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Total Gas Pressure

REPORT

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1.0 INTRODUCTION

With the cancellation of the proposed Kemano Completion Project (KCP) by the Province of British Columbia in 1995, Alcan and the province reached an agreement in 1997 to establish the Nechako Environmental Enhancement Fund (NEEF). A management committee was set up to decide how this fund should be administered and in 2001 a decision was made that the best use of the funds would be for the construction of a cold water release facility (CWRF) at Kenney Dam (Figure 1). Currently, water is released from the Nechako Reservoir at the Skins Lake Spillway, some 87 km west of Kenney Dam.

The proposed CWRF would be constructed with multiple objectives in mind, including the continued conservation of salmon species that use the Nechako River (as required under the 1987 Settlement Agreement) and release of water during the summer months to manage the river water temperatures and flows. In the context of fish requirements in the Nechako River, questions have been raised related to potential total gas pressure (TGP) levels downstream of the facility.

The Nechako Watershed Council (NWC) was formed in 1998 to provide a forum for the diverse interests in the Nechako Watershed and the communities that depend on the watershed. The intent was to work cooperatively in addressing long-standing water management and related issues. In 2002, NWC and provincial government representatives released a work plan that would lead to the construction of the CWRF at Kenney Dam. The plan, prepared by NWC, outlined the activities and costs of further studies required prior to construction of the CWRF (NWC, 2002). The plan duration is 11-years and includes a logical sequence of studies and investigations leading to the construction of the CWRF. The proposed work activities for year 2 of the plan are part of a Pre-Engineering and Environmental Review component that include the following activities:

- Activity No.1. Fish Entrainment Studies at Kenney Dam
- Activity No.2. Establishment of Release Water Temperature Criteria
- Activity No.3. Examination of Total Gas Pressure Effects on Fish

As part of Activity No.3, Triton Environmental Consultants Ltd. (Triton), in association with Dr. Larry Fidler of Aspen Applied Sciences Ltd. and Mr. Chris Wilson of Klohn Crippen Consultants Ltd., has undertaken the following eight key tasks to determine if the design alternative proposed by the Nechako Environmental Enhancement Fund Management Committee (NEEFMC) will meet current federal and provincial total gas pressure (TGP) criteria and objectives, or if site-specific criteria and objectives would need to be developed:

1. Review the current provincial and federal TGP criteria and objectives, focusing on the work recently done by Antcliffe, Fidler and Birtwell towards a new Interim Criteria.

2. Re-examine past work on TGP production undertaken for the proposed Kemano Completion Project Release Facility.

3. Establish and operate a TGP and temperature monitoring program in Knewstubb Arm and at Cheslatta Falls during the ice-free period in May to late October using continuous TGP monitoring devices. Measure TGP levels in the Cheslatta - Murray Lake System between the Skins Lake Spillway and Cheslatta Falls, including key locations along the Cheslatta River. Use the monitoring results to establish whether solar heating or primary production lead to dissolved gas supersaturation at these locations.

4. Review the available scientific literature to identify analytical studies of the gas transfer characteristics of flip bucket spillways and/or measurements of the production of TGP downstream of flip bucket spillways at existing facilities with a view to estimating the TGP levels likely to be produced by the NEEFMC design concept.

5. Set up the Triton dissolved gas model using estimated TGP levels for Kenney Dam (both in the reservoir and downstream of the flip bucket spillway and the low level outlet) along with dissolved gas production and dissipation for the Cheslatta River under the expected future discharge conditions (as proposed by the NWC), and Cheslatta Falls to estimate TGP levels in the Nechako River below Cheslatta Falls.

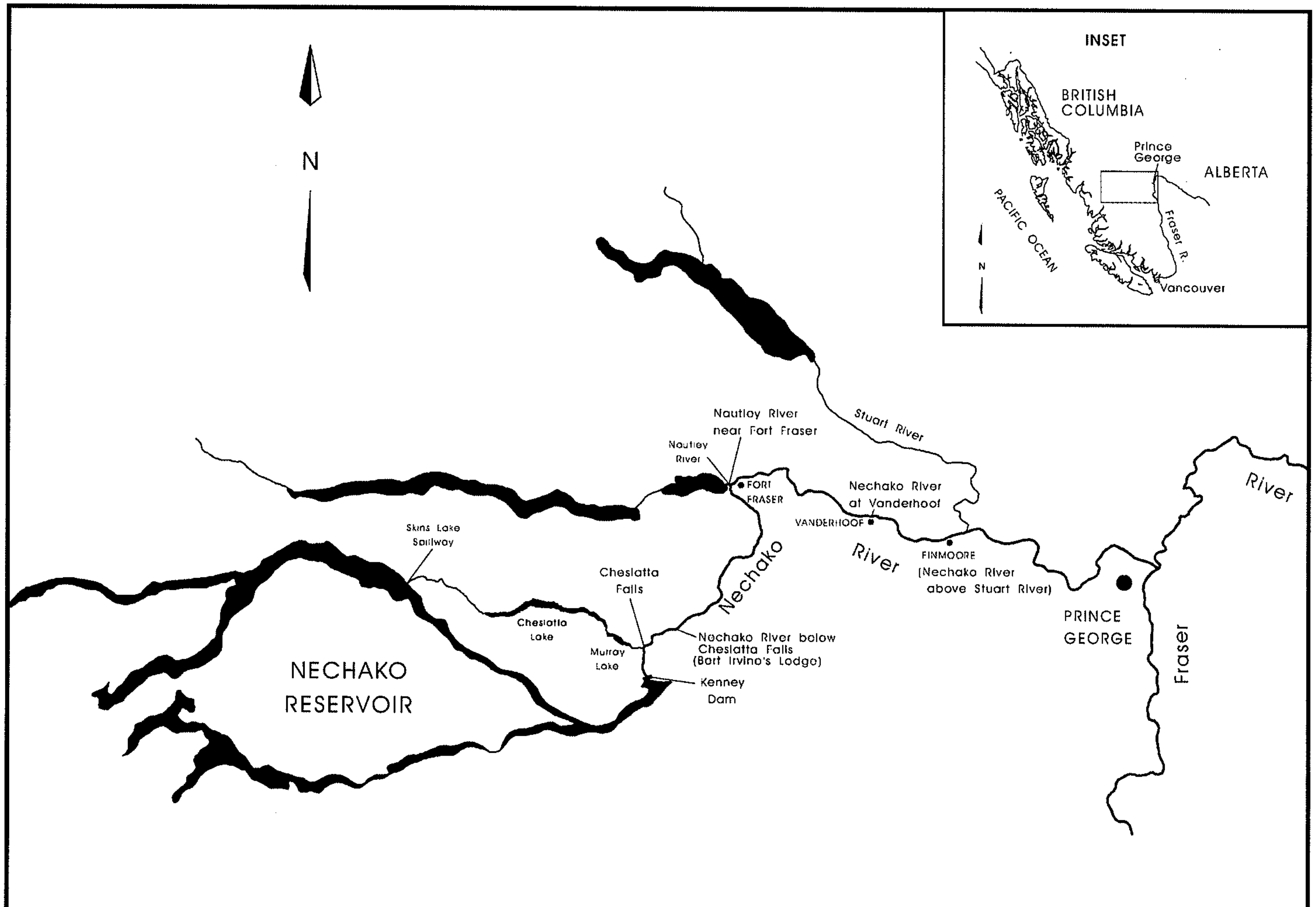
6. Review previous studies of Kenney Dam and other facilities to establish whether the hollow cone valves of the low-level discharge facility will generate dissolved gas supersaturation.

7. Identify fish species using the river that have not been examined for their susceptibility to dissolved gas supersaturation. Establish whether predicted river TGP levels are compatible with the federal and provincial guidelines. If not, consider provisions for a site-specific guideline.

8. Provide recommendations regarding the need for additional studies such as prototype and physical hydraulic model studies that could be needed to estimate the TGP that would result from operation of the proposed spillway and the ability of the NEEFMC design concept to meet current federal and provincial objectives.

The objective of this report is to present, for each task, the findings of the work done to date.

Figure 1. Nechako River Watershed



NES BACKGROUNDER | Map Ref 3473

FIGURE 1. NECHAKO RIVER WATERSHED

2.0 BACKGROUND

The feasibility of constructing and operating a CWRF at Kenney Dam has been investigated at various times since 1950 and most recently during the studies for the now cancelled KCP. These studies followed the signing of an agreement, the 1987 Settlement Agreement (Anonymous, 1987), settling a legal dispute between Alcan, the Provincial Government and the Federal government. The intent of the Agreement was to ensure the conservation of the Nechako River chinook salmon (*Onchorhynchus tshawytscha*) and protect migrating sockeye salmon (*O. nerka*) that use the Nechako River as a corridor to tributary rivers while allowing further hydroelectric development on the Nechako River.

The 1987 Settlement Agreement indicated that, should Alcan wish to complete and operate the proposed expanded hydroelectric project it first had to design and construct a multilevel water release facility at Kenney Dam. The purpose of the facility was to:

- Release cooler, hypolimnetic water from the Nechako Reservoir during the summer months; and,
- Release the water to achieve fish protection year round.

Between 1988 and early 1991 the Kemano Completion Project Design Team completed studies to establish a design concept for this facility that would meet the fish protection criteria. The Kemano Completion Project Design Team issued its report in March 1991, including a summary of the design concepts and criteria for the Kenney Dam Release Facility (Triton and Klohn Leonoff, 1991).

The design of the water release facility was formally approved on March 25, 1993 (KDRF, 1993). However, the Kemano Completion Project was cancelled in 1995 by the provincial government and the proposed structure was not constructed. The studies completed as part of the design development and approval process are a starting point for the current investigations.

As noted above, the NEEFMC re-examined the CWRF idea and directed that the fund be used to construct a CWRF at the Kenney Dam. Given the cancellation of the Kemano Completion Project, most of the design criteria for the earlier concept need to be revisited. For example, the Province of British Columbia has recently revised the B.C. Water Quality Guidelines for Dissolved Gas Supersaturation (Fidler, 2004). The revised guidelines have a direct bearing on allowable TGP levels in the Nechako River below the CWRF as the guideline for allowable TGP has been increased from 103% (as used with the KCP design) to 110%. Further, the new guidelines also permit development of site-specific TGP% limitations.

2.1 Proposed Facility

The NEEF Management Committee initially considered seven configurations for a CWRF at Kenney Dam. A preferred configuration was subsequently selected (Klohn Crippen, 2001) (see Figure 2). Conceptual layout, hydraulic capacities, construction planning and cost estimate are available in the 2001 Klohn Crippen report prepared for NEEF Management Committee: Water Release Facility at Kenney Dam, Updated Conceptual Layout and Cost Estimate.

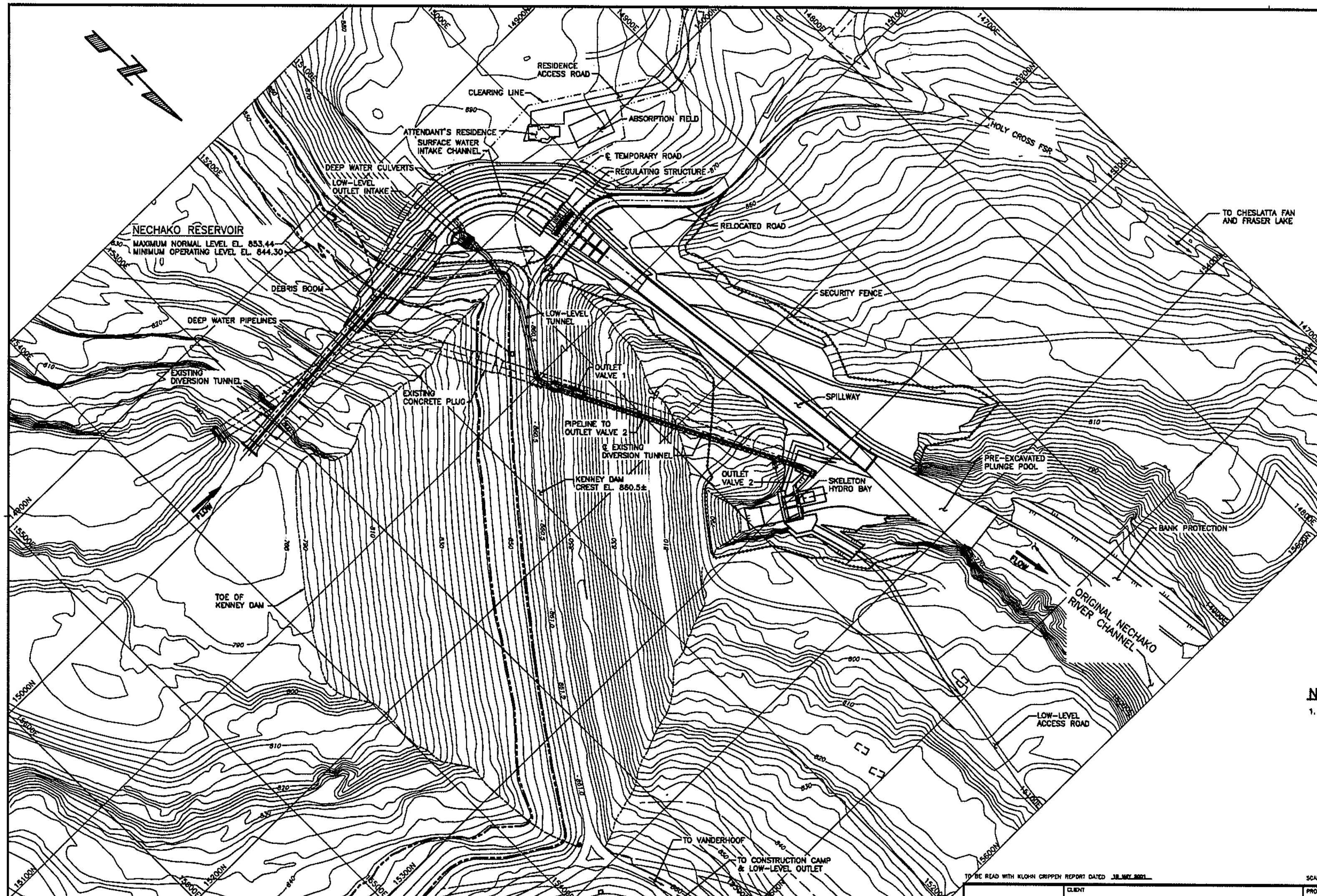
In summary, the main components of the preferred CWRF include:

- A surface-water intake channel;
- Deep-water intakes and pipelines;
- A high-level outlet regulating structure, capable of releasing water from the reservoir surface or from deep water sources, either individually or simultaneously;
- A surface spillway equipped with a flip bucket energy dissipater;
- A low-level outlet structure capable of releasing water from the reservoir surface or from deep water sources, either individually or simultaneously; and,
- The low level outlet equipped with one or more hollow-cone valves for energy dissipation and dissolved gas control.

2.2 Total Gas Pressure

Elevated total gas pressure (TGP, the sum of the partial pressures of all dissolved gases in solution: oxygen, nitrogen, water vapor, and trace gases such as argon and carbon dioxide) has been observed for many years downstream of hydroelectric facilities. Elevated levels of these gases in solution occur when water and entrained atmospheric gases are forced together under pressure in deep plunge pools below dam spillways (Shrimpton *et al.*, 1990a and b; Fidler and Miller, 1997). Aquatic organisms exposed to elevated TGP levels can develop a condition known as gas bubble trauma (GBT). Gas bubble trauma is typically characterized by the formation of gas bubbles internally and/or externally to the organism that can result in a blockage of the circulatory system, over-inflation of the swim bladder, sub-dermal lesions or extracorporeal bubble formation. Secondary consequences of high TGP levels may include impaired locomotion, increased predation, as well as an increased susceptibility to bacterial, viral, and fungal infection (Fidler and Miller, 1997).

GBT occurs when the total gas pressure exceeds atmospheric pressure. The difference between TGP and atmospheric pressure is expressed as the differential pressure (ΔP), and is positive when water is supersaturated. ΔP is usually reported in millimetres of mercury (mmHg), and TGP as a percent of sea level or local atmospheric pressure (TGP%) (Shrimpton *et al.*, 1990a and b; Fidler and Miller, 1997; Schisler and Bergersen, 1999).



NOTES:

1. TOPOGRAPHY BASED ON McELHANNEY GEOSURVEYS LTD. TOPOGRAPHIC PLAN DATED SEPTEMBER 1988 AND ON McELHANNEY ENGINEERING SERVICES LTD. SOUNDINGS PLAN DATED OCTOBER 1988.

SCALE 0 — 100m

TO BE READ WITH KLOHN CRIPPEN REPORT DATED 18 MAY 2001

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CLIENT	NECHAKO ENVIRONMENTAL ENHANCEMENT FUND
	KLOHN CRIPPEN
PROJECT	WATER RELEASE FACILITY AT KENNEY DAM
TITLE	CONCEPTUAL LAYOUT CASE E PLAN
PROJECT No.	PP1229 03
FIG. No.	FIGURE 1

3.0 TGP CRITERIA AND OBJECTIVES

3.1 Background

Earlier design criteria for the water release facility included a criterion TGP level near the toe of the dam which should be below 103% to achieve the "no risk" criteria adopted at the time (Triton and Klohn Leonoff, 1991). Since that time, new research has resulted in the guidelines for TGP for the protection of fish and other aquatic biota in shallow and deepwater habitat being updated (Fidler and Miller, 1997; Fidler, 2004). The following sub-sections outline the main points and findings of the revised guidelines.

3.2 Current TGP Criteria and Objectives

The Province of British Columbia has recently revised the B.C. Water Quality Guidelines for Dissolved Gas Supersaturation (Fidler, 2004). The revised guidelines will have a direct bearing on allowable TGP levels in the Nechako River below the CWRF. Although the final design for this portion of the facility is incomplete at this time, it is important to note that, since 1989, the maximum allowable TGP increased from 103% to 110% and that the guideline now allows for the development of site-specific TGP% limitations.

3.2.1 Criteria and Guideline Components

The original guidelines were derived following two principles:

- Protection of all fish species of all sizes in deep water environments from the effects of gas bubble trauma (GBT); and,
- Protection of juvenile fish from swimbladder over-inflation, over-buoyancy, or rupture in shallow water, including hatchery environments.

To satisfy these criteria, the guideline was divided into four separate components. The first three will be discussed below as the fourth relates only to hatchery environments.

- Guideline A
  For Water Depths Greater than One Metre: Where local water depth at a given location in a water body exceeds one metre, the maximum ΔP should not exceed 76 mmHg regardless of water ${}_{P}O_2$ levels. For sea level conditions, this corresponds to a TGP% of 110%.

- Guideline B
  For Water Depths Less than One Metre: Where local water depth at a given location in a water body is less than one metre, the guideline should be based on the following equation, which describes the threshold for swim bladder overinflation as a function of water depth and ${}_{P}O_2$ levels.

$$\Delta P_{SB} = 73.89 * h + 0.15 * {}_{P}O_2 \tag{1}$$

Where;
ΔP_{SB} = water ΔP required to initiate over-inflation of the swim bladder in rainbow trout.

h = water depth at which the fish is located in metres.

${}_{P}O_2$ = partial pressure of dissolved oxygen (mmHg) in the environmental water.

However, the maximum ΔP should not exceed 76 mmHg regardless of ${}_{P}O_2$ level. The most conservative application of the guideline will be to use Equation 1 with h = 0. For example, at a water depth of zero metres and a ${}_{P}O_2$ of 157 mmHg, the ΔP must not exceed 24 mmHg. This corresponds to a TGP% of ~ 103% at sea level. This would apply to shallow water bodies and for stream margins, where the entire area less than one metre depth is used by juvenile fish.

- Guideline C
  For Natural Background Levels Higher than the Recommended Guideline: If natural background levels of dissolved gas saturation exceed the recommended guidelines, there should be no increase in the ΔP or %TGP over the background levels. This recognizes that background levels that are higher than the recommended guidelines may be harmful to fish, and hence, any increase over background levels should not be tolerated for the protection of aquatic life.

3.2.2 Guideline Limitations

These guidelines were developed from steady state dissolved gas saturation exposures in laboratory or hatchery environments, usually involving shallow water and long exposure periods. Fish were often held in confined spaces with little swimming freedom. Some of the data upon which Guideline B is based involve restrained anesthetized juvenile fish. Consequently, the guidelines have some limitations as they do not recognize that water depth in rivers, lakes, and oceans, combined with fish depth behaviour can dramatically alter the ΔP exposure of fish and the corresponding GBT responses. Also, there are many fish species for which sensitivity to dissolved gas saturation is still unknown (*e.g.*, white sturgeon – Fidler, 2004).

3.2.3 Guidelines Application, Issues and Recommendations

A major challenge related to the application of the guidelines is to reconcile the differences between the laboratory environments in which the guideline data were developed and river, lake, and marine environments where physical and biological conditions can be much different.

Some of the physical and biological considerations are listed below:

- Variations in TGP with Time and Location (Hourly, Seasonally, and Yearly Variations);
- Variations in Flow and Compensation Depths (Hourly, Seasonally, and Yearly);
- Variations in Water Temperature (Hourly, Seasonally, and Yearly);
- Variations in Water Dissolved Oxygen (Primary Production);
- Turbine Passage;
- Spillway Passage;
- Site Specific Special Conditions;
- Ecosystem Structure;
- Migratory/Resident Species;
- Fish Behaviour, Including Depth Behaviour (i.e., Dynamic Exposures);
- Species Susceptibility (Acute and Chronic);
- Species Life Stage Susceptibility (Acute and Chronic);
- Hydrostatic Pressure;
- Habitat Use (Species, Age Class, Daily Use, Seasonal Use, Flow Dependence, and/or Temperature Dependence);
- Predation;
- Disease; and,
- Other Stress Factors (Other Pollutants, Physical Damage to the Ecosystem, etc.).

The issues identified while revising the guidelines (Fidler, 2004) included:

- Dissolved gas saturation Guideline B is unnecessarily conservative for protecting juvenile fish from swim bladder over inflation in rivers, lakes, and oceans.

- Dissolved gas saturation Guideline A (maximum sea level TGP = 110%) would provide adequate protection for juvenile fish from the effects of swim bladder over-inflation.

- Data from the literature that were used to derive dissolved gas saturation Guideline A are inconsistent and compromised by uncertainties regarding experimental methods and the reporting of TGP levels.

- The cause of mortality in fish exposed to dissolved gas saturation in the 110% to 115% range under steady state TGP and shallow water is unknown.

- The response of fish to dissolved gas saturation differs dramatically from one water body to another with available water depth in relation to the required compensation depth being an important factor.

- A single numerical guideline for free swimming fish in rivers, lakes and oceans is not practical since it cannot account for differences in the physical and biological environments that affect the response of fish to dissolved gas saturation.

In view of the above listed issues, it has been recommended that dissolved gas saturation Guideline B, as a criterion for protecting juvenile fish from the effects of swim bladder over inflation, be replaced with a new guideline that allows for the development of site specific (i.e., specific river, lake, or ocean location) guidelines for TGP. These recommendations are reflected in the Water Quality Guidelines for Total Pressure published online and updated in September 2004.
http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/tgp/tgp_over.html

3.2.4 Site Specific Guidelines (Revised Guideline B)

Site specific guidelines (Fidler, 2004) would be developed from comprehensive field studies of the actual aquatic or marine environment, perhaps supplemented with laboratory studies and computer modeling. The field studies would include aquatic or marine depth profiles as a function of controlling hydraulic parameters (runoff patterns, hydrographs, dam discharges, tides, etc.), fish species – age class distributions, habitats and seasonal use by species and age class, species and age class depth behaviour, gas bubble trauma impact studies, as well as temporal and spatial TGP distributions.

For a specific water body, studies would essentially identify the physical and biological parameters that affect species susceptibility to dissolved gas saturation/gas bubble trauma (DGS/GBT) and their integrated functional effects on the susceptibility of fish to DGS/GBT. Special attention would be given to species that have not been examined for their susceptibility to DGS/GBT.

The resulting site specific TGP guideline B might be above or below the TGP value specified by a revised Guideline A.

Given the overall size and geography of British Columbia, Fidler (2004) considers that a "one size fits all" approach would not adequately address the needs of society or the environment. To this end, a two-tiered approach to guideline development was recommended:

1. Canada-wide (British Columbia–wide) interim numeric temperature, TGP, and $_{P}O_2$ guidelines are suggested to provide generic/conservative protection to designated uses until such time as:

2. A surface water use classification is completed at a regional scale. The water use classification approach is recommended to distinguish differences in temperature, TGP and $_{P}O_2$ quality among the diversity of aquatic environments throughout Canada (British Columbia).

The process should further distinguish what water uses are practical and what level of temperature, TGP, and $_{P}O_2$ modifications are acceptable within the diversity of existing temperature, TGP and $_{P}O_2$ regimes provided in nature.

4.0 REVIEW OF PAST WORK ON TGP PRODUCTION

The subject of total gas pressure has been investigated by Alcan and the government agencies over the past two and one half decades, mainly in association with proposals to expand the Kemano hydroelectric project and construct a water release facility at Kenney Dam. These studies have included measurement of total gas pressure at Cheslatta Falls, expected re-aeration rates for atmospheric and dissolved gases over the upper 100 km of the river and studies of the expected TGP production rates at or near the proposed facility at Kenney Dam.

As noted above, total gas pressure is the sum of the partial pressures of the components of air (mainly nitrogen, oxygen, water vapor and argon) dissolved in water. In nature, the dissolved gases should be in balance with the atmosphere in proportion to their availability in air, the current atmospheric pressure and the water temperature. This state is known as 100% saturation. However, if mixtures of air (as in bubbles) and water are plunged to depth below a waterfall or spillway, the increased hydrostatic pressure will force air from the bubbles into solution. This results in an over-saturation condition (expressed as % saturation > 100%). This happens currently at Cheslatta Falls (see Section 5.0).

Previous work focused on two aspects of a proposed water release facility at Kenney Dam:

- Control of TGP during flood or cooling water releases (at flows > 60 m3/s); and,
- Control of TGP in releases from the proposed low-level outlet during the rest of the year.

The most detailed studies were conducted in the late 1980's as part of Alcan's proposed KCP project and looked at both TGP created with major releases and releases made through the low level outlet. These studies were conducted to find methods of releasing water from the then proposed facility to meet a criterion of 103% saturation within 1 km of the dam. This resulted with the selection of a spillway design (a baffle-block spillway) that was very expensive in the context of today's proposed releases and is not included in the NEEFMC proposed design. Thus, this work is not applicable to the case currently being considered.

However, the KCP design did consider the use of a hollow-cone valve to dissipate energy and control total gas pressure in the water released from the low level outlet and therefore the conclusions of the KCP studies are directly applicable to the NEEF MC design. The results in documented studies (Tennessee Valley Authority, 1967) and from hydraulic model tests (Northwest Hydraulic Consultants Ltd., 1991) were reviewed in Triton and Klohn Leonoff (1991). The studies indicated that the gas transfer efficiency of the hollow cone valve prototype would be expected to be 88% to 90% resulting in TGP levels from the low level outlet between 100% and 103% saturation. Given that the NEEFMC conceptual design for the low level outlet includes a similar hollow cone valve, , it is concluded, based on the results of the KCP studies, that similar TGP levels would be expected with this design, assuming a similar ratio between tail water elevation and the elevation of the centerline of the hollow-cone valve, or valves, was maintained.

As noted earlier, the NEEFMC decided that the design for the spillway should be changed from a baffle block spillway that was proven to control TGP at the toe of the dam with the KCP design to a more economical flip bucket spillway design that has undocumented TGP control characteristics. Our investigations into this area are discussed in Section 6.

5.0 TGP MONITORING

TGP monitoring was implemented in the spring, summer, and fall of 2004 in the reservoir near Kenney Dam (Knewstubb Arm), in the Nechako River below Cheslatta Falls and at three stations along the Cheslatta to Murray System. The monitoring was completed in ice-free conditions from May to late October 2004. The objectives of the TGP monitoring program were to assess the baseline conditions and, secondarily, to establish whether solar heating or primary production lead to dissolved gas super-saturation.

5.1 Methods

5.1.1 <u>Monitoring Locations and Station Design</u>

Water is currently released from the Nechako Reservoir at the Skins Lake Spillway (Figure 1) and passes down the Cheslatta River, through Cheslatta and Murray Lakes before passing over Cheslatta Falls and into the Nechako River. Water is plunged to depth in the stilling basin below the spillway, at the upper Cheslatta Falls and at Cheslatta Falls. Elevated TGP is generated at each of these locations and past monitoring at Cheslatta Falls documented TGP levels as high as 118%. With the proposed construction of the release facility at Kenney Dam, water will be released from both Kenney Dam and at the Skins lake Spillway and the two "streams" will join at Cheslatta Falls. Thus it is logical to monitor current conditions at Cheslatta Falls so that before/after comparisons can be drawn.

As well, during the KCP investigations related to TGP, there was some question as to what TGP levels would be expected in the reservoir prior to the water being released into the Nechako Canyon. Knowledge of these levels could influence the design of the facility so some additional *in situ* data is needed. Therefore monitoring stations were proposed at both the reservoir upstream of the dam and in the Nechako River immediately below Cheslatta Falls. Finally, as little is known about the TGP characteristics in the Cheslatta Drainage, two synoptic surveys were proposed along the Cheslatta drainage from the Skins Lake Spillway to the outlet of Murray lake (immediately above Cheslatta Falls.

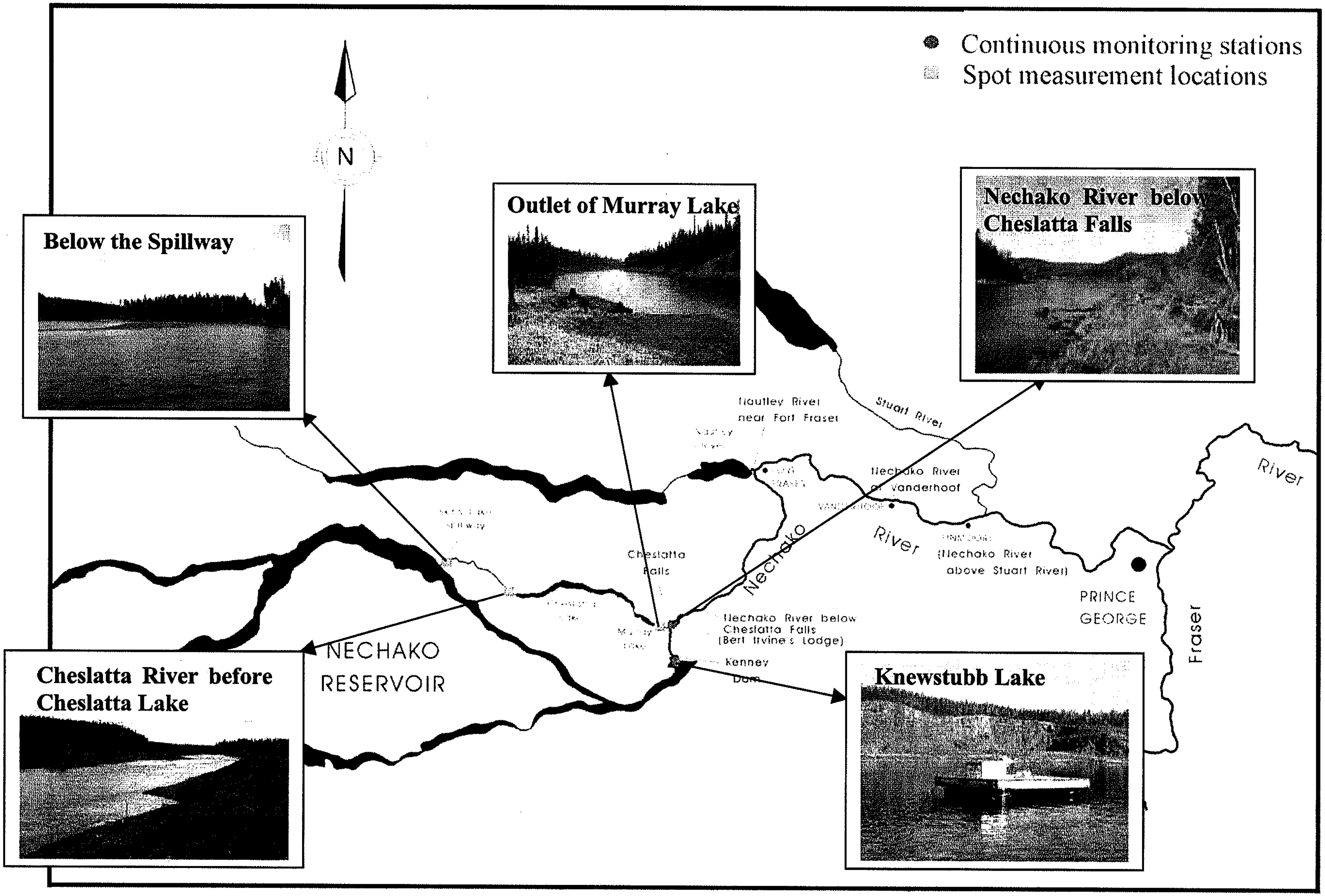
Continuous TGP monitoring devices were installed in Knewstubb Arm near Kenney Dam and downstream of Cheslatta Falls (Figure 3; Photos 1 and 2). The unit on Knewstubb Lake recorded data at two depths, approximately 4 and 55 meters below the water surface. Spot measurements were obtained from three stations along the Cheslatta to Murray Lake System: downstream of Skins Lake Spillway, upstream of Cheslatta Falls and at the outlet of Murray Lake (Figure 3). One of the recording instruments was used to record data at each site for approximately two hours.

The continuous monitoring device on Knewstubb Lake was installed on a floating platform (Photo 1) while the one on Cheslatta River was installed on the shore in an area seldom visited by anglers or the general public (Photo 2). Each monitoring device was housed in a lockable heavy-duty metal box

5.1.2 Monitoring Equipment

Continuous monitoring equipment was acquired from Common Sensing Inc. and included two TBO-DL6F units consisting of a waterproof Pelican case that contained the monitor, data logger, and the battery power supply (Photo 3). A digital display and keypad was used to operate and calibrate the meter and activate the data logger, while a laptop computer was required to modify the logging parameters and download data from the loggers. The units were also equipped with external batteries to prevent power failure and allow for continuous monitoring, up to an interval of ten minutes, over three weeks.

Figure 3. TGP Monitoring Locations (Not to Scale)



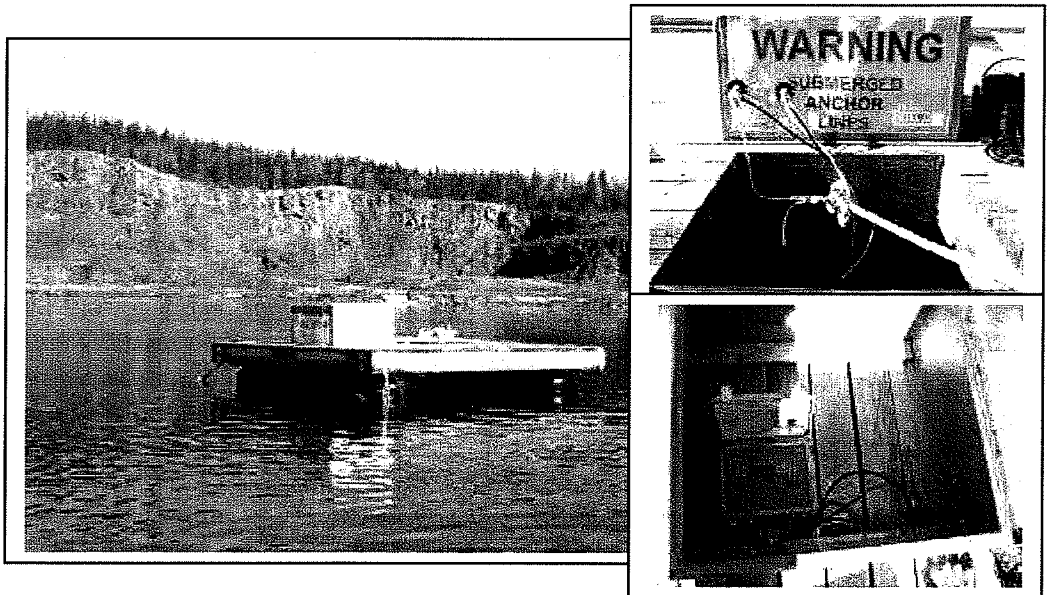


Photo 1. Knewstubb Lake Monitoring Station

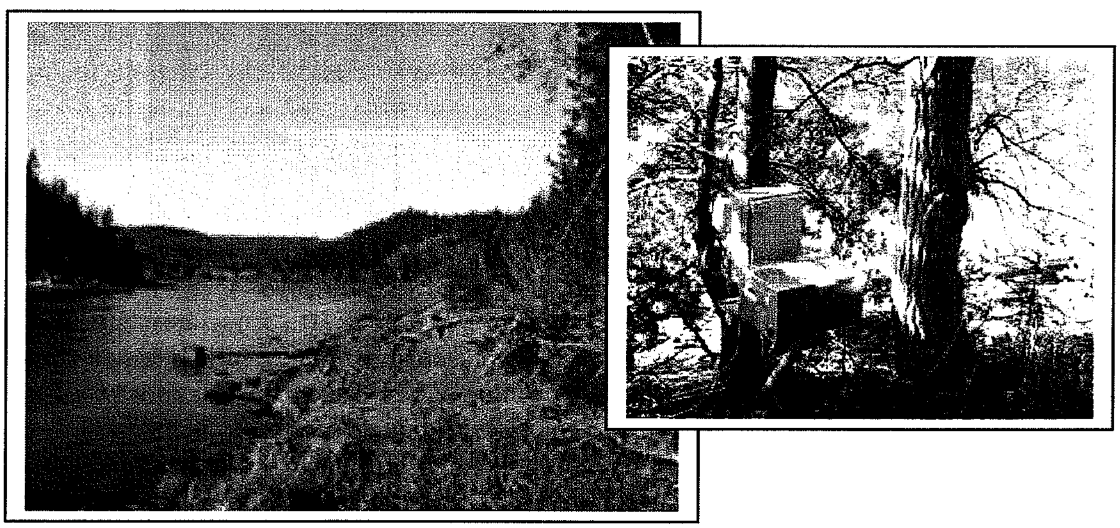


Photo 2. Below Cheslatta Falls Monitoring Station

The loggers measure and record the following parameters:

- barometric pressure or BAR (mmHg);
- water temperature or T (°C);

total dissolved gas pressure, Pt or TDGP (mmHg);

- dissolved oxygen partial pressure or $_{P}O_2$ (mmHg); and,
- dissolved oxygen concentration in ppm.

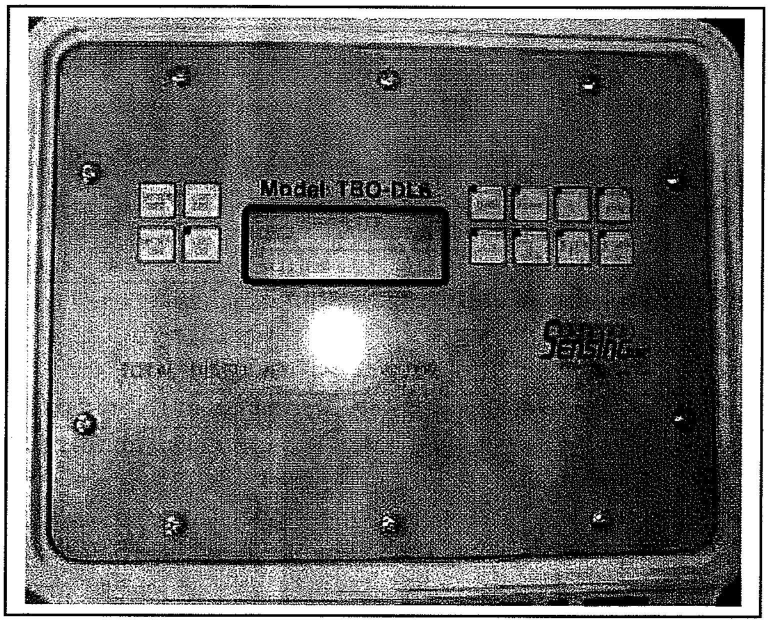


Photo 3. Logger unit showing digital screen and keypad

The temperature, dissolved gas pressure and oxygen sensors are housed in a single probe which was connected by cable to the meter/logger. The barometer is housed in the meter/logger and serves as a reference and calibration standard for both the Pt sensor and oxygen sensor. Additionally, a Relative Humidity (RH) sensor allows for more accurate calibration of the oxygen in air, and an internal temperature sensor allows computational removal of any remaining small but non-linear temperature coefficient of the barometer.

The probes were placed below compensation depth (*i.e.*, approximately 2 to 4 m) to prevent air bubble formation on the membrane. All continuous data were logged at one-hour intervals during May and June, then at ten-minute intervals for the remainder of the monitoring program to increase precision in the data.

To ensure accurate readings, the Pt sensor was exchanged approximately every three weeks with a new membrane in order to prevent condensation within the tubing. The oxygen sensor was also calibrated and serviced during each field visit. External batteries were changed at the same time.

5.1.3 Monitoring Logistics

The manufacturer's literature indicated that the instruments could record data for up to three weeks but recommended that the instruments be serviced more frequently. Triton's field plan called for servicing visits every two weeks until we gained additional experience with the equipment that would indicate the service intervals could be longer. The Equipment was installed in mid-May after ice out on the Nechako Reservoir. Details of the timing of site visits and issues related to the equipment identified during these visits are presented in Appendices I and II.

Generally, the equipment produced reliable results for the first (June) and the last (October) periods of deployment. However, during the summer months, only sporadic data were obtained at the reservoir site (Knewstubb Lake), while no data were recorded at the site below Cheslatta Falls. The following is a summary of the periods when the instruments collected reliable data. Reliable data is defined as data that is recorded when all parameters are within the expected range for each variable for the time of year and the location.

Knewstubb Lake

The logger deployed at Knewstubb Lake recorded reliable surface (4 meter depth) data for the following period:

- May 12 to June 15, 2004;
- August 15 to August 17, 2004;
- August 25 to September 4, 2004;
- September 8 to September 15, 2004; and,
- September 17 to September 29, 2004.

TGP measurements at a depth of 55 meters were obtained from May 12 to July 1, 2004.

Interruptions in the data set were caused mainly by probe sensor malfunctions. The probe contains electronic components in a sealed unit. Our experience indicates that the probe malfunctions we due to failure of the seals in the probe and consequent damaging of the electronics when water leaked into the probe. This issue can only be resolved by a design change by the manufacturer. Additionally, the deep probe sensor was lost on August 24 shortly after the instrument was re-installed. The problem was identified on the next site visit (September 2) and a replacement probe re-ordered from Common Sensing.. A new one was re-installed on October 2, 2004, however the probes did not record reliable data during October. The unit was demobilized on October 31, 2004.

Cheslatta Falls

Reliable data at the site located downstream of Cheslatta Falls are available for the following periods:

- May 23 to June 4, 2004; and,
- October 3 to October 15, 2004.

A first attempt to deploy the logger was made on May 11, 2004. At that time, the cable connecting the probe to the logger was found to be too short to maintain the probe under the required compensation depth and a cable extension was ordered. Upon delivery of an extension cable from Common Sensing, the probe and logger were successfully deployed on May 23. On June 4, after the field crew downloaded data and placed the logger in recording mode, the unit became unresponsive. After several attempts and discussion with Common Sensing from the field it was decided to send the logger back to the manufacturer for service. The Triton field crew went to re-install the logger on July 4, however a forest fire had burnt through the site and burned the previously installed unit cable. A new cable was ordered and the unit re-installed on July 19 and left in recording mode. The equipment was serviced on August 24 at which time it was observed the logger failed to record any data. The unit was re-initiated and left in recording mode until September 7. The data retrieved on September 7 proved erroneous and the unit was sent to Common Sensing for a second time. The logger was re-installed on October 3 and reliable data downloaded on October 15. This unit was demobilized on October 31, 2004.

Cheslatta to Murray System

In addition to the continuous TGP monitoring program, TGP levels from the Cheslatta to Murray System were obtained by taking spot readings of TGP levels at Skins Lake, Cheslatta River near Cheslatta Lake and at the outlet of Murray Lake, under the lower (30 to 50 m^3/s) discharge conditions, in May and October 2004. Recording at these sites lasted for approximately two hours.

5.2 Results

The results presented in this report are expressed in %TGP and/or ΔP and were obtained from the parameters measured by the data loggers using the following equations:

- %TGP=(Pt/BAR) x 100 (%) (2)
- ΔP=Pt - BAR (mmHg) (3)

Data was downloaded from the instruments and entered into a spreadsheet where the calculations were made. This data is maintained at Triton Environmental Consultants ltd. in its raw and processed formats.

5.2.1 Knewstubb Lake

ΔP recorded in Knewstubb Lake, at the surface and at depth, did not exceed the maximum ΔP of 76 mmHg recommended by the Province of British Columbia.

Surface Monitoring

Spring

TGP levels recorded in the Reservoir, approximately 4 meters below the surface, from May 12 to June 15 averaged 105% with a maximum of 110% and a minimum of 100%. ΔP averaged 32 mmHg with a maximum of 68 mm Hg and a minimum of -3 mm Hg (Figure 4).

Water temperatures ranged between 5.6 and 13.9 degrees Celsius in the spring.

Fall

TGP and ΔP recorded during the last week of August and in September presented lower levels than in the spring.

TGP recorded during the last week of August averaged 98% with a maximum of 100% and a minimum of 97%. ΔP averaged -14 mm Hg with a maximum of –1.5 mmHg and a minimum of –20.75 mmHg (Figure 4).

TGP recorded in September averaged 96% with a maximum of 98% and a minimum of 96%. ΔP averaged -25 mm Hg with a maximum of -14 mm Hg and a minimum of -35 mmHg (Figure 4).

$_{P}O_2$ presented an increasing trend with higher levels at the end of the monitoring program. $_{P}O_2$ recorded from May 12 to July 1 averaged 127 mmHg, with a maximum of 142 mmHg and a minimum of 107 mmHg. Levels in August averaged 210 mmHg, with a maximum of 229 mmHg and a minimum of 182 mmHg. $_{P}O_2$ was only recorded for the first week of September due to sensor probe issues. Levels during this week averaged 222 mmHg, with a maximum of 237 mmHg and a minimum 190 of mmHg (Figure 4).

Water temperatures ranged between 17.8 and 19.6 in August and between 12.7 and 17.8 in September.

Depth Monitoring

Spring

TGP and ΔP recorded from May 12 to July 1 presented lower levels than the spring surface monitoring and averaged 98% with a maximum of 103% and a minimum of 97%.

ΔP averaged -14 mmHg with a maximum of 18 mmHg and a minimum of -23 mmHg (Figure 4).

$_{P}O_2$ averaged 111 mm Hg with a maximum of 146 mm Hg and a minimum of 87 mm Hg (Figure 4).

Water temperatures ranged between 3.6 and 4.4 degrees Celsius.

No TGP, $_{P}O_2$, or temperature information was obtained for the fall period.

5.2.2 Nechako River below Cheslatta Falls

Spring

Data for the Nechako River below Cheslatta Falls were obtained during lower discharge conditions – 50 m^3/s in May and June and 30 m^3/s in October.

Measurements of total gas pressure recorded below Cheslatta Falls from May 23 to June 4 were all supersaturated and ΔP exceeded the maximum ΔP of 76 mmHg recommended by the province of British Columbia. TGP levels averaged 117.5% with a maximum of 118% and a minimum of 117%. ΔP averaged 122 mmHg with a maximum of 124 mmHg and a minimum of 120 mmHg (Figure 5). River flows ranged between 55 and 57m^3/s (Water Survey of Canada preliminary data).

For comparison, average TGP levels obtained below Cheslatta Falls between May 27 and July 6, 1982, were 109.2% (Envirocon, 1984). TGP measured on May 27, 2004 was 118% and was 109.9% on the same day in 1982. River flow on that date was 65.9m^3/s (Water Survey of Canada data). Note the meter used in 1982 was not the same as the one used in 2004.

$_{P}O_2$ recorded from May 23 to June 4 averaged 148 mmHg, with a maximum of 150 mmHg and a minimum of 144 mmHg. Water temperature in May and June averaged 11.3 degrees Celsius and ranged between 10.2 and 12.2.

Fall

TGP and ΔP recorded in October presented lower levels than in spring. TGP averaged 115% with a maximum of 115% and a minimum of 114%. ΔP averaged 101 mmHg with a maximum of 106 mmHg and a minimum of 99 mmHg (Figure 5).

$_{P}O_2$ levels in October averaged 172 mmHg, with a maximum of 176 mmHg and a minimum of 168 mmHg. $_{P}O_2$ differs from TGP% ΔP in that higher levels were observed during October and lower levels during May and June (Figure 5).

Water temperatures in October averaged 11.4 degrees Celsius and ranged from 10.8 to 12.5.

For comparison, in August 1985, Byres and Servizi (1986) reported TGP values near 115% at a site 500 meters downstream of Cheslatta Falls and in July and August 1986, Rowland and Jensen (1988) measured TGP% near the base of Cheslatta Falls where measurements ranged from 107.2 to 115.0%, averaging 111.0%.

Figure 4. Knewstubb TGP% Levels, May 12 - October 25, 2004

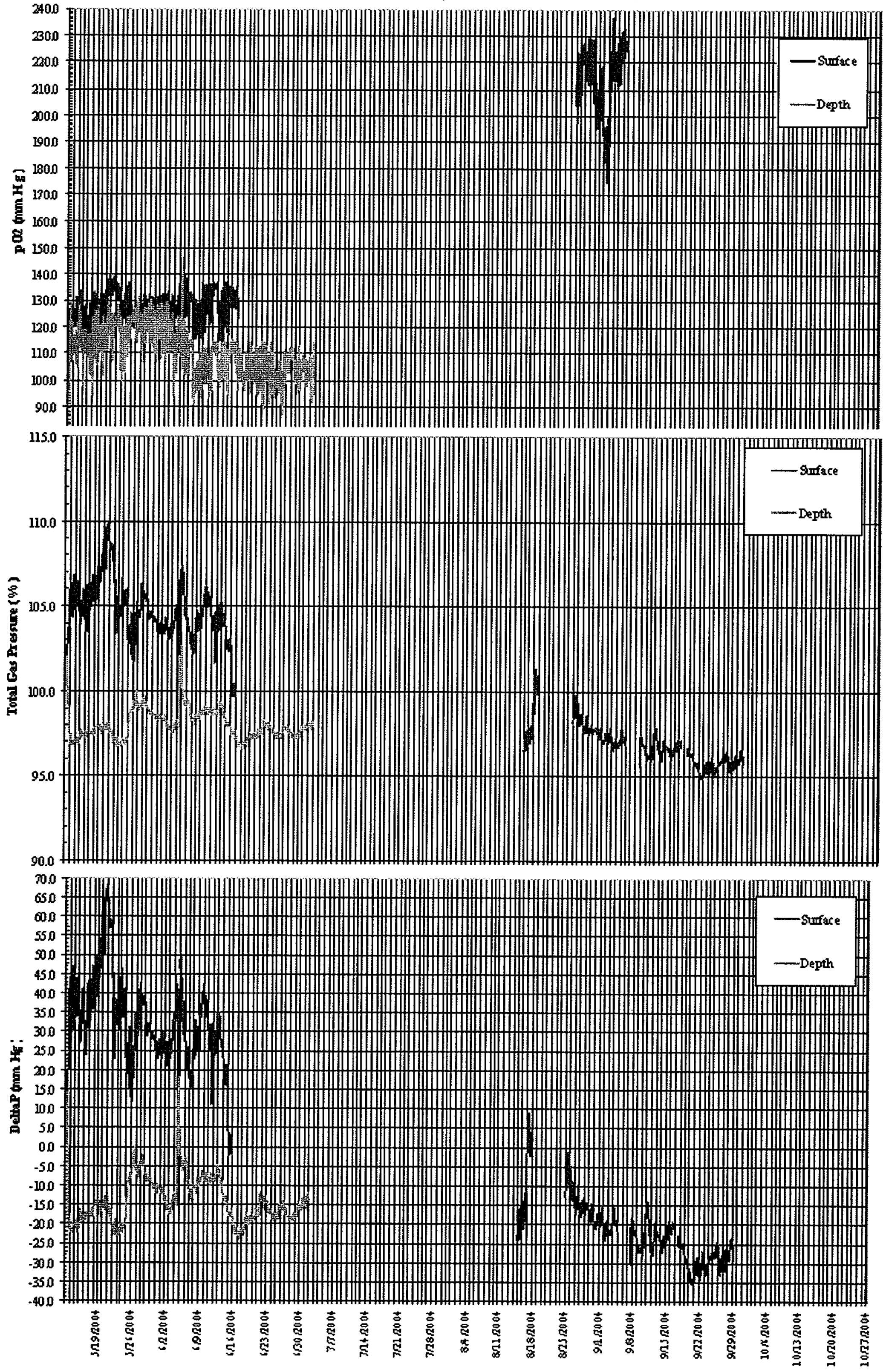
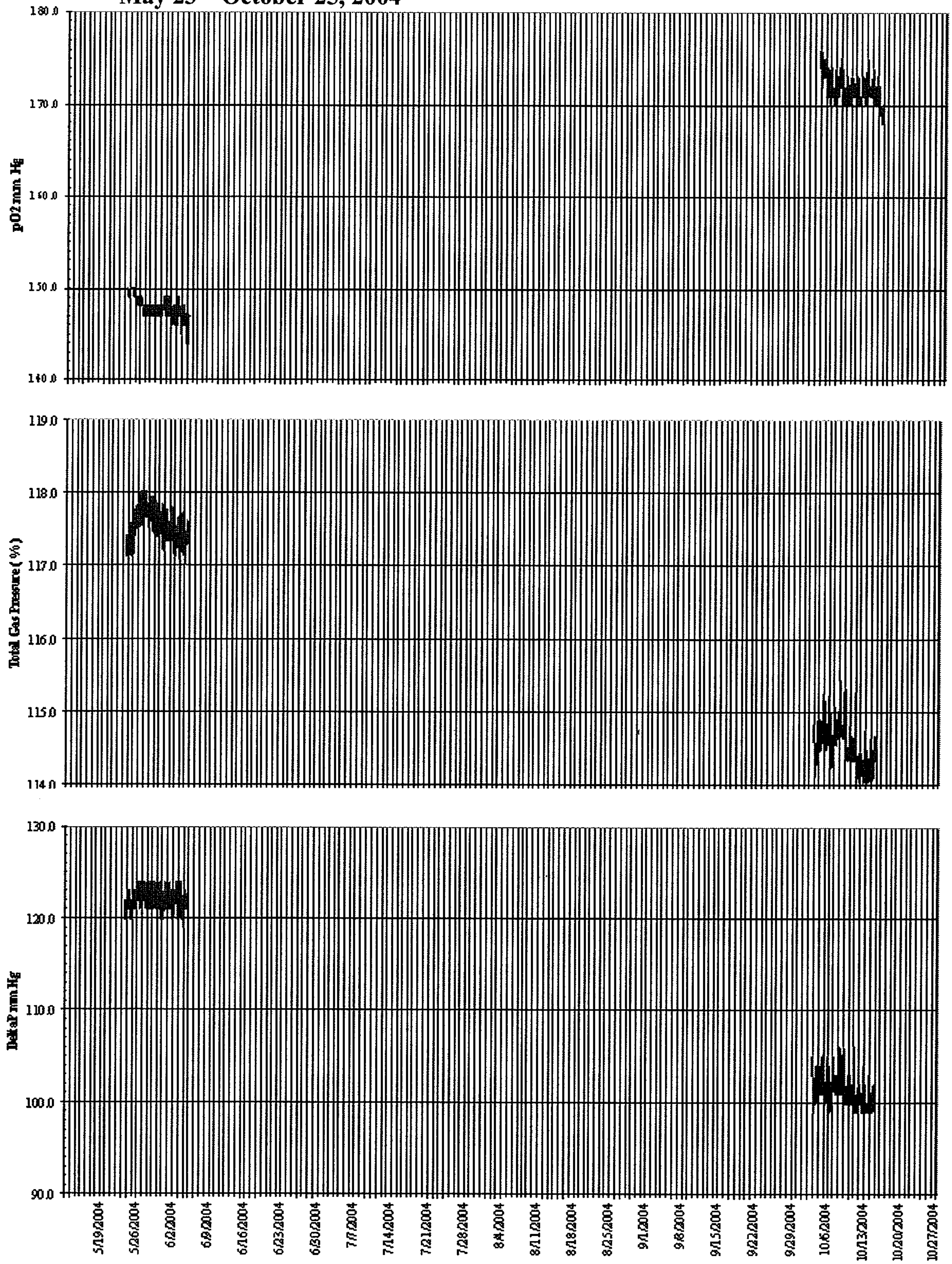


Figure 5. Nechako River below Cheslatta Falls Total and Partial Pressure Levels, May 23 – October 25, 2004



5.2.3 Murray to Cheslatta River System

TGP, oxygen and temperature recorded during the spot measurement program are presented in Table 1.

Table 1. TGP, Oxygen and Temperature Data for the Murray to Cheslatta River System

Parameters	Dates	Below Skins Lake Spillway	Before Cheslatta Falls	Outlet of Murray Lake
TGP %	May 10, 2004	113-115	109-110	105
	October 2, 2004	111-113	108	98-100
pO_2 mmHg	May 10, 2004	NA		
	October 2, 2004			
Temperature D. Celsius	May 10, 2004	NA	7.4-7.8	7.5
	October 2, 2004	11.9-12.1	11.8-12.3	11.8

5.3 Discussion

As noted, little TGP data was recorded for either Knewstubb Arm, below Cheslatta Falls, or for the Murray to Cheslatta River System during the late spring, summer, and early fall periods of 2004. The limited data collection was due to instrumentation problems experienced in the field with some additional logistical problems created by a forest fire near the monitoring sites in late June 2004 (see Appendices I and II). In terms of the instrumentation problems, consulting with others who have worked with the Common Sensing Company, the problems encountered in the Nechako system are not unique. The instruments are relatively expensive and require almost constant attention to assure any degree of success (White *et al.*, 1990; US ACE, 1994; Aspen Applied Sciences Ltd., 2001; L.E. Fidler, pers comm.). Even with close monitoring, the instruments often fail and require the attention of the manufacturer, which usually means returning the instrument for repair (as was the case in 2004). Other instruments, costing up to 5 times that of the Common Sensing instruments (*e.g.*, Hydrolab), offer more monitoring parameters, but also require close attention to the TGP and pO_2 probes and in river and lake environments have a failure rate similar to that of the Common Sensing Instruments. The problem is with the technology, which has not changed for over 45 years. Some consulting companies and agencies involved in TGP monitoring (*e.g.*, the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and Golder Associates) use up to three Common Sensing instruments simultaneously at a given site to assure acquisition of reliable data. Even then, instrument failures and contradictory data between instruments are problematic (L.E. Fidler, pers comm.). As an example of the difficulties encountered in TGP monitoring, efforts to collect data on the Columbia River have sometimes required multiple years of monitoring to acquire a single reliable data set (L.E. Fidler, pers comm.). Given the difficulties encountered in the Nechako system in 2004, it can be expected that additional monitoring will be required in 2005.

This is particularly important in terms of the TGP measurements below Cheslatta Falls and in the Murray to Cheslatta River System. The period during which TGP values are likely to be the highest is that for which there are no data. In the following sections 2004 data will be discussed, and where appropriate, important features will be examined and used to guide the 2005 monitoring.

5.3.1 Knewstubb Lake

Monitoring TGP at Depth

As noted, the TGP data at depth for Knewstubb Lake show no significant evidence of supersaturation from mid-May to early July (Figure 4). A maximum TGP of 103% occurred during two short periods. The slight supersaturation during these episodes, accompanied by under-saturation during the remainder of the monitoring period, are not surprising given the water depth (55 m) and the fact that the only likely source of DGS is currents that might draw surface supersaturated water to depth. Due to the depth, solar heating and primary production would not be a factor. Although data are missing for the remainder of the year, any supersaturation is not likely to exist for very long and would be at or below the 103% level. This was anticipated before the monitoring program began and the positioning of the probes in the deep water was simply to confirm the lack of significant supersaturation at depth. The only other possible source would be a turnover of the lake water due to surface cooling in the fall. However, the cooling would also reduce TGP levels.

It should be noted that the $_PO_2$ levels at depth are at saturation or below. The low $_PO_2$ is probably due to biological or chemical activity.

Monitoring TGP near the Reservoir Surface

In the case of the probes near the water surface (4 m deep), there was evidence of DGS in the spring as reflected by TGP levels approaching 110%. However, these lasted for only short periods (Figure 4). Clearly, solar heating was the probable cause since there are no upstream dams or falls that could act as a source. Although primary production is another possibility, the low nutrient content of the lake water is not conducive to any significant level of primary production. This is born out by the $_PO_2$ levels recorded at the surface during the elevated TGPs of 110% (Figure 4). As can be seen $_PO_2$ levels are at or below saturation. Typically, elevated $_PO_2$ levels would accompany primary production near the water surface (White *et al.*, 1990).

In the fall, TGP levels at the water surface are for the most part at equilibrium or somewhat under-saturated. It is not clear why the levels are below saturation. This is either due to falling water temperatures, circulation of deep water to the surface, or instrumentation error. The highly supersaturated $_PO_2$ levels at the surface are obviously incorrect, since they are well above saturation and as high as 237 mmHg (≈165%

saturation). This is occurring when TGPs are under-saturated; thereby, requiring highly under-saturated pN2 levels – a situation that would be difficult to explain at best.

Overall, the available data from Knewstubb Lake do not indicate a significant problem as far as TGP is concerned. This is especially true for the deeper portion of the lake. Although TGP values as high as 110% were recorded up to June 15, they were for a short period only and within the current B.C. guidelines. Nevertheless, there is the possibility that solar heating could raise TGP levels later in the summer and early fall. However, based on experience from other reservoirs and the absence of an upstream source of DGS, it is unlikely that they would rise much above 110% (Aspen Applied Sciences Ltd., 1997a and b; Aspen Applied Sciences Ltd., 2001; US ACE, 1994; L. E. Fidler, pers comm.). Still, 2005 monitoring should include provisions for additional surface monitoring to confirm this. It should be kept in mind that the release of Knewstubb Lake surface water over the Kenney Dam spillway will not occur on a frequent basis and experience with other dams indicate that TGPs downstream from dam spillways are relatively insensitive to forebay TGPs ranging up to 125% (Aspen Applied Sciences Ltd., 1997a and b; US ACE, 1994).

5.3.2 Nechako River below Cheslatta Falls

In the Nechako River below Cheslatta Falls, the failure to collect TGP and $_{P}O_2$ data from early summer to early fall, while a significant data gap for 2004, is not significant from an overall perspective. While this is the period when TGP levels are likely highest since this is the period of highest river flows, the data collected in June and October are similar (=/- 2%) to data collected by DFO (Servizi, 1986 and Rowland and Jensen, 1988). These data provide guidance on the range of TGP levels that can be generated at Cheslatta Falls. Also, data on the TGP production characteristics of dam spillways, which are, in some cases, similar indicate that TGP increases monotonically with discharge up to a specific level. Beyond that discharge, TGP is either somewhat constant or monotonically decreases with further increases in discharge (see Figure 6 for idealized examples) likely due to the depth of the stilling basin as would be the case for a waterfall. This characteristic has been observed at dams on the Columbia, Kootenay, and Pend d'Oreille Rivers in Canada and on the Columbia and Snake Rivers in the United States (Aspen Applied Sciences Ltd., 1997b; US ACE, 1994 and 1996).

Figure 7 is a plot of the 2004 discharge for the Nechako River below Cheslatta Falls. As evident, there is a period in late January when flows are high for a short time, but more importantly, there is an extended period from mid-July through late August where discharges are up to 5 times greater than those that existed when the 2004 spring and fall TGP data were collected (i.e., 280 m^3/s compared to 55 m^3/s). Thus, the potential TGP levels reflected by these data may be significantly higher than the maximum recorded in 2004.

For example, the data for May 2004 indicate a maximum TGP of around 118% (Figure 5) at a time when the discharge was about 60 cm. With discharges later on approaching 5 times this level, there is clearly potential for much higher TGP levels.

Figure 6. Idealized Example of Dam TGP Production

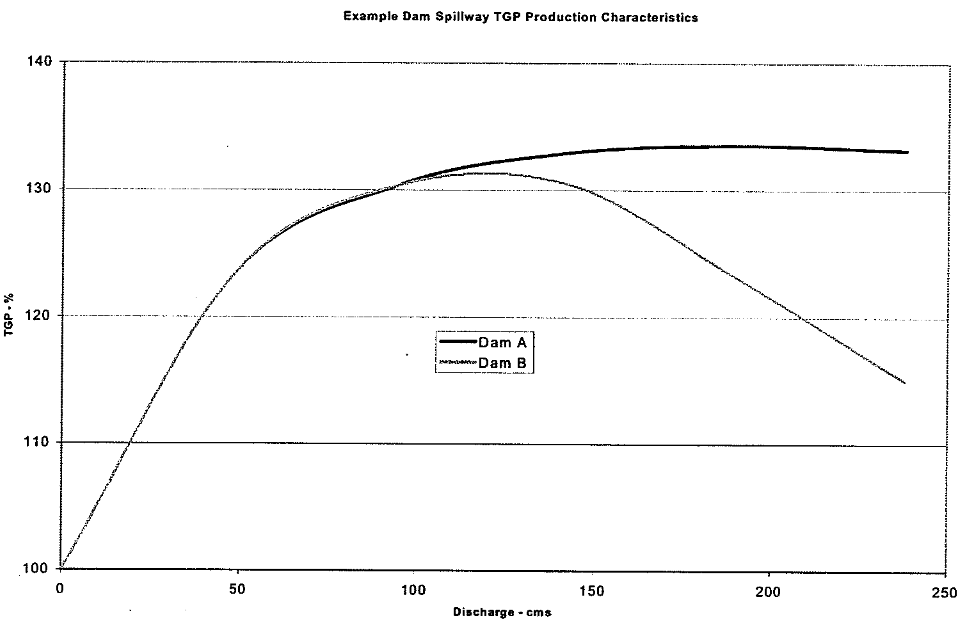
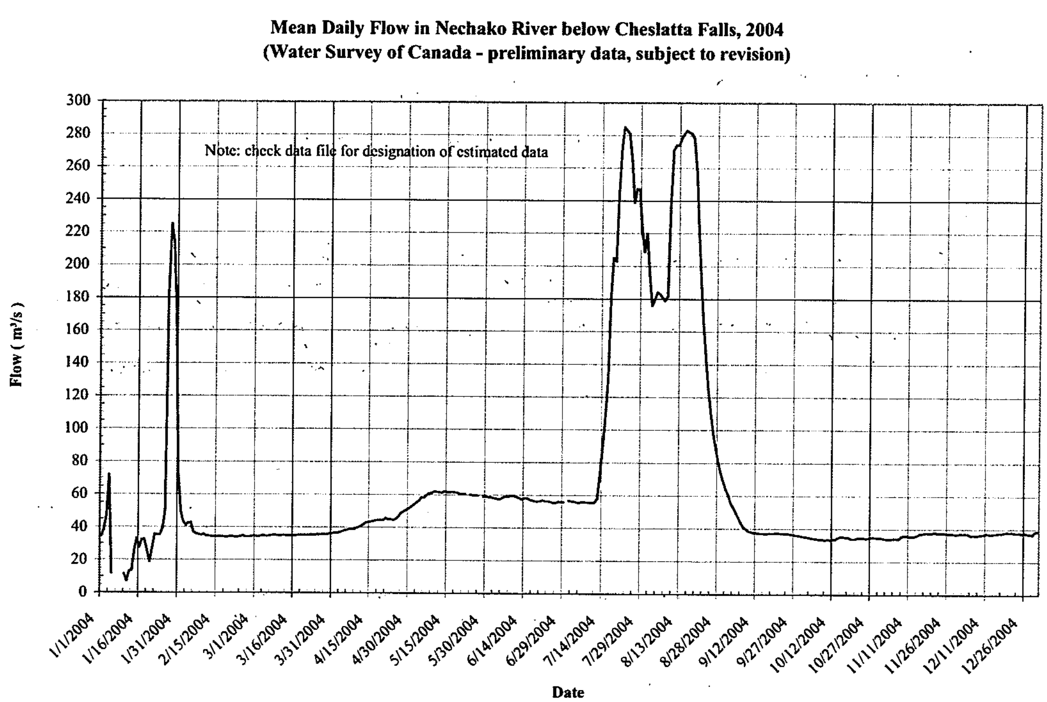


Figure 7. Nechako River Discharges below Cheslatta Falls for 2004



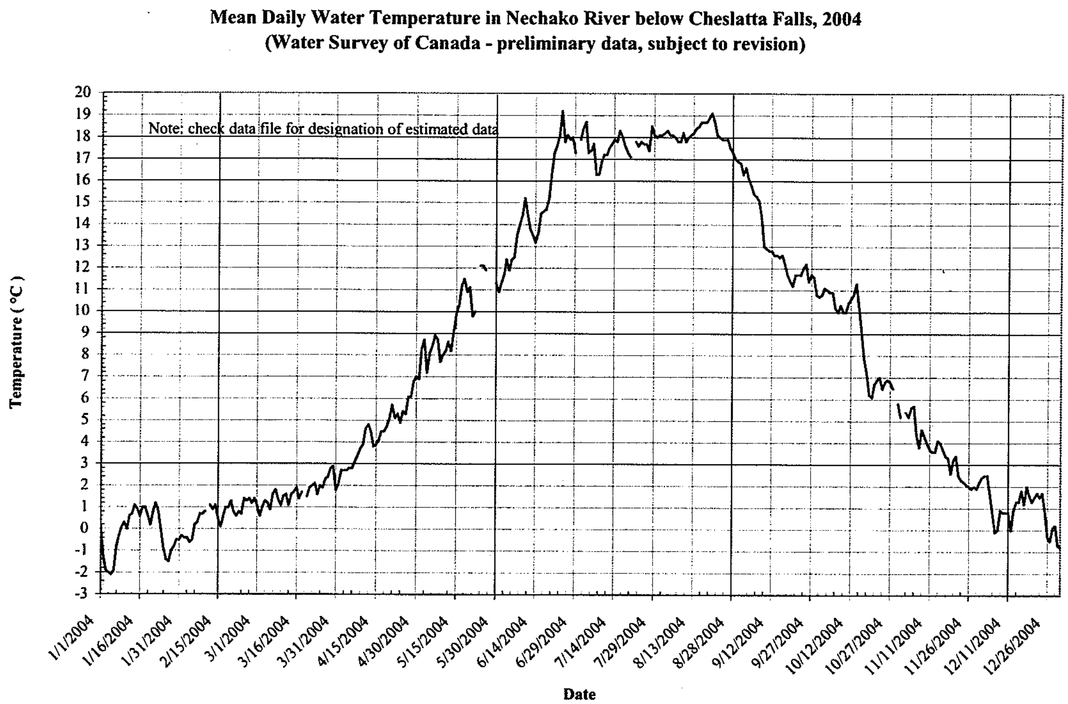
The TGP data collected below Cheslatta Falls, for the October monitoring period (Figure 5) indicate levels up to 115% at discharges of about 35 cm. Using the combined spring and summer data (*i.e.*, a TGP of 118% at a discharge of 60 cm and 115% at a discharge of 35 cm), a linear extrapolation to a discharge of 280 cm would yield a TGP in excess of 140%.

As noted earlier, Byres and Servizi (1986) reported TGP values near 115% at a site 500 meters downstream of Cheslatta Falls in August 1985. A check on river discharges at that time (WSC data) indicates levels ranging from a low of about 60 cm to a high of 290 cm. Without specific dates for the Byres and Servizi monitoring, it is difficult to determine if their data were collected during the low flow period or if, during high flows, the Falls' TGP production was on a descending limb of the TGP – discharge curve (Figure 6, Dam B).

In July and August 1986, Rowland and Jensen (1988) measured TGP% of up to 115% near the base of Cheslatta Falls. Again, a check of the river discharges during this period (WSC data) indicates levels of 60 to 270 cm. Because Rowland and Jensen conducted continuous monitoring during the period, it would indicate maximum TGPs of 115%, occurred even during the high discharge episodes. However, given the erratic performance of TGP monitoring instruments in general, it is advisable that further monitoring of the river immediately below Cheslatta Falls be conducted in 2005 to confirm the TGP production characteristics of the falls.

The situation is complicated somewhat by the potential for temperature effects compounding potential TGP effects on fish. In most river systems, high temperatures are usually encountered a couple of months following the high runoff period. That is, the spring freshet involves cooler water while subsequent high temperatures in the summer and early fall are the result of solar heating. Figure 8 is a plot of the water temperatures that occurred in the Nechako River below Cheslatta Falls in 2004. However, the situation on the Nechako River is somewhat unique in the observed high TGP levels are generated at Cheslatta Falls, certainly between mid-May and late October and possibly throughout the year. These TGP levels are above the B.C. guideline and in the range of lethality for fish, yet data on fish production in the river collected by the Nechako Fisheries Conservation Program (NFCP 2005 (in prep.) indicate that the salmon stocks in the river are being maintained at levels approaching pre-Kenney Dam records. Therefore, collection of additional data, while it would confirm that TGP levels observed in the past have been maintained to the present, may not add significantly to our knowledge base in the context of establishing design and operating criteria for the proposed release facility at Kenney Dam.

Figure 8. Water Temperature in the Nechako River below Cheslatta Falls - 2004



5.3.3 Murray to Cheslatta River System

Based on the data in Table 1, it is evident that the Skins Lake Spillway is producing elevated TGPs. Again the 2004 data do not reflect conditions during the highest discharge and temperature periods (Figures 7 and 8). As with Cheslatta Falls, there are no TGP production curves for the Skins Lake spillway (*e.g.* Figure 6). Thus, the situation regarding maximum TGPs and temperatures in the Murray to Cheslatta River System is unknown. As with Cheslatta Falls, monitoring in 2005 must focus on the TGP production characteristics of the Skins Lake spillway, especially during periods of high discharge.

6.0 REVIEW OF LITERATURE ON TGP PRODUCTION AT FLIP BUCKET SPILLWAYS

The NEEF MC recommended design concept for the water release facility at Kenney Dam includes a flip bucket spillway to convey water from a control structure on the left abutment of the dam and to safely discharge this water into the canyon beyond the toe of the dam (Klohn Crippen, 2001). Flip bucket spillways are characterized by a relatively steep chute (where water velocities can exceed 15 to 20 m/s) with a "ski-jump" shaped lower end to "flip" the water away from the dam and dissipate the energy of the water. The design concept has been in use at dams since the mid-1930s (Juon and Hager, 2000) and the hydraulic performance and design parameters well known.

Flip bucket spillways will also entrain air into the flow over their length and have been demonstrated to be a tool for the improvement of dissolved oxygen concentrations on some river systems (Emiroglu and Baylar, 2003; Wilhelms *et al.*, 1993). These characteristics, however, ensure that water discharged from the spillway will contain air bubbles which, if they are forced to depth in a plunge pool below the spillway, will result in increased gas concentrations in the discharged water and related increases of total gas pressure and consequent effects on aquatic organisms downstream of the facility (Fidler, 2004).

Research efforts have been focused on the prediction of TGP levels below dams by in the past two decades. Hibbs and Gulliver (1997) have proposed a procedure for the estimation of TGP levels below dams that can be used if some basic parameters such as plunge basin geometry and the depth of entrained bubbles can be estimated.

Gijs and Hoffmanns (1998) and Mason and Arumugam (1985) have completed reviews of different approaches to estimating scour hole depths from hydraulic jets below dams and flip bucket spillways. These studies both compared predicted scour depths with those that occurred at prototypes and both concluded that while improvements in estimation techniques have occurred over the past half century, the results should be only be used as a first approximation at proposed projects. All of the formulas require an estimate of the downstream water depth, unit discharge and an estimate of the mean particle size of the sediments in the vicinity of the plunge pool. Experience with these formulations at the Skins Lake spillway produced mixed results (either over or under estimating the actual pool depth (C.Wilson, Klohn Crippen, pers comm.) and are not considered reliable for use at the base of Kenney Dam with the information that is presently available.

Without the estimate of the depth of scour in the plunge pool, the work of Hibbs and Gulliver in estimating the depth of the bubble plume (and therefore the potential TGP concentration) concludes that accurate estimates of the effective depth of the bubble plume and the effective concentration of oxygen (or nitrogen) in the pool needed in predicting the level of gas supersaturation below the spillway is not possible. Given the difficulties in defining the geometry of the potential scour hole described above, this approach was not followed further.

As an alternate approach, a review of prototype spillway designs in western Canada was conducted and a prototype identified at the Seven Mile Dam on the Pend'Orielle River. B.C. Hydro has been monitoring TGP levels at the facility as part of their TGP studies on the Columbia River and tributaries in southern B.C. The Seven Mile Dam has a four-gate flip bucket spillway on the left bank of the river. The spillway does not have as great a head drop as is proposed at Kenney Dam (62 m versus 90 m) but does discharge spills to a "plunge pool" downstream of the dam. This pool is 60 to 100 metres deep (Spurr, 1987) and was expected to continue deepening with time.

The Seven Mile facility operates as a run of river facility with storage provided by upstream dams. Operation of the upstream dams result in high TGP levels in the Seven Mile Dam forebay (L.E. Fidler, pers comm.). TGP data were measured by B.C. Hydro in the forebay and in the tailrace in 1995, 1996, 1997 and 1998 show that during periods of spill (> than powerhouse capacity at Seven Mile) from the upstream dams that TGP levels in the forebay can reach as much as 146% and routinely can reach 117% to 135% (Figure 9). Examination of TGP data measured both upstream and downstream of the Seven Mile Dam (Figure 10) however shows that when the spillway is used, TGP levels can either increase (a negative value) or decrease (a positive value) at the facility, by as much as -12% to +15%. The decreases in TGP levels are thought to result from the aeration characteristics of the flip bucket spillway. The reasons for the increases in TGP levels are not fully understood but could result from dynamic effects (*e.g.*, rapidly increasing or decreasing upstream releases) or from the effect of the spills into the plunge pool below the spillway. However the work of Emirogolu and Baylar (2002) confirms that flip bucket spillways can efficiently aerate water passing through the spillway (and in the converse efficiently de-aerate supersaturated waters). Thus, these data should not be ignored just because the results may be inconclusive.

In the context of the current study for a facility at Kenney Dam, it is acknowledged that mechanisms controlling the increase or decrease in TGP at the Seven Mile Dam data are not well understood. A similar comment could be made at for the proposed Kenney Dam Release Facility at this time. However, the Seven Mile Data appear to indicate that increases in tailrace TGP levels of up to 12% are possible. Therefore, for the purposes of this study, it has been assumed that TGP levels below the Kenney Dam facility could increase by a similar amount.

Note by L E Fidler: Given the lack of understanding of how the Seven Mile Dam (or most other dams for that matter) produces TGP, especially in terms of the effect of the high upstream TGPs, I think that an assumption of any delta P across the dam is very weak. Again, I think that it would be best to acknowledge the lack of understanding of TGP production by the Seven Mile or Kenney Dam at this time and that to demonstrate the functionality of the analyses that follow, a value of a 10% increase across the dam was used.

Figure 9. Relationship Between Total Discharge at Seven Mile Dam and Forebay TGP (%)

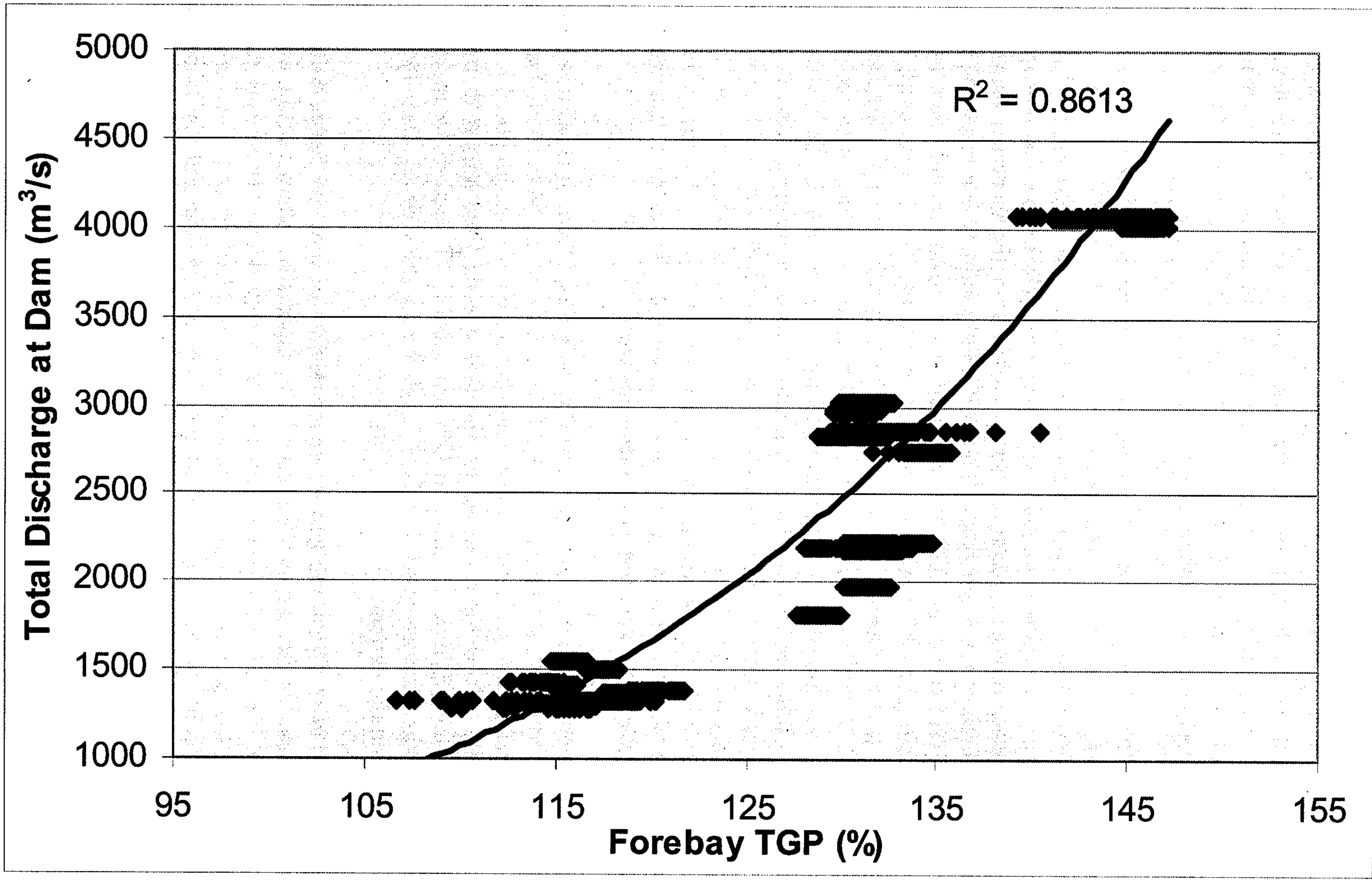
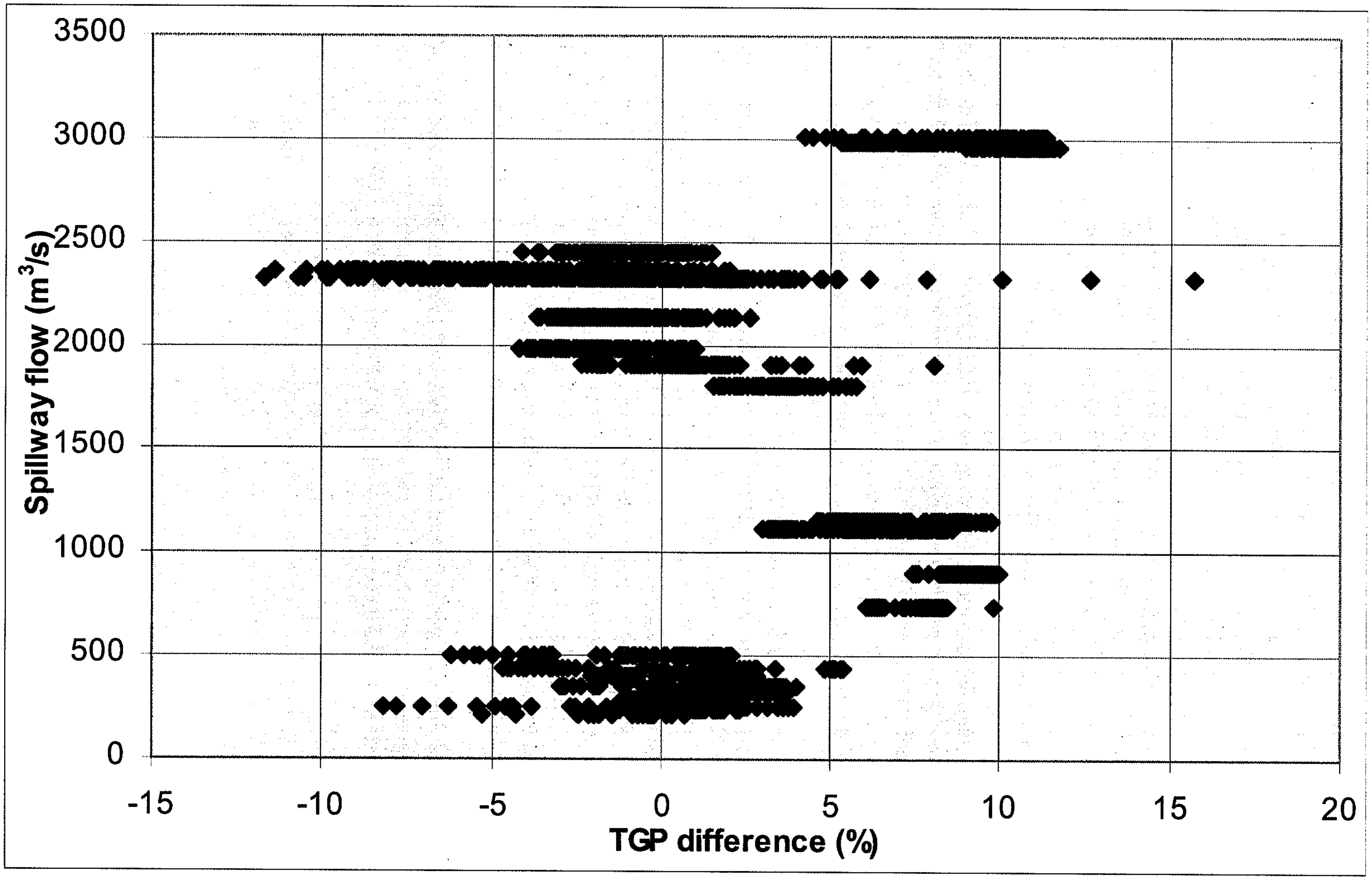


Figure 10. Relationship Between Spillway Flow at Seven Mile Dam and Difference Between Forebay and Tailrace TGP (%)



7.0 TGP MODELING IN THE NECHAKO CANYON AND RIVER

A spreadsheet model that had been used in previous studies (Envirocon, 1989) was used to provide an indication of total gas pressure (TGP) levels expected to occur in the Nechako Canyon and in the Nechako River immediately below Cheslatta Falls in response to operation of a water release facility at Kenney Dam. The model uses selected water temperatures, dissolved oxygen and nitrogen gas concentrations and TGP levels in the Nechako Canyon immediately downstream of a Kenney Dam spillway plunge pool, and selected water temperatures and dissolved oxygen and nitrogen gas concentrations in the Cheslatta River entering the Nechako River at Cheslatta Falls. It is also a "steady state" model in that it is only valid if the releases from the facility are essentially constant. To determine the sensitivity of the downstream %TGP to differing flows the model is run at a series of flows and the results compared.

Four cases included in this modeling work are summarized in Table 2. These four cases consisted of two selected reservoir release water temperatures, two sets of meteorological conditions (cool and warm), one set of initial dissolved oxygen and nitrogen concentrations, and one total gas pressure (TGP) value at the outlet of the spillway plunge pool (110%). Effectively, the alternate combinations of parameters include:

- Release water temperatures of 10°C and 12°C;
- Relatively cool or warm weather (as represented by the "response temperature" and the "kinematic exchange coefficient. The response temperature (Tr) is one that a container of water would reach if it we affected only by weather conditions. The kinematic exchange coefficient (K_{ec}) is defined as the surface heat exchange coefficient divided by the product of the mass density of water (1,000 kg/m^3) and the heat capacity of water ($4.186x10^3$ J/Kg/°C). Combinations of Tr = 15.0°C and Kec = $4.0x10^{-6}$ m/s, and Tr = 30.0°C and K_{ec} = $6.0x10^{-6}$ m/s were used to represent cool and warm meteorological conditions, respectively; and,
- Initial total dissolved gas level downstream of the spillway plunge pool of 110%.

Note that initial concentrations dissolved oxygen and nitrogen are needed for the model. Using the observed concentrations in the reservoir, these concentrations were adjusted in the same proportion as observed to reach appropriate values for a TGP of 110%.

Table 2. Nechako Canyon Dissolved Gas Modeling – Modeling Cases

Nechako Canyon Modelling

Case #	Kenney Dam Release Temp (°C)	Response Temperature (°C)	Kinematic Exchange Coefficient ($\times 10^{-6}$) (m/s)	Initial O2 Conc (mg/l)	Initial N2 Conc (mg/l)	Factor for Initial O2 Conc (mg/l)	Factor for Initial N2 Conc (mg/l)	Adjusted Initial O2 Conc (mg/l)	Adjusted Initial N2 Conc (mg/l)	TGP at outlet of plunge pool (%)
I	10.0	15.0	4.0	8.00	18.00	1.08000	1.08000	8.640	19.440	110.00
II	10.0	30.0	6.0	8.00	18.00	1.08000	1.08000	8.640	19.440	110.00
III	12.0	15.0	4.0	8.00	18.00	1.03425	1.03425	8.274	18.617	110.00
IV	12.0	30.0	6.0	8.00	18.00	1.03425	1.03425	8.274	18.617	110.00

Cheslatta River Inputs

Temp (°C)	O2 Conc (mg/l)	N2 Conc (mg/l)
15.0	10.00	18.00
15.0	10.00	18.00
15.0	10.00	18.00
15.0	10.00	18.00

7.1 Nechako Canyon Hydraulics

The model requires the hydraulic characteristics of the Nechako Canyon. The canyon has been dry for the past 52 years so the hydraulic data used were developed based on work recently conducted for the NES (EDI, 2003). Velocity versus discharge and depth versus discharge relationships for flows of 20 m^3/s, 200 m^3/s and 490 m^3/s for Nechako Canyon and Cheslatta Fan presented in EDI 2003 were initially plotted. A general relationship of canyon cross-sectional area of flow versus discharge (power curve) for the range of flows used in the dissolved gas modeling was developed and used to calculate the corresponding relationship of average cross-sectional velocity (velocity equated to discharge divided by cross-sectional area) versus discharge. This generated velocity versus discharge curve was then plotted and adjusted based on the velocity versus discharge relationship for flows of 20 m^3/s, 200 m^3/s and 490 m^3/s developed using the EDI 2003 data.

This process was repeated to develop a general relationship of canyon width of flow versus discharge (power curve) for the range of flows used in the dissolved gas modeling. This relationship was then used to calculate the corresponding relationship of average depth of flow (depth equated to flow width divided by cross-sectional area) versus discharge. This generated depth versus discharge curve was then plotted and adjusted based on the depth versus discharge relationship for flows of 20 m^3/s, 200 m^3/s and 490 m^3/s developed using the EDI 2003 data.

7.2 Reaeration Coefficient

A relationship of reaeration coefficient (K2) versus discharge was developed based on empirical equations previously used to estimate K2 values (for dissolved nitrogen at 20.0°C, base e) for Nechako River (Envirocon, 1984). The following three equations were used to develop the respective relationships of K2 versus discharge for the full range of flows used in this modeling work:

Churchill et al. (1962) *(referenced in Envirocon, 1984)*

$$K2 = 0.453\ U^{0.969}\ H^{-1.673} \qquad (2)$$

Padden and Gloyna (1971) *(referenced in Envirocon, 1984)*

$$K2 = 0.453\ U^{0.703}\ H^{-1.054} \qquad (3)$$

Thackston and Krenkel (1969) *(referenced in Envirocon, 1984)*

$$K2 = 0.98\ (\ 1.0 + U\ /\ (\ (gH)^{0.5}\ )\ )^{0.5}(\ Sg/H)^{0.5} \qquad (4)$$

where U represents the average velocity (ft/s), H represents the average depth of flow (ft), g represents gravitational acceleration = 32.2 ft/s², and S represents slope of the water surface.

The reaeration rate used in this modeling was the average of the values obtained from using equations (2), (3), and (4) for the full range of flows used in this dissolved gas modeling.

The reaeration coefficient is also temperature dependent, and can be converted to another temperature as follows:

$$K2(T) = K2(20)\,(\,1.024^{(T-20)}\,) \qquad (5)$$

where K2(20) represents the value of the reaeration coefficient at 20.0°C/hr; and T represents the local water temperature (°C).

The value of K2 is related to the inverse ratio of the molecular diameters of oxygen and nitrogen (Byres and Servizi 1986), and therefore K2 for oxygen can be calculated from K2 for nitrogen and argon as follows:

$$K2(O2) = 1.068\; K2(N2{+}Ar) \qquad (5)$$

7.3 Modeling Procedure

7.3.1 Nechako Canyon

The following summarizes the methodology used to model water temperature and dissolved oxygen and nitrogen gas concentrations, and calculate TGP in the Nechako Canyon:

- For the selected Nechako Reservoir release water temperatures it was assumed that the reservoir release water temperatures remained unchanged from the reservoir to the discharge of the spillway. Given the short travel time through the facility this is a reasonable assumption; and,
- selected meteorological parameters and initial dissolved oxygen and nitrogen concentrations as noted in Table 1.

As noted in the previous section, the Seven Mile Canyon data provide an indication that an increase in TGP, below the proposed spillway, in the magnitude of 10% to 12% is possible. Therefore, an increase in TGP below the dam of 10% has been assumed in the modeling of downstream TGP levels through the Nechako Canyon and at Cheslatta Falls.

Water temperature, dissolved oxygen and dissolved nitrogen were then modeled at each kilometer along the canyon and at the end of the canyon (9.2 km length). Each modeling case was run based on the canyon hydraulic conditions for flows through the canyon ranging from 14.2 m^3/s to 509 m^3/s.

7.3.2 Downstream of Cheslatta Falls

At Cheslatta Falls, flows from the Nechako Canyon will combine with flows released from the Skins Lake spillway and routed through Cheslatta and Murray Lakes to Cheslatta Falls. The limited data available from this study indicate that current TGP levels in the spring and early summer could reach 118% (Figure 5) and in the fall could be as high as 115%. This is consistent with data collected by the Department of Fisheries and Oceans in the mid 1980's (Department of Fisheries and Oceans, 1984). However, given the uncertainties regarding the maximum TGP production characteristics of the Skins Lake Spillway and Cheslatta Falls (Section 5), the measured spring and fall TGPs of 118% and 115%, respectively, will be used in the modeling activity to demonstrate the functionality of the model only. Once 2005 TGP monitoring is complete, more accurate Skins Lake and Cheslatta Falls TGP information will be incorporated into the modeling.

The following summarizes the parameter values used in the calculations of TGP% in the Nechako River immediately downstream of Cheslatta Falls.

- Cheslatta River water temperature of 15.0°C. This is generally representative of water temperatures at the end of June);
- Dissolved oxygen concentrations of 10.0 mg/l (typical of the observations at Cheslatta Falls in 2004);
- Calculated dissolved nitrogen concentrations typical of those recorded in the reservoir at Cheslatta Falls in 2004 (selected 18.0 mg/l).

These values were held constant for all of the modeling cases.

Using this assumed data, the modeled water temperature and dissolved oxygen and nitrogen concentrations for the downstream end of the Nechako Canyon were blended with the Cheslatta River water temperature and dissolved oxygen and nitrogen concentrations. The saturation concentrations of oxygen and nitrogen were calculated based on the blended temperature and then adjusted for local barometric pressure (assumed to remain at 694 mm Hg).

7.4 Results

7.4.1 Nechako Canyon

Results for the four dissolved gas modeling cases for Nechako Canyon are presented in Figures 11 to 14 as plots of calculated TGP% versus distance downstream for Nechako Canyon flows of 14.2 m^3/s to 509 m^3/s. These results give us a first indication of the reaeration characteristics of the Nechako Canyon under both cool and warm weather and at alternate release water temperatures. These data indicate that TGP% will drop as water passes through the canyon with the amount of reaeration related to weather (less drop in warmer weather), rate of discharge from the spillway (with the magnitude of the drop inversely proportional to the rate of discharge). There is a slightly greater amount of reaeration at a release temperature of 12°C when compared to 10°C but this is not considered significant at this time. These relationships are as expected as reaeration is a function of both water temperature and time and these two functions tend to work in opposing directions.

7.4.2 Downstream of Cheslatta Falls

Results for the four dissolved gas modeling cases at Cheslatta Falls are presented graphically as plots of calculated TGP versus Cheslatta River flow from 5.0 m^3/s to 50.0 m^3/s for Nechako Canyon flows of 14.2 m^3/s to 509 m^3/s (Figures 15 to 18). At Cheslatta Falls the TGP% and flow from the Nechako Canyon is combined with the TGP% and flow passing over Cheslatta Falls into the Nechako River. Generally this water will be warmer than that passing down the Nechako Canyon and will have a greater TGP% because of the plunging of the water over Cheslatta Falls. Thus, the combining of the two water sources will see the TGP% of the combined flow increase with:

- Directly with an increasing proportion of the Cheslatta River discharge compared with the Nechako Canyon discharge; and,
- A greater amount at a release water temperature of 10°C compared with 12°C.

It is important to note that these preliminary modeling results indicate that TGP% immediately below Cheslatta Falls would be limited to approximately 117% in the worst case. This is very similar to TGP% levels observed today and although they exceed the current TGP guidelines (Section 3.2) current salmonid production from the Nechako River does not appear to be limited by these levels. Caution should be used in interpreting these results because of the assumptions that have been made as proposed discharge regimes at Kenney Dam and at Skins Lake Spillway. The parameters used here for discharge have been selected to bracket the range of possibilities suggested in NWC discussions to date.

Further, as current research is unable to predict the expected depth of the plunge pool or the expected TGP % at the end of the plunge pool we are left with making assumptions for the modeling based on the observations from the Seven Mile Dam. There remain some unexplained variances in that data but we have assumed a worst case from these observations for use in the modeling.

Figure 11. Nechako Canyon Total Gas Pressure vs Distance Downstream: To=10°C, Tr=15.0°C, k=4.0x10^{-6}m/s

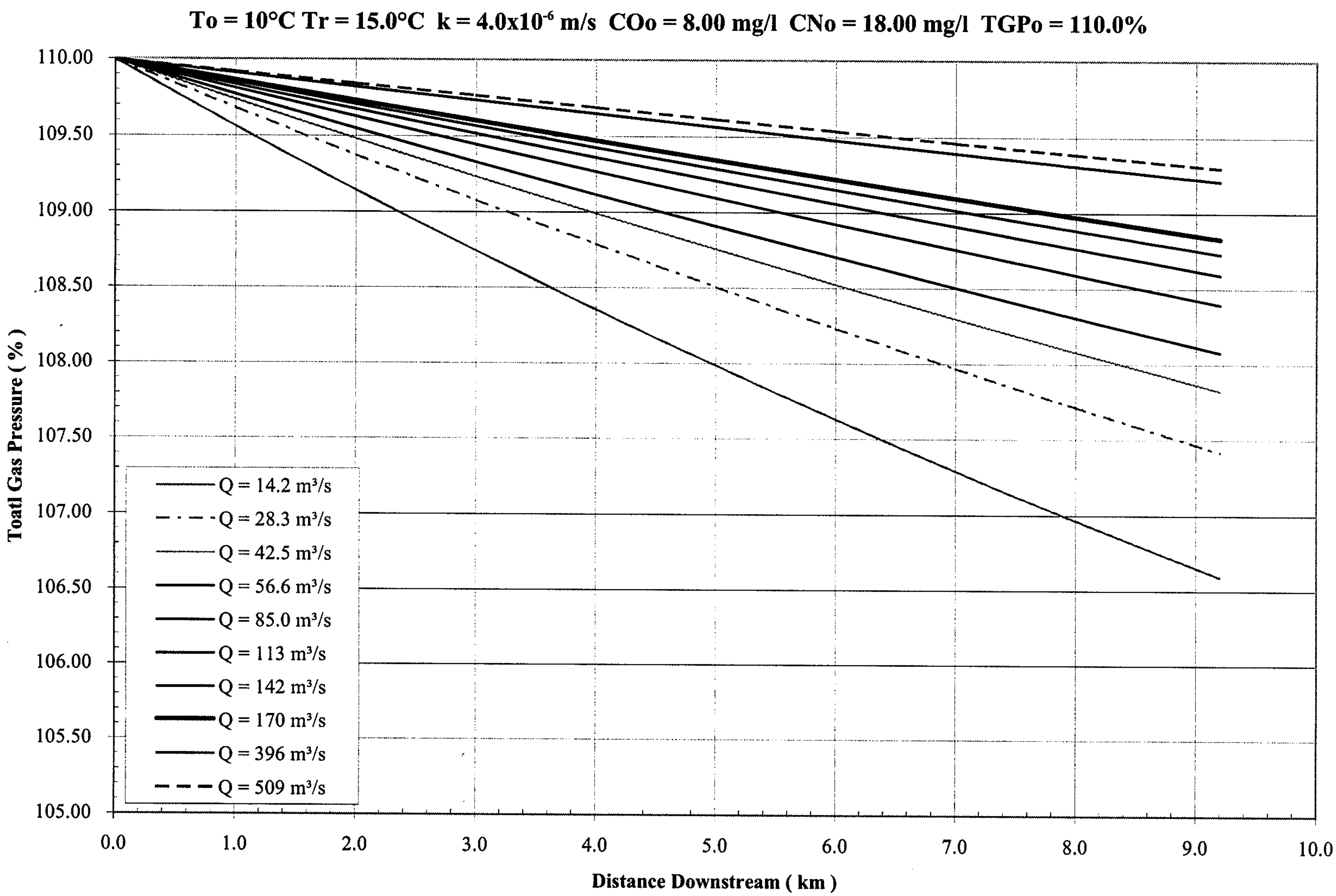


Figure 12. Nechako Canyon Total Gas Pressure vs Distance Downstream: To=10°C , Tr=30.0°C, k=6.0x10^{-6}m/s

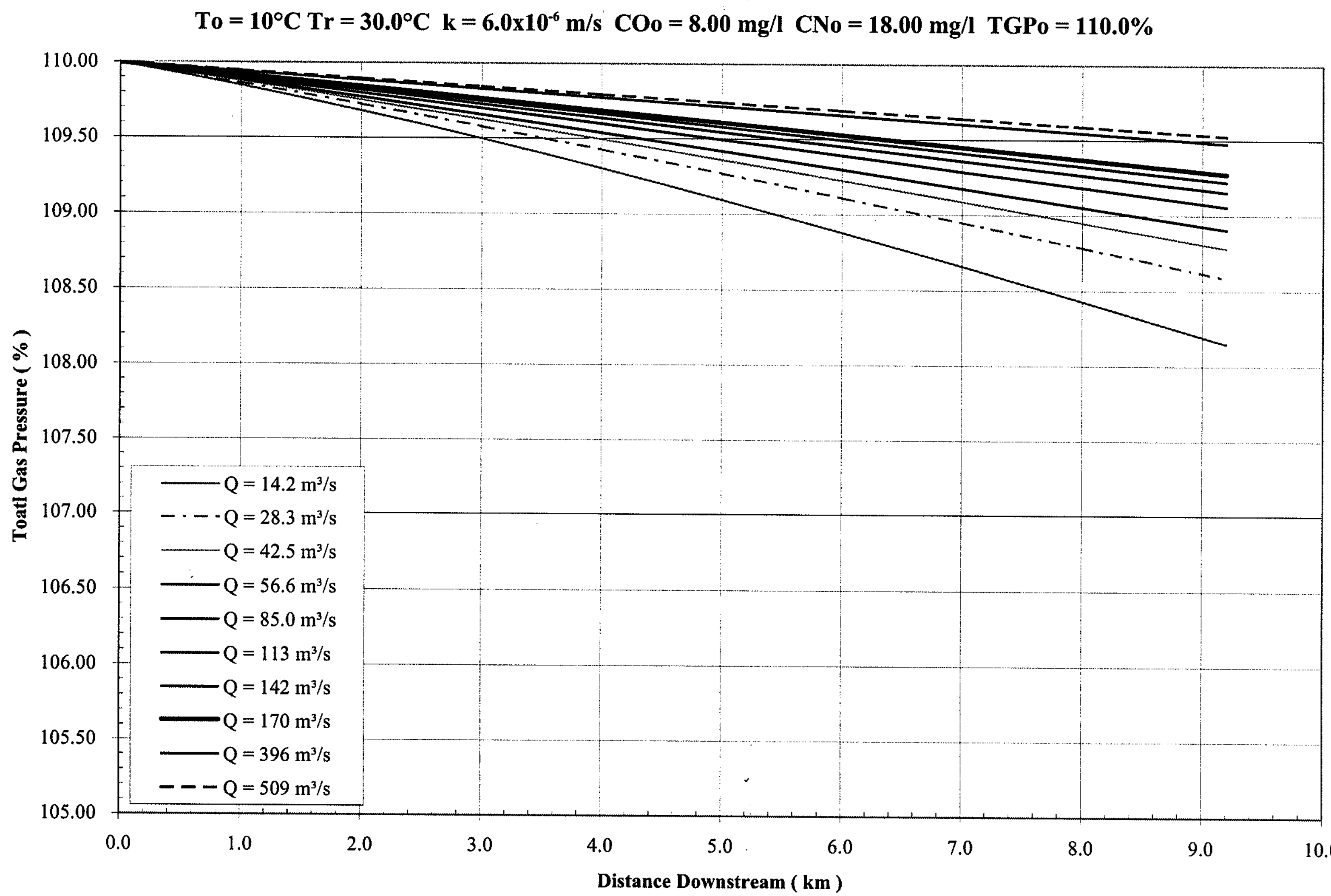


Figure 13. Nechako Canyon Total Gas Pressure vs Distance Downstream: To=12°C, Tr=15.0°C, k=4.0x10^{-6}m/s

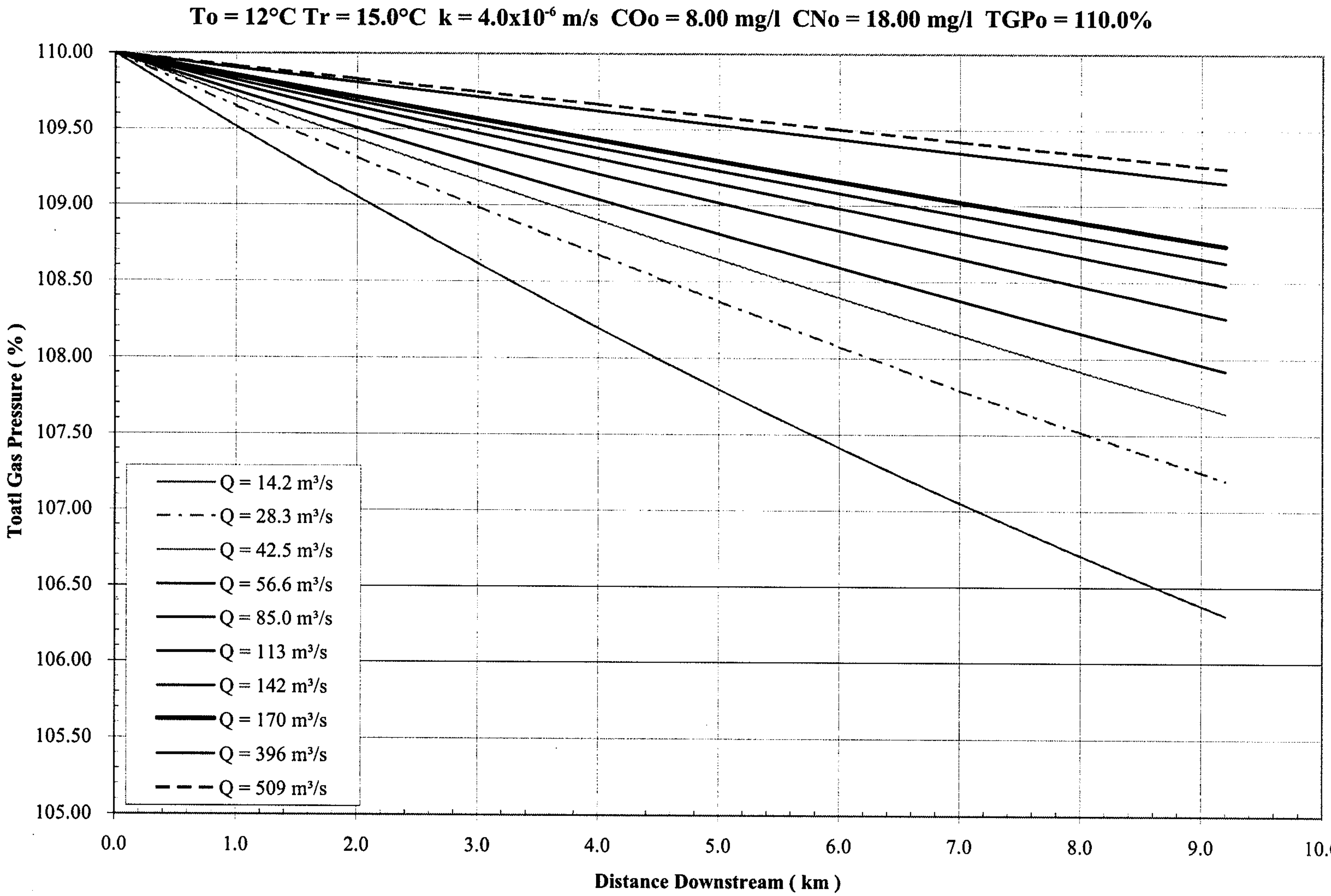
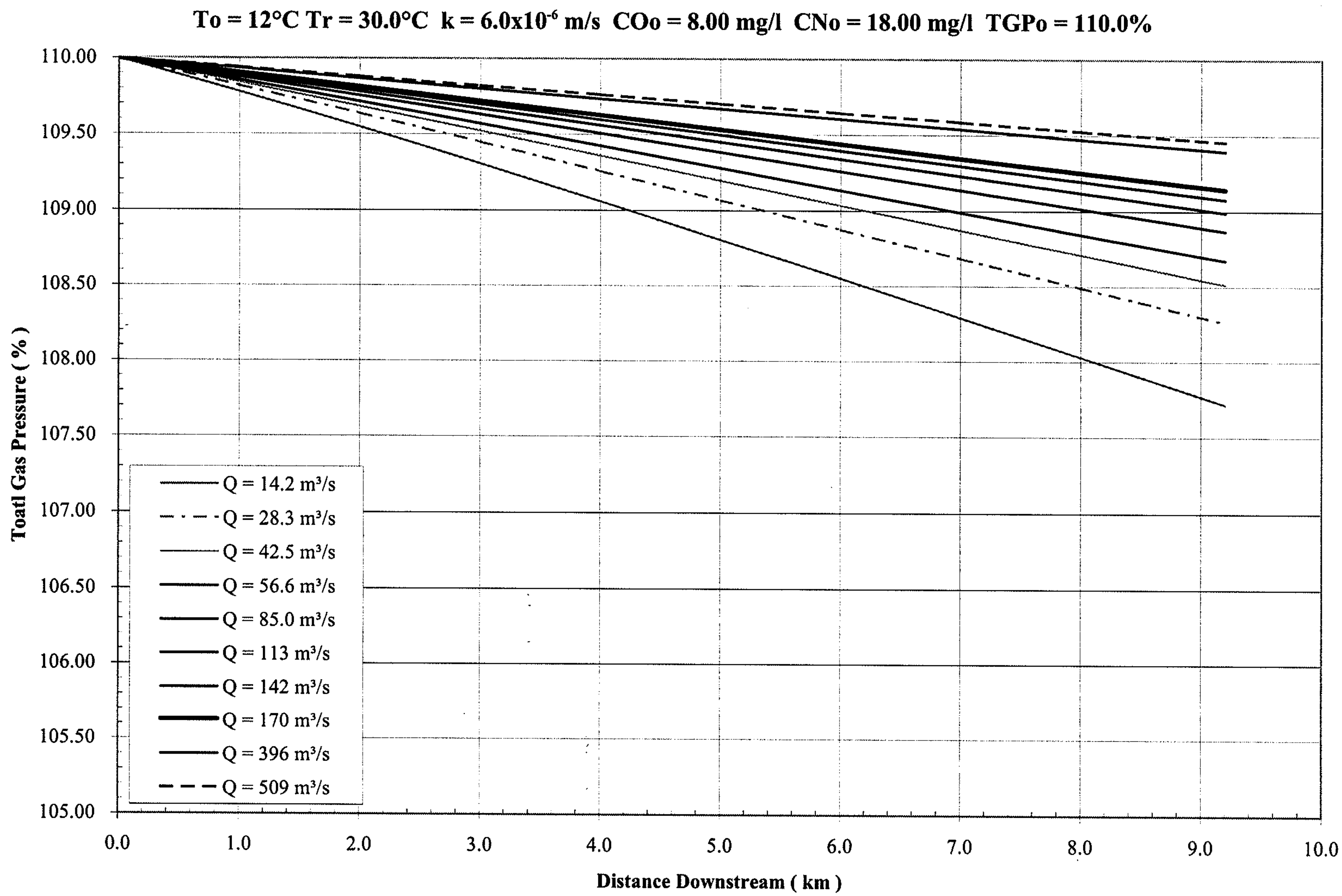


Figure 14. Nechako Canyon Total Gas Pressure vs Distance Downstream: To=12°C, Tr=30.0°C, k=6.0x10^{-6}m/s



Additional work will be necessary once the proposed discharge regimes are confirmed. Generally, the amount of re-aeration that can occur in the canyon (a time dependent process) is inversely proportional to the rate of flow (*i.e.* it takes less time for water to pass through the canyon at a greater flow). Thus TGP levels just upstream of Cheslatta Falls will be greater at higher flow releases from Kenney Dam (but still lower than expected immediately below Kenney Dam). However, when these releases are combined with releases from the Skins lake Spillway, passing over Cheslatta Falls, the combined flow will increase in water temperature (which will result in a lower DGS level but maintain the TGP) resulting in a increase in TG saturation %. As well, these water passing over Cheslatta Falls will add to the TGP load. The mitigating factor is the "dilution" capacity of the higher flows from Kenney Dam (% of total flow below Cheslatta Falls coming from Kenney Dam is greater than at lower Kenney Dam releases), limiting the overall gain from the Cheslatta Falls TGP load. The basis information needed to examine these issues is provided as part of the sensitivity analyses reported above and can be used in the future to calculate the resulting TGP levels of alternate flows from each reservoir release facility.

If additional data is collected at Cheslatta Falls in 2005 and it indicates, as expected, that the current TGP regime remains in the range suggested by our calculations to date, consideration will have to be given to the development of a site specific TGP guideline as outlined in section 3.2.4 of this report and the current TGP guidelines.

Figure 15. Nechako River Below Cheslatta Falls Total Gas Pressure vs Cheslatta River Flow: To=10°C, Tr=15.0°C, k=4.0x10^{-6}m/s

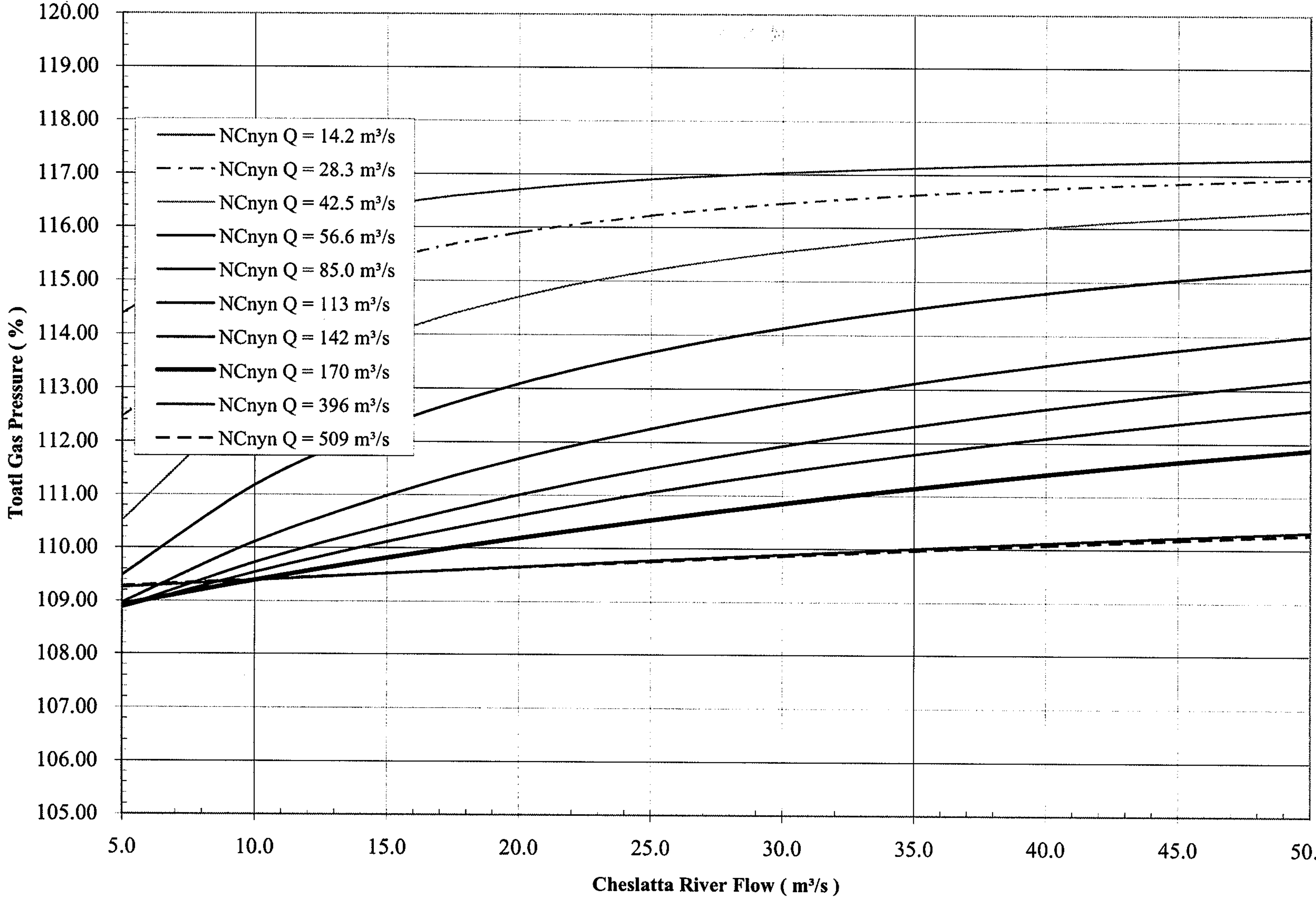


Figure 16. Nechako River Below Cheslatta Falls Total Gas Pressure vs Cheslatta River Flow: To=10°C, Tr=30.0°C, k=6.0x10^{-6}m/s

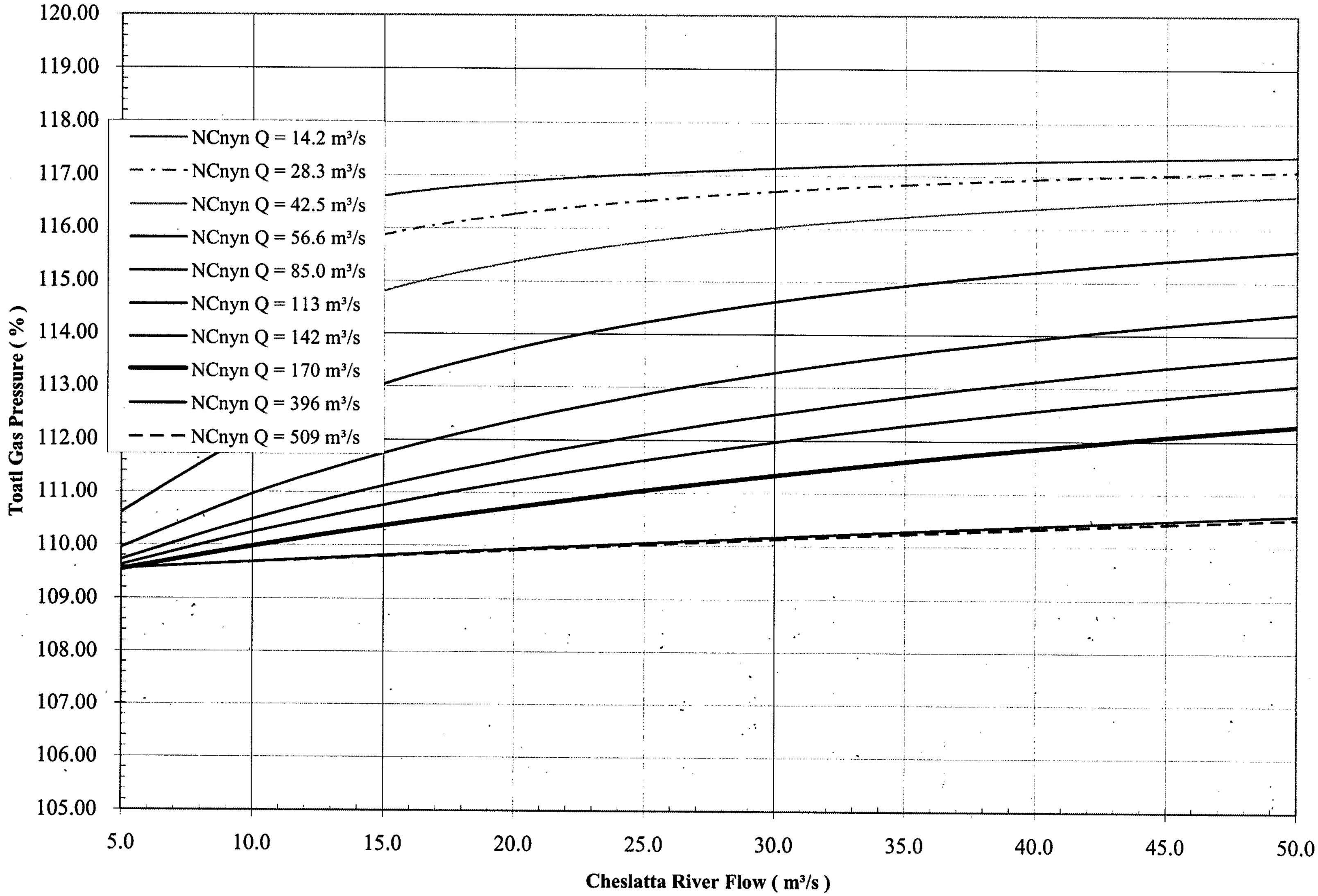


Figure 17. Nechako River Below Cheslatta Falls Total Gas Pressure vs Cheslatta River Flow: To=12°C, Tr=15.0°C, k=4.0x10^{-6}m/s

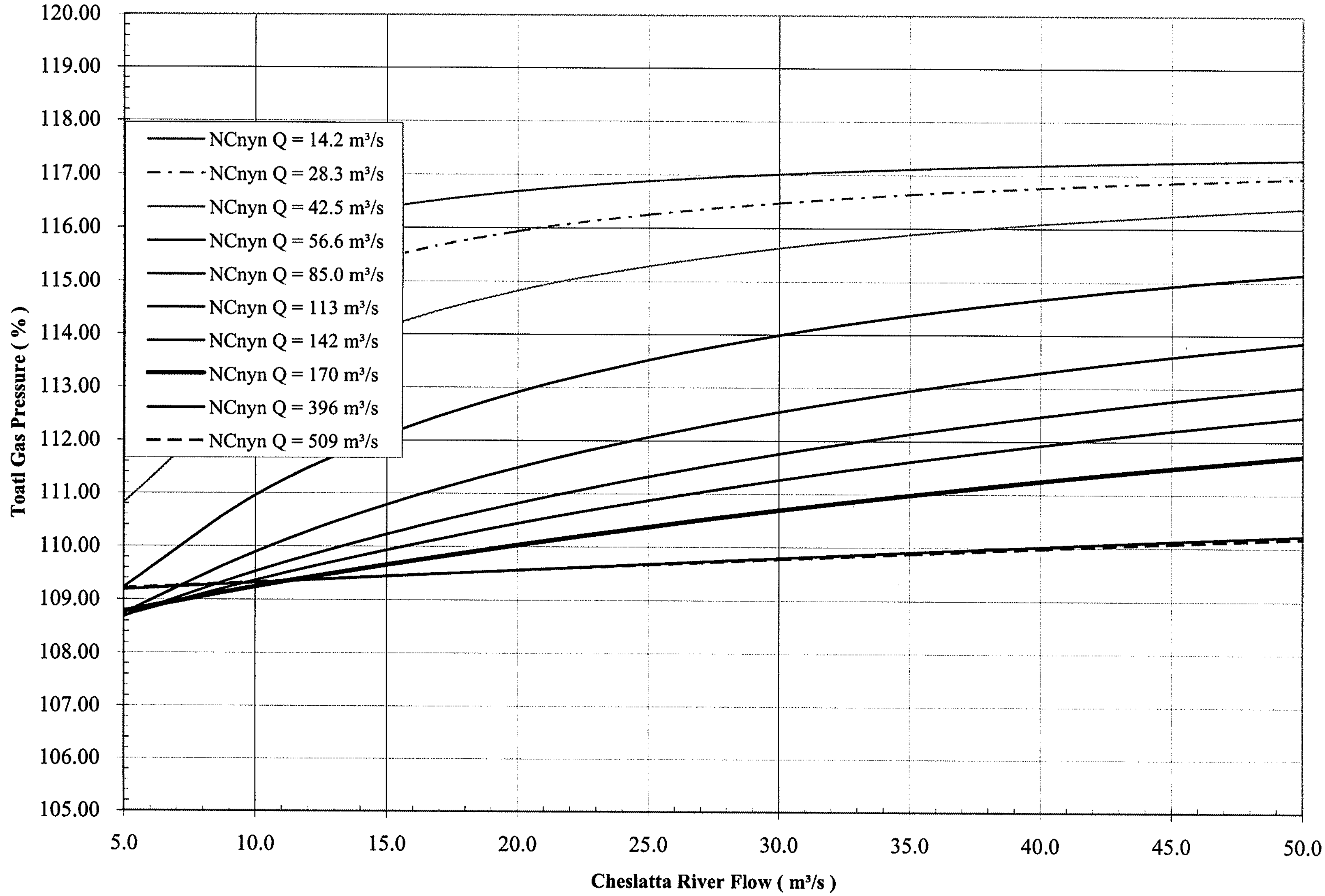
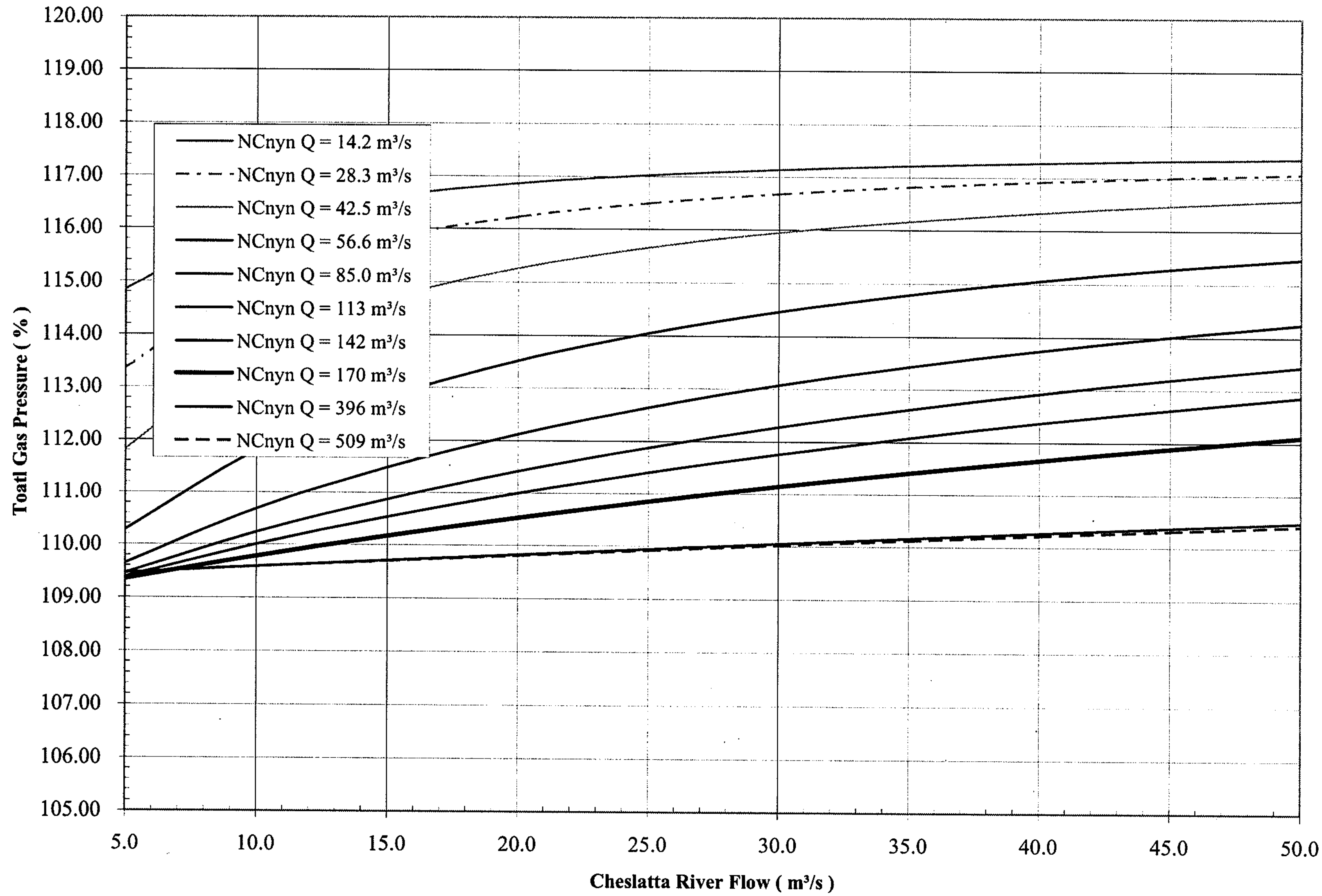


Figure 18. Nechako River Below Cheslatta Falls Total Gas Pressure vs Cheslatta River Flow: To=12^{0}C, Tr=30.0^{0}C, k=6.0x10^{-6}m/s



8.0 FISH SPECIES USING THE NECHAKO RIVER

The Nechako River provides habitat for many species of fish during various stages of their life cycle. The following species have been observed below Cheslatta Falls by conducting electro-shocking and rotary screw trapping (NFCP, 2003) and other Nechako River sampling:

- Chinook Salmon *(Oncorhynchus tshawytscha)*
- Bull Trout (*Salvelinus confluentus)*
- Rainbow Trout (*O. mykiss)*
- Sockeye Salmon *(O. nerka)*
- Coho Salmon *(O. kisutch)- limited number*
- White Sturgeon *(Acipenser transmontanus)*
- Northern Pikeminnow (*Ptychocheilus oregonensis*)
- Burbot (*Lota lota*)
- Mountain Whitefish (*Prosopium williamsoni*)
- Lake Trout *(Salvelinus namaycush)*
- Longnose Dace *(Rhinichthys cataractae)*
- Leopard Dace (*R. falcatus*)
- Peamouth Chub (*Mylocheilus caurinus*)
- Redside Shiner (*Richardsonius balteatus*)
- Largescale Sucker (*Catostomus macrocheilus*)
- Aleutian Sculpins *(Cottus aleuticus)*
- Sculpins *(Cottidae sp.)*
- Brook lamprey *(Lampetra richardsoni)*
- Brassy Minnow (*Hybognathus hankinsoni*)

Life histories of these various fish species were reviewed along with timing of each life stage presence in the Nechako River. These were summarized in a companion report in November 2004 titled: "Towards a Decision on a Release Water Temperature for a Cold Water Release Facility at Kenney Dam", authored by Triton Environmental Consultants and Aspen Applied Sciences.

During a workshop held to discuss the proposed release water temperature (Triton, 2004), the above list of species was reviewed to identify any sentinel species that would be the focus of further discussion. A sentinel species is one of particular conservation or economic importance that should be given special consideration, when identifying water temperature objectives for the main-stem river. The key points made during this portion of the discussion were as follows:

Species	Comments
Chinook Salmon	Species of conservation interest (1987 Settlement Agreement)
Bull trout	Provincially listed but only use the Nechako River during the spring out-migration of sockeye salmon smolts.
Rainbow trout	Species of local interest for development of sports fishery. Only use the main-stem Nechako for rearing as adults. Spawning and early rearing take place in tributaries.

Species	Comments
Sockeye salmon	Species of interest during annual migration to spawning grounds in tributary watersheds. Small population of river rearing fish in upper river is unlikely to be sentinel species. Water temperatures are not an issue during their spring downstream migration.
Coho salmon	Very small population using the Nechako main-stem. Although listed as endangered in Fraser watershed, the size of the population is unlikely to result in it being a sentinel species.
White Sturgeon	Listed provincially but critical temperature needs likely in June rather than July and August when a water release facility would be operated.
Northern Pikeminnow	Not considered a sentinel species
Burbot	Not considered a sentinel species
Mountain Whitefish	Not considered a sentinel species
Lake trout	Not considered a sentinel species
Longnose dace	Not considered a sentinel species
Leopard dace	Not considered a sentinel species
Peamouth chub	Not considered a sentinel species
Redsided shiner	Not considered a sentinel species
Largescale sucker	Not considered a sentinel species
Sculpins	Not considered a sentinel species
Brassy Minnow	Not considered a sentinel species
Brook Lamprey	Not considered a sentinel species

In the context of release water temperature only, it was concluded that chinook salmon is a sentinel species for the upper and middle Nechako River. Sockeye salmon is a sentinel species during their upstream migration in late July and August and that white sturgeon is a sentinel species during June spawning and possibly during July and August incubation.

Fidler and Miller (1997) plotted data records for pacific salmon species, cutthroat and steelhead trout reported by separate authors as time to mortality versus water ΔP. Sockeye salmon presented a ΔP threshold for mortality at about 125 mm Hg (sea level TGP% about 116%). The threshold for cutthroat was slightly lower at a water ΔP of 116 mm Hg (sea level TGP% about 115%). For steelhead trout a threshold with characteristics very similar to that for sockeye salmon and cutthroat trout was indicated at a water delta P of about 115 mm Hg (sea level TGP% about 115%).

Chinook salmon presented a water ΔP threshold in the vicinity of 130 to 140 mm Hg (sea level TGP% about 117% to 118%), but also another ΔP threshold at 76 to 78 mm Hg. Finally, coho salmon presented a threshold indicated at a water ΔP of about 133 mm Hg (sea level TGP% about 117%). However, there were many mortalities indicated at a water ΔP of 87 mm Hg which may also represent a lower threshold. There were no mortality data below this level or between this level and the higher 130 mm Hg level to support this hypothesis.

Counihan *et al.* (1998) studied the effects of dissolved gas supersaturation on white sturgeon (*Acipenser transmontanus*) larvae in the Columbia River. The authors exposed white sturgeon larvae to mean total dissolved gas (TDG) levels of 118% and 131% saturation in laboratory bioassay tests. Gas bubble trauma (GBT) was manifested as a gas bubble in the buccal cavity, nares, or both and it first occurred at developmental stages characterized by the formation of the mouth and gills. Exposure times of 15 min were sufficient to elicit these signs in larvae in various stages of development. No mortality was observed in larvae exposed to 118% TDG for 10 d, but 50% mortality occurred after a 13-d exposure to 131% TDG. Since the exact depth distribution of dispersing white sturgeon larvae in the Columbia River was unknown, the authors cautioned these results may represent a worst-case scenario if white sturgeon larvae are dispersed at depths with insufficient hydrostatic pressure to compensate for high TDG levels.

Hildebrand (1992) assessed the extent of GBT in fish, resulting from the high total dissolved gas levels below Hugh Keenleyside Dam. Holding cage studies revealed that for rainbow trout fry and juveniles exposed to high TGP (>120%) levels in surfaces waters (< 1.0 m depth), 50% mortality occurred at less than 16 hours exposure for juveniles and 24 hours for fry. The length of exposure required to induce mortalities in adult bull trout, rainbow trout, largescale sucker and walleye held in surface waters at TGP values of 119-122% was less than six hours; exposure times of 12-13 hours resulted in 100% mortality. Fish of all species and sizes held at a depth of 3.0 m or greater were unaffected by GBT. Examination of fish captured during the study indicate that sucker species showed the highest incidence of GTB symptoms (3% of the total catch), rainbow trout and mountain whitefish presented an incidence of GBT of 0.7% and 0.4% respectively.

Krise and Smith (1991) assessed the tolerance of juvenile lake trout (*Salvelinus namaycush*) exposed to gas supersaturation ranging from ΔP 9 to ΔP 159 mm Hg above saturation for 30 days. Growth and survival were virtually equal in all treatments. Survival ranged from 93% at ΔP 42 to 99% at ΔP 126. There were no signs of gas bubbles on fish at ΔP 75 or less.

Therefore, in the context of fish sensitivity to TGP, the literature seems to indicate that rainbow trout and sucker species are the most sensitive species of those studied to date.

9.0 CONCLUSIONS

1. Total gas pressure measured in the Nechako River at Cheslatta Falls in 2004 is consistent with earlier measurements with peak values near 117%;
2. Total gas pressure measured in the Nechako Reservoir indicates that reservoir releases would have TGP levels near saturation both at depth and near the surface;
3. Review of the literature indicated that the current state of the art for predicting requires measurements at the completed facility before the available models can be used to predict TGP% below the spillway plunge pool with any certainty. Given that the proposed facility has not been constructed, this data cannot be measured and the predictive models are of little use.
4. As a result, this study relies on prototype TGP data collected at BC Hydro's Seven Mile Dam for use in estimating the expected TGP levels below the proposed facility. The Seven Mile Dam has a similar spillway to that proposed for Kenney Dam. These results indicate that expected TGP% below the plunge pool could be from near saturation to as much as 110%.
5. The preliminary steady state modeling documented in this report indicates that TGP % will decrease over the length of the Nechako Canyon but will increase at Cheslatta Falls because of the influence of water released from the Skins Lake Spillway. In a worst case, these levels could approach those observed at Cheslatta Falls in 2004.
6. The literature indicates that rainbow trout and sucker species are the most sensitive species to TGP% of those studied to date and should be considered as sentinel species for the Nechako River. As the expected TGP levels at Cheslatta Falls could exceed the current provincial guideline of 110%, there may be a need to consider development of a site specific TGP guideline that would consider these two species.

10.0 RECOMMENDATIONS

1. The limited amount of TGP data collected during the summer months in 2004 indicates that the current observations are similar to those collected by Servizi (1986) and Roland and Jensen (1988). Additional data collection may not add significantly to our knowledge of TGP conditions on the Nechako River. However, in the event that it is decided to collect additional information, it is recommended that a focused program of data collection be carried. The equipment from Common Sensing can be used for this work but will have to be closely monitored to make sure it is collecting the required information. Further, it is recommended that duplicate instruments be used at each location on an alternating basis (5 days at one site and then serviced and relocated to another site) and that data collection be focused on mid- to late June, one week in July as flows typically increase (July 12 to 21) and in the second week of August when flows and water temperatures are typically near their annual peak.

2. Ongoing research being conducted in association with hydro-electric projects both in Canada and the United States should be monitored as plans for the CWRF are refined to determine if any advances are being made in the estimation of the TGP production characteristics of flip bucket spillways.

3. The TGP data from the BC Hydro's Seven Mile Dam project should be analyzed in further detail to define the driving forces behind TGP levels at that dam and to determine if the flip bucket spillway will in fact maintain TGP levels in the plunge pool at less than 110% saturation as is indicated by that data.

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APPENDIX I

HISTORY OF TGP DATA COLLECTION SERVICING ISSUES, 2004

History of TGP Data Collection Servicing Issues -2004

May 11th, 2004 - Reservoir and at Cheslatta Falls

- TGP meters installed at the Reservoir
- Meter logging properly
- Meter was not installed under Cheslatta Falls as the cable was too short.

May 23rd, 2004 - Reservoir Unable to communicate with data logger using serial cable and therefore no download was completed.

- Meter was deployed under Cheslatta Falls
- No membrane change was completed, as membranes had not yet been received from Brian D'Aoust.

June 4th, 2004 - Reservoir and at Cheslatta Falls

- Membranes changed at both the Reservoir and Cheslatta Falls.
- Still unable to communicate with data loggers using serial cable as a result the parallel cable was used to download the data from both sites.
- After download was completed at Cheslatta falls and the data logger was place back in logging mode the logger became unresponsive.

June 10th-11th, 2004 - Cheslatta Falls

- During Index Sampling in reach one; Brian D'Aoust was contacted, via satellite phone, regarding the data logger at Cheslatta Falls that was completely unresponsive. After talking with him, it was decided that the data logger should be removed from the field and taken back to the Prince George office.
- Once received by the Prince George office, under the instruction of Brian D'Aoust, everything possible was tried to reboot and make the data logger responsive. All attempts were unsuccessful.
- The logger was sent down to Brian D'Aoust for further inspection.

July 4th, 2004 - Cheslatta Falls

- An attempt was made to re-install the data logger at Cheslatta Falls. This was not completed, however, because upon arrival at the site it was found that the key for the lock box had been lost during the fire and that over a meter of the probes cable was melted due to fire exposure.
- The data logger at the reservoir was not downloaded as no key was available to open lock box but both membranes were changed.

July 19th, 2004 - Cheslatta Falls

- The data logger and new cable were installed at Cheslatta Falls. Logger was left plugged into an external battery source and in logging mode.

July 28th, 2004 - Reservoir

- The data logger on the reservoir was downloaded using the parallel cable as Brian D'Aoust provided only (no we had two) one serial cable, upon the return of the Cheslatta unit and it was mistakenly left in the Cheslatta case.
- Both membranes were changed on the reservoir.
- Unit was out of power upon arrival and was left logging and plugged into a newly charged external battery. (Internal battery died July 5th after 56 days)
- Temperature reading from both the 15 ft and 60 ft probes became strange ~ 2 hours after the membranes were changed.

August 12th, 2004 - Reservoir

- NES crew checked data logger at reservoir. Logger was turned on and it was checked to make sure it was still logging, which it was. The probes were not pulled to the surface during this time.

August 24th, 2004 - Reservoir and Cheslatta Falls

- Upon arrival at both the reservoir and the falls both data loggers were found to be without power. The external battery died on August 19th at the reservoir; however at Cheslatta Falls we are unsure when the logger lost power, as no data was logged for this period of time.
- Both loggers were downloaded successfully using the serial cable.
- Membranes were changes at both sites.
- The 60 ft probe on the reservoir was found to be missing its oxygen sensor.
- The broken probe was removed from the field and taken back to the Prince George office.
- Both loggers were left in log on mode and plugged into new external batteries.
- No data was found to be present from July in the file downloaded from the Cheslatta Falls logger.

NOTES:

In reviewing the data we noted the following:

June 23rd, 2004 - Reservoir

- A noticeable change in water temperature (0 @ 14:05 and 56.7 @ 15:05) was recorded by the reservoir probe located at 15ft. Strange reading such as these continued until our last download on August 24, 2004.
-

June 23rd, 2004 - Cheslatta Falls

- A large forest fire around Kenny Dam began around this time in June and lasted until June 28th, 2004.

July 1st, 2004 - Reservoir

- The data logger at the reservoir became low on power with power being completely lost on July 5th, 2004.

CONCLUSIONS

After much discussion about what may have caused the issues present at this time we have come up with the following possible explanations and recommendations.

The Reservoir Data

On the 23rd of June the 15ft probe began to record strange and incorrect temperature readings, it is possible that, as the probes are only held together using pressure, water is leaking into the probes circuit board. This in turn could cause incorrect readings from the probe. During membrane changes it is also possible the pressure seals in the probe are not resealing properly causing water damage. Movement of the oxygen sensor during membrane changes may contribute to this problem. Additionally, such movement may have caused the oxygen senor in the 60 ft probe to become loose and eventually fall out after the last membrane change on July 28th, 2004.

The Cheslatta Falls Data

It possible that logger was not properly put into logging mode before it was left on July 19th, 2004 . It is also possible, however, that the probe in the river has also received some water damage to its circuit board causing it to stop working.

RECOMMENDATIONS

In order to check our assumptions we recommend that during the next sampling trip, scheduled for Tuesday the 7th of September, that all the probes be checked for possible water damage and that the oxygen sensors be checked to ensure they are tightly held in place on the probe. Additionally, the parameters being recorded, such as temperature and oxygen, will be monitored every minute for ~15 minutes, to ensure the readings taken are correct, before the logger is left on its own. If the readings are incorrect, Brain D'Aoust will be contacted via satellite phone and corrections will try to be completed in the field. In the event corrections cannot be completed in the field the logger will be removed and taken back to the Prince George office.

APPENDIX II

SUMMARY OF TGP INSTRUMENT OPERATIONS AND DATA QUALITY

CHESLATTA FALLS

Field work dates		Status of data
Logger started	Logger downloaded	
May 10 and 11, 2004	May 10 and 11, 2004	In situ monitoring for 2 hours. TGP ranged between 111% and 115% The logger was not installed as extra cable was needed
May 23, 2004	June 04, 2004	Mean TGP: 117.5% Once data were downloaded, the logger was started in logging mode at this point the logger became unresponsive.
June 04, 2004	June 11, 2004	Logger still unresponsive, it was sent back to Commen Sensing
July 04, 2004	-	Crew went on site to deploy the logger, however the recent forest fire destroyed the cable left on site thus the logger was not installed.
July 19, 2004	August 24, 2004	The data logger and new cable were installed at Cheslatta Falls on July 19, 2004. The logger failed to log data. The logger was started with new battery and left on logging mode.
August 24	September 07, 2004	Data retrieved do not make sense. The logger was sent to ComenSensing again
October 3, 2004	October 15, 2003	TGP ranged between 113 and 115%

RESERVOIR

Field work dates		Status of data
Logger started	Logger downloaded	
May 12, 2004	May 23, 2004	Could not download data with serial cable.
May 23, 2004	June 04, 2004	Surface Mean TGP May 12-June 04:105% Depth Mean TGP May 12-June 04: 97%
June 04, 2004	July 04, 2004	The data logger at the reservoir was not downloaded as no key was available to open lock box (the key was left at Cheslatta site and was burnt during the forest fire) but both oxygen membranes were changed.
July 04, 2004	July 28, 2004	Surface TGP June 04-July 1 ranged from 103% to 120%. Thus the data seems inconsistent. Between July 19 to July 20 the data do not make sense (i.e., TGP=54%) Depth TGP June 04-July 1 ranged between 97% and 98% Logger stopped recording on July 1.
July 28, 2004	August 12, 2004	NES crew checked data logger at reservoir. Logger was turned on and it was checked to make sure it was still logging, which it was. (*However Excel data for this day do not make sense!*) The probes were not pulled to the surface during this time.
August 12, 2004	August 24, 2004	July 28-August 28: The data retrieved did not make sense, the oxygen probe set a depth was lost.
August 24, 2004	September 07, 2004	TGP at the surface ranged between 97-98%. (Note that the first day the TGP data were too low). The logger battery died on September 4.
September 7, 2004	October 2, 2004	TGP at surface ranged between 95 and 97% Batteries died on September 29.

SPOT MEASUREMENTS AT VARIOUS LOCATIONS (2 HOUR INTERVALS)

A. Cheslatta River

	Below Spillway	Before Upper Cheslatta Falls	Outlet of Murray Lake
May 10, 2004	Could not download the logger but the unit read 115% and a compensation depth of about 4.6 feet.	TGP ranged from 104 to 108%	TGP ranged from 103% to 105%
October 2, 2004	TGP ranged from 100% to 111% (?)	TGP ranged from 99% to 108% (?)	TGP ranged from 97% to 100%

B. Reservoir

Date	TGP% Surface	TGP% Depth
May 13 –June 4	103-109	97-100
June 5 – June 14	102-106	97-99
June 15-June16	101 –108 Note during three hours on June 16 TGP dropped from 11 to 86 then went back to 101.	96-97
June 17 – June 19	102-120	96-97
June 19 - July 1	90-16 (drop in pressure)	97-98
July 1-August 14	Not reliable	Not reliable
August 15-August 17	96-101	Not reliable
August 18-24	Not reliable	No data
August 25 – Sept. 4	97-99	No data (no probe)
Sept 5-Sept 7	No batteries	No data (no probe)
Sept 8- Sept 15	96-97	No data (no probe)
Sept 15-17	No batteries	No data (no probe)
Sept 18-Sept 28	95-96	No data (no probe)
Sept 29-October 2	No batteries	No data (no probe)

Note: Term "not reliable" refers to data that was found not to be within any reasonable range (either very low or very high or temperatures data that was not within any previously recorded range.