PERFORMANCE MEASURE INFORMATION SHEET #28

LOWER COLUMBIA RIVER: TGP

Objective / Location	Performance Measure	Units	Description	MSIC
Fish / Lower Columbia River	Total Gas Pressure	# days TGP exceeds 115%	Number of days that TGP production exceeds a threshold reported to cause cardiovascular bubble growth in fish	10%

Description

Monitoring of total dissolved gas levels below Hugh Keenleyside (HLK) Dam throughout the 1990s indicated that use of the spillways often produced total gas pressure (TGP) levels in excess of 140 per cent saturation. TGP levels of this magnitude have been shown to cause fish mortality in shallow water environments in less than 5 hours (e.g., Antcliffe et al. 2002). However, actual signs of gas bubble trauma (GBT) observed in fish were generally low (Hildebrand 1991, Prince et al. 2000). BC Hydro undertook a program of studies involving the modeling of TGP production by HLK Dam and examined methods of modifying the operations of the dam to reduce TGP. Experimental testing involving selective use of specific low-level port and spillway gate settings was subsequently undertaken to develop a protocol for minimizing TGP production in the lower Columbia River. This resulted in development of a model that recommends real-time dam operations to reduce TGP, and revisions to the facility's local operating orders that significantly reduce TGP production. The current operating protocol followed by BC Hydro has been shown to minimize the TGP production for any head/flow combination at HLK Dam.

Arrow Lakes Generating Station (ALH) can divert up to 1115 m^3/s (~40 000 cfs) of the flows away from the ports at HLK Dam where TGP is produced, and pass it through its generators where no TGP is produced. This has been shown to significantly reduce downstream TGP levels. However, high TGP levels remain a concern downstream of HLK Dam to the point in the river where flow from ALH has fully mixed. Operational protocols to reduce the production of high TGP levels at HLK Dam are considered important to reducing impacts in this area of the river.

Given the mitigating effect of ALH operations and current operating protocols at HLK Dam on TGP production, different operating alternatives to reduce TGP levels in the lower Columbia River were not considered during the Columbia WUP. However, the Consultative Committee expressed concern that operating regimes developed to support other objectives on Arrow Lakes Reservoir and below HLK Dam may increase TGP levels and increase the risk to fish below the dam.

Performance Measure

During the WUP, efforts at tracking the potential impact on TGP production focused on tracking the height differential between Arrow Reservoir elevations and tailwater elevations below HLK Dam. Previous experience had shown that TGP production increases dramatically as this height differential crossed 17 m. However, the group expressed discomfort with these early attempts in that they used monthly elevations as their inputs whereas TGP production tends to be brief in duration ("spiky"). Further, the group noted that TGP production was both a function of head differential and flows. A second attempt to track TGP production involved creating a series of daily flows and elevations based on historical fluctuations superimposed on the monthly output from the HYSIM model of alternatives. This analysis considered TGP production as both a function of head and flows, based on a model developed by Aspen Applied Sciences.

For the NTS analysis, the same performance measure and model (Aspen 2003) was used to report out on TGP production in the lower Columbia River across the four NTS scenarios. The modeling imposes daily deviations in flow simulated from historical data onto the monthly outputs of the NTS scenarios for the years 1940-1999. In addition, this PM captures the fact that the Arrow Lakes Generating Station (ALGS) can divert up to 1115 m^3/s (~40,000 cfs) of the flows away from the ports at the HLK Dam where TGP is produced, and pass it through its generators where no TGP is produced.

Calculations

Simulated daily elevations for the Arrow Lakes Reservoir and simulated daily flows from the Arrow Reservoir and past Brilliant Dam were provided. Tailwater elevations were calculated as a function of flows out of Arrow and flows out of Brilliant using the following approximation:

TW = 1293.72+18.606*ln(ARR_Q+0.224*MAX(BRD_Q,3.156)+0.0019*(MAX(BRD_Q,31.56)^2-0.00148*MAX(BRD_Q,31.56)*ARR_Q+42.82

where:
TW = tailwater elevation estimate at Keenleyside (ft)
ARR Q = Arrow total discharge (kcfs)
BRD Q = Brilliant discharge (kcfs) or 31.56 which ever is greater

The portioning of water between HLK Dam and the Arrow Lakes Generating Station follows a complex set of rules, where ALGS discharge is a function of tailwater elevation (TW) and elevation of the Arrow Lakes Reservoir. An example of these curves for a tailwater elevation of 417 m is provided below.

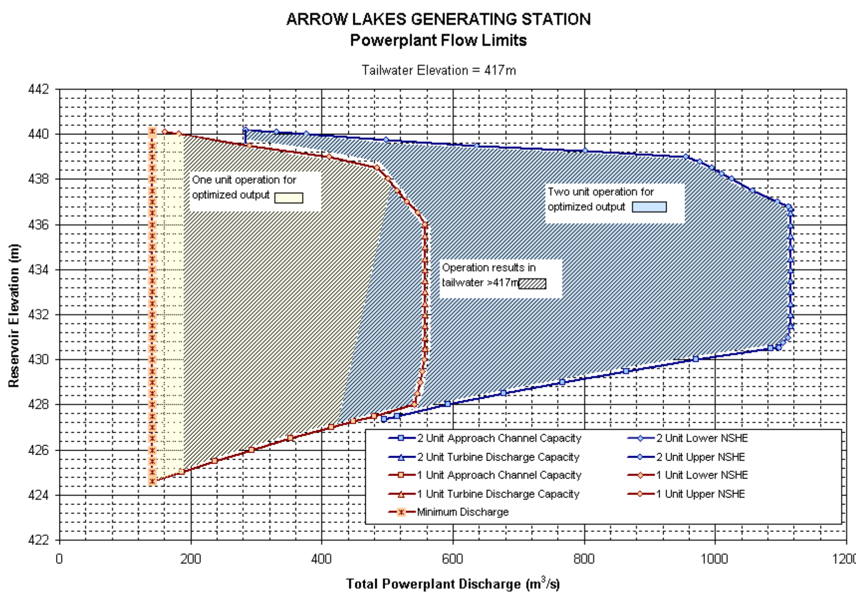


Figure 1. ALGS Releases as a Function Tailwater Elevation and Arrow Lakes Reservoir Elevation

A summary of these operating curves for TW elevations 417 m, 418 m, 419 m, 420 m and 423 m was made in the form of a lookup table. The table is considered an approximation as it simplifies some operational decisions between using one or two units. It is assumed, for these purposes, that ALGS will always maximize output for a given elevation on Arrow Reservoir.

Table 1. ALGS Flows as a Function of Tailwater Elevation and Arrow Lakes Reservoir Elevation

		TW (m)				
		1	2	3	4	5
Arrow Elev. (m)		417	418	419	420	423
	0	0	0	0	0	0
	424.59	142	142	142	142	
	425	187.04	187	187	194	
	425.5	237.5	237.5	237.5	214.6	
	426	293.2	293	325	315	
	426.5	352.4	375	375	385	
	427	414.47	450	450	475	
	427.5	514.71	514.7	537.5	535	142
	428	592	592.2	592.2	592.2	331.9
	428.5	676.8	6768	676.8	676.8	456.4
	429	767	767.3	767.3	767.3	574
	429.5	864.6	864.6	864.6	864.6	684.2
	430	970	970.5	970.5	963.2	773.6
	430.5	1084.09	1085.6	1076	1046.2	831.1
	431	1115	1101.7	1091.5	1080.7	886
	431.5	1115	1110.8	1100.5	1089.6	941.2
	432	1115	1115	1108.4	1097.3	996.6
	432.5	1115	1115	1115	1104.4	1050.6
	433	1115	1115	1115	1115	1077.3
	433.5	1115	1115	1115	1115	1083.8
	434	1115	1115	1115	1115	1090.4
	434.5	1115	1115	1115	1115	1096.7
	435	1115	1115	1115	1115	1103.1
	435.5	1115	1115	1115	1115	1109.2
	436	1115	1115	1115	1115	1115
	436.5	1115	1115	1115	1115	1115
	437	1096.1	1115	1115	1115	1115
	437.5	1057.9	1112.6	1115	1115	1115
	438	1024.7	1075.6	1115	1115	1115
	438.5	996	1043	1103.5	1115	1115
	439	965	1012.9	1068.2	1115	1115
	439.5	637.1	982.6	1036.5	1098.5	1115
	440	377.4	897.8	1007.4	1070	1115
	440.1	331.3	832.7	1001.8	1057.6	1115
	440.7	284	508	960	1021.7	1115

For TGP calculations, it was assumed that flows past HLK Dam were the difference between Arrow outflows and ALGS outflow. In cases where this resulted in a negative number (due to approximation error), this was truncated at zero.

For each of the NTS scenarios, TGP production was modelled as a function of daily average HLK discharge and the head differential between the Arrow Lakes Reservoir and the tailwater to yield daily average TGPs. A portion of the resulting look-up table used in the calculation is provided in Table 2.

Relative risk factors were applied to the modeling to represent thresholds for gas bubble trauma in fish. Based on the literature, risk factors for time to 20% mortality for juvenile rainbow trout range from near zero at a TGP of 115% up to 100 at a TGP of 145%. Two threshold TGPs were chosen for applying the risk factors; 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 as a conservative measure. Although the risk factor does not take into account the depth behaviour of fish, it was considered appropriate for the NTS analyses since it would be applied in exactly the same way across all of the NTS scenarios and all years of analyses. It assumes that fish behaviour is unchanged between each scenario and between each year of analysis.

Table 2. TGP Production as a Function of Head Differential (m) and Discharge from HLK (cms)

Discharge	Head - m >	HLK TGP% as a function of Discharge and Total Head						
V	16.00	16.25	16.50	16.75	17.00	17.25	17.50	17.75
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
25	136.9	136.9	136.9	136.9	136.9	136.9	136.9	136.9
50	136.9	136.9	136.9	136.9	136.9	136.9	136.9	136.9
75	136.8	136.9	136.9	136.9	136.9	136.9	136.9	136.9
100	101.9	102.0	102.0	102.0	102.0	136.9	136.9	136.9
125	102.2	102.3	102.3	102.4	102.4	136.9	136.9	136.9
150	102.5	102.6	102.7	102.7	102.7	136.9	136.9	136.9
175	102.8	102.9	103.0	103.1	103.1	136.9	136.9	136.9
200	103.1	103.2	103.3	103.4	103.4	136.9	136.9	136.9
225	103.4	103.5	103.5	103.6	103.7	136.9	136.9	136.9
250	103.7	103.7	103.7	103.9	104.0	136.9	136.9	136.9
275	103.9	103.9	103.9	104.1	104.2	136.9	136.9	136.9
300	104.2	104.2	104.1	104.3	104.5	136.9	136.9	136.9
325	104.4	104.4	104.3	104.5	104.7	136.9	136.9	136.9
350	104.6	104.6	104.6	104.8	104.9	136.9	136.9	136.9
375	104.7	104.8	104.8	104.9	105.0	136.9	136.9	136.9
400	104.9	105.0	105.0	105.1	105.2	136.9	136.9	136.9
425	105.1	105.2	105.2	105.3	105.4	136.9	136.9	136.9
450	105.2	105.3	105.3	105.4	105.5	136.9	136.9	136.9
475	105.4	105.5	105.5	105.6	105.7	136.9	136.9	136.9
500	105.5	105.6	105.6	105.7	105.8	136.9	136.9	136.9
525	105.7	105.8	105.8	105.9	106.0	136.9	136.9	136.9
550	105.8	105.9	106.0	106.1	106.1	136.9	136.9	136.9
575	106.0	106.1	106.1	106.2	106.3	136.9	136.9	136.9
600	106.1	106.2	106.3	106.4	106.5	136.9	136.9	136.9
625	106.2	106.3	106.4	106.6	106.7	136.9	136.9	136.9
650	106.3	106.4	106.5	106.6	106.7	136.9	136.9	136.9

In summary, the calculation for each scenario is:

1. The head differential between Arrow Lakes Reservoir (HLK Dam forebay) elevation and the tailwater below the dam is calculated for each day using the formula described above.
2. The TGP for each daily time step in each year is obtained from a reference table (Table 2 above) based on the relationship between head differential (step 1) and the total Arrow discharge.
3. The number of days of TGP in excess of a threshold (e.g., 115%) are counted over the entire year, and over the June through August period alone[1] for each of the 60 simulation years.
4. Summarize all statistics (Figures 2 and 3).

Results

Regardless of the simulation period used, the results are consistent in that Scenario D (no NTS) would perform significantly worse than the "with NTS" scenarios in all of the 60 simulation years. Scenario B (3.0 MAF) would perform generally better than Scenarios A and C in reducing the number of days that TGP levels below HLK Dam would exceed 115%.

[1] Both simulation periods were used for the NTS analysis as a seasonal analysis carried out during the Columbia WUP showed that, across all alternatives and all years, TGP production above 115% was limited to the late June to end of August period.

As shown in Figures 4 and 5, this same pattern holds true across a broad range of thresholds (100-136%). None of the scenarios would cause TGP levels to exceed 138%.

Figure 2. Total Gas Pressure – Number of Days > 115% – All Year

	Scen A	Scen B	Scen C	Scen D
Max	193	144	195	280
90th	86	78	87	149
Mean	36	31	38	82
Med	25	17	24	75
10th	0	0	0	25
Min	0	0	0	7

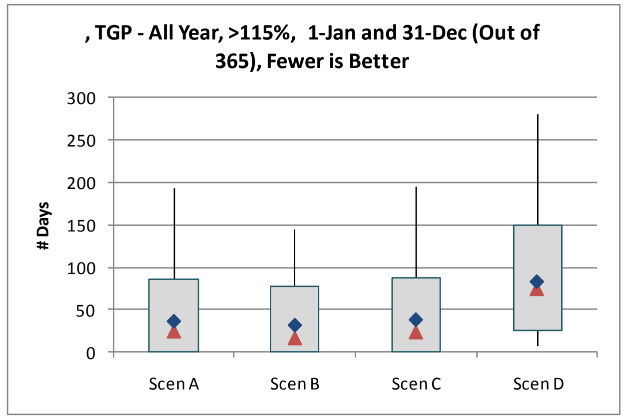


Figure 3. Total Gas Pressure – Number of Days > 115% – June to August

	Scen A	Scen B	Scen C	Scen D
Max	81	86	79	92
90th	53	45	49	73
Mean	20	17	20	32
Med	11	9	13	24
10th	0	0	0	0
Min	0	0	0	0

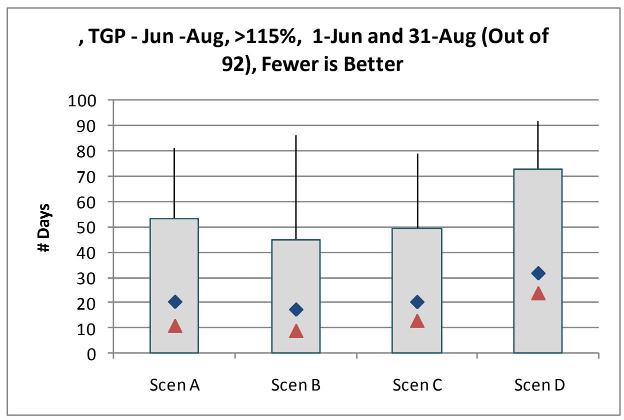


Figure 3. Mean Number of Days above a Range of TGP Thresholds over the Entire Year

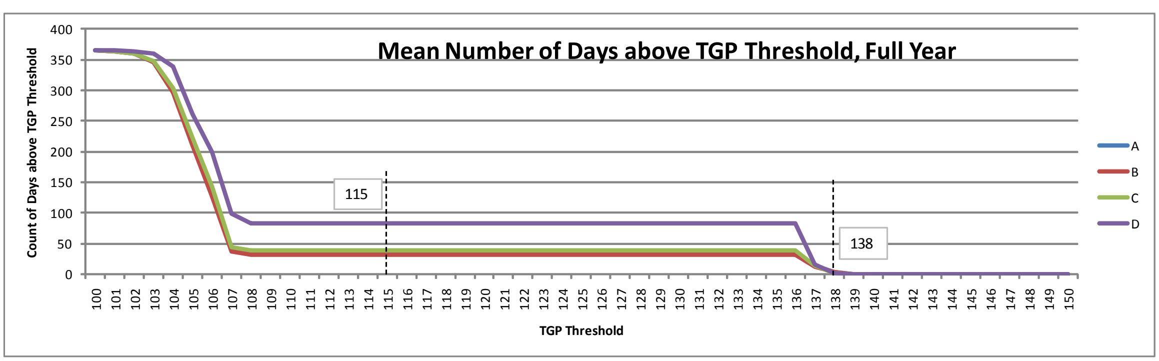
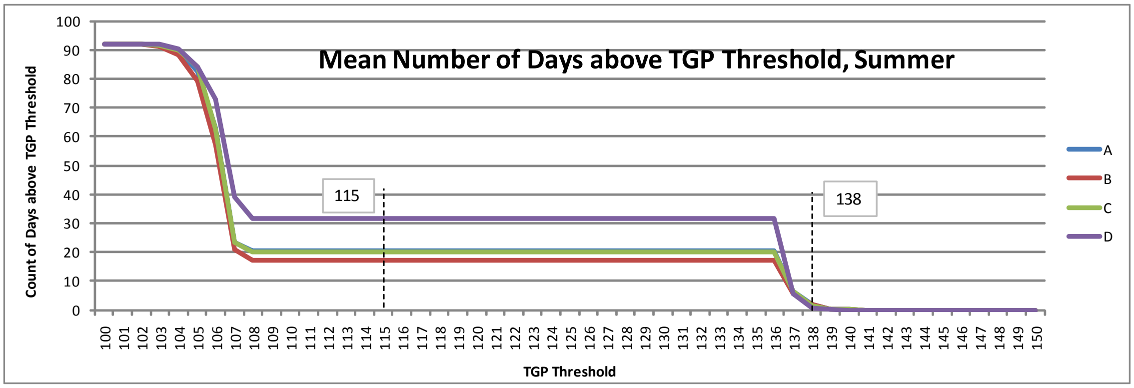


Figure 3. Mean Number of Days above a Range of TGP Thresholds over the Summer Period



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