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3.4 TOTAL DISSOLVED GAS (TDG) MONITORING – 2001: RESPONSE OF DISSOLVED GAS SATURATION DOWNSTREAM OF THE SWIFT NO. 1 PROJECT TO REDUCED TURBINE AIR INFLOW (WAQ 4)

3.4.1 Study Objectives

The following objectives for this study were developed through consultation with the Aquatic Resource Group (ARG) and Washington Department of Ecology (WDOE).

- Develop high-resolution correlations (curves) between turbine operation and TDG at Yale, Swift No. 1 and Swift No. 2 on a seasonal basis.
- Determine safe (i.e., no destructive cavitation) generating range for Swift No. 1 turbines with the air vent completely closed.
- Determine if reducing (not eliminating) air flow into turbines reduces TDG saturation in project tailwaters.
- Determine if reducing (not eliminating) air flow into turbines causes destructively high cavitation levels within the turbine and draft tube.
- Conduct biological sampling of captured fishes for signs of Gas Bubble Trauma (GBT) in the Yale and Swift No. 1 tailwaters.

These objectives were designed to (1) build on existing information collected since 1995; (2) determine the ability to modify turbine operations to meet state water quality standards; and (3) assess the biological effects of supersaturated tailwaters.

3.4.2 Study Area

The study area includes the Swift No. 1 forebay and tailrace, Swift No. 2 canal, Swift No. 2 forebay and tailrace, Yale forebay and tailrace, and the Merwin tailrace.

3.4.3 Methods

Task 1: Develop Correlations Between TDG and Turbine Operation

Correlations between turbine operation and TDG are presented for Yale and Swift No. 1. These relationships are used to determine the generation range for each project that results in exceedences of state TDG standards.

For each project, TDG was monitored (usually at 10 minute intervals) with a Common Sensing TBO-DL6 meter. Units were tested at Yale and Swift No. 1 individually to determine the relationship on a per unit basis. Generation schedules were developed that allow each unit to operate at a specified level for a period of time necessary to (1) allow TDG to equilibrate, and (2) provide enough samples to reduce sampling error. Operating levels were at 10-MW intervals and include the entire generating range of each unit.

Two seasons, summer and winter, will be monitored to assess seasonal variability of TDG. These 2 seasons were chosen based on reservoir stratification characteristics and potential pressure differences (within the turbines) due to different reservoir levels between the 2 seasons. In summer, reservoirs are strongly stratified; in winter, reservoirs become isothermal. It is not known whether this is significant, but it is important to determine whether differences in TDG do exist. In addition to the differences in reservoir stratification, reservoir levels vary between summer and winter. Typically, reservoirs are kept full during the summer recreation season and drafted in fall for flood management. The differences in head may cause differences in pressure within the turbine, which may affect the rate at which gases are dissolved into solution.

Task 2: Determine if Reducing Airflow into the Swift No. 1 Turbine (Unit 11) Reduces Tailrace TDG

Correlations between TDG and generation at Swift No. 1 will be made with the air vent fully closed and at various restriction levels. Correlations will show whether restrictions in airflow result in reduced TDG in the tailwaters. A plywood board will be used to seal off 50 percent of the air intake. To achieve more restrictive airflow, plywood strips will be used to seal the intake at levels above 50 percent (e.g., 60, 70, 80, and 90 percent).

At each restriction level between 50 and 100 percent, TDG will be monitored throughout the generation range at 10 MW intervals. At each generation interval, TDG will be allowed to stabilize before moving to the next generation level.

Task 3: Determine at What Generation Level Air Flow Restrictions Cause Destructively High Cavitation Levels Within the Turbine and Draft Tube

The air vent at Swift No. 1 (unit 11) will be capped while the unit operates throughout its range. The air vent will be capped using a ¾-inch plywood board that will be wired to the outside grating. As the unit begins operating, air will begin entering the unit, sealing the plywood against the outside vent. When the unit is not operating, the wire will prevent the board from falling off the intake grating. Tests of cavitation will be performed at 10-MW intervals (to include motoring). Tests will monitor changes in draft tube pressure, bearing noise and vibration. These indices will be used to assess the potential for destructive cavitation.

For each restriction level used in Task No. 2, the unit will be monitored for signs of abnormal cavitation. Draft tube pressure will be used as the primary index of cavitation. A qualitative assessment will also be made based on noise and vibration of the unit at each generation and air vent restriction level.

Task 4: Biological Sampling of Fishes for Signs of Gas Bubble Trauma (GBT) in the Swift No. 1 Tailwaters

The presence of emboli in fishes indicates some level of exposure to supersaturated waters. While it is difficult to determine the severity of that exposure from visual observations, the presence of emboli is an indication that there may be a biological problem.

The Applicants propose using trapped fishes from entrainment work (AQU 6) at Swift No. 1 to evaluate the presence or absence of GBT. The number of fish and species sampled will depend on capture efficiency of the trap during the entrainment study. It may become necessary to sub-sample fishes caught during the entrainment study. If so, a sub-sampling design plan will be developed by the ARG. Once the trap is in place, a decision will be made by the ARG to determine the extent of sampling required to establish the presence or absence of GBT.

During each trapping day, all captured fishes will be sampled; therefore, no fish will remain in the trap for more than 24 hours. Examinations for the presence or absence of emboli will be made using a variable magnification (6x-40x) dissecting scope. Prior to examination, fish will be placed in a non-lethal bath of MS-222. Unpaired fins (caudal and dorsal) will be used as the primary location for observing emboli. Emboli are not only easy to detect in fins, but emboli persist in the fins longer than in other external areas including the lateral line or gills (Hans et. al. 1999). If emboli are present on the fins, a ranking system will be used to quantify the percent coverage of emboli on the fins.

The ranking system as described by the Fish Passage Center (1999) will be used as follows:

Rank 1: less than 5% emboli coverage of fin
Rank 2: 5–25%
Rank 3: 26–50%
Rank 4: above 50 %

Final results will include number of fish sampled, number of fish with signs of GBT and the percent coverage (rank) of emboli on the fins for fish exhibiting signs of GBT.

3.4.4 Key Questions

No key watershed questions are associated with this study.

3.4.5 Results

Data collection for this study is partially complete. Therefore, this section provides only a partial presentation of the results. Results of seasonal variation in TDG and the potential for gas bubble trauma in fishes are provided in study WAQ 5.

Along with the preliminary results from this study, a summary of existing information (1996–1999) is presented. This summary will consolidate background information to use in evaluating and developing solutions to reduce TDG in project tailwaters.

3.4.5.1 Correlations Between Generation and TDG

Figures 3.4-1 and 3.4-2 depict the relationship between TDG and generation at the Yale and Swift No. 1 powerhouses. These relationships are based on normal operations and do not reflect any modifications to the air intake system. These figures are intended as a baseline for future studies to help evaluate the effects of modifications to the air admission system or other system components. Figure 3.4-1 depicts the percent of TDG saturation while operating Yale Unit No. 2 during a week in summer. Figure 3.4-2 provides similar information for the 3 Swift No. 1 units.

Correlations for both Swift No. 2 and Merwin have not been fully developed and are not included in this report. However, when those data are available they will be presented to the ARG.

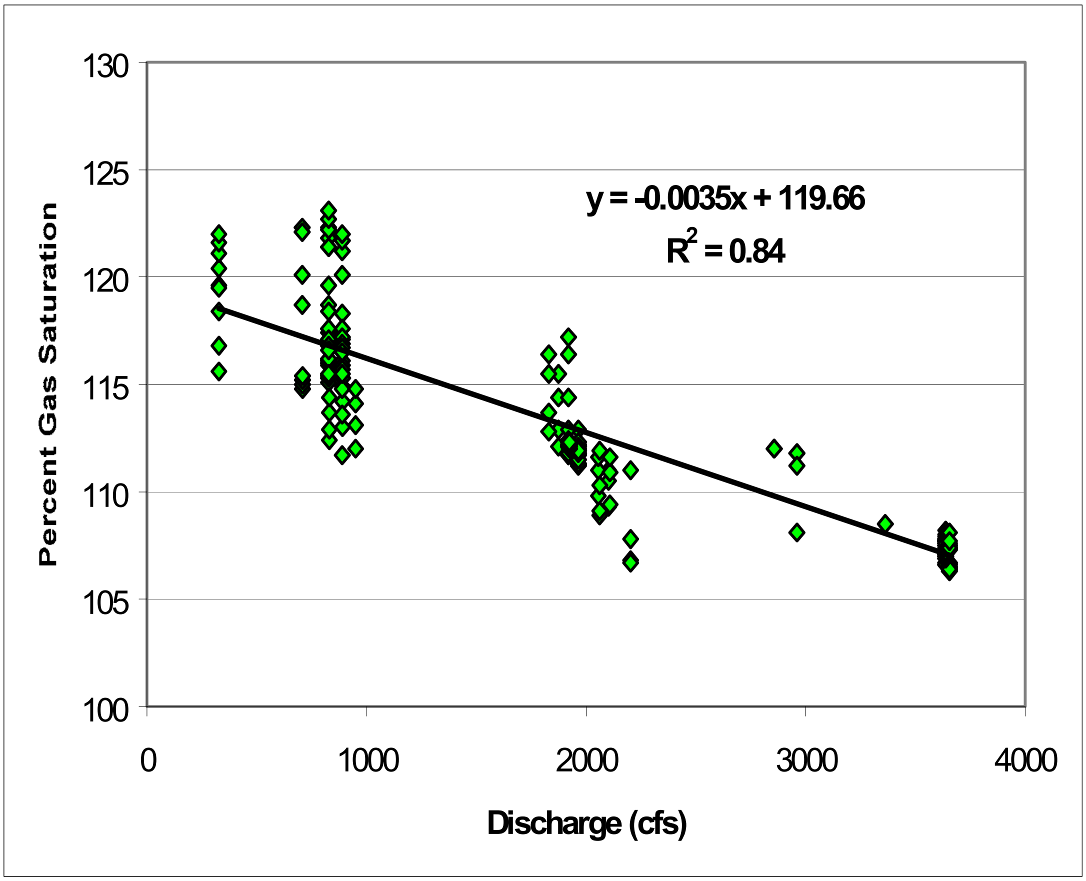

Figure 3.4-1. Percent saturation (n = 259) in relation to Unit No. 2 turbine operation at Yale powerhouse July 21-26, 1996.

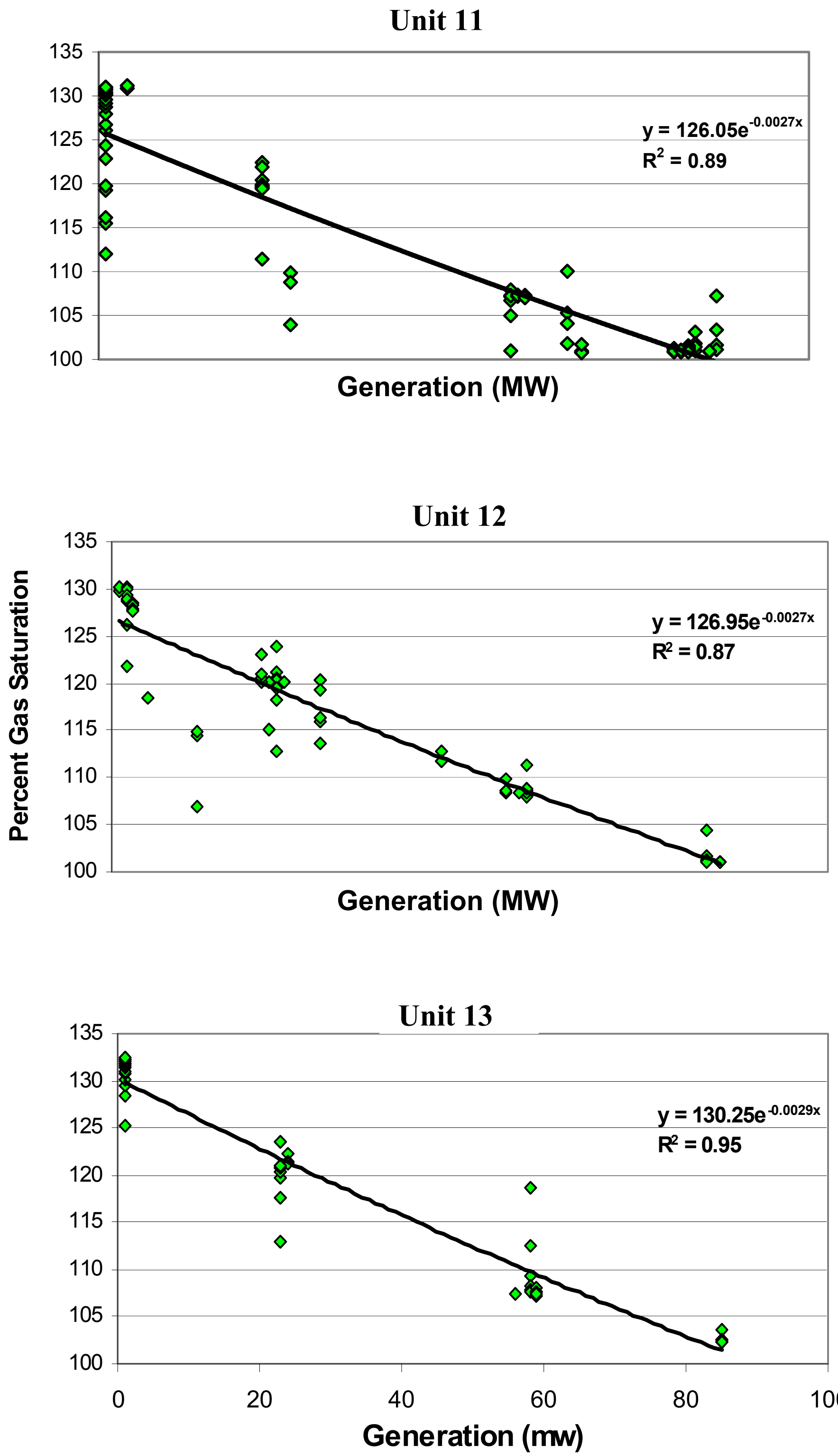

Figure 3.4-2. Relationship between generation and percent gas saturation at Swift No. 1 Units No. 11, 12 and 13 in August 1999.

3.4.5.2 Results of Reducing Air Flow into the Yale and Swift No. 1 Turbine (Unit 11)

Figure 3.4-3 shows the results of capping the air vent at Yale (Unit 1) between discharges of 0 and 1500 cfs (0 and 20 MW). At levels above 1500 cfs (or 20 MW), the unit was allowed to draw air in naturally. The resulting correlation produces more of a bell-shaped curve rather than the characteristic linear relationship when the air intake is unobstructed. With the air vent capped at lower generation levels, TDG saturation in the tailwaters is less when compared to Figure 3.4-1.

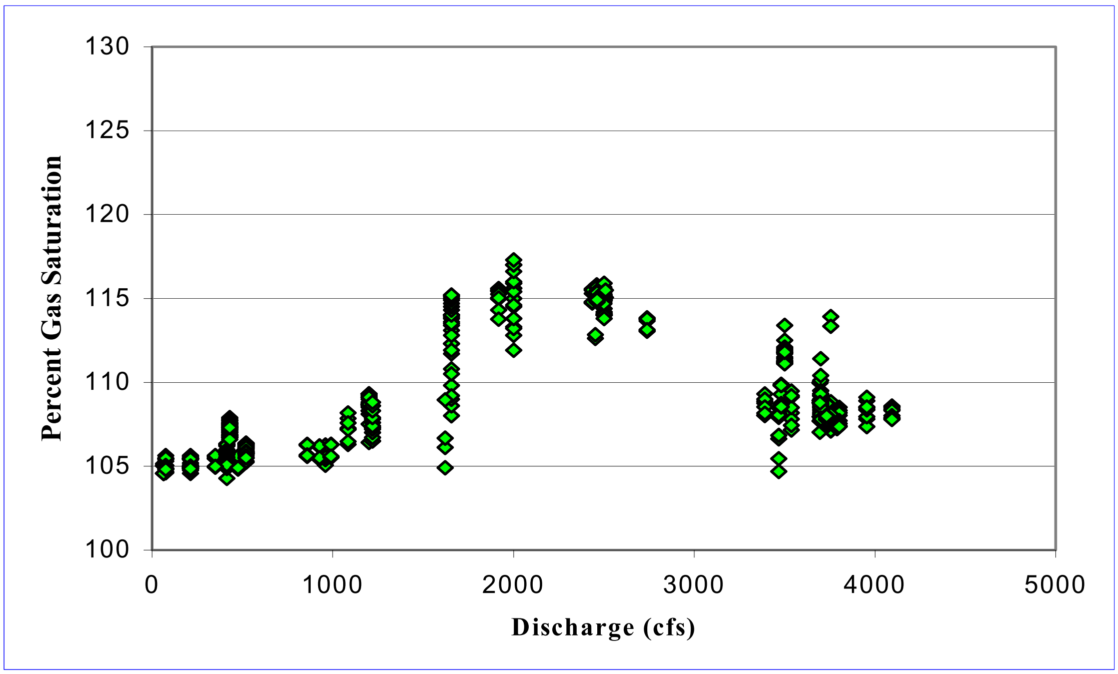

Figure 3.4-3. Percent saturation (n = 366) relative to project (Units 1 and 2) discharge at Yale powerhouse (with air regulation valve modified) in summer 1997 and 1998.

Figure 3.4-4 compares the relationships between TDG and generation at Swift No. 1 (Unit 110) with an air vent that is capped to restrict 100 and 50 percent of the airflow. The 100 percent capping maintains TDG below 110 percent between 10 and 70 MW.

Figures 3.4-5 and 3.4-6 display the time series response of TDG to changes in generation. These illustrations are useful in understanding the response of TDG immediately following changes in generation and during any equilibration phase.

Figure 3.4-7 depicts the differences between TDG measured at the Swift No. 1 tailrace and TDG measured at the canal check structure (about 1 mile downstream of the Swift No. 1 powerhouse). The chart is helpful in determining the dissipation of TDG through the canal and the travel time of supersaturated water in the tailrace to reach the check structure.

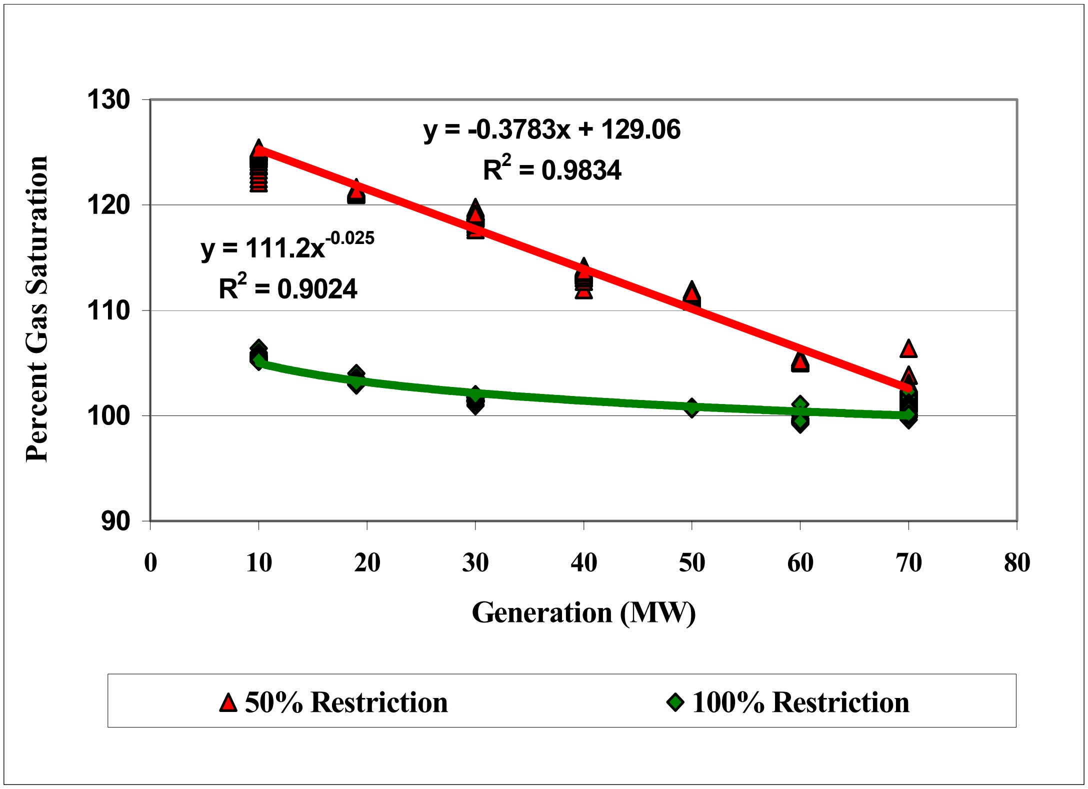

Figure 3.4-4. Relationships between TDG and generation at Swift No. 1 (Unit 11) when the air vent is blocked to restrict 100 and 50 percent of airflow in October 2001.

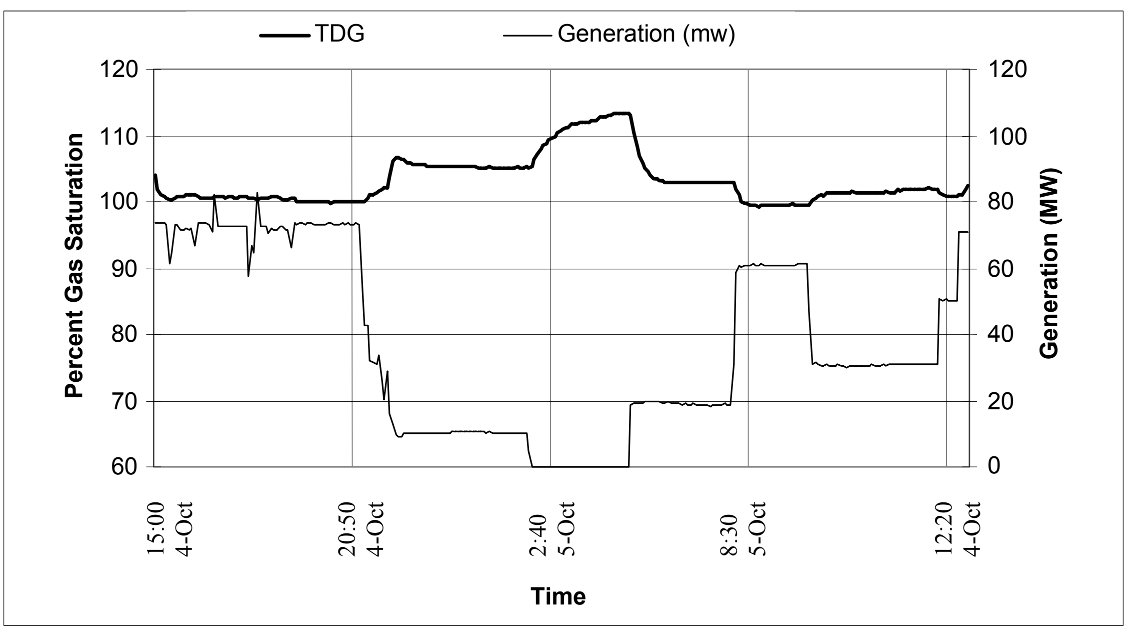

Figure 3.4-5. Percent gas saturation and generation while the outside air vent is 100 percent capped at the Swift No. 1 tailrace (Unit No. 11) in October 2001.

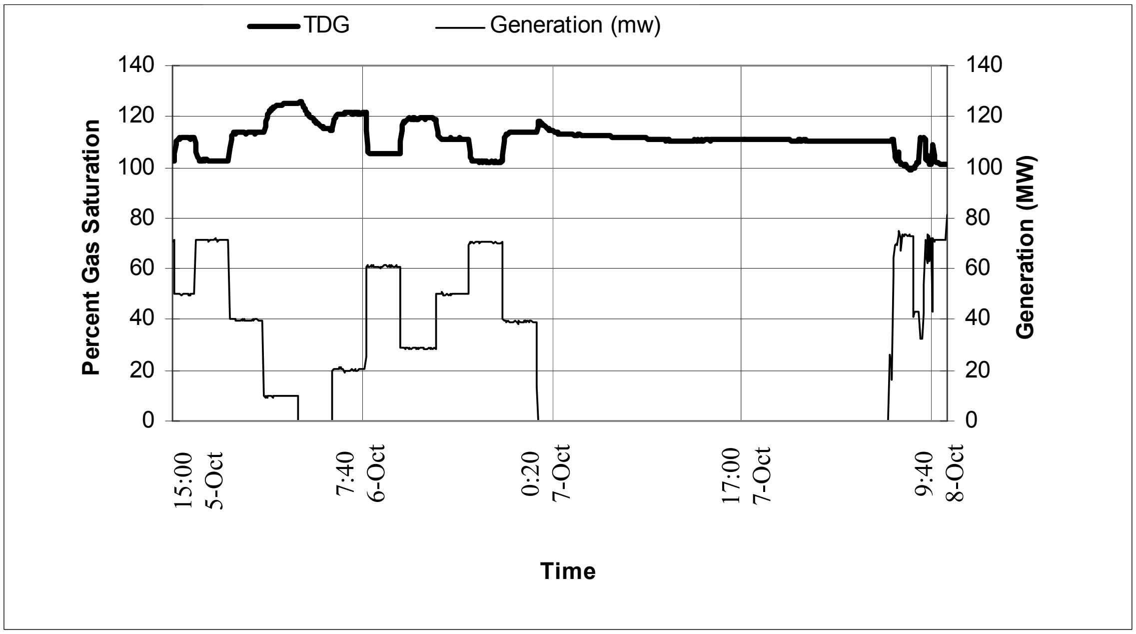

Figure 3.4-6. Percent gas saturation and generation while the outside air vent is 50 percent blocked at the Swift No. 1 tailrace (Unit No. 11) in October 2001.

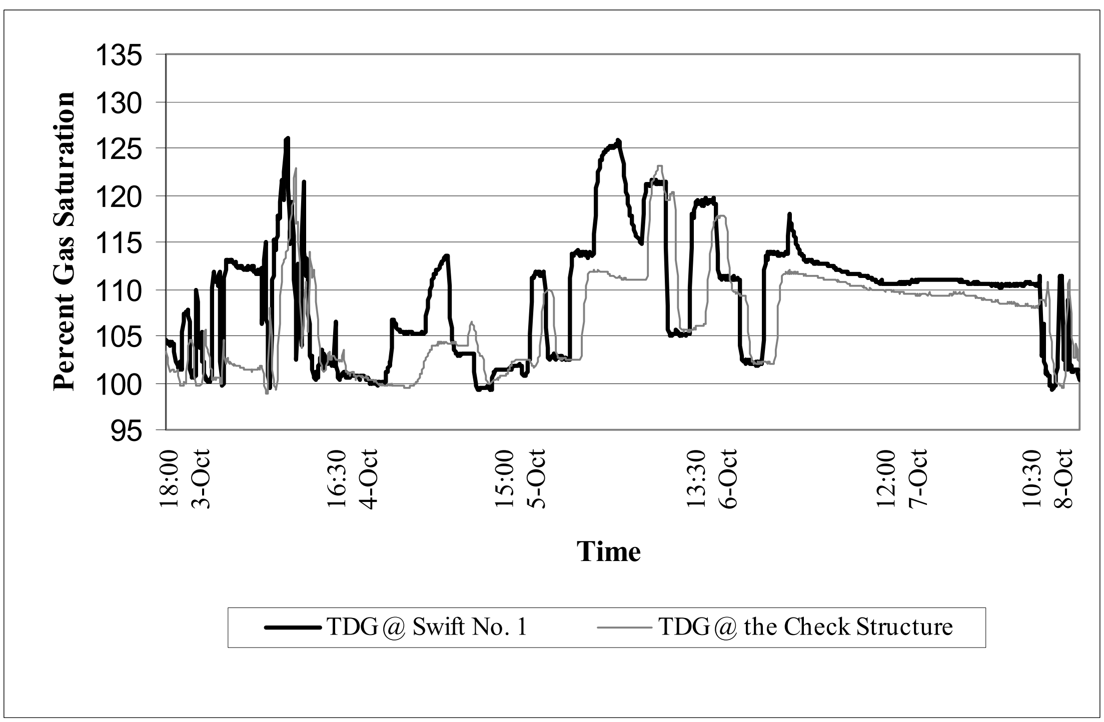

Figure 3.4-7. Percent gas saturation over time between the Swift No. 1 tailrace and check structure in the Swift canal in October 2001.

3.4.5.3 Potential for Cavitation

Table 3.4-1 provides measurements of draft tube pressure at Swift No. 1 in response to increased wicket gate openings (or generation) while the air vent is capped. Under normal conditions (air vent unobstructed) the draft tube pressure is between 2 and 6 PSI.

Table 3.4-1. Draft tube pressure (fluctuation) as a function of wicket gate or generation at the Swift No. 1 powerhouse (Unit 11).

Wicket Gate Opening	Generation (MW)	Percent Gas Saturation	Draft Tube Pressure (PSI)
20%	8	-	2
30%	18	-	4-4.5
40%	28	102	6-8.5
50%	38	101	9-12
60%	47	100	10-11
70%	59	100	6
84%	70	100	6

Task 4: Biological Sampling of Fishes for Signs of Gas Bubble Trauma in the Swift No. 1 Tailwaters.

Results of this study component are not yet available, but will be presented in WAQ 5.

3.4.6 Discussion

Since 1995, PacifiCorp has been monitoring TDG at its Lewis River projects. Most of this work focused on Yale as a result of Yale relicensing studies. However, in recent years, work has expanded to include monitoring at the Swift projects, and efforts to monitor the persistence and behavior of TDG downstream of project tailwaters.

Through these studies, the relationship between TDG and project operations is clear. The difficulty, however, arises in the development of solutions to eliminate or reduce TDG created by project operations in a way that does not adversely effect project operations (e.g., cavitation).

Based on past studies, the following information is known about the behavior and relationship of TDG to project operations. These bullets form the basis for our understanding of the relationship between TDG and project operations.

- Supersaturation is evident at Yale, Swift No. 1 and to a lesser extent at Swift No. 2.
- The cause of supersaturation at all projects is the air intake system.
- There is an inverse relationship between gas saturation and generation (discharge). This is due to increased water flow and volume as generation increases, thereby limiting the ability of the air intake system to over-saturate the tailwater.

- The capping of the air vents at low generation levels effectively reduces TDG in tailwaters.

- Capping the air vent at mid-generation levels causes cavitation and pressure differentials in the draft tube that are destructive or cause premature wear, and may reduce turbine efficiency. As a result, capping (100 percent restriction) the air vent through mid-generation levels is not possible.

- Leaving the air vent capped while the units at Swift No. 1 are ramped down to motoring causes the water to remain in the turbine, which causes the turbine to draw on excessive amount of energy from the transmission line to motor.

- TDG dissipates quickly in water that is flowing from the tailrace and into project reservoirs or the Swift canal.

- If tailwaters are supersaturated at the time a powerhouse goes off line, TDG does not dissipate quickly and persists for at least 24 hours.

Although much is known about the relationship between TDG and project operations, there remain specific questions on various aspects of over-saturation, risks associated with Gas Bubble Disease (GBD) and seasonal variation of TDG. These specific questions include the following:

- Why does motoring at Swift No. 1 appear to over-saturate project tailwaters despite a capped airvent?
- Are the implemented changes to the air intake system at Yale working?
- How does turbine efficiency change with increased restrictions on turbine airflow?
- How are tailwater areas treated or classified by WDOE?
- Does a biological risk (to aquatic species) related to TDG exist downstream of project facilities?
- Do seasonal variations in TDG exist?
- What is the effect of restricting the air vent between 50 and 90 percent (specifically at Swift No. 1) on both cavitation potential and TDG?

3.4.6.1 Air Vent Manipulation

It is clear that restricting airflow into the turbines reduces TDG at all generation levels (Figure 3.4-4). However, it is also known that at certain levels, typically between 30 and 60 percent of a units' operating range, the restriction of airflow causes unacceptable cavitation and pressure differentials in the turbine (Table 3.4-1). Therefore, even though blocking the air vent fixes the TDG problem, it is not possible at all generation levels.

In 2001, it was determined that a 50 percent airflow restriction provided no benefit to TDG at the Swift No. 1 tailrace (Figure 3.4-4). It is the intent in early April 2002 to define whether a restriction between 50 and 90 percent reduces TDG in the Swift No. 1

tailwaters. This information may yield a broader range in which the units can operate while limiting TDG and turbine cavitation.

Another aspect to consider in modifying the air intake is turbine efficiency; that is, the amount of power produced over the amount of water discharge. It is likely that efficiency of the units will change by restricting airflow into the turbine, as one of the purposes of the air intake system is to enhance turbine efficiency. A test of efficiency will be completed with the work scheduled in early February 2002. The test will include looking at turbine output at different air vent restriction levels.

3.4.6.2 Project Automation

Based on past study results, there are 2 areas which have the potential, through automation, to effectively reduce TDG while at the same time maintaining turbine flexibility, which is required for system reliability. These include air flow and turbine unit automation. Air flow automation is a mechanical solution, while turbine automation relies on the number of turbine units at each powerhouse to limit the amount of time any one unit operates in the saturation zone (saturation zone is defined as the generation range of any unit that produces TDG above 110 percent).

Air Flow Automation

Automation of the airflow into each turbine could be a valuable mechanism in achieving the goal of reducing TDG, while allowing flexible operation. Before automation of the air vent can occur, however, it must be known whether airflow restrictions, other than at 100 percent, reduce TDG. In addition, the airflow restriction cannot increase cavitation or cause draft tube surging (pressure differential). If an acceptable restriction level can be found in the mid-range generation then automation of the air intake system is a practical solution to at least part of the TDG problem.

Turbine Automation

Once the safe range of airflow restriction is known, the units can be automated to further reduce the potential for over-saturation by avoiding operation in saturation zones (e.g., 20–50 megawatts). If it is known that operation of any unit between 20 and 50 MW causes over-saturation (and air restrictions cause cavitation) then the units can be automated to provide the necessary generation to meet system load. Because changes need to occur immediately, a computer would control automation of the units. For example, if load was 40 MW, it may take 2 or 3 units operating in the safe zone through automation to achieve the 40 MW, rather than one unit operating in the saturation zone without any automation.

Automation does have its drawback. Because changes need to occur immediately, it may be necessary to have all units synchronized to the system during periods of generation. Currently, units are synchronized (brought on-line) as needed. Whether this would cause undue wear is unknown.

3.4.6.3 Elevated TDG Levels at Zero Discharge

While capping the air vent (100 percent restriction) provides lower saturation levels in the Swift No. 1 tailwaters, there is a noticeable increase in TDG when the units are either motoring or at zero discharge (Figure 3.4-5). Reasons for this unexpected rise in TDG are not known. It may be related to (1) warming of the tailwaters as the units remain idle, which decreases the affinity of water to hold gases; or (2) just before the units are taken off-line, the tailwaters may receive a pulse of oversaturated water that does not have the opportunity to dissipate as there is no water coming through the turbines to displace the oversaturated tailrace water. It is possible that both of these conditions contribute to the persistence of saturation once the units come off-line. Based on past studies, however, it is likely related to the same relationship observed in all previous studies: higher volumes of water (discharge) decrease the ability of the units to oversaturate the tailwaters. This relationship is responsible for the characteristic inverse correlations seen in all previous studies.

3.4.6.4 Conclusions and Recommendations

Because the air vent restrictions are effective in reducing TDG, it is apparent that any mitigation of TDG will likely include some air flow restrictions. While this does not guarantee that TDG will meet state water quality standards all of the time, it certainly limits the potential for exceedences to occur.

A further mitigation alternative may include automation of the project turbines to limit the amount of time the units operate in the "saturation zone". This would be especially helpful (and potentially more effective) at projects such as Swift No. 1, which provides load following resources and has 3 turbine units. The addition of air vent modifications coupled with automation at Swift No. 1 is one potential solution in mitigating over-saturation of dissolved gas in the Swift No. 1 tailrace.

3.4.7 Schedule

This study will extend into 2002, with the following scheduled activities:

- April 2002 Air vent testing at Swift No. 1
- April 2002 Monitoring TDG and operations at Swift No. 2 and Merwin

Results of this next phase will be presented as study WAQ 5.

3.4.8 References

Fish Passage Center. 1999. Fish Passage Center 1998 annual report. Report to the Bonneville Power Administration, Fish Passage Center of the Columbia Basin Fish and Wildlife Authority, Portland, OR.

Hans, K.M., M.G. Mesa, and A. Maule. 1999. Rate of disappearance of gas bubble trauma signs in juvenile salmonids. Journal of Aquatic Animal Health 11:383-390.

3.4.8 Comments and Responses on Draft Report

This section presents stakeholder comments provided on the draft report, followed by the Licensees' responses. The final column presents any follow-up comment offered by the stakeholder and in some cases, in italics, a response from the Licensees.

Commenter	Volume	Page/ Paragraph	Statement	Comment	Response	Response to Responses
J. Sampson, Technical Advisor to the Conservation Groups	1	WAQ 04-1	Methods	This reader would like to know the depths at which TDG probes were deployed at each station. Where is this information available?	All probes were submerged 10 feet.	
J. Sampson, Technical Advisor to the Conservation Groups	1	WAQ 04-7 para 1	"With the air vent capped at lower generation levels, TDG saturation in the tailwaters is less than when compared to Figure 3.4-1."	This statement is incomplete. The following should be added after this sentence: "Nevertheless, between discharges of 1500 and 3000 cfs, TDG in the Yale tailrace still violates water quality standards."	This statement is correct based on Figure 3.4.4 which shows that TDG levels remain below the state standard of 110 % throughout the generation range of each turbine when the air vent is restricted 100 % (capped). However, as stated in the report, it is not possible to cap the air vent at all generation levels due to physical constraints such as cavitation and pressure differentials within the turbine and draft tube. Both conditions are destructive to the units and would result in premature wear or damage.	
J. Sampson, Technical Advisor to the	1	WAQ 04-7 para 3	"Figures 3.4-5 and 3.4-6 display the time	Figure 3.4-5 indicates that at zero generation (October 5th, 2:40), TDG exceeds the water quality criterion of	The cause as to why the tailrace remains over-saturated after the units are	

Commenter	Volume	Page/ Paragraph	Statement	Comment	Response	Response to Responses
Conservation Groups			series response of TDG to changes in generation."	110% supersaturation. This should be explained in the text following this statement.	taken off-line remains unknown. An explanation would be speculative. However, some things are known that may contribute to this prolonged saturation period and those will be added to the final report.	
J. Sampson, Technical Advisor to the Conservation Groups	1	WAQ 04-10 2nd bullet	"Capping the air vent at mid-generation levels… may reduce turbine efficiency."	The following should be added at the end of this bullet. "Capping air vents does not resolve the TDG problem at mid-generation levels (e.g., Figure 3.4-3)."	See response to WAQ 4-7 (paragraph 1) above. A clarification of this point will be made and the following text will be added to end of this bullet. "As a result, capping (100 percent restriction) the air vent through mid-generation levels is not possible."	