Dissolved Gas Supersaturation Monitoring At Three Hydroelectric Generating Facilities in the Yukon, Canada, in August of 1997 and 1998

B. L. Antcliffe and A. von Finster

Department of Fisheries and Oceans
555 West Hastings Street
Vancouver, British Columbia, V6B 5G3

1999

Canadian Technical Report of Fisheries and Aquatic Sciences 2275

Fisheries and Oceans Canada   Pêches et Océans Canada

Canada

Canadian Technical Report of
Fisheries and Aquatic Sciences 2275

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DISSOLVED GAS SUPERSATURATION MONITORING AT THREE HYDROELECTRIC GENERATING FACILITIES IN THE YUKON, CANADA, IN AUGUST OF 1997 AND 1998.

by

B.L. Antcliffe[1] and A. von Finster[2]

Department of Fisheries and Oceans
555 West Hastings Street
Vancouver, British Columbia V6B 5G3

[1] Bio-engineering Support Division
Habitat and Enhancement Branch
Department of Fisheries and Oceans
#360 – 555 West Hastings Street
Vancouver, British Columbia, Canada V6B 5G3

[2] Yukon Area Office
Habitat and Enhancement Branch
Department of Fisheries and Oceans
100 - 200 Range Road
Whitehorse, Yukon, Canada Y1A 3V1

Cat. No. Fs 97-6/2275E ISSN 0706-6457

Correct citation for this publication:

Antcliffe, B.L., and A. von Finster. 1999. Dissolved gas supersaturation monitoring at three hydroelectric generating facilities in the Yukon, Canada, in August of 1997 and 1998. Can. Tech. Rep. Fish. Aquat. Sci. 2275.

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ABSTRACT

The Department of Fisheries and Oceans conducted dissolved gas supersaturation monitoring at three hydroelectric generating facilities in the Yukon, Canada, in August of 1997 and 1998. The three facilities were Whitehorse Rapids, Aishihik, and Mayo. The purpose was to conduct an initial reconnaissance program and use the results to identify future monitoring and assessment needs in preparation for relicensing of the facilities under the *Yukon Waters Act*. At all facilities, total gas pressure measurements were below acute levels for all species and life history phases of interest. Concern remains in regard to chronic effects in shallow water habitat, particularly during periods of warm water temperatures. Recommendations for further sampling and biological investigations include: TGP sampling below Whitehorse Rapids Dam and in the Aishihik tailrace to assess potential chronic effects; TGP sampling below the Wareham Lake Dam spillway; and fish utilisation of shallow water habitat where low-level TGP is sustained over long periods of time.

RÉSUMÉ

Le ministère des Pêches et des Océans a effectué une surveillance continue du taux de sursaturation des gaz dissous dans trois centrales hydroélectriques du Yukon (Canada) – Whitehorse Rapids, Aishihik et Mayo – au cours du mois d'août 1997 et du mois d'août 1998. L'objectif était de mener à bien un programme de reconnaissance préliminaire et d'utiliser les résultats pour évaluer les besoins futurs en surveillance et en évaluation en vue de la reconduction de la licence d'exploitation des installations en vertu de la *Loi sur les eaux du Yukon*. Les concentrations gazeuses totales enregistrées se sont révélées en dessous des seuils de toxicité pour toutes les espèces à tous les stades de développement présentant un intérêt. La possibilité d'effets chroniques sur les habitats en eau peu profonde, en particulier pendant les périodes où l'eau est plus chaude que la moyenne, reste un point à éclaircir. À cet effet, on recommande d'effectuer les mesures et études biologiques supplémentaires suivantes : mesures de la concentration totale des gaz dissous au-dessous du barrage des rapides de Whitehorse et dans le canal de fuite d'Aishihik pour évaluer les effets chroniques potentiels; mesure de la concentration totale des gaz dissous au-dessous du déversoir du barrage du lac Wareham; et enfin, études de la fréquentation des eaux peu profondes par le poisson lorsque la concentration totale des gaz dissous se maintient à un niveau faible pendant de longues périodes.

1.0 INTRODUCTION

Three hydroelectric generating facilities in the Yukon will require relicensing in the near future: Whitehorse Rapids, Aishihik, and Mayo. Their water licenses, issued pursuant to the *Yukon Waters Act*, expire in year 2000 for Whitehorse Rapids and Mayo and in year 2002 for Aishihik. As part of the relicensing process, DFO will be assessing a variety of fisheries issues, including dissolved gas supersaturation (DGS).

The purpose of this study was to measure DGS at the Whitehorse Rapids, Aishihik, and Mayo hydroelectric generating facilities. As a reconnaissance, it consisted of spot measurements taken at each facility under existing operating conditions during August 19 to 26, 1997 and August 25 to 27, 1998. Our intent was to use the results of the initial reconnaissance program to identify future monitoring and assessment needs for relicensing. It was anticipated that any future monitoring would be the responsibility of Yukon Energy Corporation. Prior to conducting this study, no DGS data were found in the literature for any of the three Yukon hydro facilities.

2.0 BACKGROUND INFORMATION

2.1 DGS and TGP

Dissolved gas supersaturation (DGS) is a condition, which exists in natural and man-made water bodies. It occurs when the partial pressures of atmospheric gases in solution exceed their respective partial pressures in the atmosphere. The level of dissolved gas tension in water is most often expressed in terms of the total gas pressure (TGP), defined as:

$$TGP = pN_2 + pO_2 + pH_2O$$

where pN_2 = partial pressure of dissolved nitrogen as well as the partial pressure of argon and all other trace atmospheric gases (in mmHg), pO_2 = partial pressure of dissolved oxygen (in mmHg), and pH_2O = vapour pressure of water (in mmHg).

TGP expressed in terms of percent total gas pressure is defined as:

$$TGP\% = 100 \cdot (pN_2 + pO_2 + pH_2O)/\ pAtm$$

where pAtm = atmospheric pressure.

DGS can also be defined as the ΔP (the difference between TGP and atmospheric pressure):

$$\Delta P = pN_2 + pO_2 + pH_2O - pAtm.$$

When ΔP is greater than 0.0 mmHg, water is supersaturated with dissolved gases.

Elevated DGS may occur as a result of a number of processes, including water discharge through hydroelectric facilities, thermal heating (e.g., solar radiation, cooling water effluent), ingestion of air into pumping systems, oxygen supplementation in hatcheries, oxygen production by aquatic plants, or natural water falls. Below hydroelectric facilities, DGS is caused when air entrained in water released over spillways, through ports or other hydraulic structures plunges to depth. At depth, elevated hydrostatic pressure forces gas from inside the air bubble into solution. Turbines themselves may also generate TGP if hydraulic conditions produce elevated hydrostatic pressure near the face of turbine blades, such that gas is forced into solution.

2.2 Gas Bubble Trauma

Gas Bubble Trauma (GBT) refers to the physiological signs that appear in fish exposed to high levels of DGS. The major signs of GBT include: bubble formation in the cardiovascular system, causing blockage of blood flow and death; overinflation of the swim bladder, leading to rupture, overbuoyancy, and possibly death; extracorporeal bubble formation in gill lamella of large fish or in the buccal cavity of small fish, which may lead to blockage of respiratory water flow and death by asphyxiation (Fidler 1997). Other signs of GBT which may compromise the survival of fish exposed to DGS over extended periods of time include sub-dermal emphysema or blistering of body surfaces or the lining of the mouth, exopthalmia, ocular lesions, loss of swimming ability, altered blood chemistry, and reduced growth (Fidler 1997).

2.3 Existing Water Quality Guidelines

The U.S. Environmental Protection Agency (1986) published DGS water quality guidelines that recommend a maximum TGP of 110% of local atmospheric pressure. However, new data indicate that this guideline may not provide adequate protection for all fish populations, especially juvenile life stages of Pacific salmon, rainbow trout, and other species. The B.C. Ministry of Environment, Lands and Parks, Environment Canada, and the Department of Fisheries and Oceans (DFO) therefore developed DGS guidelines for B.C. (Fidler 1997). These guidelines establish a maximum ΔP of 76 mm Hg (110% TGP, referenced to sea level barometric pressure) for water deeper than 1m, and ΔP between 24 mm and 76 mm Hg for water less than 1 metre deep (103% to 110% TGP, for sea-level conditions). These guidelines do not take into account site-specific concerns, such as fish habitat and life history stage, which must be considered in the application of the guidelines. The guidelines are also based largely on steady-state lab bioassay data. Thus, in some situations (e.g., where fish spend most of there time below the compensation depth), the guidelines may be overly conservative. The guidelines could also be not conservative enough in other situations, for example under conditions of shallow water habitat and warmer water temperature (which could be caused by the spilling of warmer surface water over a dam spillway).

3.0 METHODS

3.1 Hydro Facilities and Sampling Sites

Dissolved gas supersaturation was monitored at several locations upstream and downstream of three Yukon hydroelectric generating facilities: Whitehorse Rapids, Aishihik, and Mayo. The hydroelectric generating facilities and sampling sites are described below, by facility.

3.1.1 Whitehorse Rapids

The Whitehorse Rapids Generating Facility (40 MGW) is located on the Yukon River in Whitehorse. It consists of the Whitehorse Rapids Dam with two spill gates (Photo. # 1 and 2); a power canal to channel water to turbine units #1, 2, and 3; turbine unit #4 and it's tailrace channel (which enters the river below the dam but above the release from turbine units #1,2, and 3); a fish barrier weir, located downstream of the spill gates but upstream of the end of the tailrace from unit #4; and a fish ladder, which enters immediately downstream of the barrier weir. Figure 1 shows the configuration of the project and some sampling sites.

DGS sampling was conducted at the Whitehorse Rapids facility in 1997 and 1998. In 1997, two sampling sites were located upstream of the Whitehorse Rapids facility. The first was offshore of the boat launch located on the south east end of Schwatka Lake and the second immediately downstream of Canyon City. It was necessary to sample a several km upstream of the dam, rather than directly in the forebay, in order to sample water representative of that which flows through the spill gates. Sites immediately downstream of the dam in 1997 were located below the two low-level spill gates but upstream of the barrier weir (sampling location shown in Photo. #3); in the tailrace of unit #4; and downstream of the weir and the confluence of unit #4 (sampling location was in the lower right-hand corner of Photo. #2). Sites located further downstream included one near the infilled section of Robert Service Way, one at the foot of Main Street, near the WP&YR station; one at the upstream end of the MacIntyre Flats, and the final site immediately downstream of the mouth of Croucher Cr.

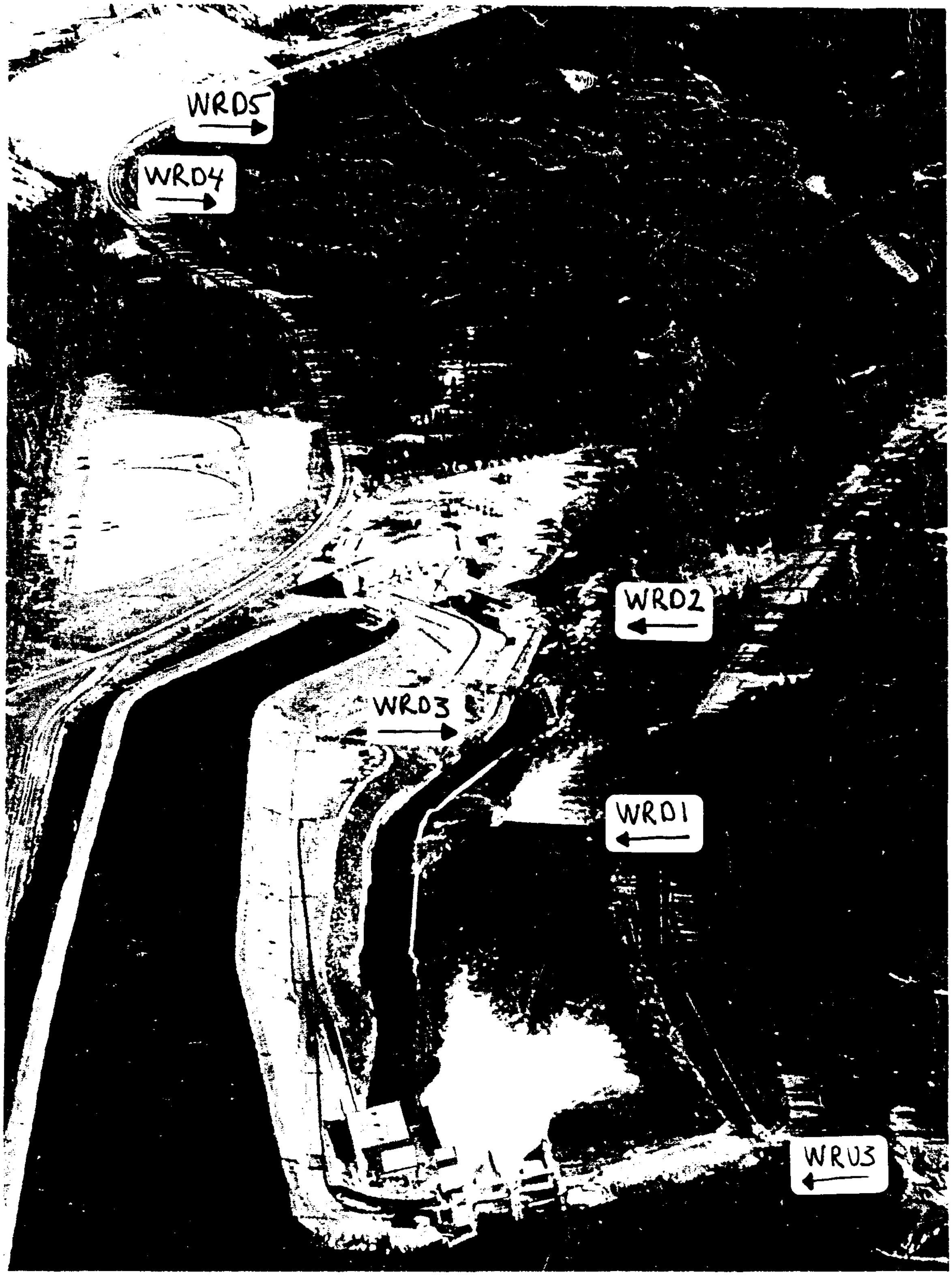

Figure 1. Whitehorse Rapids Generating Facility, in Whitehorse, Yukon, showing selected DGS sampling sites. Reprinted with permission from Yukon Energy Corporation.

In 1998, the upstream sampling site was located just upstream of the Whitehorse Rapids facility, just a few meters upstream of the inlet for the fish ladder. Downstream sampling sites were similar to those sampled in 1997, however, fewer sites were sampled.

Detailed descriptions of the sampling sites are provided in Appendix 2B (1997) and 3 (1998).

3.1.2 Aishihik Generating Station

Aishihik is a 30 MGW generating facility located about 130 km west of Whitehorse on the East Aishihik River. Water storage is regulated primarily by the Aishihik Lake control structure. Canyon Lake serves as a headpond and provides limited storage. A 5.8 km power canal carries water from Canyon Lake to the intake structure, where water drops 175 metres and flows through a 915m pressure tunnel to two turbines. Two draft tubes carry water out of the generating station into the 1 km long tailrace channel, which flows into the West Aishihik River. The configuration of the project is shown on Figure 2.

In 1997, upstream sampling sites were located on Aishihik and Canyon Lakes. Downstream sampling sites were located in the tailrace channel, as shown in Photo. # 4 and 5, and the Aishihik River, downstream of the confluence of the tailrace channel with the East and West Aishihik Rivers. In 1998, the tailrace channel was resampled, at approximately the same location as in 1997. A more detailed description of sampling sites is provided in Appendix 4 (1997 sampling) and 5 (1998 sampling).

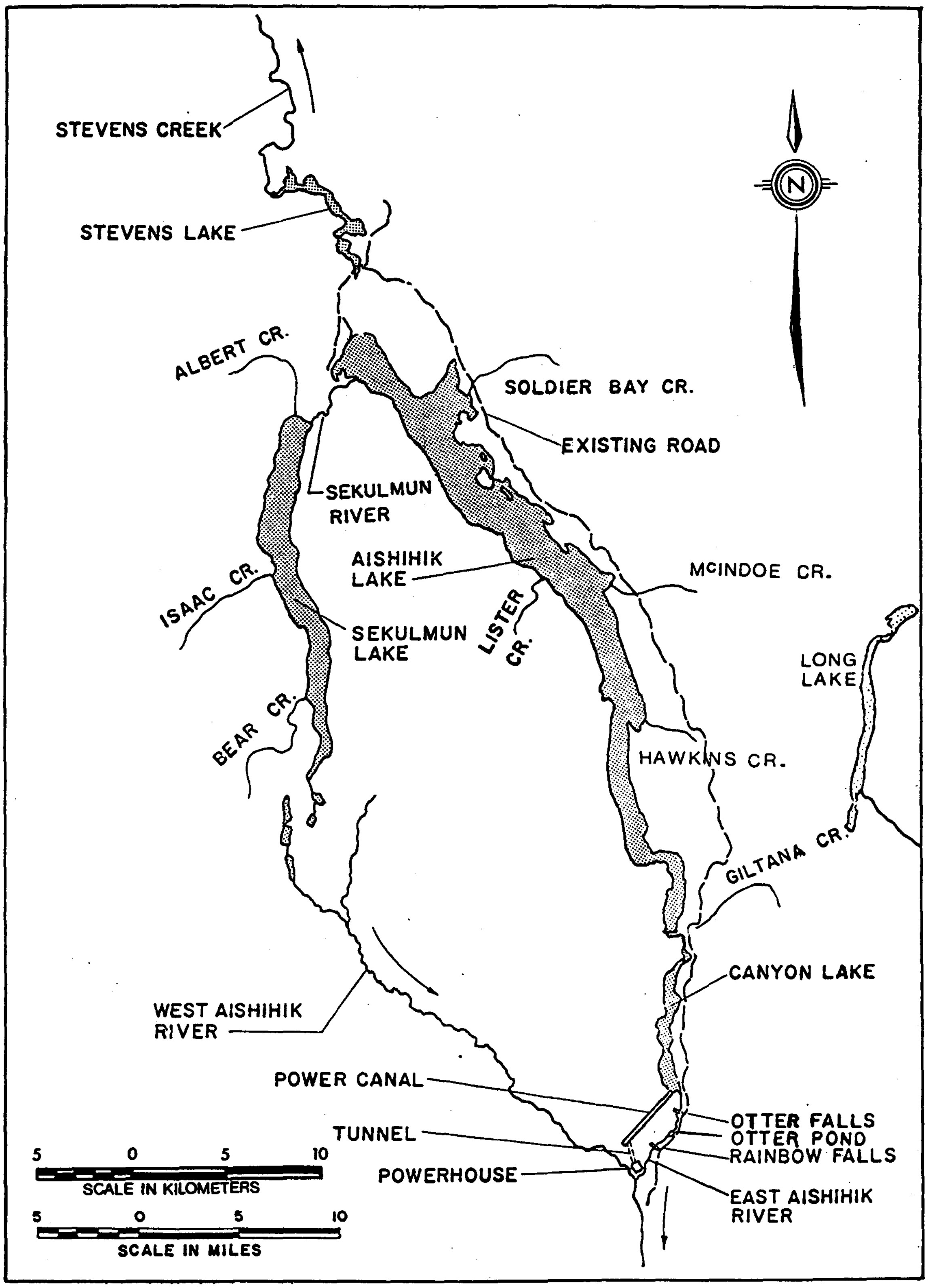

Figure 2. Aishihik Generating Station. Modified from Brown (1975).

3.1.3 Mayo Facility

The Mayo facility consists of the Mayo Storage Dam at the outlet of Mayo Lake (Photo. #6). A second dam (Wareham Dam) is located about 40 km downstream on the Mayo River and impounds water to form Wareham Lake (Photo. #7). The inlet to the generating facility is located immediately upstream of the dam on the east side of the river. The generating plant comprises two 2.5 MGW turbines. Exhaust water from the turbines joins the river about 500 meters downstream of the dam (Photo. #8). A spillway releases water from the dam to the river channel below (Photo. #9).

The Mayo facility was sampled in 1997 only. Sampling sites were located upstream of the Mayo Storage Dam, immediately downstream of the release (near the large rock shown on the left-hand side of Photo. #6), and further downstream on the Mayo River at the bridge located upstream of the confluence with Davidson Creek. At Wareham Dam, sampling sites were located immediately upstream of the dam at the inlet to the generating facility, downstream of the spillway (immediately upstream from the generating station), at the turbine outflow, and further downstream on the Mayo River at the Silver Trail/Mayo Road bridge. Detailed descriptions of sampling sites can be found in Appendix 7.

3.2 Sampling Design

Sampling was generally conducted in well-mixed, representative areas. The probe was allowed to equilibrate for 15 minutes, or until readings had stabilised, before measurements were recorded. Where possible, measurements were taken below the compensation depth (which is approximately 1m for approximately every 10% TGP), to prevent bubble formation on the membrane, which may lead to erroneous TGP readings. The probe was agitated to dislodge any bubbles that may have formed.

Barometric pressure (BP), total gas pressure (P_T), partial pressure of oxygen (pO_2), and temperature, were measured directly at each sampling location. The following derived variables were reported: percent total gas pressure ($P_T\%$), ΔP, oxygen (mg/l and percent saturation), and partial pressure of other gases - primarily nitrogen but including argon and other trace atmospheric gases (P_T . pO_2).

Yukon Energy provided readings of flows in various locations conditions during sampling.

3.3 Instruments and Calibration

All measurements were taken using a TBL-O total dissolved gas monitor, manufactured by Common Sensing Inc. (Clark Fork, Idaho). One meter was set-up by Common Sensing and Point Four Systems (Port Moody, B.C.). for data logging (meter 1), while the second was for taking spot measurements only (meter 2).

Both instruments were calibrated at least once daily using local atmospheric pressure (station pressure), obtained from the local airport. Temperature was calibrated in the lab using a high grade calibration thermometer. The instruments were also calibrated in air, prior to taking each measurement, by setting P_T equal to the barometric pressure (and ensuring ΔP equalled zero), percent saturation of total dissolved gases [% Satn P_T] equal to 100% in air. Percent oxygen saturation was also set to 100% in air.

3.4 Quality Control / Quality Assurance

All measurements were taken in duplicate at each sampling site using two TGP meters. In 1998, measurements from one meter were used, as the other meter was malfunctioning. Upstream measurements were generally taken first, to ensure that the TGP meters were producing measurements representative of typical background levels.

4.0 RESULTS

4.1 Whitehorse Rapids

DGS and temperature data for the Whitehorse Rapids facility are summarised in Table 1 (1997 data) and 1 (1998 data). Raw data and more detailed descriptions of sampling locations are presented in Appendix 2A, 2B, and 3. The 1997 data shown in Table 1 are the average of the two measurements taken at each site. There was good correlation between the duplicate measurements. For the 12 sets of measurements taken at this site (Appendix 2A), the average difference between the TGP measurements from the two meters was 0.3% TGP. The 1998 data are for one meter only (see Appendix 3), as the second meter was malfunctioning.

4.1.1 1997 Data

Upstream of the Whitehorse Rapids Dam, TGP ranged from 101.6% (ΔP = 11mmHg) at a depth of 1m, and 102.1% to 102.6% (ΔP = 11 to 19mmHg) at a depth of 3m. Immediately downstream of the two spill gates (just upstream of the barrier weir), DGS was elevated to 113.5% TGP (ΔP = 94mmHg) at a depth of 1.6m depth. There was no elevated DGS from the #4 turbine tailrace, where the measured TGP levels were similar to those found at upstream control sites. Flow from the tailrace diluted downstream TGP levels to 110.7% (ΔP = 75mmHg) at a distance of approximately 500 m downstream from the Dam. Further downstream, TGP was 101.8% (ΔP = 13mmHg) near the Robert Service Campground, and 102.6% (ΔP = 18mmHg) at Robert Service Way. These sites likely monitor flow from the #1,2 and 3 turbine units. Slightly higher TGP levels were recorded further downstream, at the well-mixed sites, where TGP ranged from 105.7% to

107.3%. These sites included the Yukon River at the WP&R railway, and near MacIntrye and Croucher Creeks.

Dissolved oxygen was high at all sites sampled (range: 9.2 to 10.2 mg/L). There was little difference in temperature between upstream (15.2 °C) and downstream locations (14.8 °C to 15.1°C).

Flows at the various locations were 471-497 cms during sampling, which are similar to the long time (44 - 86) average for August total which was 491 cms.

Table 1. Summary of DGS and Temperature Data for the Whitehorse Rapids Hydroelectric Facility, sampled from August 19 to 22, 1997.

Site ID	Site Description	Depth m	TGP %	ΔP mm Hg	Temp. °C
WRU1	Upstream control - site 1	3	102.6	19	15.2
		1	101.6	11	15.2
WRU2	Upstream control - site 2	3	102.1	15	15.2
WRD1	Downstream from spill gates	1.6	113.5	94	14.9
WRD2	Downstream of #4 turbine (and spill)	1.5	110.7	75	15.0
WRD3	Tailrace of #4 turbine	3	102.6	18	14.8
WRD4	Downstream - at Robert Service Way campground	1	101.8	13	15.1
WRD5	Downstream - at Robert Service Way	2	102.6	18	15.1
WRD6	Downstream - at WP&R railway	2.7	105.7	40	15.2
WRD7	Downstream - above MacIntyre Cr.	3	106.5	46	15.1
WRD8	Downstream - below MacIntyre Cr.	1.5	106.7	47.5	15.6
WRD9	Downstream - above Croucher Creek	3	107.3	51.5	15.6

* See Appendix 2A and 2B for more descriptive site locations and raw data.

4.1.2 1998 Data

The upstream control site had a similar TGP to that found in 1997, even though a different site was monitored in 1998. With the exception of one measurement (WRD2 - August 26), the data suggest that TGP levels were lower in 1998 than in 1997. This difference is likely temperature related, as the water temperature was approximately 2-3 °C cooler in 1998. Variations in flow may also explain these differences. On August 25, 1998, the TGP measured just downstream from the spill gates and turbine #4 was 110.7%, compared to 102.4% at the upstream site on the same day. The TGP at this same site was 103.1% the following day. The 110.7% TGP measured on Aug. 25, 1998 seemed too high for the flow and temperature conditions noted. Also, all of the TGP measurements on Aug. 26, 1998 were consistent with expected levels based TGP production characteristics and dilution. Thus, the unseemly high TGP recorded on Aug. 25, 1998 immediately below the combined discharge from the spill gates and turbine #4 may have been related to differences in flow, or an instrument error caused by bubbly water, which is typical at this site. Bubbly water causes erroneously high TGP readings because the pressure in the bubbles is greater than that in the water, and hence gas goes from the bubbles into the silastic tubing. The instruments were re-calibrated on the evening of August 25, 1998.

Table 2. Summary of DGS and Temperature Data for the Whitehorse Rapids Hydroelectric Facility, sampled from August 25 to 27, 1998.

Site ID	Site Description	Depth m	TGP %	ΔP mm Hg	Temp. °C
WRU3	Upstream control - site 3 (Aug. 25)	1	102.4	17	12.9
WRU3	Upstream control - site 3 (Aug. 26)	1	102.5	18	12.9
WRD1	Downstream from spill gates	1.5	103.6	26	12.9
	(Aug. 26)	0.5	104.3	30	12.9
WRD2	Downstream of #4 turbine and spill (Aug. 25)	1	110.7	74	12.8
WRD2	Downstream of #4 turbine and spill (Aug. 26)	1	103.1	22	12.9
WRD5A	Downstream - at Robert Service Way	1.5	101.7	11	12.9
		1	101.8	13	12.9
WRD6A	Downstream - at WP&R railway	1.5	101.8	12	12.9
		1	101.8	13	12.9

* See Appendix 3 for more descriptive site locations and raw data.

4.2 Aishihik Generating Facility

Tables 3 and 4 summarise the DGS and temperature data for the Aishihik Generating Facility from 1997 and 1998, respectively. The 1997 data represent the average of two measurements taken with different meters at each site. The average difference in readings between the two meters was 0.5% TGP. The 1998 data are from one meter only (see Appendix 5). More detailed descriptions of sampling locations and raw data are shown in Appendices 4 (1997) and 5 (1998).

4.2.1 1997 Data

Background TGP levels in Aishihik and Canyon Lakes ranged from 104.2% (ΔP = 29 mmHg) to 101.8% (ΔP = 12 mmHg). TGP was elevated to 112.2% (ΔP = 84 mmHg) in the tailrace channel, at a depth of 0.6m. Downstream of the confluence of the East and West Aishihik Rivers and the tailrace channel, TGP was diluted 102.3% (ΔP = 16 mmHg).

Dissolved oxygen ranged from 9.2 to 10.3 mg/L (Appendix 4).

Table 3. Summary of DGS and Temperature Data for the Aishihik Generating Facility, sampled on August 21, 1997.

Site ID	Site Description*	Depth	TGP %	ΔP mm Hg	Temp. °C
AU1	Aishihik Lake –upstream control site 1	3	103.7	24	12.7
AU2	Aishihik Lake –upstream control site 2	2	104.2	29	13.3
AU3	Canyon Lake – upstream control site 3	2	101.8	12	14.6
AD1	Tailrace Channel	0.6	112.2	84	14.8
AD2	Downstream - at confluence of east and west Aishihik R. and tailrace	0.6	102.3	16	14.7

* See Appendix 4 for more descriptive site locations and raw data.

4.2.2 1998 Data

TGP in the tailrace was slightly lower in 1998 compared to 1997. This difference is likely related to the lower water temperature in 1998 (10.8 °C) compared to 1997 (14.8 °C).

Table 4. Summary of DGS and Temperature Data for the Aishihik Generating Facility, sampled on August 27, 1998.

Site ID	Site Description*	Depth	TGP %	ΔP mm Hg	Temp. °C
AD1	Tailrace Channel	1.5	108.5	58	10.8
		1.0	108.0	55	10.8

* See Appendix 5 for more descriptive site locations and raw data.

4.3 Mayo Facility

The Mayo Facility was sampled in 1997 only. DGS and temperature data are summarised in Table 5 for the Mayo Lake storage dam, and in Table 6 for the Wareham Dam (generating station and spillway), on the Mayo River. Appendix 6 and 7 present raw data and detailed descriptions of sampling locations, respectively. Appendix 6 shows that there was good correlation between the duplicate measurements taken at each site. The average difference in readings between the two meters was 0.3% TGP. The averages of the two data points for each site are shown in Tables 5 and 6.

At the Mayo Storage Dam, TGP at the upstream site (104.2%, ΔP = 30 mmHg) was similar to that measured downstream of the dam (103.4 % to 104.3%, or ΔP = 24 to 30 mmHg).

TGP upstream of the Wareham dam was 102.2% (ΔP = 16 mmHg), and it was elevated to 105.6% (ΔP = 39 mmHg) below the spillway, at a sampling depth of 0.6m. TGP was 103.9% (ΔP = 27 mmHg) downstream of the turbine outflow, at a sampling depth of 2m, and 105.4% (ΔP = 38 mmHg) downstream of the flow from the turbines and spillway, at a depth of 0.6m. At Silver Trail bridge on the Mayo River, TGP was reduced to 103% (ΔP = 21 mmHg), at a depth of 1.6m.

Temperature was similar upstream and downstream of the storage dam, and the Wareham dam. Dissolved oxygen was high (>9.4 mg/L) at all sampling sites.

Table 5. Summary of DGS and Temperature data for the Mayo Lake Storage Dam, sampled on August 26, 1997.

Site ID	Site Description*	Depth	TGP %	ΔP mm Hg	Temp. °C
MSU1	Mayo Lake upstream control	2	104.2	30	13.4
MSD1	Mayo River ≈60m d/s of Mayo Dam	0.8	103.4	24	13.3
MSD2	Mayo River ≈3 km d/s of Mayo Dam at Davidson Creek bridge.	0.8	104.3	30	13.5

* See Appendix 6 and 7 for more descriptive site locations and raw data.

Table 6. Summary of DGS and Temperature data for Wareham Dam and Generating Station, sampled on August 26, 1997.

Site ID	Site Description*	Depth	TGP %	ΔP mm Hg	Temp. °C
MWU1	Mayo R., upstream of Wareham dam	2	102.2	16	12.3
MWD1	Mayo R., downstream from spillway (but upstream of turbine outflow)	0.6	105.6	39	12.2
MWD2	Mayo R. at turbine outflow	2.0	103.9	27	11.7
MWD3	Mayo R. 100m d/s of turbine outflow (also d/s of spillway flow)	0.6	105.4	38	12.2
MWD4	Mayo R. 9 km d/s of Wareham dam at Silver Trail/Mayo Road Bridge	1.6	103	21	12.9

* See Appendix 6 and 7 for more descriptive site locations and raw data.

5.0 DISCUSSION

5.1 Whitehorse Rapids

In 1997 DGS was slightly elevated downstream of the two spill gates (ΔP = 94 mmHg, TGP=113.5%, depth=1.6m), however, flow from turbine #4 diluted the level of dissolved gas tension to ΔP = 75 mmHg (TGP=110.7%, depth =1.5m), at a distance of approximately 500 m downstream from the spill gates. The B.C. water quality guidelines recommend that ΔP not exceed 76 mmHg for water greater than 1m deep (Fidler 1997). ΔP levels in excess of 76mmHg can lead to acute signs of GBT, while ΔP levels between 24 and 76 mmHg can lead to chronic signs (e.g., swimbladder overinflation, bubble formation in the gut). The first acute signs that tend to occur when ΔP levels exceed 76 mmHg are extracorporeal interlamella bubble formation and subdermal emphysema of external skin surfaces, both of which affect juvenile and adult fish. The threshold for bubble growth to occur in the vascular system, which can lead to death, begins at a slightly higher ΔP of approximately 115 mmHg. And the higher the ΔP levels, the shorter the time to mortality. Downstream of the Whitehorse Rapids Dam TGP was below the threshold for bubble growth to occur in the vascular system. However, some TGP measurements were in the range where mortality has been observed in the literature (ΔP between 76 and 115 mmHg). The cause of mortality when TGP is greater than 76mmHg but below 115mmHg is unknown, may be related to chronic effects which ultimately lead to death.

Water depth is a major factor in determining whether these ΔP thresholds will lead to the acute or chronic signs of GBT, because the hydrostatic forces at depth act to prevent bubble growth. For every 1m of water depth the hydrostatic forces compensate for approximately 73.89 mmHg of dissolved gas supersaturation (i.e., an additional 73.89 mmHg is required to initiate a particular acute or chronic GBT sign). The compensation depth required to protect fish from signs of GBT associated with 113% TGP is therefore 0.3m. Thus, if fish remain below this depth, intracorporeal or extracorporeal bubble growth (if it has not already been initiated) or swim bladder overinflation will not occur. When fish occupy habitat above this depth, bubble growth begins or, depending on the initial inflation pressure in the swimbladder (which may be determined by the fish independently of DGS), the swimbladder may begin to overinflate. If fish return below the compensation depth, bubble growth would stop or reverse providing the fish moves to a depth below that which bubble growth began, or the swimbladder would deflate. If fish move below the compensation depth, but not back to that depth at which bubble growth started, then bubble growth may continue at ΔP levels lower than those required to initiate growth.

The Yukon River at the Whitehorse Rapids flows from Marsh lake to the south to Lake Lebarge to the north. There were no barriers to the upstream migration of fish prior to the construction of dams on the river. A wide range of fish species have been captured or observed in the general location of the dam, including chinook salmon (*Oncorhynchus tswatyscha*); rainbow trout (*O. gairdneri*); lake trout (*Salvelinus namaycush*); Arctic grayling (*Thymallus arcticus*); least cisco (*Coregomus sardinella*); lake (humpback) whitefish (*C. clupeaformis*); broad whitefish (*C. nasus*); round whitefish (*Prosopium cylindricum*); inconnu (*Stenodus leucichthys*); northern pike (*Esox lucius*); lake chub (*Couesius plumbeus*); longnosed sucker (*Catostomus catostomus*); burbot (*Lota lota*); and slimy sculpin (*Cottus cognatus*). Two other species, the pygmy *whitefish (Prosopium coulteri*) and the Arctic lamprey (*Lampetra japonica*) may be present but have not yet been observed or identified. Most species are present in small numbers. The exceptions are the chinook salmon, which are present as returning adults and as rearing or migrating juveniles; Arctic grayling, as adults and sub-adults; and long-nosed suckers, primarily as adults.

Chinook salmon are widely distributed in the Yukon River basin and are valued economically and culturally. Working models of their utilisation of habitats have been developed by habitat managers on the basis of a wide range of investigations by DFO staff and other persons. Emergent chinook salmon have been captured in the Yukon River downstream of the Whitehorse Rapids dam as early as the beginning of May. The emergent chinook are expected to utilise shallow, relatively still near shore waters after emergence and prior to growing large and strong enough to function effectively in deeper, swifter water. During this period they are expected to spend much or most of their time in or associated with the upper layers of the coarse substrate found in much of the area.

TGP is likely elevated only during spill conditions (typically June to September) and effects a relatively short stretch of the river. During some time periods in July, juvenile chinook salmon would likely remain below the compensation depth of 0.3m during the spill period save during short excursions to capture specific food items. The measured TGP value of 113% on August 22, 1997 was unlikely to have caused significant effects on the juvenile chinook salmon utilising the area.

The DGS levels near the infill section of the Robert Service Way were below the acute GBT threshold of ΔP = 76 mmHg in 1997 and 1998. The most sensitive chronic GBT sign is overinflation of the swimbladder, which occurs at ΔP thresholds described by the following equation (from Fidler 1997):

$$\Delta P_{SB} = 73.89 \bullet h + 0.15 \bullet pO_2 \qquad \text{(Equation 1)}$$

Using the 1997 data recorded for site WRD4 near Robert Service Way (pO_2 = 144 mmHg, water depth ≈ 1m), the threshold ΔP for swimbladder overinflation is 95 mmHg. The maximum ΔP recorded in this area was 15 mmHg at a depth of 1m. Similarly, low levels of DGS (ΔP = 10 to 20 mmHg, water depth ≈ 2m) were measured near the infill section of the Robert Service Way at site WRD5). This indicates that swimbladder overinflation would not have been a problem at either of these sites. Other chronic effects which occur at these thresholds (e.g., bubble formation in the gut), would also not be expected to occur at the low DGS levels measured.

1997 TGP levels measured in the Yukon River further downstream, from the foot of Main Street to Croucher Creek, ranged from 105.5% to 107.7% (ΔP = 39 to 55 mmHg, for water depths from 1.5 to 3m), which were less than the ΔP recommended guideline for deep water (76 mmHg). Using the measured pO_2 of 148 mmHg in equation 1 yields a threshold ΔP for swimbladder overinflation of 55 mmHg at a water depth of 0.45m. ΔP levels measured at all four sites sampled downstream of Main Street were below this threshold, ranging from 39 to 55 mmHg (depth 1.5m to 3m). ΔP in shallower water (e.g. 0 to 1m depth) would be similar, assuming that the sites were well-mixed vertically. Chronic GBT should therefore not occur, provided fish utilise water deeper than 0.45m.

1997 DGS levels recorded further downstream on the Yukon River, near the WP&YR railway station and MacIntyre Flats were slightly higher (ΔP = 39 to 55 mmHg) than those recorded at the Robert Service Way sites (ΔP = 10 to 20 mmHg). These data suggest that the water near the Robert Service Way was not well-mixed with flow from the spill gates, but rather reflected flow from the #1,2, and 3 turbines. Since these turbines do not generate any significant TGP, this provides some protection for fish which use this important habitat, including use by chinook salmon and possibly Arctic grayling for spawning.

The 1997 TGP suggest that there could be some chronic effects in shallow water habitat during sustained periods of low-level TGP and warm water temperatures. These risks, however, do not apply to eggs, which are more resistant to DGS up to about 110% TGP (Jensen 1988). In addition, these risks do not apply to the Robert Service Way area, as it does not appear to be affected by flows from the spill gates. The 1998 TGP data (which were collected under lower water temperatures) were sufficiently low that acute or chronic effects would not be anticipated, even over a long duration such as the June to September spill period. It is likely that TGP only exceeds the recommended guideline for deep water during spill conditions (typically June to September), and warmer water temperature.

The relatively low levels of DGS measured downstream of the spill gates are not surprising, given that the spill gates act as low-level ports, and the discharge appears to have a horizontal velocity component. This would tend to prevent much or most of the water from plunging to depth, where hydrostatic pressure would force gas from inside air bubbles into solution. Although some turbines may produce DGS as a result of air entrainment, at Whitehorse Rapids, turbines #1 to 3 and #4 do not produce any significant DGS.

5.2 Aishihik Generating Facility

TGP was not measured below the Aishihik Lake Storage dam. The physical characteristics of the facility are such that elevated TGP is unlikely.

In 1997 TGP was elevated in the generating facility's tailrace channel to 112.2% (ΔP= 84 mmHg, 0.6 m depth, temperature=14.8°C). The slightly lower TGP measured in 1998 (TGP=108.0%, ΔP= 55 mmHg, 1m depth, temperature=10.8°C) may be related to a cooler water temperature.

The water depth in this channel is typically very shallow. Although maximum water depths of up to 1 to 1.5 m may be found, the average water depth is much lower. During 1997, the water depth was approximately 0.2 metres on average, and 0.3 to 0.35 m in the thalweg. The utilisation of the channel or the Aishihik River to which it discharges by fish has been little studied. However, some species are thought to use this channel.

Acute signs of GBT generally occur at ΔP levels in excess of 76 mmHg, and hence were unlikely to occur in this situation. Acute signs of GBT include bubble growth in the cardiovascular system, causing blockage of blood flow and death, extracorporeal interlamella bubbles, leading to blockage of respiratory water flow and death by asphyxiation, and subdermal emphysema.

The first chronic sign of GBT is overinflation of the swim bladder, which can cause buoyancy problems, and place additional swimming demands and stress on fish. These chronic effects may eventually lead to mortalities, either directly or through increased vulnerability to predation. Other chronic signs of GBT include accumulation of gas or bubble formation in the gut and buccal cavity.

The threshold for swimbladder overinflation (Equation 1, with water pO_2=158 mmHg) is ΔP= 24 mmHg for a depth of zero metres and 83 mmHg for a depth of 0.8 m. To avoid buoyancy problems, fish would need to continually occupy habitat less than about 0.8 m deep. This exceeds the maximum depth available at various locations within the tailrace at the time of sampling. Although the duration of elevated TGP in the tailrace is unknown, it is unlikely that they will remain elevated for a sustained period of time. Thus, given the shallow water depth in this channel, the TGP at the flows prevailing during the 1997 sampling may be too high for protection of juvenile fish from chronic effects, such as swimbladder overinflation and bubble formation in the gut. If spawning occurs in the channel, there would be little risk to eggs because the internal pressure inside salmonid eggs ($\approx$ 10%) will act to offset external TGP up to 110%. Any water depth over the eggs would also provide additional protection from elevated TGP (approx. 10% for every 1 m depth). The lower TGP recorded in 1998 present less risk to juvenile fish, and little or no risk to eggs, as a result of cooler water temperatures.

5.3 Mayo Facility

TGP was not elevated downstream of the Mayo Storage Dam, and dissolved oxygen was high. The discharge of about 33 cms from the dam was high for the season but lower than would be expected at spring freshet. The freshet may occur at any time between mid May and mid June, and usually results in discharge over the overflow weir and through the gates. The overflow weir comprises a stepped structure discharging onto an apron of coarse granular material. There is no opportunity for the water to plunge to depth. TGP is therefore unlikely to be a problem.

At the Wareham Dam, TGP was slightly elevated downstream of the spillway (105.6% TGP; ΔP =39 mm Hg, at 0.6 m). The discharge from the turbines had lower DGS (103.9% TGP or ΔP = 27 mmHg, at 2 m). Acute GBT would not occur at these levels of dissolved gas tension. Using equation 1, with water pO_2 =152 mmHg, the threshold ΔP for chronic GBT is 67 mmHg at 0.6 m depth. At all locations sampled downstream of the spillway, the maximum ΔP measured in 0.6 m of water was 38 mmHg. Juvenile fish would have to continuously occupy habitat less than 0.2 m deep before ΔP levels of 38 mmHg could lead to buoyancy problems or bubble formation in the gut.

The fish species assemblage present in the Mayo River downstream of the Wareham Dam is expected to be essentially the same as that of the Whitehorse Rapids Dam, with the possible addition of spawning chum salmon. Passage has not been provided over the Wareham Dam. Successful spawning and incubation by chinook salmon does not occur upstream of the generating power plant tailrace. Emergence timing of chinook has not been determined. Habitat utilisation by emergent juveniles is less well understood than at Whitehorse Rapids Dam.

Sampling for TGP occurred late in the summer, at a time when juvenile chinook salmon would be expected to have grown to a size where they would preferentially utilise water deeper than 0.2 meters. Excursions to shallower waters would probably be limited to the pursuit of specific food items.

Temperature data (Appendix 6) suggest a weak thermocline in Wareham lake, with warmer surface water released over the spillway and slightly cooler water released through the turbines. However, the difference in temperature between water released over the spillway and that passed through turbines was small ($\approx$ 0.5°C).

It was difficult to find appropriate sampling locations below the spillway because of high water velocity and turbulent water with entrained air. When the probe is placed into water with air bubbles present, accurate TGP readings cannot be obtained. The pressure in the bubbles is greater than that in the water, and hence gas goes from the bubbles into the silastic tubing, causing very high, erroneous readings (e.g. 170% TGP).

The characteristics of the spillway suggest that TGP should be elevated. Air entrained in the spilled water appears to plunge to depth in the plunge pool, providing conditions appropriate for the elevation of TGP. However, TGP may dissipate quickly in the river downstream of the spillway. Further sampling should be conducted during spill conditions to confirm the 1998 measurements.

6.0 CONCLUSIONS

A reconnaissance of the three principal hydroelectric facilities in the Yukon was undertaken between August 19 - 26, 1997, and August 25 – 27, 1998, for the purpose of conducting spot measurements of TGP. Flows were not varied for the purposes of the measurements. Measurements were below acute levels for the species and life stages of fish that occupy the various habitats. Concern remains in regard to chronic effects on some life stages of fish in shallow water habitat, particularly during periods of warm water temperature. Recommendations for further sampling and biological investigations follow, by facility.

7.0 RECOMMENDATIONS

7.1 Whitehorse Rapids

7.1.1 Further TGP sampling

TGP should be measured during conditions of high spill volumes and warm water temperatures to determine whether the recommended guideline of 110% is met under various conditions, and to assess potential chronic effects.

7.1.2 Biological investigations

If future sampling reveals significant concern in regard to chronic effects, then biological investigations may be required. These would include fish behaviour and micro-habitat utilisation by emergent and juvenile chinook salmon in the waters downstream of the Whitehorse Rapids dam to the extent of TGP elevation, with particular emphasis on the utilisation of shallow water habitats.

7.2 Aishihik

7.2.1 Further TGP sampling

TGP should be measured in the tailrace and downstream in Aishihik River under the range of expected flows through and by the turbines. This would include periods of generation and non-generation, specifically the latter to see if hydrostatic pressure on the turbine blades or in the draft tubes generates DGS. TGP measurements during winter high releases and warmer water temperature are also particularly important. The duration of elevated TGP should also be estimated to determine whether the exposure period is long enough to cause chronic effects.

7.2.2 Biological investigations

Seasonal utilisation, by fish species and life history, stage of waters of the tailrace and the Aishihik River downstream of the tailrace should be determined. This information will be useful for assessing exposure, and the effects of TGP measurements on fish found in the tailrace channel.

7.3 Mayo

7.3.1 Further TGP sampling

As noted above, TGP measurements in the Mayo River downstream of the Wareham dam spillway were considered to be lower than expected, based on the volume of spill and the spillway configuration. A further limited program of measurement is recommended under a high flow and a moderate flow regime to confirm that spill does not elevate TGP to levels of concern. Decisions on further sampling should be made at the conclusion of the analysis of the data from these tests.

Further sampling is not required at the Mayo Storage Dam.

7.3.2 Biological investigations

If future sampling reveals elevated TGP downstream of the Wareham Dam spillway, then biological investigations may be required to determine exposure and potential effects. Emergence periods for Mayo River chinook salmon, and subsequent behaviour and micro-habitat utilisation by juvenile chinook salmon should be determined, with particular emphasis on the utilisation of shallow water habitats.

8.0 ACKNOWLEDGEMENTS

We would like to thank Yukon Energy Corporation for their cooperation in this study. We would also like to thank Gail Faulkner and others for providing review comments on the manuscript.

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APPENDIX 1: Photographs

Photo. #1 Whitehorse Rapids Dam showing discharge from two spill way gates.

Photo. #2 Whitehorse Rapids Dam showing discharge from two spill way gates, and fish screens blocking fish access into the turbine unit #4 tailrace. Sampling site WRD2 located 75m downstream of fish screens on east river bank.

Photo. #3 Sampling at site WRD1, the Yukon River downstream of the spill gates at Whitehorse Rapids Dam, and immediately upstream of the fish collection chamber and weir, east bank.

Photo. #4 Tailrace channel at Aishihik Generating Station.

Photo. #5 Sampling in the Aishihik tailrace channel (site: AD1)

Photo. #6 Mayo Storage Dam. The downstream sampling site (MSD1) was located near the large rock in the left-hand corner of the photo.

Photo. #7 Wareham Lake Dam and spillway. The inlet to the generating facility is located immediately upstream of the dam on the east side of the river.

Photo. #8 Wareham Lake Dam generating station on the Mayo River, approximately 500 m below the Wareham Lake Dam and spillway structure.

Photo. #9 Wareham Lake Dam spillway.

APPENDIX 2A: 1997 Raw Data for Whitehorse Rapids

Site*	Date	Time	Depth m	Meter	P_T mmHg	P_T %	BP mmHg	ΔP mmHg	pO_2 mmHg	O_2 mg/l	O_2 % Sat.	$P_T - pO_2$ % Sat.	$P_T - pO_2$ mmHg	Temp. °C
WRU1	08/19/97	16:48	3	1	724	102.8	703	20	147	9.4	-	103.3	-	15.1
		16:48	3	2	720	102.4	703	17	158	-	106.2	-	563	15.2
		17:10	1	1	715	101.7	703	12	147	9.4	-	101.8	-	15.2
		17:10	1	2	714	101.5	703	10	159	-	107	-	554	15.2
WRU2	08/19/97	15:10	3	1	719	102.2	704	15	149	9.5	-	102.2	-	15.2
		15:10	3	2	718	102.0	704	14	151	-	102.3	-	567	15.2
WRD1	08/22/97	11:10	1.6	1	791	113.5	697	94	158	10.2	-	114.9	-	14.9
		11:10	1.6	2	790	113.5	697	94	159	-	107.8	-	632	14.9
WRD2	08/22/97	11:50	1.5	1	773	110.7	697	76	155	10.0	-	11.7	-	15.0
		11:50	1.5	2	771	110.7	697	74	155	-	105.9	-	615	14.9
WRD3	08/19/97	11:15	3	1	725	102.7	707	18	147	9.5	-	103.3	-	14.8
		11:15	3	2	728	102.4	712	17	151	-	100.6	-	577	14.8
WRD4	08/20/97	11:50	1	1	721	102.2	706	15	144	9.3	-	103.0	-	15.0
		11:50	1	2	717	101.4	707	10	145	-	97	-	571	15.1
WRD5	08/20/97	12:15	2	1	727	102.9	707	20	143	9.2	-	104.3	-	15.1
		12:15	2	2	707	102.2	721	15	140	-	94.9	-	580	15.1
WRD6	08/20/97	12:45	2.8	1	746	105.5	706	39	150	9.6	-	106.3	-	15.2
		12:45	2.6	2	747	105.8	707	40	153	-	101.9	-	595	15.2
WRD7	08/20/97	14:27	3	1	753	106.5	707	46	148	9.5	-	108	-	15.1
		14:27	3	2	751	106.4	707	45	149	-	100.2	-	602	15.1
WRD8	08/20/97	15:20	1.5	1	754	106.8	706	49	148	9.4	-	108.4	-	15.6
		15:20	1.5	2	752	106.5	707	46	150	-	101.5	-	602	15.5
WRD9	08/20/97	16:00	3	1	760	107.7	706	55	150	9.5	-	109	-	15.5
		16:00	3	2	754	106.9	706	48	150	-	100	-	606	15.6

APPENDIX 2B: 1997 Sampling Sites for Whitehorse Rapids

Site*:	Description:
WRU1:	Schwatka Lake, approximately 2.5 km upstream of Whitehorse Rapids Dam (opposite Chadburn lake boat launch), in centre of channel. Upstream control site 1.
WRU2:	Yukon R., approximately 6 km upstream of Whitehorse Rapids Dam (about 300m downstream of Canyon City), along the west bank. Upstream control site 2.
WRD1:	Yukon R., downstream of spill gates at Whitehorse Rapids Dam, and immediately upstream of fishway collection chamber and weir, along the east bank. This site measures elevated DGS from spill gates only.
WRD2:	Yukon R., downstream of spill gates and weir, and 75m downstream of the confluence of #4 turbine flow, along with east bank. Directly across from Yukon Energy Corporation. This site measures DGS contribution from spill gates and #4 turbine.
WRD3:	Yukon R., in tailrace of #4 turbine, approximately 100m upstream from the fish screens, along the north-west bank. This site measures DGS from #4 turbine.
WRD4:	Yukon R., 1.5 km downstream from Whitehorse Rapids Dam, immediately downstream from Robert Service Way Campground along the west bank. This site measures mainly flow from #1, 2, and 3 turbines.
WRD5:	Yukon R., 1.8 km downstream from Whitehorse Rapids Dam, adjacent to Robert Service Way, along the west bank. This site appears to measure mainly flow from #1, 2, and 3 turbines.
WRD6:	Yukon R., 4 km downstream from Whitehorse Rapids Dam, 50m upstream of WP&YR railway station (at the foot of Main Street), on the west bank. This site is well-mixed, and it measures combined flow from spillway gates, turbine #4, and #1,2, and 3 turbines.
WRD7:	Yukon R., 9.5 km downstream from Whitehorse Rapids Dam, and 300 m upstream of mouth of MacIntyre Creek, east bank. This site is well-mixed.
WRD8:	Yukon R., 9.7 km downstream from Whitehorse Rapids Dam, and 100 m upstream of mouth of MacIntyre Creek, west bank. This site is well-mixed.
WRD9:	Yukon R., 12.5 km downstream from Whitehorse Rapids Dam, and 300 m downstream of Croucher Creek, centre of channel. This site is well-mixed.

APPENDIX 3: 1998 Raw Data and Sampling Sites for Whitehorse Rapids

Site*	Date	Time	Depth m	Meter	P_T mmHg	P_T %	BP mmHg	ΔP mmHg	pO_2 mmHg	O_2 mg/l	O_2 % Sat.	$P_T - pO_2$ % Sat.	$P_T - pO_2$ mmHg	Temp. °C
WRU3	08/25/98	15:50	1	1	710	102.4	694	17	132	9.1	93	-	566	12.9
	08/26/98	13:40	1	1	713	102.5	695	18	134	9.0	-	-	568	12.9
WRD1	08/26/98	10:40	1.5	1	722	103.6	697	26	155	10.4	-	-	555	12.9
		11:00	0.5	1	727	104.3	697	30	152	10.3	-	-	563	12.9
WRD2	08/25/98	16:45	1.0	1	770	110.7	696	74	143	9.7	-	-	616	12.8
	08/26/98	13:15	1.0	1	717	103.1	696	22	155	10.4	-	-	551	12.9
" D5A	08/16/98	14:25	1.5	1	707	101.7	696	11	139	9.4	-	-	556	12.9
		14:25	1.0	1	707	101.6	696	11	137	9.2	-	-	559	12.9
" D6B	08/26/98	15:00	1.5	1	709	101.7	697	12	150	10.1	105	-	548	12.9
		15:00	1.0	1	709	101.8	697	13	150	10.1	104	-	547	12.9

Site*: Description:

WRU3: Yukon R., east side, just upstream of Whitehorse Rapids Dam, across from marina. Approx. 3m upstream of the water inlet for the fishway. Upstream control site 3.

WRD1: Yukon R., downstream of spill gates at Whitehorse Rapids Dam, and immediately upstream of fishway collection chamber and weir, along the east bank. This site measures elevated DGS from spill gates only.

WRD2: Yukon R., downstream of spill gates and weir, and 75m downstream of the #4 turbine flow, along east bank. Directly across from Yukon Energy Corporation. This site measures DGS contribution from spill gates and #4 turbine.

WRD5A: Yukon R., adjacent to Robert Service Way at the viewing platform approximately100m south of the northern end of the walkway (closest to the Robert Service Way campground). Similar to 1997 sampling site, using shore (not boat) access.

WRD6A: Yukon R. downstream from Whitehorse Rapids Dam at the WP&YR railway station (just opposite the train station), along the west bank. This site was very close to the location sampled in 1997 (within 500 m). This site is well-mixed, and it measures combined flow from spillway gates, turbine #4, and #1,2, and 3 turbines.

APPENDIX 4: 1997 Raw Data and Sampling Sites for Aishihik

Site*	Date	Time	Depth m	Meter	P_T mmHg	P_T %	BP mmHg	ΔP mmHg	pO_2 mmHg	O_2 mg/l	O_2 % Sat.	$P_T - pO_2$ % Sat.	$P_T - pO_2$ mmHg	Temp. °C
AU1	08/21/97	16:40	3	1	705	104.2	677	27	146	9.9	-	103.9	-	12.6
		16:40	3	2	698	103.1	678	21	143	-	100.2	-	555	12.7
AU2	08/21/97	15:34	2	1	707	104.2	678	30	147	9.9	-	103.7	-	13.2
		15:34	2	2	706	104.1	678	28	143	-	143	-	565	13.3
AU3	08/21/97	14:30	2	1	695	102.5	677	17	133	9.0	-	104.6	-	14.6
		14:30	2	2	686	101	679	7	136	-	93.8	-	55	14.6
AD1	08/21/97	12:20	0.6	1	779	112.3	693	86	159	10.3	-	112.7	-	14.8
		12:20	0.6	2	777	112.0	695	82	157	-	107	-	620	14.8
AD2	08/21/97	18:15	0.6	1	711	102.2	695	15	142	9.2	-	103.1	-	14.7
		18:15	0.6	2	711	102.3	696	16	146	-	100.7	-	564	14.7

Site*: Descriptions:

AU1: Aishihik Lake, 500m upstream of control structure, centre of channel. Upstream control site 1.
AU2: Aishihik Lake, immediately upstream of control structure. Upstream control site 2.
AU3: Immediately u/s of Canyon Lake control structure. Upstream control site 3.
AD1: Tailrace channel (east side), 250m upstream of confluence of east and west Aishihik River, and tailrace. Site measures flow from power canal
AD2: Aishihik River (east side), 8 km downstream of confluence of east and west Aishihik River, and tailrace channel. This site measures flow from power canal, after dilution by east and west Aishihik River

APPENDIX 5: 1998 Raw Data and Sampling Sites for Aishihik

Site*	Date	Time	Depth m	Meter	P_T mmHg	P_T %	BP mmHg	ΔP mmHg	pO_2 mmHg	O_2 Mg/l	O_2 % Sat.	$P_T - pO_2$ % Sat.	$P_T - pO_2$ mmHg	Temp. °C
AD1	08/27/98	10:50	1.5	1	747	108.5	689	58	150	10.5	105.0	103.9	587	10.8
		10:50	1.0	1	744	108.0	688	55	145	10.3	-	-	588	10.8

Site*: Descriptions:

AD1: Tailrace channel (east side), 250m upstream of confluence of east and west Aishihik River, and tailrace. Approximately same sampling location as in 1997 (within 75m). Site measures flow from power canal.

APPENDIX 6: 1997 Raw Data for the Mayo Facility

Site*	Date	Time	Depth m	Meter	P_T mmHg	P_T %	BP mmHg	ΔP mmHg	pO_2 mmHg	O_2 mg/l	O_2 % Sat.	P_T - pO_2 % Sat.	P_T - pO_2 mmHg	Temp. °C
MSU1	08/26/97	16:00	2	1	725	104.2	695	30	153	10.1	-	103.7	-	13.3
		16:00	2	2	724	104.1	695	29	153	-	104	-	570	13.4
MSD1	08/26/97	17:00	0.8	1	720	103.4	696	24	147	9.8	-	103.8	-	13.3
		17:00	0.8	2	-	103.2	-	-	-	-	-	-	-	-
MSD2	08/26/97	17:40	0.8	1	725	104.3	696	30	150	10.0	-	104.3	-	13.5
		17:40	0.8	2	-	-	-	-	-	-	-	-	-	-
MWU1	08/26/97	10:15	3	1	720	102.6	702	18	138	9.4	-	104.6	-	12.3
		10:15	3	2	728	103.6	703	25	139	-	93.8	-	588	12.3
		10:20	2	1	717	102.0	703	14	139	9.5	-	103.6	-	12.2
		10:20	2	2	720	102.4	703	17	138	-	93.5	-	581	12.3
		10:30	1	1	716	101.9	702	14	140	9.5	-	103.4	-	12.4
		10:30	1	2	717	102.1	703	14	139	-	93.7	-	578	12.4
MWD1	08/26/97	11:45	0.6	1	746	105.5	707	38	154	10.5	-	105.4	-	12.1
		11:45	0.6	2	747	105.7	707	40	155	-	104.4	-	591	12.1
MWD2	08/26/97	11:28	2	1	734	103.7	707	26	148	10.2	-	104.4	-	11.6
		11:28	2	2	734	104.0	707	27	149	-	100.1	-	585	11.8
MWD3	08/26/97	12:10	0.6	1	745	105.3	707	38	152	10.4	-	105.7	-	12.1
		12:10	0.6	2	745	105.4	707	38	154	-	102.8	-	592	12.2
MWD4	08/26/97	14:00	1.6	1	732	103	710	22	149	10.1	-	103.3	-	12.8
		14:00	1.6	2	730	102.9	710	20	151	-	100.9	-	578	12.9

APPENDIX 7: 1997 Sampling Sites for the Mayo Facility

Site*:	Description:
MSU1:	Mayo Lake, approximately 400 m upstream of Mayo dam, centre of old river channel. Upstream control site.
MSD1:	Mayo River, approximately 60 m downstream of Mayo Dam, north side of river. Measures undiluted flow from Mayo Dam.
MSD2:	Mayo River at Davidson Creek bridge, south-east side (approx. 3 km downstream of Mayo Dam). Well-mixed site.
MWU1:	Mayo River, upstream (u/s) of Wareham dam, at the inlet to the generating station. Upstream control site.
MWD1:	Mayo River, downstream of spillway (but upstream of turbine outflow). Site measures flow from spillway only.
MWD2:	Mayo River, at outflow from westerly turbine. Site measures flow from turbines only (flow from spillway is separated by a weir).
MWD3:	Mayo River 100m downstream of turbine outflow (also downstream of spillway), east bank. Site measures flow from spillway and turbines.
MWD4:	Mayo River at Silver Trail Bridge (approx. 9 km downstream of Wareham Dam), east bank. Well-mixed site.