TGP Performance Measures for the Columbia River WUP

A Brief Summary

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Prepared for
Bob Westcott
B.C. Hydro
Castlegar, B.C.

Prepared by
Larry E. Fidler, Ph.D.
Aspen Applied Sciences Ltd.
Kimberley, B.C.

1.0 Introduction

Since its completion in 1969, the Hugh L. Keenleyside (HLK) Dam on the Columbia River has been a source of dissolved gas supersaturation (DGS). In the early 1970s, Clark (1976 and 1977) measured TGP%[1] levels of up to 133% in the river immediately below the dam. Throughout the 1980s and 1990s, B.C. Hydro, the operator of the HLK Dam, conducted numerous studies involving the monitoring of DGS and its effects on fish populations of the river (Maxwell 1985, Hildebrand 1991, R, L & L. Environmental Services Ltd. 1984, 1995; Prince et al. 2000). In general, TGP% levels often exceeded 140% at certain times of each year and lasted for varying periods. TGPs of this magnitude can kill fish in shallow water environments in less than 5 hours (Weitkamp and Katz 1980, Fidler and Miller 1997, Antcliffe et al. 2002). Yet, actual signs of gas bubble trauma (GBT) observed in fish were generally low (Hildebrand 1991, Prince et al. 2000). Nevertheless, B.C. Hydro undertook a program of studies involving the modeling of DGS production by the HLK Dam and examining methods of modifying the operations of the dam to reduce DGS (Aspen Applied Sciences Ltd. 1995, 1997, 1998, 1999). These studies were initiated, in part, by the publication of Canada guidelines for the protection of aquatic life from the effects of DGS (Fidler and Miller 1997). The guidelines called for a maximum TGP% of 110% with special provisions for juvenile fish in shallow water. The results of the B.C. Hydro studies led to a revision to the dam's local operating orders that significantly reduced river DGS levels. Yet, the levels were still above the Canada guidelines for extended periods during certain years. In the late 1990s, work was initiated by the Columbia Power Corporation to develop a hydroelectric generating facility at the HLK Dam. Initial studies indicated that with the Arrow Lakes Generating Station (ALGS) in place, DGS levels would be significantly reduced below those achieved under the revised local operating orders (Aspen Applied Sciences Ltd. 1996, 1997, and1998).

Earlier monitoring studies of the impacts of DGS to fish in the Columbia River, downstream from the HLK Dam, showed low incidence of GBT signs in live fish (Hildebrand 1991). An exception was a supplemental study in which live fish were held in cages in shallow water. In this study, fish died from GBT much sooner than would be indicated by the measured TGP. However, a later review of the data (Aspen Applied Sciences Ltd. 2002) showed that the actual TGP levels were much higher that had been measured (see below).

The Hildebrand (1991) study, like all studies to date of GBT in fish, was limited by the fact that, although it is relatively easy to monitor live fish for signs of GBT, it is extremely difficult to establish if mortality is occurring. Very high levels of mortality (from any cause) are required before dead fish can actually be observed in a river environment, especially one the size of the Columbia River (Ebel 1969, White et al. 1991, Lutz 1995). In addition, dead fish can sink to the bottom of the river and GBT affected fish can be consumed by predators; thus, removing them from any sample population.

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[1] In this report, both ΔP and TGP% will be used to express levels of dissolved gas supersaturation (DGS). This is consistent with the recommendations contained in "Standard Methods for the Examination of Water and Wastewater", 19th Edition, APHA, AWWA, WEF. ΔP is defined as the difference between total dissolved) gas pressure (TGP) and barometric pressure. ΔP is a standard readout from most commercial instruments available for measuring DGS. TGP% is calculated with respect to local barometric pressure.

In 1998, Water Use Planning (WUP) was initiated by the B.C. Minister of Employment and Investment (MEI), the Minister of Environment, Lands, and Parks (MELP)[2], and BC Hydro as a public consultation approach to optimize water allocation and use associated with BC Hydro's facilities across a range of public, provincial, and federal issues.

The Columbia River WUP was initiated in 2002 and river DGS produced by the HLK Dam was a principal component to be addressed by way of TGP performance measures (PMs). Specifically, TGP PMs were to be developed as a means of assessing proposed dam operational alternatives. The PMs were to be based on existing dam/powerplant operational and environmental constraints, data from the literature, and novel data collected specifically for performance measure development from the Columbia River. In the case of the HLK Dam, operational alternatives were to be compared using TGP PMs applied to simulated operations based on a common set of a continuous time series of historical inflows. Complicating the assessment of different operational alternatives was the fact that the B.C. Hydro watershed computer models that generated dam inflows and discharges were limited to monthly average flows. This limitation did not allow any reliable quantitative means of weighing the relative risk of GBT in fish under the dynamic exposure conditions that exist in the Columbia River. In the Columbia River, TGP levels often change on a daily basis (Aspen Applied Sciences ltd. 1995 and1998) and fish depth behaviour (a critical factor in the response of fish to DGS) is unknown. Furthermore, the only data available to evaluate GBT risk was laboratory data from the literature involving fish exposed to DGS in shallow water (e.g. 0.25 m) environments, under steady state conditions. An added complication was that the response of fish to GBT is dependent on water temperature, which, in the Columbia River, varies throughout the year. Clearly, before the Columbia River WUP process could proceed, in terms of the effects of DGS, solutions had to be found to these limitations.

2.0 TGP Performance Measure Development and Application

Overcoming the limitations described above initially involved three separate analyses. The results of these analyses were eventually integrated into a combined analysis that yielded the required TGP PMs, the historic daily average flow scenarios, and an evaluation of the TGP benefits derived from different dam operational alternatives. The separate analyses were: 1) derivation of the TGP production characteristics of the Hugh Keenleyside Dam under all potential operational scenarios, 2) development of a daily average flow formulation that could be applied to the monthly average flow data from the B.C. Hydro watershed models, and 3) development of a GBT risk assessment methodology. These are described as follows.

2.1 Hugh Keenleyside Dam TGP Production Characteristics

Over the last decade, B.C. Hydro sponsored the development of the HLK/TGP/GBT computer model for evaluating the effects of DGS on the Columbia River resulting from the operations of the HLK Dam (Aspen Applied Sciences Ltd. 1995, 1996). Although the model predicts TGP levels downstream from the dam for all dam operational configurations, it does so only for a single configuration at a time. In order to assess the river TGPs for thousands of days of operation, it was necessary to modify the output of the program to facilitate rapid application of the model predictions.

[2] MELP and its associated responsibilities has subsequently (2002) been reorganized into the Ministry of Water, Land, and Air Protection (MWLAP), Ministry of Sustainable Resource Management (MSRM), and the Crown Corporation Water and Land.

This was accomplished by running the program for a range of discharges and total heads. The results, which were tabulated as discharge, total head, and river TGP were then incorporated into an Excel spreadsheet using lookup tables (Aspen Applied Sciences Ltd. 2003). Once daily average dam discharges and total heads were developed, the Excel spreadsheet allowed thousands of daily calculations to be performed in a matter of seconds.

2.2 HLK Daily Average Discharge and Total Heads

B.C. Hydro was able to develop monthly average HLK heads and discharges for the range of operational alternatives that were to be examined under the Columbia River WUP. Through a perturbation analysis, these data were modified by superimposing daily average discharges and total heads for 15 years of historical dam operations. These data were then incorporated into the HLK Dam TGP production Excel spreadsheet to yield daily average TGPs for the full range of operational alternatives.

2.3 GBT Risk Assessment Methodology

In the case of GBT risk to fish, time to 20% mortality data from the literature for juvenile rainbow trout were developed into a relative risk factor that included the effects of water temperature (Aspen Applied Sciences Ltd. 2003). The relative risk factor, which was an inverse exponential function, expressed the risk per day of GBT mortality (20%) as a function of TGP and water temperature. Numerically, the risk factor ranged from near zero at a TGP of 115% up to 100 at a TGP of 145%. In applying the relative risk factor to the Excel spreadsheet data, it was important to recognize that there is some TGP threshold in the Columbia River below which there is no GBT impact. At present, this threshold is unknown. However, to assure that the risk factor analyses did not include TGP levels that were too low (i.e., which might distort the analyses results), two threshold TGPs were chosen for applying the risk factors. These were 115% and 120%. The 115% threshold represents the threshold for cardiovascular bubble growth in fish (Fidler and Miller 1997). While the 120% threshold was chosen somewhat arbitrarily, it was considered conservative relative to the incidence of GBT in fish that were observed by Hildebrand (1991). Although the risk factor does not take into account the depth behaviour of fish, it was considered appropriate for the WUP analyses since it would be applied in exactly the same way across all operational alternatives and all years of analyses. Essentially, it assumes that fish behaviour is unchanged between each operational alternative and between each year of analysis.

3.0 Application of the Relative Risk Assessment

The relative risk assessment Excel spreadsheet was used to examine four HLK Dam operational alternatives. These included a base case, Alt 7B 1MAF, Alt 7B 2MAF, and Alt 11B. The analyses were performed by summing the relative risk over the 15 years of daily average discharge and total head data and comparing HLK Dam operations with and without the ALGS. The results of the analyses are shown in Tables 1 and 2.

Table 1: Results of Operational Alternative Risk Factor Analyses.

HLK and ALGS	Base Case	Alt 7B 1MAF	Alt 7B 2MAF	Alt 11B
# days head differential > 17m	1041	1807	1201	486
average head differential (m)	12.5	14.4	14.2	12.1
# days over all 15 years above 115%	170	92	193	39
# days over all 15 years above 120%	12	18	26	1
ave TGP June, July, August across 15 year	109	108	109	107
total GBT risk (115%), summed over all 15 years	531	337	545	92
total GBT risk (120%), summed over all 15 years	114	182	194	6
HLK only - no ALGS influence				
	Base Case	Alt 7B 1MAF	Alt 7B 2MAF	Alt 11B
# days head differential > 17m	1041	1807	1201	486
average head differential (m)	12.5	14.4	14.2	12.1
# days over all 15 years above 115%	170	92	193	39
# days over all 15 years above 120%	12	18	26	1
ave TGP June, July, August across 15 year	115	121	109	110
total GBT risk (115%), summed over all 15 years	33796	98594	32195	11550
total GBT risk (120%), summed over all 15 years	33336	98418	31479	11343

Table 2: Results of Operational Alternative Risk Factor Analyses (Log_{10}).

HLK and ALGS	**GBT Risk Ranking based on Log10 Cumulative Risk Factor**			
	Base Case	Alt 7B 1MAF	Alt 7B 2MAF	Alt 11B
# days head differential > 17m	2	4	3	1
average head differential (m)	2	4	3	1
# days over all 15 years above 115%	3	2	4	1
# days over all 15 years above 120%	2	3	4	1
ave TGP June, July, August across 15 year	3	2	4	1
total GBT risk (115%), summed over all 15 years	2.7	2.5	2.7	2.0
total GBT risk (120%), summed over all 15 years	2.1	2.3	2.3	0.8
HLK only - no ALGS influence	**GBT Risk Ranking based on Log10 Cumulative Risk Factor**			
	Base Case	Alt 7B 1MAF	Alt 7B 2MAF	Alt 11B
# days head differential > 17m	2	4	3	1
average head differential (m)	2	4	3	1
# days over all 15 years above 115%	3	2	4	1
# days over all 15 years above 120%	2	3	4	1
ave TGP June, July, August across 15 year	3	4	1	2
total GBT risk (115%), summed over all 15 years	4.5	5.0	4.5	4.1
total GBT risk (120%), summed over all 15 years	4.5	5.0	4.5	4.1

Table 1 shows the dramatic improvement to the Columbia River TGP environment that was achieved with the addition of the ALGS. Cumulative (15 years) relative risk factors dropped by two to three orders in magnitude over those without the ALGS. This was even with the HLK Dam operating under the new operating orders that have been in place since 1996. These operating orders were a dramatic improvement over the way the dam was operated between the time the dam was completed and the early 1990s. Table 2 is the same as Table 1 except that the cumulative relative risk numbers have been converted to $\log_{10}$ numbers. This essentially provides an order of magnitude comparison between the numbers.

One of the concerns expressed early in the WUP performance measure investigations was the precision of the analyses in terms of evaluating different operational alternatives. Specifically, if there were large uncertainties in the derivations of the performance analyses, the results might be distorted to the extent that incorrect choices might be made in terms of which alternative was best in terms of GBT in the Columbia River. Early on, it was acknowledged that because the way the daily average discharges and total heads were generated, the approximate nature of the HLK Dam TGP production characteristics spreadsheet, and the uncertainties associated with the development of the relative risk assessment methodology, the analyses results were probably valid only if large differences between the operational alternatives could be shown. Given the orders of magnitude difference between the analyses results for HLK Dam operations with and without the ALGS, it is clear that the risk of GBT to fish in the river with the ALGS operational is extremely small. Furthermore, with the ALGS present, the differences between cumulative risk factors for the different operational alternatives are exceptionally small in comparison to the order of magnitude differences for the with/without ALGS comparisons. Based on this assessment, it was concluded that the cumulative risk assessment analyses were not sensitive enough to make valid comparisons between the various operational alternatives in terms of GBT. As a result, TGP was removed from the WUP process.

4.0 Recommendations

Although it was concluded that TGP was not an important factor in comparing the different operational alternatives of the WUP, it is nevertheless important from the perspective of the dramatic reductions that have taken place in Columbia River TGP since the early 1990s. As noted, Hildebrand (1991) found low levels of GBT signs in free-swimming fish. Once the 1990 river TGP levels were reexamined (Aspen Applied Sciences Ltd. 2002), it was established that rather than being in the 119% - 121% level, as measured by Hildebrand, they were in the 137% - 140% range, which is consistent with the rapid deaths of the caged fish observed by Hildebrand (1991). The extremely high TGPs were the result of the dam spillways being operated exclusively for more than 200 days continuously during 1990. This was probably one of the worst configurations that the dam could be operated in terms of DGS and far from the configurations specified by the current local operating order. It would be extremely valuable to run the 1990 operations through the cumulative risk assessment analyses. It is anticipated that the difference between the 1990 operations and those specified by the current local operating order (without the ALGS) might produce at least an order of magnitude difference in cumulative risk factors. Overall, between 1990 and the current local operating order with the ALGS, there could potentially be up to 4 orders of magnitude improvement in GBT risk in the Columbia River. The documentation of these comparisons would demonstrate the significant improvements to the Columbia River TGP that have been achieved over the past decade. At present, there is no single document that records these improvements.

References

Antcliffe, B.L., L.E. Fidler, and I.K. Birtwell. 2002. Effect of dissolved gas supersaturation on the survival and condition of juvenile rainbow trout (Oncorhynchus mykiss) under static and dynamic exposure scenarios. Can. Tech. Rep. Fish. Aquat. Sci. 2370: 70 p.

Aspen Applied Sciences Ltd. 1995. Columbia River Total Dissolved Gas Pressure Reduction Study. Contract report to B.C. Hydro, Safety and Environment, Castlegar, B.C. by Aspen Applied Sciences Ltd., Cranbrook, B.C.

Aspen Applied Sciences Ltd. 1996. Revisions to the B.C. Hydro HLK/TGP/GBT Computer Program 1995. Contract report to Strategic Fisheries, Safety & Environment, Burnaby, B.C. by Aspen Applied Sciences Ltd., Cranbrook, B.C.

Aspen Applied Sciences Ltd. 1997. TGP reduction at the Hugh Keenleyside Dam as a Result of Power Production. In:"Keenleyside 150 MW Powerplant Project, Consolidated Project Report." Prepared by Columbia Power Corporation for the B.C. Environmental Assessment Office.

Aspen Applied Sciences Ltd. 1998. TGP reduction at the Hugh Keenleyside Dam as a Result of Power Production. Contract report to Klohn Crippen, Vancouver, B.C. by Aspen Applied Sciences Ltd., Cranbrook, B.C

Aspen Applied Sciences Ltd. 1999. Analysis of 1998 dissolved gas monitoring data for the Hugh Keenleyside Dam. Contract report to Columbia Power Corporation, Castlegar, B.C. by Aspen Applied Sciences Ltd., Cranbrook, B.C.

Aspen Applied Sciences Ltd. 2002. TGP Performance Measures for the Columbia River Water Use Planning Process A Review and Evaluation of Relevant Information and Data. Contract report to B.C. Hydro, Safety and Environment, Castlegar, B.C. by Aspen Applied Sciences Ltd., Kimberley, B.C.

Aspen Applied Sciences Ltd. 2003. TGP Performance Measures for the Mica Water Use Plan, A Derivation Summary. Contract report to B.C. Hydro, Safety and Environment, Castlegar, B.C. by Aspen Applied Sciences Ltd., Kimberley, B.C.

Ebel, W.J. 1969. Supersaturation of nitrogen in the Columbia River and its effect on salmon and steelhead trout. U.S. National Marine Fisheries Service, Fishery Bulletin 68: 1-11.

Fidler, L.E., and Miller, S.B. 1997. British Columbia Water Quality Criteria for Dissolved Gas Supersaturation - Technical Report. Contract report to the B.C. Ministry of Environment, Department of Fisheries and Oceans, and Environment Canada. Aspen Applied Sciences Ltd., Cranbrook, B.C., Canada.

Hildebrand, L. 1991. Lower Columbia River Fisheries Inventory - 1990 Studies. Vol. 1, Main Report. Contract report by R.L. & L. Environmental Services Ltd., Edmonton, Alberta to B.C. Hydro, Environmental Resources, Vancouver, B.C.

Lutz, S.C. 1995. Gas supersaturation and gas bubble trauma in fish downstream from a Midwestern reservoir. Trans. Am. Fish Soc. 124: 423-436.

Maxwell, D.F. 1985. Keenleyside-Murphy Project Water Quality Monitoring 1983 - 1984. Draft interim report. B.C. Hydro, Environmental and Socio-Economic Services, Engineering Division.

Prince, A., Powell, C., and L. Fidler 2000. Depth distribution patterns of telemetered Columbia River rainbow trout. A field investigation of fish behavior in response to total dissolved gas levels below

Hugh L. Keenleyside Dam. Contract report for BC Hydro Strategic Fisheries Power Supply Operations, Burnaby, B.C.

R.L. & L. Environmental Services Ltd. 1984. A water quality and aquatic resource inventory for the proposed Murphy Creek project on the Columbia River, B.C. – 1982 – 1983 Investigations. Rep. Prep. For B.C. Hydro, Vancouver, B.C.

R.L. & L. Environmental Services Ltd. 1995. Seasonal and operational survey of total gas pressure in the Columbia River Basin – 1995. Contract report to B.C. Hydro by R.L. & L. Environmental Services Ltd., Castlegar, B.C.

R. L. & L. Environmental Services Ltd. 2002. Fisheries Resource Information and TGP Risk Assessment for the Canadian Portion of the Lower Columbia River Basin. Contract report to Columbia River Integrated Environmental Monitoring Program by R.L. & L. Environmental Services Ltd., Castlegar, B.C.

Weitkamp, D.E., and M. Katz. 1980. A review of dissolved gas supersaturation literature. Trans. Am. Fish. Soc. 109: 659-702.

White, R.G., Phillips, G., Liknes, G., Brammer, J., Conner, W., Fidler, L., Williams, T., and W. Dwyer. 1991. Effects of Supersaturation of Dissolved Gases on the Fishery of the Bighorn River Downstream of the Yellowtail Afterbay Dam. Montana Cooperative Fishery Research Unit, Montana State University, Bozeman, Montana. Final report to the U.S. Bureau of Reclamation.