 November 1999.

4.0 SUMMARY AND RECOMMENDATIONS

A preliminary analysis of the 1999 TGP monitoring data has confirmed many of the findings reported in previous reports (Aspen Applied Sciences Ltd. 1995; Millar et al. 1996; R.L. & L. 1999a, 1999b). Typically, the highest downstream TGP concentrations were always associated with spillway discharge from HLK, with Spillway 1 producing the highest TGP levels. When low level ports were the primary discharge mechanism, downstream TGP levels were substantially lower, with LLO 3 and LLO4 producing the least amount of TGP. As with previous TGP investigations downstream of HLK, a 13 hour delay was observed between an operational change at HLK and equilibrium TGP readings at the Robson station. Sufficient data were not available to determine whether or not this delay was flow dependent.

A cursory examination of the data found one episode when a single low level port (LLO 4) was used exclusively and discharge was held constant for more than 13 hours. Normal dam operations typically used a combination of low level ports and spillways to discharge water. Further analysis of the data may yield additional individual or paired gate settings that were maintained for the minimum 13 hour equilibrium period.

These data have been transferred to Aspen Applied Sciences Ltd. to check against the existing HLK model and to determine if further monitoring is necessary to resolve modelling discrepancies. These data are also being used to compare monitoring data from the Brilliant tailrace with the DOE Columbia River station near Waneta to determine if mass balance gas estimates from upstream sites consistently predict downstream gas levels.

Preliminary examination of 1998 data from HLK by Aspen Applied Sciences Ltd. suggests the current model may underestimate TGP measurements with certain gate combinations but accurately reflects others. The incorporation of the 1999 extended data set into the model may help resolve these issues. The existing monitoring database for HLK extends over many years and encompasses a large range of flow and operational conditions. Gas production models using HLK operations are quite complex and it is yet to be established if steady state models can accurately predict TGP formation at HLK. However, it is obvious from this and other monitoring data, that any use of spillways at HLK results in TGP values that exceed B.C. water quality guidelines.

In past years during some flow conditions (i.e., when the head differential exceeds 17.5 m and discharge via the ports can only be accomplished at fully open gate settings), small incremental changes in flows would have been accomplished by switching to spill discharge, thereby substantially increasing downstream TGP levels. In 1999, several instances occurred where these types of small incremental changes in discharge from HLK were avoided. This was achieved through BC Hydro efforts to consolidate small changes in flow into larger incremental changes that allowed the continued use of low level ports to meet the target volume releases. This type of consolidation resulted in major TGP reduction benefits and should be encouraged in the future.

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