Geotechnical
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Technical Memo

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To: Thompson Falls Interagency Technical Team

From: Steve Rainey, GEI Consultants, Inc.

Date: 5/14//2007

Re: Total Dissolved Gas (TDG) at Thompson Falls

The purpose of this memorandum is to give a short description of the total dissolved gas (TDG) issue at many Pacific Northwest hydro projects, then to briefly summarize apparent implications on TDG dynamics at Thompson Falls Hydroelectric Project (Thompson Falls), in order to initiate dialogue about how this project actually reduces TDG levels at all except the highest river discharges, relative to historic dissolved gas levels below the falls. *The implication is that the project may not need to mitigate for elevated TDG levels, either structurally or operationally*.

Background

Current Thompson Falls Hydroelectric Project Total Dissolved Gas Data Monitoring Program

The US Fish and Wildlife Service asked PPL Montana (PPLM) to monitor total dissolved gas at Thompson Falls, during development of the Biological Evaluation, as part of the Endangered Species Act consultation process. Since hydro projects often impound water, and spill is common during the spring freshet, elevated TDG levels downstream of spillways occur for a few months each year. An important issue is whether the data reflects TDG levels greater than the maximum allowable (110 percent) level referenced in the Clean Water Act (CWA). When spillway gas levels increase above the CWA TDG cap, there may be an effort by the state or federal government to induce implementation of TDG abatement measures. This memorandum addresses that potential occurrence.

(Note: this memorandum also addresses the manner in which TDG uptake is thought to occur below the Main Dam spillway and falls. In 2004, TDG measurements were taken from a monitoring station in the immediate Main Dam spillway tailrace. A discussion of why the measurements at this monitoring station may be misleading, and how that influences the issue of whether TDG abatement mitigation measures are required at Thompson Falls, is presented at the end of this memorandum.)

General Description of Typical Hydro Project Operations with Elevated Total Dissolved Gas Levels

Spill at hydroelectric dams usually increases downstream TDG levels, and occurs when river discharge exceeds turbine hydraulic capacity. Since no additional flow can pass the project's turbines, it must pass over the spillway. Since the height of dam typically provides much of the energy head for generation of power, spillway flow transfers much of that potential energy to the spillway tailrace, where turbulence dissipates that excess energy. During spill, total dissolved gas supersaturation occurs, and often exceeds the 110 percent saturation limit stipulated in the CWA. The CWA is intended to protect fish from lethal levels of TDG, which can create gas bubble trauma symptoms. It has been shown that TDG levels on the order of 140 percent result in embolisms and the appearance of tiny gas bubbles in fish tissues, resulting in elevated mortality rates. Conversely, it has been shown that Columbia and Snake River juvenile salmon and steelhead have no gas bubble trauma symptoms at levels of <u><</u>120 percent TDG in spillway tailraces. Gas bubble trauma studies downstream of Cabinet Gorge, where TDG levels reach 135%, showed little sign of adverse impacts to non-anadromous species in 2000 (need citation).

Cause of Total Dissolve Gas Supersaturation and Related Information

As spill discharge passes into the spillway tailrace, it typically plunges into a deep armored stilling basin, designed with enough volume to dissipate energy for the maximum design flood discharge. The intent is to confine energy dissipation in the armored zone, so that erosion does not scour and undermine the spillway or other dam features – thereby leading to potential structural failure.
As spill plunges into a deep spillway stilling basin, a turbulent energy dissipation zone is created, characterized by unsteady flow and high shear forces. Vertical circulation cells often take turbulence aeration to depth, where hydrostatic pressure collapses bubbles, *forcing them into solution* and elevating TDG levels (gas absorption).

TDG carrying capacity depends on temperature and ambient pressure, consistent with Gauss's Law. (The same amount of total dissolved gas content that constitutes 100 percent saturation at one water temperature, will be supersaturated if the water temperature is higher, and ambient pressure is the same. This memorandum is not intended to address gas absorption in that degree of detail.

TDG supersaturation is an unstable condition, and if the river channel downstream of a spillway is sufficiently wide and shallow, and with an appreciable enough hydraulic gradient, channel boundary roughness will force flow to "tumble" in a manner where there is increased water surface exposure of ambient air conditions. Where this kind of open-channel flow conditions occur, TDG levels rapidly drop back to near the stable, 100 percent saturation level in less than a mile (distance varies from site to site).

However, if there is a reservoir backed up to near the powerhouse tailrace, as at Thompson Falls, the normal river gradient is reduced and the flow regime becomes more stable. Lower reservoir velocities result in less turbulence, and elevated TDG levels are locked in after entering the impoundment. If there are elevated wind levels, enough shear can be created to induce the vertical circulation necessary to reduce TDG levels in the reservoir. Otherwise, the elevated reservoir TDG levels wane slowly, and on the basis of delayed replenishment by lower level TDG inflows.

Other relevant information

- Spillway stilling basins have their own signature, and induce an outflow TDG level that is higher than the forebay TDG level. As spillway flow passes into a deep spillway stilling basin, memory of forebay TDG levels is erased. TDG level downstream of a spillway is a direct result of the spillway signature (stilling pool configuration and inflow hydraulic conditions), air and water temperatures, and atmospheric pressure.

- For that component of flow passing through turbines, there is very little TDG uptake. Turbine energy is extracted at a high rate (through generation of power), and little energy remains as flow discharges from turbine draft tubes. (In 2003, PPLM had TDG monitors stationed downstream of the new powerhouse. This monitor showed that under normal operating conditions, flow passing through the powerhouse did not have elevated TDG levels.) While there is a turbine boil in the powerhouse tailrace, aeration from turbulence is at a lower level, resulting in a powerhouse tailrace TDG level nearly the same as the forebay. Therefore, *passing flow through a turbine is a way to minimize TDG uptake*.

- Tailrace Mixing and the Gas Balance Equation: *(Turbine Flow x PH Tailrace TDG) + (Spillway Flow x Spillway Tailrace TDG) divided by Total River Discharge = Composite* *(mixed) TDG downstream of the project*. This assumes a reservoir backwater just downstream of the powerhouse (as at Thompson Falls). Therefore, *passing a larger percentage of total river discharge through the powerhouse reduces downstream composite TDG during spill periods*.

Previous Total Dissolved Gas Abatement Efforts

The U.S. Army Corps of Engineers (USACE) initiated a comprehensive five-year study of total dissolved gas supersaturation and abatement at their Lower Snake and Columbia River hydroelectric projects in the mid-1990's, titled the Dissolved Gas Abatement Study (DGAS). This effort was based on the perceived need (by the fisheries agencies and tribes) to increase survival of juvenile salmon outmigrants, by passing as many as possible over the spillway rather than through turbines or intake screen and bypass systems. However, the number of fish that could be passed in spill discharge was limited by CWA TDG limits (110 percent). The conundrum was that water quality standards for TDG were designed to protect aquatic species, but these regulations were forcing more fish to pass through lethal turbines. The study included a gas bubble trauma monitoring program, which concluded that a TDG level of 120 percent below spillways could be sustained without detectable damage to salmon and steelhead, and an annual waiver was granted so that higher spill levels could route more fish over spillways. (Note: the effects of 120 percent TDG were not studied in the context of non-migratory fishes, so the regulatory agencies were not willing to grant annual waivers indefinitely.)

Meanwhile, an entire array of gas abatement measures at spillways was investigated. The common denominator for these design approaches was to keep turbulence downstream of spillways from going to depth, thereby limiting gas absorption. The principles of the approaches studied can be considered at other hydro projects where gas abatement may be required (including Thompson Falls). (Note: one option was to increase turbine capacity at hydro projects, thereby reducing spill levels by the added turbine discharge capacity.)

Site-Specific Subjective Assessment of Total Dissolve Gas Dynamics at Thompson Falls

Generally, TDG levels downstream of the spillway increase as spill discharge increases. In Figure 1 the blue data points and regression curve (Blue Curve) from 2006 TDG field data show this is true at Thompson Falls. These data were collected at the high bridge (HB), several hundred yards downstream of the spillway and falls. However, there are unusual and mitigating circumstances at this location, relative to other hydro power projects. Figure 2 is an aerial view of the Main Dam spillway tailrace. Note that there is no formal spillway stilling basin. There doesn't need to be, as the spillway is built on bedrock and erosion/scour is not a concern. Further, the depth on the bedrock shelf immediately downstream of the spillway apron appears *not* to be deep enough (though there are a few deeper pools) for appreciable gas absorption to occur on the basis of required hydrostatic pressure. The rock shelf extends downstream to the falls, and to a deeper downstream pool where there *is* enough depth for appreciable TDG uptake. (Therefore, TDG measurements collected at the base of the spillway, and above the falls, may not be accurate. See the last section of this memorandum for additional discussion of this issue.)

Three Configurations and Operating Conditions

Three configuration and operating conditions relating to the Main Dam spillway and falls (and TDG readings at the HB, TDG monitoring site) are referenced below, and in the subsequent discussion of the central issue – whether Thompson Falls increases TDG levels.

1. The true baseline is the **Pre-Dam condition**, where all total river discharge passed over the falls and increased TDG at the HB location. TDG readings for the Pre-Dam condition

can be never attain since the spillway structure is in place and influences readings downstream of the falls. However, as river discharge increased, can assume that river plunge into the deep natural pool below the falls would have increased TDG levels at the HB site.

2. For the current **Normal Dam Operating condition**, spill discharge passing the Main Dam spillway entails gas uptake from the composite of flow passing over the spillway and falls, and into the deep natural pool below the falls. This is based on TDG measurements at HB. However, the first 23,000 cfs of river discharge is normally passed through the powerhouses (when operating at full turbine capacity). That amount of total river discharge passing the powerhouse (as depicted from 2003 TDG data collection below the new powerhouse), does not have higher TDG reading than forebay, and may actually be slightly lower. Only the flow above turbine capacity passes over the spillway and falls (as represented by the Blue Curve).

3. On occasion, the **Turbine Load-Rejection condition** will occur. This happens when electrical generation cannot be delivered onto the regional power grid, due to an unexpected emergency. Powerhouse turbines go off-line, and all flow passes the spillways. This happens intermittently for brief periods of time. In 2003, PPLM had TDG monitors stationed downstream of the new powerhouse (Figure 2). These showed that under normal operating conditions, flow passing through the powerhouse did not have elevated TDG levels. However, during load rejection, when the powerhouse was off-line, discharge passing this gage was exclusively from the Main Dam spillway and TDG levels abruptly increased until turbines were back on line. (Note: total river discharge was approximately 30,000 cfs during the dates shown in Figure 2, and there were not enough data points to develop a regression curve.) These 2003 data points represent TDG levels close to the Pre-Dam Operation.

The Figure 1 Blue Curve depicts 2006 HB TDG readings as a function of total river discharge for the Normal Dam Operating condition, (2) above. Note that conditions (1) and (3) would also have their own HB TDG data points and regression curve, if that data were available. Further, if the respective curves were to the left of the Blue Curve, HB TDG levels would be higher for a given total river discharge than for the Blue Curve. (Conversely, if the curves were to the right of the Blue Curve, HB TDG levels would be lower than for the Blue Curve.) Paraphrased, higher TDG levels would be generated at the HB, with the same total river discharge and all flow passing over the falls. The implication is that the Normal Dam Operating condition results in lower TDG at HB than the Turbine Load-Rejection condition, at all river discharges. The only uncertainty is whether the same is true for the Pre-Dam condition.

Total River Discharge Ranges

It is useful to discuss three levels of total river discharge, when assessing whether Thompson Falls increases TDG uptake at the location with the highest total dissolved gas readings – the HB monitoring location.

Low River Discharge Level (total river discharge ≤ 23,000 cfs) – This range of river discharge occurs 85 percent of the time (Figure 5). There is no spill during Normal Dam Operations and HB TDG readings are less than if total river discharge were passing the falls with either the Pre-Dam or Turbine Load-Rejection conditions.

High River Discharge Level (total river discharge > 80,000 cfs) – This high river discharge occurs less than one (1) percent of the time, and has not occurred since before 2003. It was stated earlier that HB TDG levels below the falls generally increase as spillway discharge increases for each condition described above. However, when total river discharge is very high, the tailwater elevation downstream of the spillway and falls rises enough to backwater the falls, and there is a reduced plunging action into the deep pool below the falls. It is unknown whether the rate of increase in HB

TDG at very high total river discharges tapers off, or even drops to a lower level, during river discharges in this range. The Normal Dam Operating and Turbine Load-Rejection conditions could be expected to have higher HB TDG readings than the Pre-Dam condition during very high river discharges, since the spillway adds approximately 35-40 feet of energy during this condition. The positive TDG abatement influence of passing 23,000 cfs through the powerhouse turbines (at lower river discharges) no doubt has a very small influence over HB TDG levels for very high river total discharges.

Middle River Discharge Level (23,000 – 80,000 cfs total river discharge) – At the lower end of this total river discharge range, spill discharge is at a lower level (e.g., < 20,000 cfs spill) for the Normal Dam Operating condition, and HB TDG readings are relatively low (< 115 percent). Examples of different river discharges and HB TDG levels are discussed below and describe the positive influence on HB TDG of routing a large percentage of flow through turbines. At the higher end of the middle river discharge range, a bigger percentage of river discharge passes over the spillway for Normal Dam Operating condition, and it is suspected that HB TDG levels for the Normal Dam Operating and Turbine Load-Rejection conditions exceed levels for the Pre-Dam condition. At some intermediate total river discharge, I suspect there is a *cross-over river discharge,* above which the HB TDG would be higher for both the Normal Dam Operating and Turbine Load-Rejection conditions than for the Pre-Dam condition. Although the cross-over discharge magnitude is unknown (as there is no Pre-Dam HB TDG regression curve), it is expected that the percentage of time river discharge is at, or above, this level is less than five (5) percent as depicted on Figure 4.

Premise

Normal Dam Operating Condition Total Dissolve Gas Levels at High Bridge are nearly always lower than for the Pre-Dam Condition

Reason

The primary TDG uptake is in the deep pool immediately downstream of the Main Dam and falls, as measured at the HB site. Prior to the dam, the total river discharge passed the deep pool below the falls, and created progressively higher TDG levels at higher river discharges. The current Normal Dam Operating condition routes up to 23,000 cfs through the two powerhouses (where TDG does not increase for this component of total river discharge). With up to 23,000 cfs less river flow passing the pool below the falls, HB TDG readings are proportionately lower for the Normal Dam Operating condition than for the Turbine Load-Rejection and Pre-Dam conditions (if the Pre-Dam conditions data were available).

Discussion

The Blue Curve in Figure 1 represents the 2006 TDG levels at HB for the Normal Dam Operating condition, relative to total river discharge. The red data points and regression curve (Red Curve) in Figure 1 are meant to represent the condition where the total river discharge is the same, but turbines are not operating and the entire river discharge is passing over the spillway and falls. As noted, TDG data for the Pre-Dam condition does not exist, and only a few 2003 data points for the Load Rejection condition (Figure 2). Therefore, for illustration, we have developed the Red Curve as a surrogate for the Load Rejection Curve, and subtracted 23,000 cfs from the total river discharge for each data point on the Blue Curve. (For example, 40,000 cfs river discharge in 2006 gave Blue Curve HB TDG levels of 112-113 percent, which included 23,000 cfs through the turbines and 17,000 cfs over the spillway. To attain the related Red Curve data points, it was assumed that the total river discharge of 17,000 cfs, and zero turbine discharge, created the same 112-113 percent TDG levels. This supposes that 17,000 cfs spill creates the same HB TDG level, whether the turbines pass zero or 23,000 cfs. Concurrently, if the assumption is made that the entire 40,000 cfs were passing the spillway, with no turbines operating, HB TDG levels increase to 122 percent. Again, this assumes that 40,000 cfs spill creates the same HB TDG whether turbines are operating or not.)

The Red Curve, as described above, could represent either the Pre-Dam condition, or the Turbine Load Rejection condition. The primary difference in the two conditions is believed to be the additional energy that enters the falls tailrace with the spillway structure in place (the Turbine Load-Rejection condition). The Turbine Load-Rejection condition results in higher energy flow (due to passage over the 50- foot high spillway, at a lower river stage), which increases turbulence in the pool below the falls, and takes more aeration to depth. This means the Turbine Load-Rejection condition results in incrementally higher TDG uptake below the falls, relative to the Pre-Dam Condition.

The 2003 data showed that HB TDG levels of 114-116 percent occurred during Load Rejection conditions for river discharges of approximately 30,000 cfs, compared to the Red Curve TDG HB readings of 118 percent and Blue Curve TDG HB readings of approximately 108 percent.

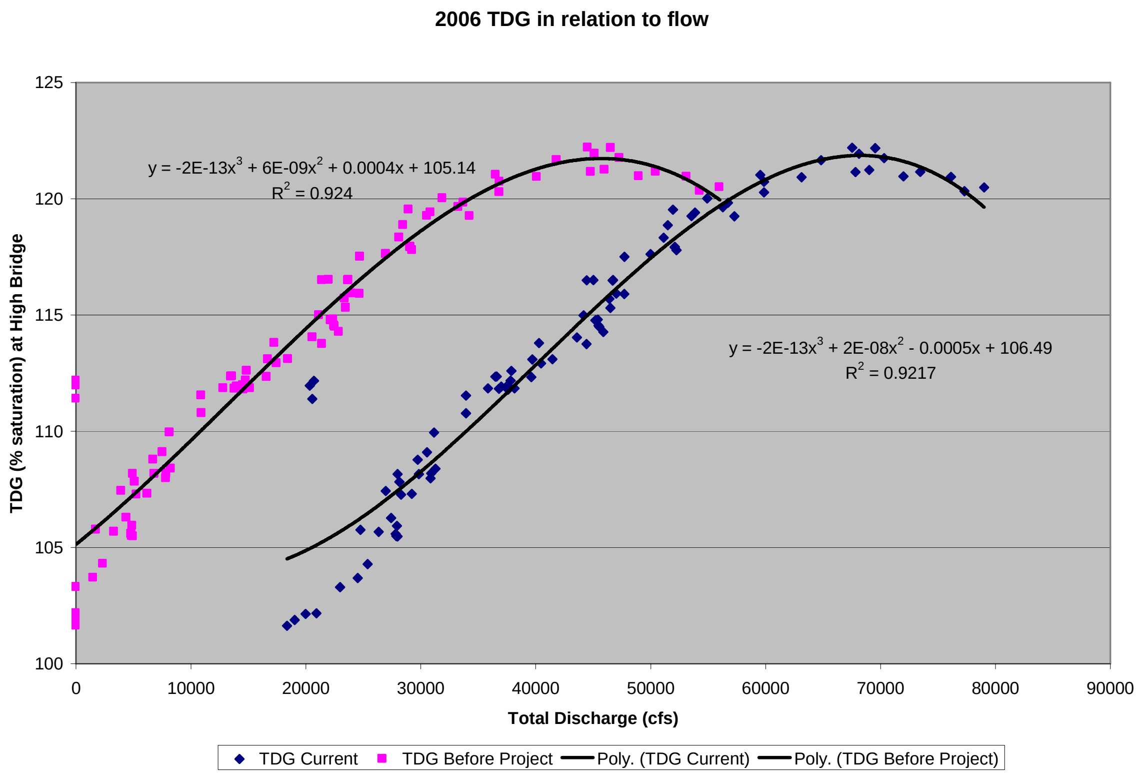

Figure 1 – Total Dissolved Gas Levels at the Thompson Falls High Bridge Monitoring Station, before and after hydro development (see above explanation).

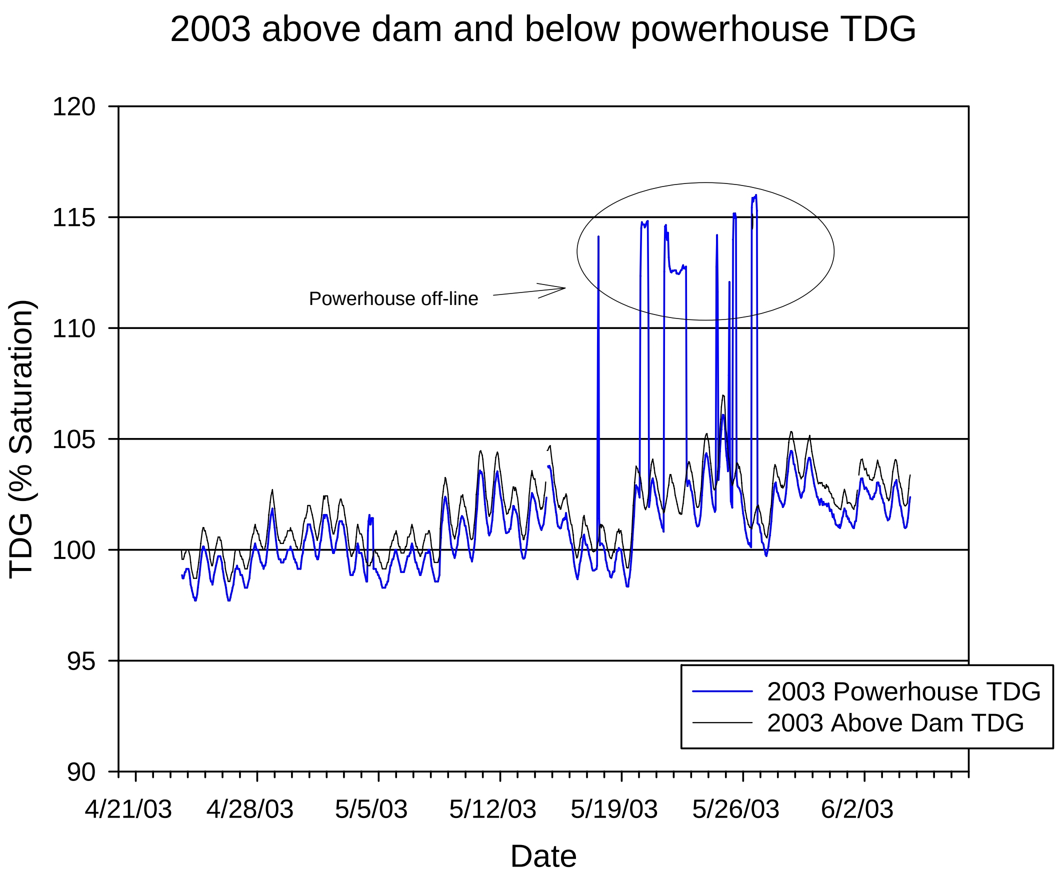

Figure 2 – TDG as measured above the dam and below the new powerhouse in 2003.

Figure 3 – Aerial photo of Main Dam Spillway.

Total Dissolve Gas Levels at the High Bridge Monitoring Station for Different Total River Discharge Levels

As examples of TDG abatement benefits of passing the first 23,000 cfs of river discharge through turbines, different levels of spill are considered below. In each case, the Blue Curve (Normal Dam Operating condition) HB TDG levels are compared with the Red Curve (which approximate the Turbine Load-Rejection and Pre-Dam conditions).

Low Normal Dam Operation Spill Levels (33,000 cfs total river discharge and 10,000 cfs spill):

Normal Dam Operation (Blue Curve) - Figure 4 shows the roughness of the channel downstream of the spillway apron, and upstream of the deep pool below the falls. At low levels of spill, there is a hydraulic jump near the downstream end of the spillway apron that dissipates some of the energy from spill. Additional energy is lost as spill flow passes over the rough channel in Figure 4, before plunging into the deep pool below the falls. Whereas the forebay TDG level was approximately 102–104 percent, a spill discharge of 10,000 cfs (assuming a river discharge of 33,000 cfs and powerhouse discharge of 23,000 cfs from Figure 1) increases TDG at the high bridge to 110 percent. Mixing downstream of the two powerhouses reduces the total river discharge TDG to below 110 percent (the gas balance formula can be used to get approximate Birdland Bay TDG readings).

Turbine Load-Rejection and Pre-Dam Conditions (Red Curve, Figure 1) – At low levels of spill with the Normal Dam Operation (river discharge = 33,000 cfs and spill discharge = 10,000 cfs), TDG levels are lower at the high bridge than the Pre-Dam condition, where the entire river (33,000 cfs) would be passing over the falls and plunging into the deep pool immediately downstream of the falls. Figure 1 shows that the TDG levels would be approximately 119 percent at HB if spill is 33,000 cfs (the entire river discharge). *Therefore, the hydro project development reduces TDG levels approximately nine (9) percent during the low spill scenario, by passing 23,000 cfs through turbines.*

Further, 119 percent TDG occurred in 2006 at a river discharge of 56,000 cfs spill (Normal Dam Operations – 33,000 cfs spill and 23,000 cfs powerhouse discharge).

Figure 4 – Steep center thalweg and "falls" roughness.

Mid-Level Spill (25,000 cfs)

Normal Dam Operations - For 25,000 cfs spill, the river discharge in Figure 1 is 48,000 cfs (23,000 cfs powerhouse and 25,000 cfs spill). The Blue Curve shows TDG at approximately 116 percent.

Load Rejection and Pre-Dam Conditions (Red Curve, Figure 1) – For the same river discharge of 48,000 cfs, the Pre-Dam condition entailed the total river discharge of 48,000 cfs over the falls. From Figure 1, this would yield a TDG level of approximately 121 percent. Further, to get a 121 percent TDG with current configuration, and 23,000 cfs through the powerhouse, a river discharge of 70,000 cfs (48,000 cfs spill and 23,000 cfs powerhouse) would be required. *Therefore, the hydro project development reduces TDG levels approximately five (5) percent during the referenced mid-level spill scenario, by passing 23,000 cfs through turbines.*

High Level Spill Discharges

As total river discharge increased from 33,000 cfs to 48,000 cfs, the influence of passing 23,000 cfs through the powerhouse turbines diminished from a nine (9) percent TDG reduction to a five (5) percent TDG reduction. As discussed, under the "Total River Discharge Ranges" section (page 4), the positive gas abatement influence of passing 23,000 cfs through turbines diminishes as total river discharge increases, until a *cross-over discharge* is reached. Above that unknown river discharge, it is suspected that both the Normal Dam Operating and Turbine Load-Rejection conditions increase TDG levels, relative to the Pre-Dam condition. One explanation for the lower Pre-Dam TDG levels at higher river discharges is the considerably higher tailrace elevation below the falls, which increases 10 feet at the two powerhouses between 10,000 and 50,000 cfs total river discharge. This backwaters and reduces the plunge of spilled discharge at the falls, which may decrease the rate of HB TDG increase, relative to total discharge. However, there is still appreciable turbulence from the high spill discharge creating vertical circulation in the deep pool, taking aeration to depth and increasing TDG uptake, just not to the same degree as at lower levels of spill.

Whether an asymptote is reached for the Normal Dam Operating condition (where TDG does not increase above a limiting TDG level) is not known, since data collection in the last few years has not measured TDG at a total river discharge above 79,000 cfs (in 2006). Figure 5 shows that total river discharge does not exceed 80,000 cfs over one (1) percent of the time, and the high river discharge of 79,000 cfs (2006) was the greatest discharge during TDG data collection that commenced in 2003.

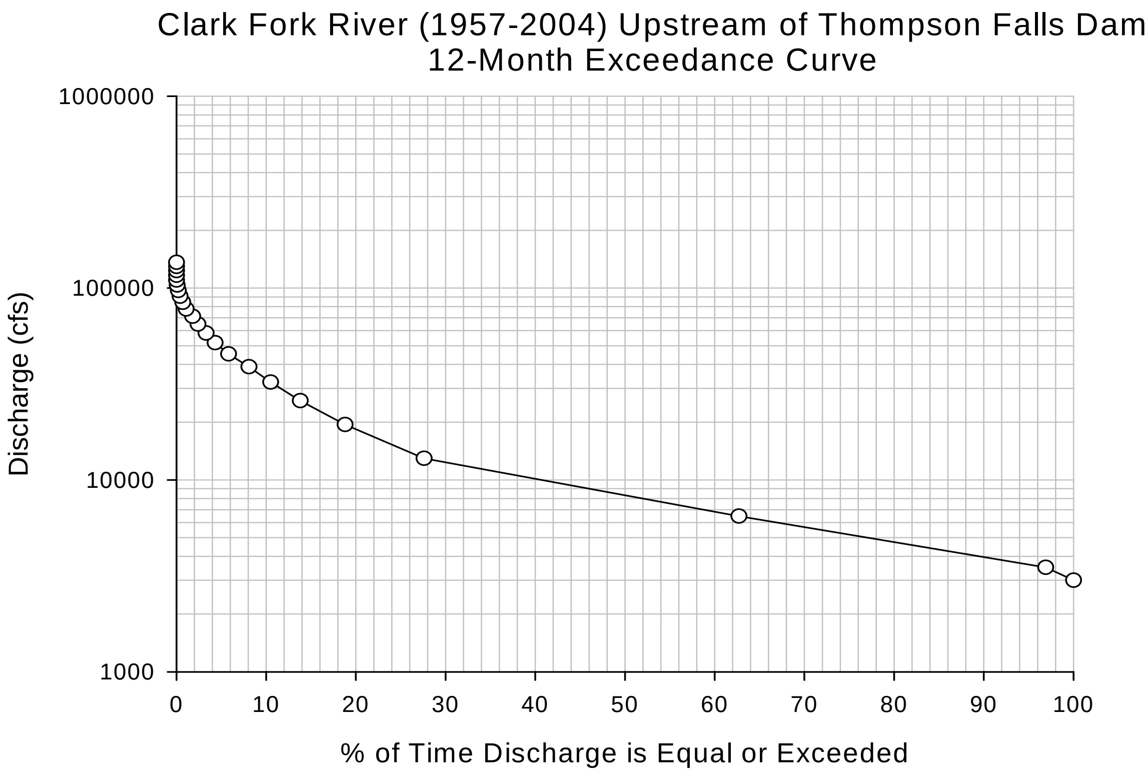

Figure 5 – River Discharge Exceedence Curve.

Reduced Downstream Total Dissolve Gas Levels Due to Mixing of Spill and Powerhouse Discharges

Figure 6 shows that mixing of lower TDG powerhouse discharge and higher TDG spillway discharge results in intermediate gas levels downstream of the Thompson Falls project than at the High Bridge monitoring station. The gas balance formula (page 3) gives a close indication of the Birdland Bay TDG readings. Note that this monitor is less than two miles downstream of where the powerhouses discharge into the Clark Fork River. The highest river discharge and TDG levels for 2003-2006 were 79,000 cfs and 117 percent. This shows how mixing influences the highest High Bridge monitoring station readings (123 percent). It also shows that the High Bridge TDG readings of 123% were confined to a several hundred yard reach of river between the deep gas uptake pool below the spillway/falls and the two powerhouses. At this location, mixing and dilution of higher TDG spillway discharge with lower TDG (the same as the forebay TDG level) occurred.

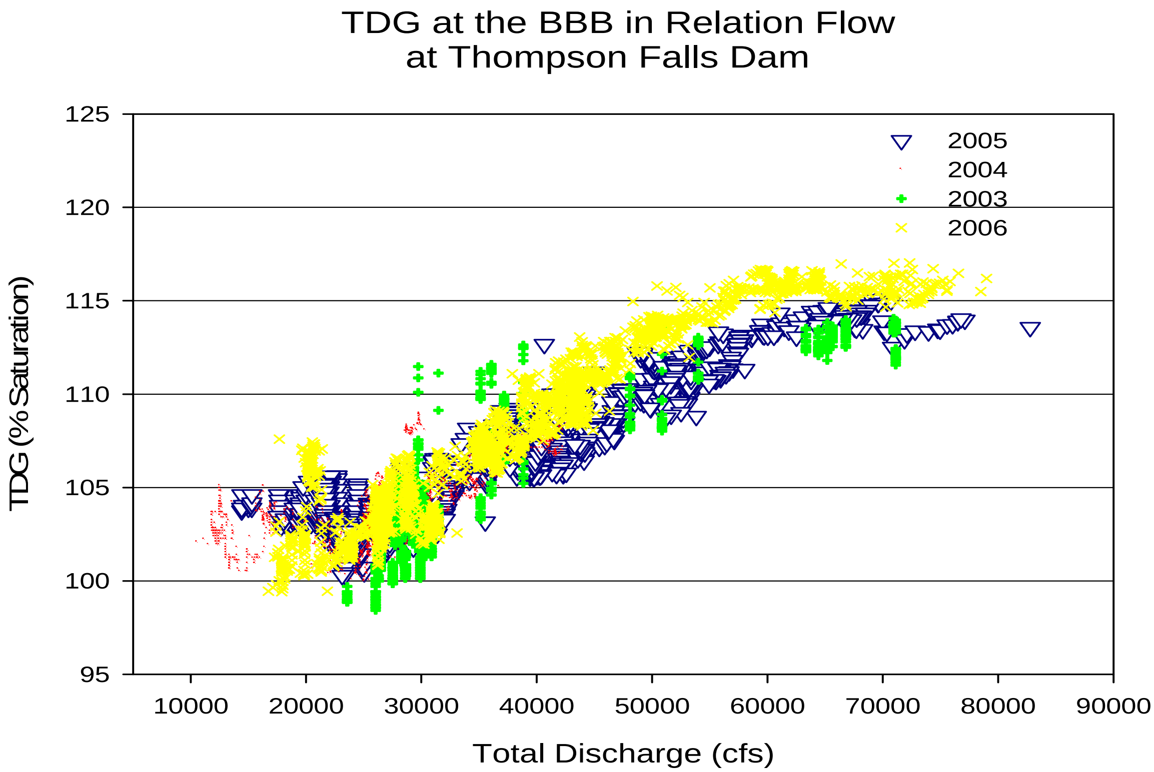

Figure 6 – TDG at the Birdland Bay Monitoring Station, 2003 - 2006

Conclusions: Thompson Falls Gas Abatement

1. The primary question addressed in this memorandum is whether the Normal Dam Operation results in higher TDG levels. The baseline is presumed to be the Pre-Dam condition.

2. The location of greatest total dissolved gas uptake is believed to be, on the basis of accumulated data at different PPLM monitoring stations, the HB location.

3. TDG levels at Thompson Falls did not exceed 123 percent during the 2003-06 TDG monitoring period, at a maximum total river discharge of 79,000 cfs. This is far lower than locations such as Cabinet Gorge, where spillway tailrace TDG levels reach 140 percent.

4. TDG levels two miles downstream of Thompson Falls, at the Birdland Bay monitoring station, did not exceed 117 percent during the 2003-06 TDG monitoring period.

5. It was shown in the Columbia and Snake Rivers, though extensive research, that TDG levels of ≤120 percent did not result in detectable gas bubble trauma symptoms. It is unknown, however, whether non-anadromous fish species would be adversely impacted from relatively short exposure to 123 percent TDG levels at Thompson Falls. However, it is questionable whether the 123 percent TDG level at Thompson Falls has any adverse impact on indigenous fish populations.

6. The Normal Dam Operating condition abates TDG, relative to the Pre-Dam condition, by routing up to 23,000 cfs around the primary TDG uptake zone (below the spillway and falls), and through turbines.

7. The Normal Dam Operating condition abates TDG, relative to the Turbine Load-Rejection condition, by routing up to 23,000 cfs around the TDG uptake zone, and through turbines.

8. I believe the Pre-Dam condition did not increase TDG uptake below the spillway and falls as much as the Turbine Load-Rejection condition, because of the additional 30-50 feet of energy added by the presence of the spillway in the Turbine Load-Rejection condition (which increased turbulence and conditions increasing TDG uptake below the falls).

9. The Red Curve in Figure 1 is probably most representative of the Turbine Load-Rejection condition, although it predicts TDG HB readings slightly higher than the 2003 Turbine Load-Rejection data for the approximately 30,000 cfs river discharges during those dates.

10. Both the Red Curve, and limited 2003 Turbine Load-Rejection data suggest that the Normal Dam Operating condition TDG HB levels are always lower than the Turbine Load-Rejection condition levels, for any total river discharge.

11. For the first 23,000 cfs of total river discharge (lower river discharge levels), the Normal Dam Operating condition entails less flow passing into the deep pool below the falls, and thus entails lower TDG HB levels than the Pre Dam condition (where all river discharge passed the falls and deep pool immediately downstream.)

12. For higher river discharges (above 80,000 cfs), Normal Dam Operating condition spill discharge is high enough that the TDG benefit of passing the first 23,000 cfs through turbines is overridden, and I believe the Normal Dam Operating condition will yield higher HB TDG levels than the Pre-Dam condition. However, this occurs less than approximately one (1) percent of the time.

13. For total river discharges of 23,000 – 80,000 cfs, there is a *cross-over discharge* below which HB TDG levels are lower than the Pre-Dam condition, and above which HB TDG levels are higher than the Pre-Dam condition. If that change-over level is 50,000 cfs total river discharge, Figure 5 suggests that the Normal Dam Operating condition would have lower HB TDG levels 96 percent of the time. If that cross-over discharge is 70,000 cfs, the Normal Dam Operating condition would reduce HB TDG relative to the Pre-Dam condition 98 percent of the time. However, further monitoring will not resolve the magnitude of the cross-over total river discharge, since Pre-Dam HB TDG data is not available.

14. Therefore, the question of whether it is appropriate to continue to monitor TDG levels, or investigate structural measures to abate TDG, is raised. In theory, additional TDG monitoring should lead to additional information that will aid in resolving outstanding questions and/or issues. TDG data collection from 2003 -2006 has given a reasonable scope of understanding of TDG dynamics at Thompson Falls. It appears timing is appropriate to address what additional measures are necessary, if any.

15. Gas abatement measures at Thompson Falls, if required by the state or federal government, would not be successful if employed at the spillway structure. Since the TDG uptake zone is the deep pool immediately downstream of the falls, that is where direct structural measures would be required. The primary means of reducing TDG uptake at this location would be to add turbine capacity (probably not economically viable) or fill and cap deep zones in the bypass reach to keep turbulence from going to depth. This would be costly, entail a considerable length of the bypass reach channel, and would transfer energy further downstream.

This analysis suggests that TDG levels below the spillway and falls rarely exceed 123 percent, which is a low level compared to hydro projects such as Cabinet Gorge (TDG reaches 140 percent). There is no research that suggests 123 percent TDG exposure for short periods may induce adverse impacts to non-anadromous fish. Routing 23,000 cfs through project turbines also routes flow around the primary gas uptake area at the falls below the spillway. The Pre-Dam passage of total river discharge at the falls increased TDG levels, especially at low – medium stages. These observations beg the question of whether enough TDA monitoring at Thompson Falls has occurred, and whether there is a need for additional studies and monitoring. In short, it is reasonable for PPLM to request that the resource agencies provide a sound rationale and appropriate next steps, for committing additional resources to TDG monitoring and/or gas abatement studies.

Appendix

Total Dissolve Gas Data Collection Immediately Below the Spillway

In 2004, TDG readings were taken at the base of the Main Dam spillway, and at the HB location. Figure 7 shows the difference in TDG readings at the two sites. The first impression is that the falls is not contributing an appreciable amount to TDG uptake. However, I believe that there is insufficient depth for much TDG uptake in the shallow bedrock channel between the spillway and

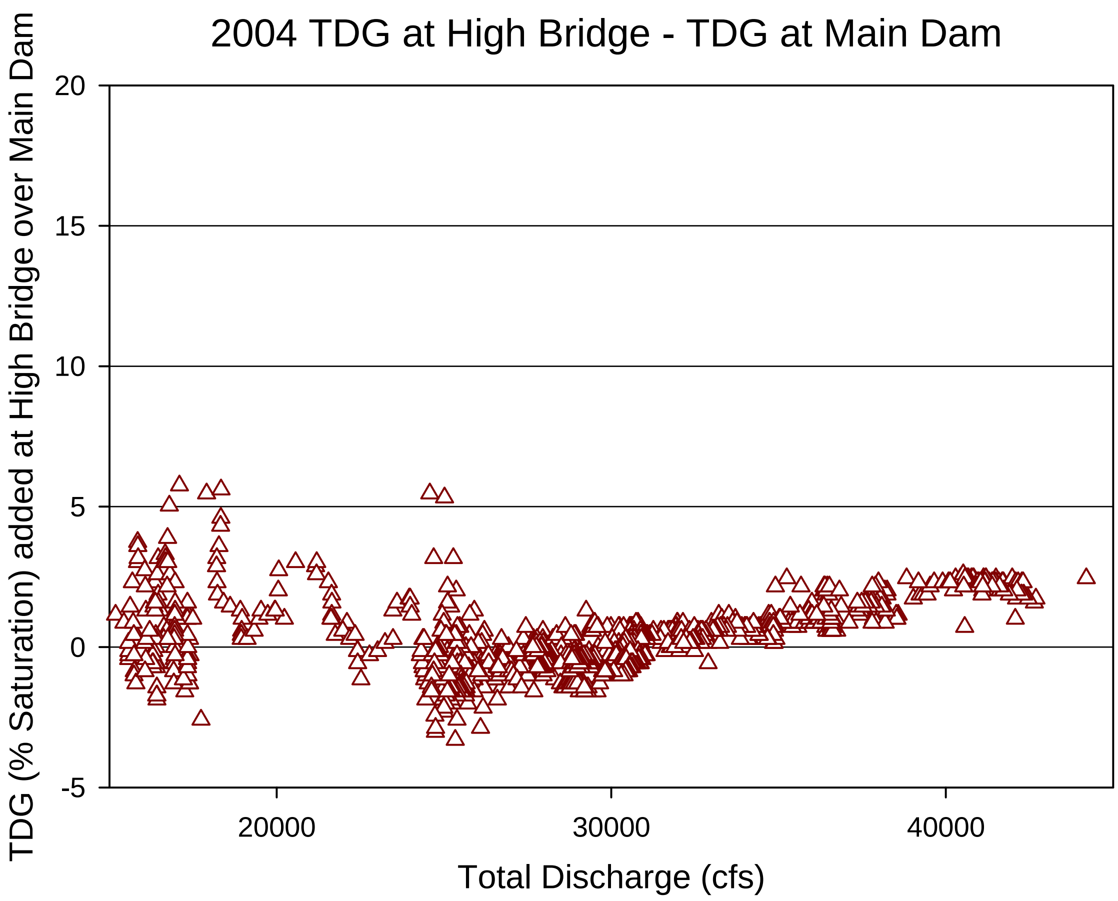

Figure 7 – Apparent TDG component of the 2004 HB TDG reading contributed by the falls.

falls. Rather, appreciable spill energy is being transferred to the deep pool below the falls, where turbulence is dissipated. This deep pool is where most of the TDG uptake is occurring. The following is an excerpt from the USACE's report on the Dissolved Gas Abatement Study, which pertains to this issue:

(ES1.08. SUMMARY OF INVESTIGATIONS)

a. Field Investigations.

Much experience and knowledge has been gained through the data collection efforts and the near-field investigations conducted below the Corps projects. Initially, measurements of TDG were made by boat at a distance of 2,500 feet or more downstream of the spillway stilling basins where TDG levels were expected to be the highest near the end of the aerated spillway plume. With advances in instrumentation and on-board data logging, the Corps was able to develop methods for deploying instruments directly below the spillway. Peak TDG levels much higher than previously measured or expected were observed. TDG levels as high as 170 percent were measured near the spillway's endsill of the non-deflected Ice Harbor spillway. The TDG levels dropped off very rapidly to less than 130 percent within the first 2,500 feet downstream of the stilling basin and then began to stabilize at levels less than 125 percent as the flow continued to move downstream. Similar trends have been observed at other projects both with and without spillway flow deflectors. The near-field tests have shown that a significant and rapid decrease in TDG occurs within the aerated plume exiting the spillway's stilling basin. Because flows from the spillway flow deflectors tend to force higher energy flow out into the tailrace channel, they not only prevent the flow from plunging deep into the spillway stilling basin (reducing the initial uptake in TDG), they also promote a rapid decrease in TDG by extending the boundaries of a more turbulent aerated plume.

The following is surmised, relative to where TDG uptake is occurring at Thompson Falls

- If TDG measurements are in a highly turbulent zone (such as immediately below a spillway), readings will be artificially high relative to a downstream location such as the HB, because the TDG levels drop in intervening zones of waning turbulence. This is due to residual "tumbling" of water that releases unstable TDG in solution to the atmosphere.
- Since there are few areas of depth in the immediate spillway tailrace, but appreciable turbulence and aeration, little absorption of TDG should be occurring in this zone during spill. Therefore, there is uncertainty whether elevated 2004 TDG readings below the spillway were artificially influenced by a high density of aeration bubbles in this turbulent zone.
- At low spill levels, some of the energy is dissipated between the spillway and falls, due to surface roughness and the hydraulic jump at the base of the spillway apron. But residual energy combines with the vertical drop at the falls to transfer composite energy to the deep pool below the falls. I believe this is where the primary TDG uptake occurs during spill.
- Since the primary energy dissipation appears to occur in the deep falls tailrace pool, the TDG levels upstream (in the immediate spillway tailrace) are erased when they pass into the deeper pool below the falls. That is where the presence of (1) pool volume and (2) pool depth combine to create the vertical circulation necessary to take aeration to depth, and expose it to the hydraulic pressures required for TDG uptake.
- Therefore, TDG readings at the base of the spillway appear to be misleading, and the HB reading (at a location far enough downstream to reflect a more stable TDG level) appears to be the most useful for measuring the *composite* TDG uptake for the spillway and falls.
- It is inappropriate to try to segment TDG uptake downstream of the Main Dam spillway at Thompson Falls, since the spillway and falls are a composite system.