Total Dissolved Gas Control Plan

Thompson Falls Hydroelectric Project
FERC Project Number 1869

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1.0 Introduction

1.1 Background

PPL Montana, LLC is owner and operator of the Thompson Falls Dam (No. 1869), located on the Clark Fork River near Thompson Falls, Montana. The current Federal Energy Regulatory Commission (FERC or Commission) license was issued to Montana Power Company (now PPL Montana) in 1979 and is scheduled to expire on December 31, 2025.

Montana Water Quality Standards (Montana Department of Environmental Quality [MDEQ], Circular DEQ-7, 2008) sets a standard of 110% of saturation for Total Dissolved Gas (TDG). This water quality standard was developed to protect fish from high levels of TDG, which may cause Gas Bubble Trauma (GBT). GBT can cause injury and, in severe cases, death to fish. TDG levels in excess of 110% can occur for a few months each year during the spring freshet downstream of hydroelectric project spillways.

On February 12, 2009 the FERC issued an Order Approving Construction and Operation of Fish Passage Facilities for the Thompson Falls Hydroelectric Project. The FERC Order required PPL Montana to:

> a. For the remainder of the license (through 2025), in consultation with the Thompson Falls Technical Advisory Committee (TAC) and subject to U.S. Fish and Wildlife Service approval, PPL Montana will develop and implement operational procedures to reduce or minimize the TDG production at Thompson Falls Dams during periods of spill. Future modifications to prescribed operations may be determined from ongoing evaluations, as necessary, and determined appropriate by MDEQ.
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> b. For the remainder of the license (through 2025), in consultation with the TAC and subject to U.S. Fish and Wildlife Service approval, PPL Montana will continue to collaborate with MDEQ, Avista, MFWP, and other entities toward reducing the overall systemic gas supersaturation levels in the Clark Fork River, occurring from a point downstream of Thompson Falls Dam to below Albeni Falls Dam.
>
> c. For the remainder of the license (through 2025), all bull trout detained through the sampling loop at the Thompson Falls Fish Ladder will routinely be examined for signs of GBT; with results of such observations permanently recorded. Should GBT symptoms be discovered, then PPL Montana will consult the TAC on the need for immediate corrective actions and subsequently implement any new studies or potential operational changes (to the ladder or the dam) which may be required by the U.S. Fish and Wildlife Service and MDEQ, in order to mitigate GBT concerns.

The MDEQ has requested that PPL Montana prepare a TDG Control Plan and an Annual Report of PPL Montana's activities to measure and control TDG in the Clark Fork River at the Thompson Falls Hydroelectric Project. This report is intended to comply with this request, and the terms of the FERC Order.

1.2 Cause of TDG Supersaturation and Related Information

Gas bubble trauma (GBT) is a condition that affects many aquatic organisms residing in fresh or marine waters which are supersaturated with atmospheric gases. Both natural and human-induced processes are known to create supersaturated waters. When water plunges into a pool, air becomes entrained regardless of whether the plunge is a natural waterfall or a dam spillway (Weitkamp and Katz, 1980). Supersaturation at hydroelectric projects is primarily caused by water containing gas that was dissolved under a higher than atmospheric pressure.

At many dams, water passing over the dam (known as spill) plunges into a deep armored stilling basin. (Stilling basins are designed to confine energy dissipation in the armored zone, so that erosion does not scour and undermine the spillway.) As spill plunges, 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 gas into solution and elevating TDG levels (gas absorption).

At the Thompson Falls Hydroelectric Project, the spillway is built on bedrock therefore scour is not a concern. For this reason, there is no formal spillway stilling basin and no plunge pool to create excessive TDG. Nonetheless, TDG downstream of the Thompson Falls Project often exceeds the Montana Water Quality Standard of 110% saturation during the spring freshet. The Thompson Falls Project was built on a natural river falls (Thompson Falls, Figures 1-1 and 1-2). No data on TDG during the pre-Project time period are available. However, the natural waterfalls likely elevated TDG in the Clark Fork River.

TDG carrying capacity depends on temperature and ambient pressure. 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% 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 is the case 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.

Figure 1-1. View of Thompson Falls, Montana

View of Thompson Falls, Montana (in background) and the Clark Fork River (in foreground), at the site of the Main Dam of the Thompson Falls Hydroelectric Project. Circa 1908. Woodworth Photo. Photo courtesy of the University of Montana, K. Ross Toole Archives.

Figure 1-2. View of Thompson Falls, Montana

View of Thompson Falls, Montana (in background) and the Clark Fork River (in foreground), circa 1908. Woodworth Photo. Photo courtesy of the University of Montana, K. Ross Toole Archives.

1.3 Goals and Objectives of the Total Dissolved Gas Plan

PPL Montana developed this plan to summarize the TDG data collected from 2002 to 2010 in the Thompson Falls Hydroelectric Project area, and to propose operational procedures to reduce or minimize the TDG production at Thompson Falls Dams during periods of spill in 2011.

PPL Montana will continue to collaborate with MDEQ, Avista, MFWP, and other entities with a long term goal of reducing the overall systemic gas supersaturation levels in the Clark Fork River, occurring from a point downstream of Thompson Falls Dam to below Albeni Falls Dam. In the short term, PPL Montana proposes to continue experimentation with the spillway operating schedule with a goal of finding a feasible spillway operating plan which minimizes TDG without impeding fish passage.

Future modifications to operational procedures will be developed through ongoing monitoring and experimentation as determined through consultation with the TAC and approval by MDEQ.

The February 2009 FERC Order for the Thompson Falls Hydroelectric Project specifies that:

> Annually, by April 1 of each year for the remainder of the license (expires 2025), PPL Montana will prepare and submit to the Service for approval a report of the previous years activities, fish passage totals, and next year's proposed activities and other fisheries monitoring that may result in intentional as well as incidental take of bull trout. The report will quantify the number of bull trout proposed to be incidentally taken by each activity and summarize the cumulative extent of incidental take from all previous year activities.

It is PPL Montana's intention to include a summary of the results of the previous year's TDG monitoring in the annual report, as well as a proposal for the next year's monitoring and spillway operation plan.

2.0 Methods

2.1 Measurement of TDG

All field work was performed by PPLM personnel. PPLM uses Hydrolab Series 4 and 5 DataSondes fitted with TDG sensors to collect TDG data. DataSonde TDG sensors are calibrated by the manufacturer, Hydrolab, every two- three years. At the beginning of the year, TDG sensors are compared to each other for accuracy and brought to within 1 mmHg of each other if necessary. Sensor membranes are pressure tested by PPLM to approximately 1000 mmHg at the beginning of the spill season. Each membrane is used once during the spill season.

Deployment periods for the DataSonde units were three - four weeks. Biological and sediment fowling is not a problem at the water temperatures found at the project site over this length of time. All parameters including pH, specific conductivity, DO and turbidity are calibrated at the beginning of each 4 week deployment period. During calibrations, sensors are cleaned and batteries replaced. Time and date are checked. A calibration check sheet is used (Appendix B). The stated accuracy of the TDG sensor is +/- 1.5 mm Hg over a range of 400 - 1400 mmHg.

Barometric pressure (BP) has been measured by an Onset Computer Corp HOBO Microstation Barometric Pressure Smart Sensor with a stated error of +/- 1.5 mbar = 1.1 mmHg at 25^{o}C and a maximum error of +/- 2.5 mbar = .9 mm Hg over the temperature range -10^{o}C to +60^{o}C. The barometer is mounted approximately 6 feet above the floor of the Control Room in the old powerhouse. The elevation of the barometer is approximately 2381.2 msl.

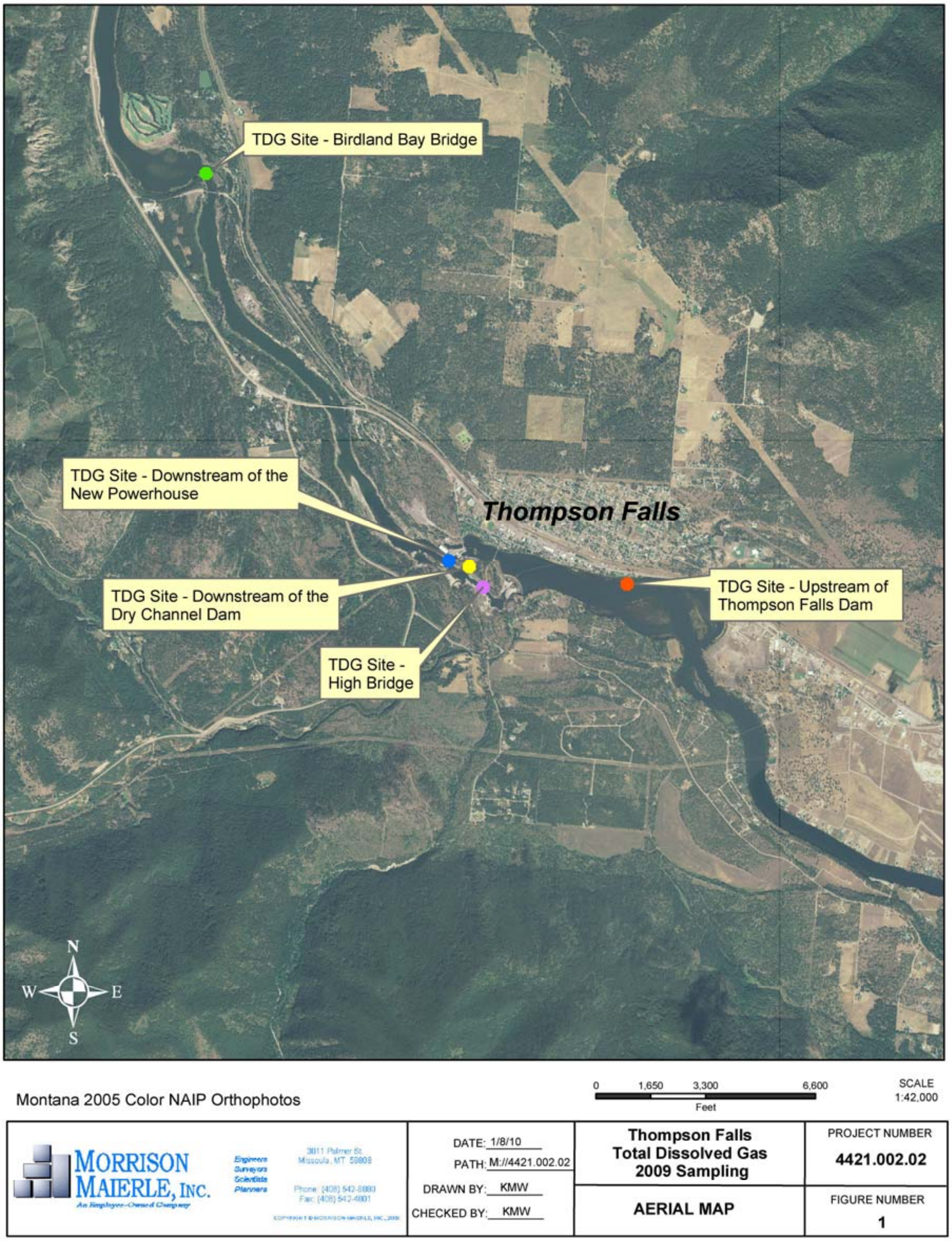
TDG has been monitored in the Thompson Falls Hydroelectric Project area since 2003. Sites that have been monitored include 1) above dam, 2) immediately below the Main Dam, 3) below the Dry Channel Dam, 4) High Bridge, 5) Birdland Bay Bridge, and 6) below the powerhouse (Figure 2-1). Not all sites were monitored in all years. The High Bridge monitoring site captures information on TDG at a location that is downstream of the Main Dam spillway and the falls, but is upstream where the Dry Channel Dam spill enters the river. The Birdland Bay Bridge monitoring site captures information on the level of TDG entering Noxon Rapids Reservoir.

In 2008, TDG was monitored at two locations immediately downstream of the Main Dam spillway. This is a difficult location for monitoring of TDG because of the high level of turbulence that occurs at this site. One sensor was washed downstream during high flows.

In 2009, TDG monitoring was conducted at the above dam site, High Bridge, and Birdland Bay Bridge.

In 2010, monitoring was conducted above the dam, at the High Bridge, below the Dry Channel Dam, and at Birdland Bay Bridge.

Figure 2-1. Map of TDG Monitoring Locations



2.2 Evaluation of Impact of Operational Procedures on TDG

In 2006, 2007, and 2008, a spillway operational procedure was implemented for the purpose of attracting upstream migrating adult salmonids to the right bank of the Main Dam spillway. This operational procedure was a part of a series of studies undertaken to determine the optimal method of providing upstream adult fish passage at the Project. Ultimately, the TAC made a unanimous decision that the preferred approach to fish passage was to construct a full height ladder on the right bank of the Main Dam spillway. With the fish ladder on the right bank, it will be desirable to operate the spillway in such a way as to attract fish to the right bank to the degree possible. However, concerns have been raised that the "fish passage" spillway operational plan may increase TDG.

Therefore, in 2009, the spillway operational procedure was revised to reflect the operations used during the pre-2006 time period to assess if the operation of the spillway has an impact on TDG.

During spring and summer 2010, the fish ladder was under construction at the Main Dam. The spillway was operated to minimize spill at the Main Dam to protect the construction site from large flows. For this reason, the Dry Channel spillway was used as soon as discharge exceeded powerhouse capacity. Spill was not released through the panels on the Main Dam spillway until June 5, when total river discharge exceeded 46,000 cfs. This was an unusual spillway operating procedure, and was unique to this one year during the ladder construction. A TDG monitor was installed below the Dry Channel spillway, but washed out during the high flow and has not been recovered to date. TDG data was successfully recorded at the above dam, High Bridge, and Birdland Bay Bridge sites in 2010.

2.3 Evaluation of Potential Biological Impacts

Electrofishing downstream of Thompson Falls Dam between the Main Dam and the Highway 200 Bridge was conducted during high flow time periods in both 2008 and 2009. This area was chosen for crew safety and because fish in this reach of river have the highest possibilities of showing symptoms of the GBT. Sampling occurred when flows were higher than 50,000 cfs, which is the discharge at which TDG begins to approach 115% of saturation at Birdland Bay Bridge.

Electrofishing was conducted with an 18.5 foot, aluminum hull Wooldridge boat with a gasoline generator and a Smith-Root VVP 15A rectifier using 120-160 volts with 4-6 amps. The waveform setting varied and was dependent on conductivity in the river system, which varies seasonally. Two booms were attached to the hull extending 4 feet past the bow with four dangling electrodes per boom. Shocking crews consisted of the boat driver and two netters. Captured fish were put in a 100 gallon holding tank before being measured (total length). All electrofishing was done during daylight hours. Most fish sampled were within 1 meter of the surface, where potential effects from TDG are greatest.

Examination of fishes (all species) included gills, lateral line, and fins. Fish were examined for bubbles, which can be very fine, or off coloring or fraying or unhealthy changes from normal morphology. Procedures were consistent from year to year, although no written Standard Operating Procedures (SOP) have been developed. If written SOP are needed for future efforts, they will be included in the annual monitoring plan which is prepared by PPL Montana and approved by the TAC.

3.0 Results

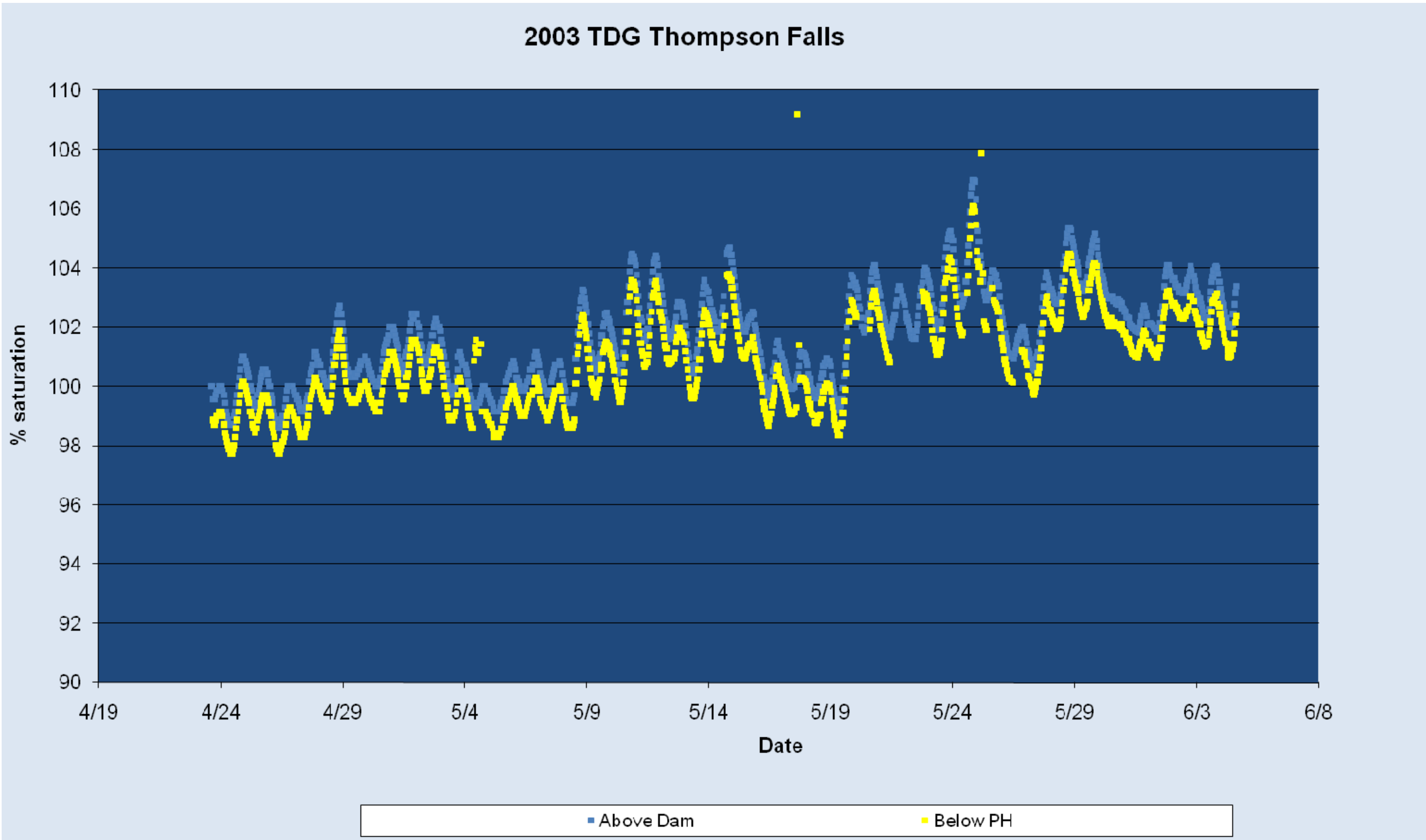
3.1 General Pattern of TDG Levels in the Thompson Falls Project Area

3.1.1 Non-Spill Time Periods

TDG upstream of the Thompson Falls Project, measured in the forebay, is generally between 100-105% of saturation regardless of river flow.

Downstream of the Project, TDG varies with discharge. During non-spill time periods, when total river flow is < 23,000 cfs, all river flow passes through the powerhouse. River flow passing through turbines is stripped of TDG to a slight degree. TDG measurements collected above the Project and below the powerhouse have found that TDG in the powerhouse tailrace is generally 1-2% lower than TDG in the forebay (Figure 3-1)

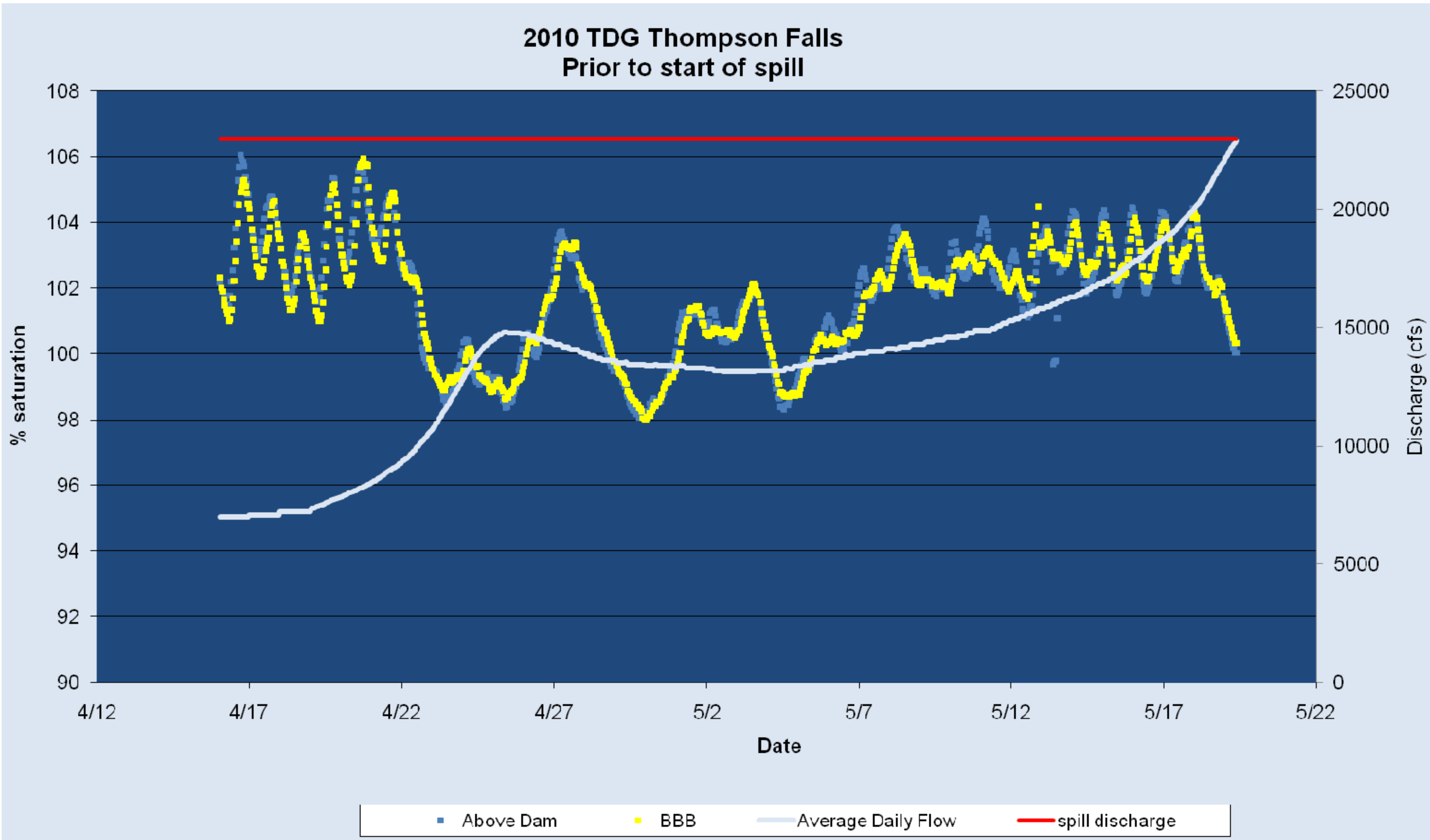
Figure 3-1.



TDG as percent saturation measured upstream of the Thompson Falls Hydroelectric Project (above Dam) and downstream of the Thompson Falls Hydroelectric Project powerhouse (below PH) in 2003.

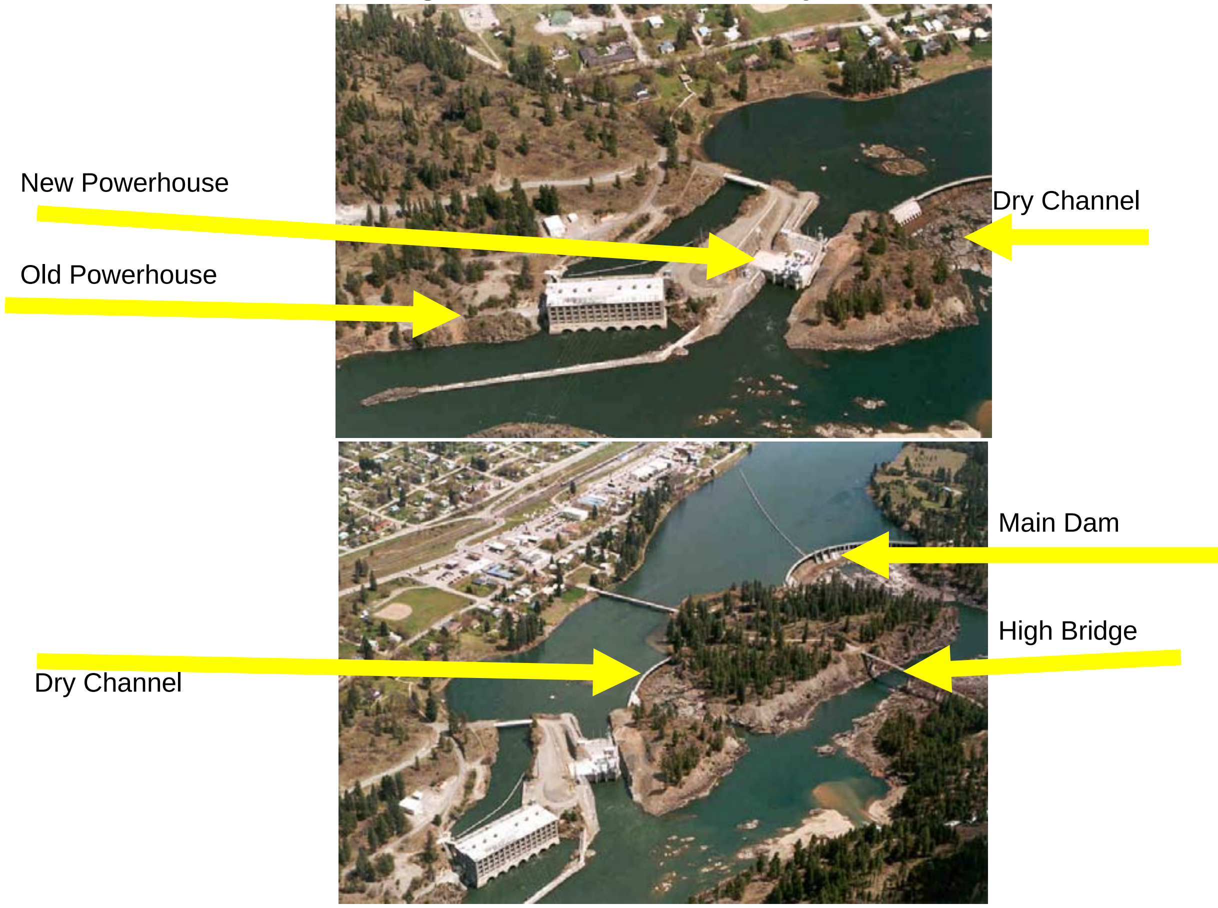
During the non-spill time period, when total river discharge is less than or equal to 23,000 cfs, TDG as measured at the Birdland Bay Bridge is generally equal to or slightly less than the TDG measured in the forebay (above Project site) (Figure 3-2). The Birdland Bay Bridge site is the downstream-most measurement site in the Project area. River water at this site is a mixture of water that has passed through the Thompson Falls Project powerhouses mixed with water coming from upstream. This upstream water has passed through or over the Project spillways and over the falls. Prospect Creek also enters the Clark Fork River downstream of the Main Dam spillway and upstream of Birdland Bay Bridge. Even during non-spill time periods, there is always some water in the channel that flows over the falls, largely as a result of seepage and leakage at the Main Dam (Figure 3-3). As Figure 3-2 shows, during the non-spill time period, the TDG of water leaving the Thompson Falls Project site is essentially the same or slightly less than the TDG of water entering the Thompson Falls Project site.

Figure 3-2.



TDG measured upstream of the Thompson Falls Hydroelectric Project and at the Birdland Bay Bridge (BBB) in early spring 2010, when total river discharge was less than powerhouse capacity.

Figure 3-3. Overview of Project Site.



Note that there is water in the channel downstream of the Main Dam even though no spill is occurring.

3.1.2 Spill Period

When river discharge exceeds powerhouse capacity, flow passes over the spillways, then passes over the natural falls, adding TDG at both points. The levels of TDG in the Clark Fork River at the Project site vary from year to year, depending on the discharge and configuration of spillway panels. Higher flows create higher levels of TDG, up to a point, however, relationship between flow and TDG is non-linear. At the highest levels of discharge, TDG at sites downstream of the Project levels off and remains relatively constant (Figures 3-4 and 3-5).

During peak discharge time periods, TDG exceeds 115% in the Clark Fork River, as measured at the High Bridge (Table 1), which is downstream of the Main Dam but upstream of the powerhouses (Figure 3-5).

TDG dissipates downstream of the High Bridge. In addition, low TDG water from the powerhouses mixes with higher TDG water that has passed over the spillways and falls.

Therefore, TDG is lower at the Birdland Bay Bridge than it is at the High Bridge (Table 1). Water entering Noxon Rapids Reservoir has an average peak TDG of approximately 110-116%, depending on discharge (Figure 3-4). However, there is considerable variability in TDG at higher discharge (Figure 3-5). The range of TDG entering Noxon Rapids Reservoir at discharge in excess of 60,000 is approximately 112-118% (Figure 3-5).

Table 1.

	High Bridge						
	2003	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Percent of year (in hours) TDG > 110%	N/A	5.1	11.8	17.2	7.9	N/A	11
Percent of year (in hours) > TDG 115%	N/A	0.2	4.6	10.5	2.4	N/A	6
Percent of year (in hours)> TDG 120%	N/A	0.0	0.0	4.4	0.0	N/A	0
	BBB						
	2003	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Percent of year (in hours)> TDG 110%	2.6	0.0	4.1	9.8	0.7	14	5
Percent of year (in hours)> TDG 115%	0	0.0	0.0	3.5	0.0	8	0
Percent of year (in hours) > TDG 120%	0	0.0	0.0	0.0	0.0	0	0
Percent of year discharge > 23,000 cfs (spill)	11.7*	17.9	16.1	23.2	22.0	20.4	20.9
Percent of year discharge > 45,000 cfs	0.3	0	3.6	7.7	2.2	14.2	5.6

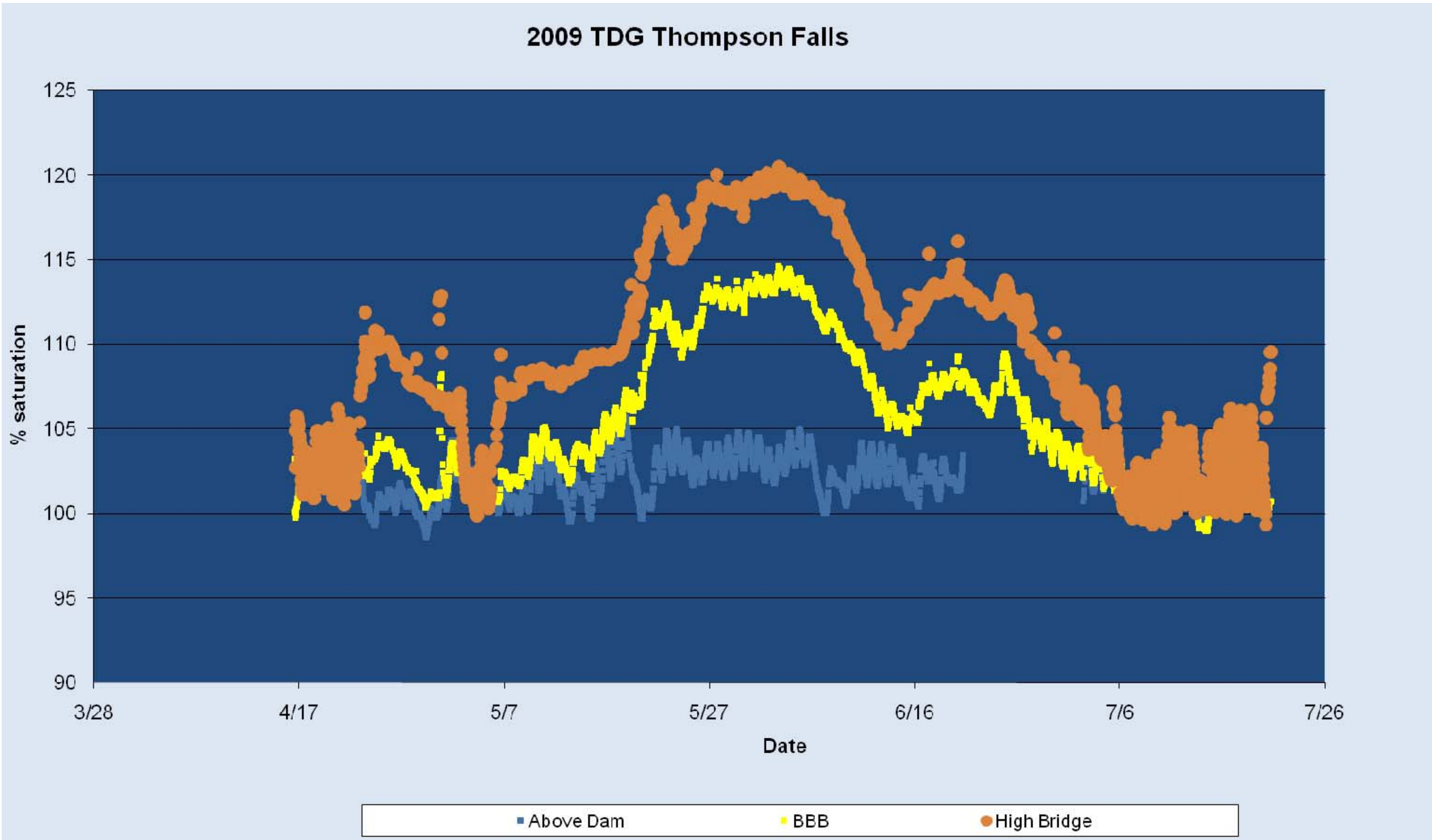
*Incomplete data set (data stopped recording June 4)

Percentage of time when TDG exceeds 110%, 115%, and 120% at the two downstream measuring sites in the Thompson Falls Project tailrace. Percent of time when discharge is greater than 23,000 cfs, the level when spill occurs and the percent of time when discharge > 45,000 cfs.

TDG increases with increasing discharge, up to a point. At the highest levels of discharge, TDG tends to remain constant. Figure 3-5 shows TDG as measured at the Birdland Bay Bridge in 2008, which is the year with the highest peak discharge since the study began. In this year, TDG increased with increases in discharge in a linear pattern until approximately 60,000 cfs. Above that level of discharge, TDG did not continue to increase linearly, but averaged approximately 116%.

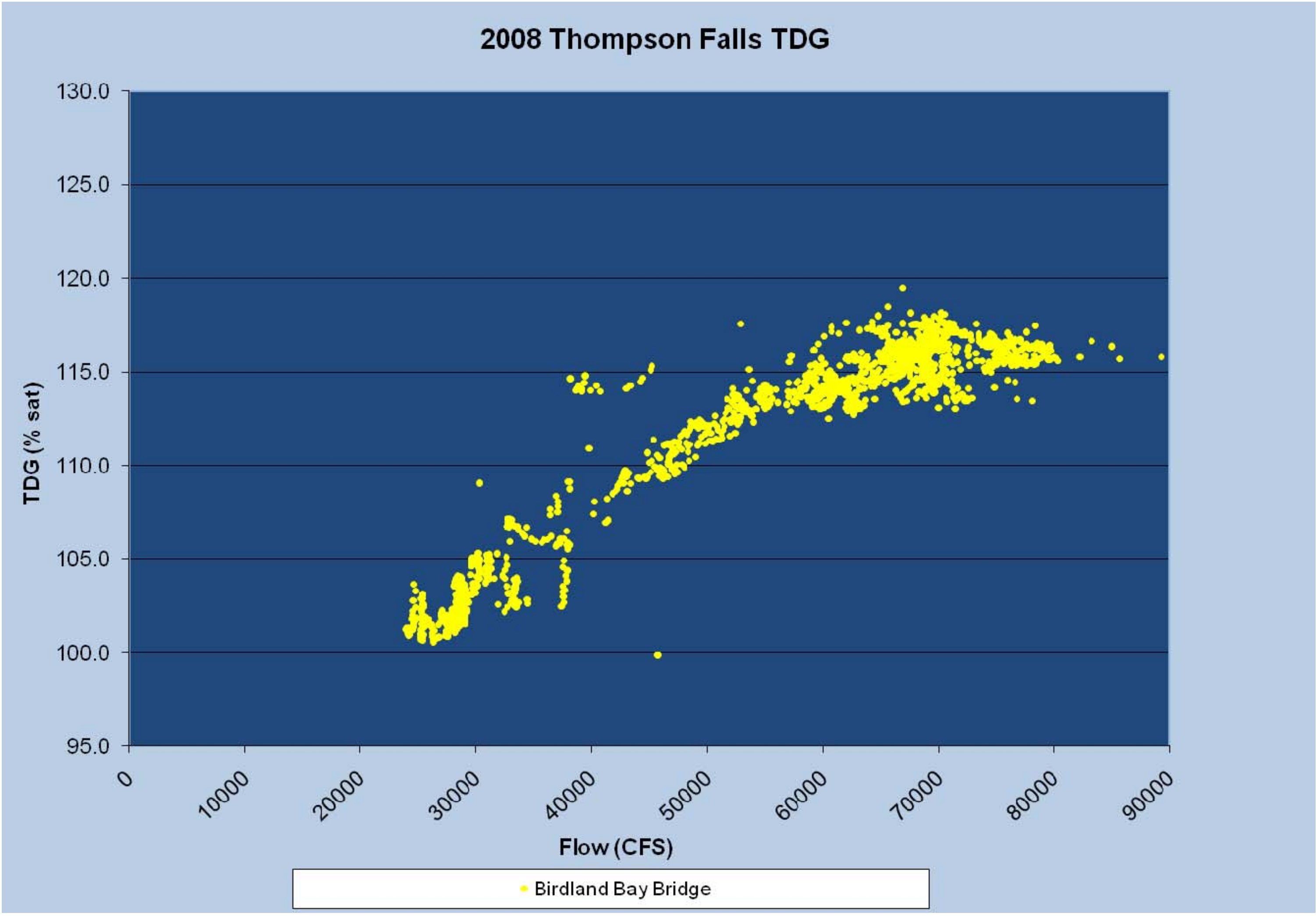
It is apparent that TDG increased with increasing discharge up to about 65,000 cfs. Above that discharge, increasing discharge had little effect on TDG at Birdland Bay Bridge. In 2008, TDG exceeded the 110% water quality standard when total river discharge exceeded 45,000 cfs (Figure 3-5).

Figure 3-4.



TDG measured at the Thompson Falls Hydroelectric Project site upstream of the Project (Above Dam), at the Birdland Bay Bridge, and at the High Bridge in 2009

Figure 3-5.



TDG measured at the Birdland Bay Bridge in 2008, plotted with total discharge in cfs in the Clark Fork River.

A Technical Memorandum prepared by GEI Consultants, Inc. in 2007 (Appendix A) summarized the results of the TDG studies conducted from 2003 to 2007. This memorandum drew the following conclusions:

- For discharge up to 23,000 cfs, all river flow passes through the powerhouses. At this discharge, little or no flow passes over the spillway and falls. Therefore, TDG below the Project is lower at this level of discharge than would have been the case in the pre-Project condition, when all river discharge passed the falls and deep pool immediately downstream.

- For higher river discharges (above 80,000 cfs), spill discharge is high enough that the TDG benefit of passing the first 23,000 cfs through turbines is overridden, and the normal operating conditions will yield higher TDG levels than the pre-Project condition. However, this occurs less than approximately 1% of the time.

- For total river discharges of 23,000-80,000 cfs, there is a *cross-over discharge* below which TDG levels are lower than the pre-Project condition, and above which TDG levels are higher than the pre-Project condition. If that change-over level is 50,000 cfs total river discharge, the TDG levels are lower now than during the pre-Project condition 96% of the time. If that cross-over discharge is 70,000 cfs, normal operating conditions would reduce TDG relative to the pre-Project condition 98% of the time. However, further monitoring will not resolve the magnitude of the cross-over total river discharge, since pre-Project TDG data are not available.

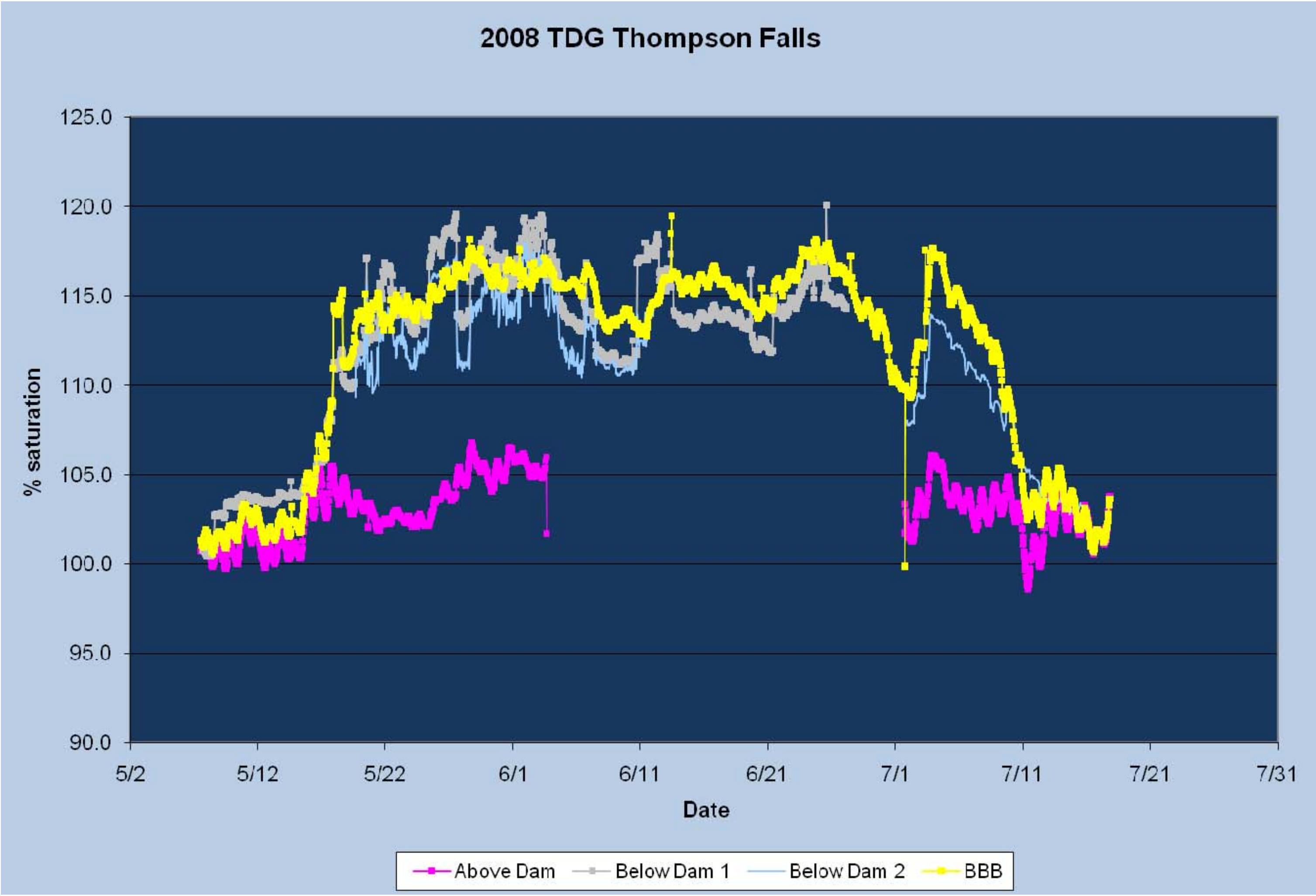
- Gas abatement measures at Thompson Falls, if required by the state or federal government, would not be successful if employed at the spillway structure. Since the TDG uptake zone is the deep pool immediately downstream of the falls, that is where direct structural measures would be required. The primary 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.

Additional monitoring has been conducted since 2007. Results of monitoring conducted in 2008-2010 are detailed in the following sections.

3.2 2008 Total Dissolved Gas Monitoring

In 2008 there were two Hydrolabs installed below the dam: below dam 1 (BD1) and below dam 2 (BD2). Both were installed in the same location on the log sluice (right bank), but one was installed earlier in the spring at a lower elevation. BD2 was installed later, about 5-6 feet higher on the wall. There was no High Bridge Hydrolab this year (2008) but the above dam and Birdland Bay Bridge sites were monitored as in previous years. Both the above dam sensor and the BD2 sensor suffered failures during part of the year; hence there are some missing data points (Figure 3-6). Measurements of TDG at the Main Dam site are problematic as a result of the amount of turbulence at this location. The water is “frothy” and full of bubbles, making accurate measurements of TDG difficult. This is apparent in the scatter in the data points for the two below dam monitors (Figure 3-6). For this reason, the results from these monitors should be considered rough approximations, rather than precise measurements of TDG.

Figure 3-6.

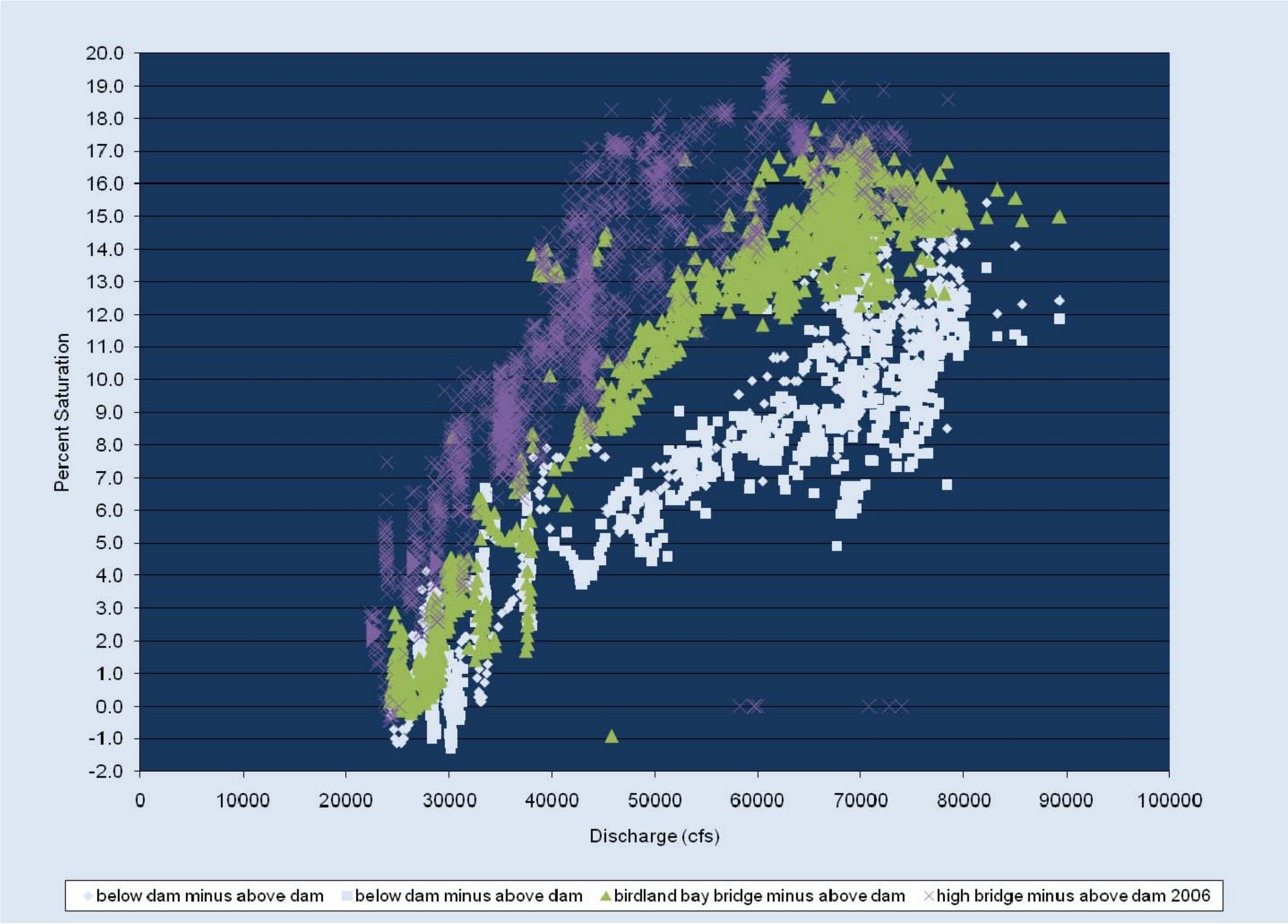


TDG measured above the Thompson Falls Hydroelectric Project (Above Dam), at two sites at the Main Dam log sluice (Below Dam 1 and Below Dam 2), and at Birdland Bay Bridge in 2008.

During 2008, the below dam TDG was about 6-10% higher than the above dam TDG during the spill season (Figure 3-6). This is approximately how much TDG is added to the water as a result of spill over Thompson Falls Dam.

For much of the 2008 runoff season, the Birdland Bay Bridge site had higher TDG than the below dam sites (Figure 3-6). This means that the river must increase in TDG after it passes over the Main Dam. These results lend credence to the theory that TDG is added at the falls below the dam. The amount of TDG added at the falls can be estimated by using data collected at the High Bridge in other years. The runoff in 2006 was similar in magnitude to the runoff in 2008, so 2006 data were selected for use in this analysis. Using 2006 High Bridge TDG data plotted against total discharge, it is apparent that both the Main Dam and the falls add TDG to the Clark Fork River (Figure 3-7).

Figure 3-7.



TDG measured below the dam and at Birdland Bay Bridge in 2008, subtracted from the above dam measurement taken at the same date and time, plotted against total discharge in cfs. High Bridge TDG measured in 2006 is also subtracted from above dam measurements collected at the same date and time.

On Figure 3-7, the difference between TDG measured above the dam and TDG measured at various locations below the dam was determined by subtracting TDG measurements taken below the dam from those taken above the dam at the same date and time. A difference of zero indicates that the below dam measurement and the above dam measurement were the same. A positive number indicates that the below dam measurement was higher than the above dam measurement.

Table 2 presents the mean TDG at differing ranges of total river discharge at the above dam, below dam, High Bridge, and Birdland Bay Bridge locations. Table 3 shows how TDG changes in a downstream direction. A positive number indicates that TDG increased by this amount in comparison to the measurement station located upstream. A negative number indicates that TDG decreased in comparison to the measurement station upstream.

Table 2.

Total Discharge (cfs)	AD Mean	AD Range	BD Mean	BD Range	HB* Mean	HB* Range	BBB Mean	BBB Range
23,000 - 30,000	101.52	99.74-104.77	103.25	100.41-104.80	106.51	101.75- 111.71	102.18	100.57-105.08
30,000 - 40,000	102.74	98.62-105.74	105.56	103.15-111.35	111.69	107.47- 117.01	105.65	102.20-114.80
40,000 - 50,000	103.32	101.24-104.87	108.98	107.23-111.95	116.41	112.38- 121.81	110.63	99.86-115.31
50,000 - 60,000	103.30	101.95-105.10	111.11	108.70-117.12	120.25	116.37- 122.19	113.59	111.30-117.56
60,000 - 70,000	103.58	101.86-106.46	113.74	109.56-120.05	121.62	119.37- 123.58	115.32	112.48-119.49
70,000 - 80,000	104.76	101.71-106.82	115.39	110.43-119.52	120.58	118.67- 121.97	115.99	113.06-118.17
80,000 - 90,000	104.99	103.63-105.75	117.26	114.58-119.06	N/A		115.90	115.59-116.64

Mean TDG at differing range of total river discharge. Data for High Bridge was collected in 2006. Data for other sites collected in 2008. AD = Above Dam, BD = Below Dam and is the mean for BD1 and BD2, HB = High Bridge, BBB = Birdland Bay Bridge.

Table 3.

Discharge (cfs)	BD - AD	HB* - BD	BBB - HB
23,000 - 30,000	1.73	3.26	-4.33
30,000 - 40,000	2.82	6.13	-6.05
40,000 - 50,000	5.66	7.43	-5.77
50,000 - 60,000	7.81	9.14	-6.66
60,000 - 70,000	10.15	7.88	-6.29
70,000 - 80,000	10.63	5.19	-4.59
80,000 - 90,000	12.26	N/A	N/A

Mean TDG as it changes in a downstream direction at varying levels of total river discharge. BD-AD = Below Dam TDG minus Above Dam TDG, HB-BD = High Bridge TDG minus Below Dam TDG, BBB-HB = Birdland Bay Bridge TDG minus High Bridge TDG.

At low levels of spill (23,000 cfs to approximately 30,000 cfs) there is considerable scatter in the estimates of TDG added at the Main Dam (Figure 3-7). However, water passing over the Main Dam at this level of discharge increases in TDG 1.73% on average, with a range of from -1% to +4% in comparison to the above dam TDG. Increasing total discharge results in increasing amounts of TDG added to the water at the Main Dam. At total discharge above 65,000 cfs there is a wide range in scatter in the results (Figure 3-7). At this level of spill, turbulence in the tailrace is extreme and TDG measurements are not necessarily reflecting a stable condition in the water (Figure 3-8). However, based on the data available, at total river discharge in excess of 60,000 cfs the water passing over the Main Dam increases in TDG by approximately 10%.

Downstream of the Main Dam, water passes over the falls where it picks up additional TDG. On Figure 3-7, the difference between the light blue squares and the purple crosses reflect the TDG added by the falls. The amount of TDG added by the falls varies with discharge, with an average of 3.3% added at low levels of discharge (between 23,000 cfs and 30,000 cfs), increasing to approximately 9% at higher levels of discharge (between 50,000 and 60,000 cfs). At the highest discharges measured, the contribution of the falls to total TDG declines. At discharge in excess of 60,000 cfs, the falls are backwatered, and therefore there is less of a plunge and less TDG added to the water (Figure 3-8).

These results support the hypothesis that both the Main Dam and the falls contribute TDG to the Clark Fork River, and that the relative contributions of these two features varies with discharge. At the flows less than 60,000 cfs, the falls appear to contribute more TDG than the Main Dam. However, at the highest levels of flow, the Main Dam contributes more TDG than the falls.

The green triangles on Figure 3-7 depict the TDG at Birdland Bay Bridge in comparison to the above dam level of TDG. As described above, TDG at Birdland Bay Bridge is less than at the High Bridge because of dilution from the water passing through the powerhouses and dissipation of TDG as the river flows downstream.

Figure 3-8. Thompson Falls Main Dam Tailrace.

Photographs of the Thompson Falls Main Dam tailrace, taken June 20, 2006. At this time the estimated total discharge in the Clark Fork River at the Project site was 60,000 cfs. Note the high level of turbulence below the Main Dam in the lower photo. The upper photo shows the falls below the Main Dam backwatered at this level of river flow.

3.3 2009 Total Dissolved Gas Monitoring

3.3.1 Measurements of TDG in the Project Area

Similar to past years, TDG in 2009 was lowest above the Project, highest at the first measurement site below the Project (at the High Bridge), and intermediate at the most downstream site at the Birdland Bay Bridge (Figure 3-2). TDG levels declined downstream of the High Bridge as a result of mixing with river flow coming through the powerhouse and, potentially, some degassing as the river moves downstream.

3.3.2 Spillway Panel Operations

In 2006, PPL Montana implemented a specialized spillway operation schedule in an effort to determine if fish can be attracted to the right bank of the Main Dam. This “fish” spillway schedule, depicted in Figure 3-9, was implemented during spill operations in 2006, 2007, and 2008. Data collected on TDG during this period indicated that TDG levels may be have been slightly higher during the years when the “fish” spill schedule was implemented than during previous years when the “non-fish” schedule, depicted in Figure 3-10, was in place.

In order to test this theory, operations of the spillway were returned to the “non-fish” schedule during 2009.

Photos 1 and 2 show the Main Dam spillway, with the spill bays numbered. Each spill bay contains 6 spill panels. When opened, the panels release 235 cfs at full pool. Figures 3-9 and 3-10 display the “fish” and the “non-fish” schedule spillway opening schedule.

A visual comparison of the “fish” *vs.* the “non-fish” operating schedule indicates that TDG levels are higher by approximately 2-3% under the “fish” operating schedule, when total flow is in excess of approximately 45,000 cfs (Figures 3-11 and 3-12).

Photo 1. The right and center of the Main Dam, with bays numbered.

Photo 2. The left bank of the Main Dam at the Thompson Falls Project, with the spillway bays numbered.

Figure 3-9. Operational Plan for the Main Dam Spillway.

Thompson Falls Main Dam Spillway -"Fish" Spill Schedule

BAY NUMBER																																				**Lift Gates**	**Total Flow (cfs)**
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
		1	1	1																																3	23,705
		1	1	1																												6	6	6	6	27	29,345
		1	1	1													6	6	6	6												6	6	6	6	51	34,985
		1	1	1					6	6							6	6	6	6												6	6	6	6	63	37,805
		1	1	1					6	6							6	6	6	6	6	6										6	6	6	6	75	40,625
		1	1	1					6	6							6	6	6	6	6	6								6	6	6	6	6	6	87	43,445
		1	1	1			6	6	6	6							6	6	6	6	6	6								6	6	6	6	6	6	99	46,265
		1	1	1			6	6	6	6							6	6	6	6	6	6					6	6	6	6	6	6	6	6	6	117	50,495
		1	1	1	6	6	6	6	6	6							6	6	6	6	6	6					6	6	6	6	6	6	6	6	6	129	53,315
		1	1	1	6	6	6	6	6	6							6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	153	58,955
		6	6	6	6	6	6	6	6	6							6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	168	62,480
6	6	6	6	6	6	6	6	6	6	6	6						6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	186	66,710
DRY CHANNEL SPILLWAY (12 Bays)																																					
6	6	6	6	6	6	6	6	6	6	6	6																									72	83,630
Radial Gates (Bays 16 and 17)																																					
													Both - Full-Open - 11,000 cfs per bay																								105,630

Operational plan for the Main Dam spillway when the “fish” spill schedule is in place. Each lift bay contains 6 panels. Opening a panel releases ~235 cfs. As river flow increases, panels are opened to attract fish to the right bank and detract fish from going to the left bank.

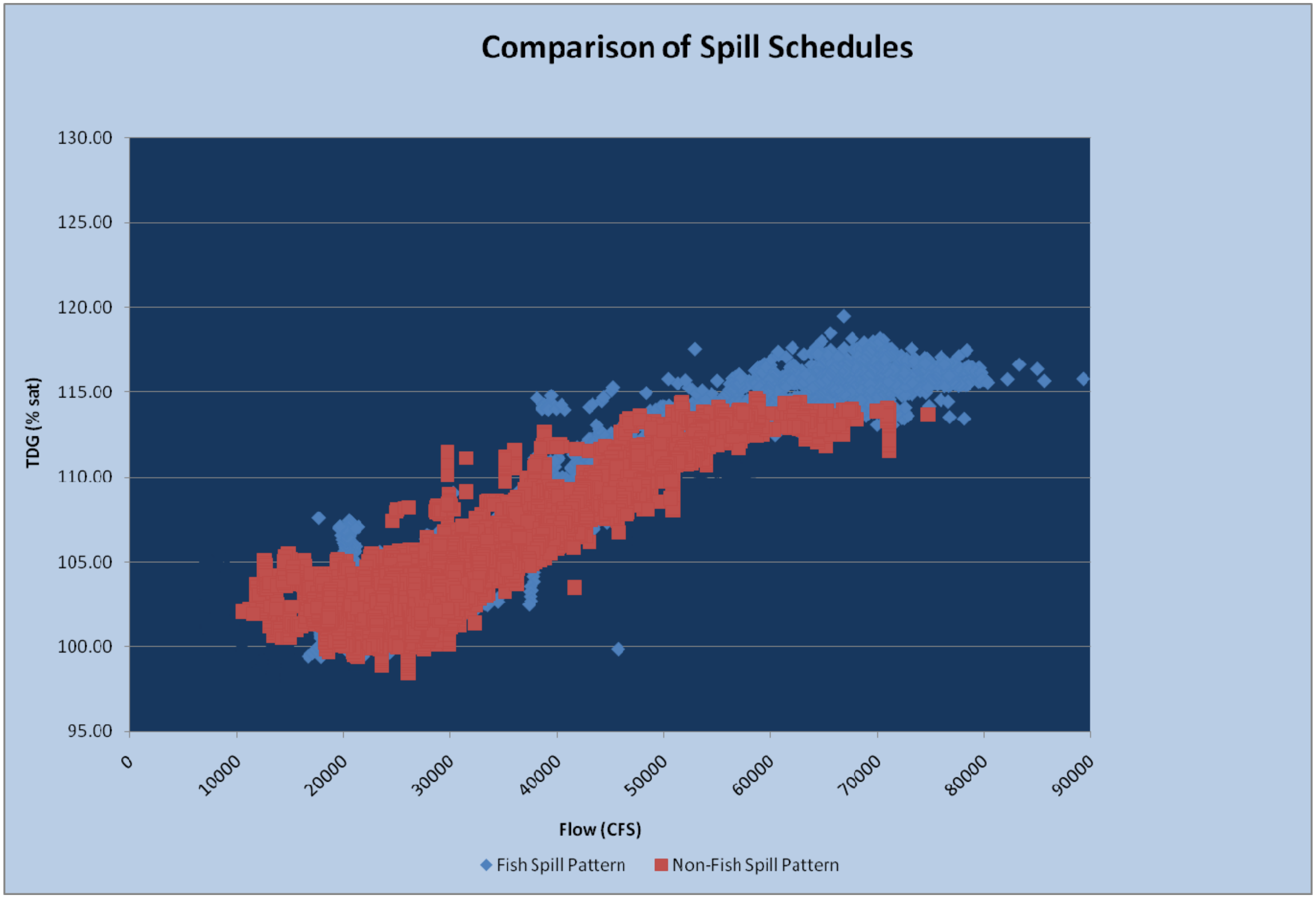
Figure 3-10. Operational Plan for the Main Dam Spillway.

Thompson Falls Main Dam Spillway - Baseline (non-fish) Spill Schedule

BAY NUMBER																																				**Lift Gates**	**Total Flow (cfs)**
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
																												6	6	6	6	6	6	6	6	48	34,280
										6	6																	6	6	6	6	6	6	6	6	60	37,100
										6	6														6	6	6	6	6	6	6	6	6	6	6	78	41,330
							6	6	6	6	6														6	6	6	6	6	6	6	6	6	6	6	96	45,560
							6	6	6	6	6											6	6	6	6	6	6	6	6	6	6	6	6	6	6	114	49,790
				6	6	6	6	6	6	6	6											6	6	6	6	6	6	6	6	6	6	6	6	6	6	132	54,020
				6	6	6	6	6	6	6	6								6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	150	58,250
6	6	6	6	6	6	6	6	6	6	6	6								6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	174	63,890
6	6	6	6	6	6	6	6	6	6	6	6						6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	186	66,710
DRY CHANNEL SPILLWAY (12 Bays)																																					
6	6	6	6	6	6	6	6	6	6	6	6																									72	83,630
Radial Gates (Bays 16 and 17)																																					
													Both - Full-Open - 11,000 cfs per bay																								105,630

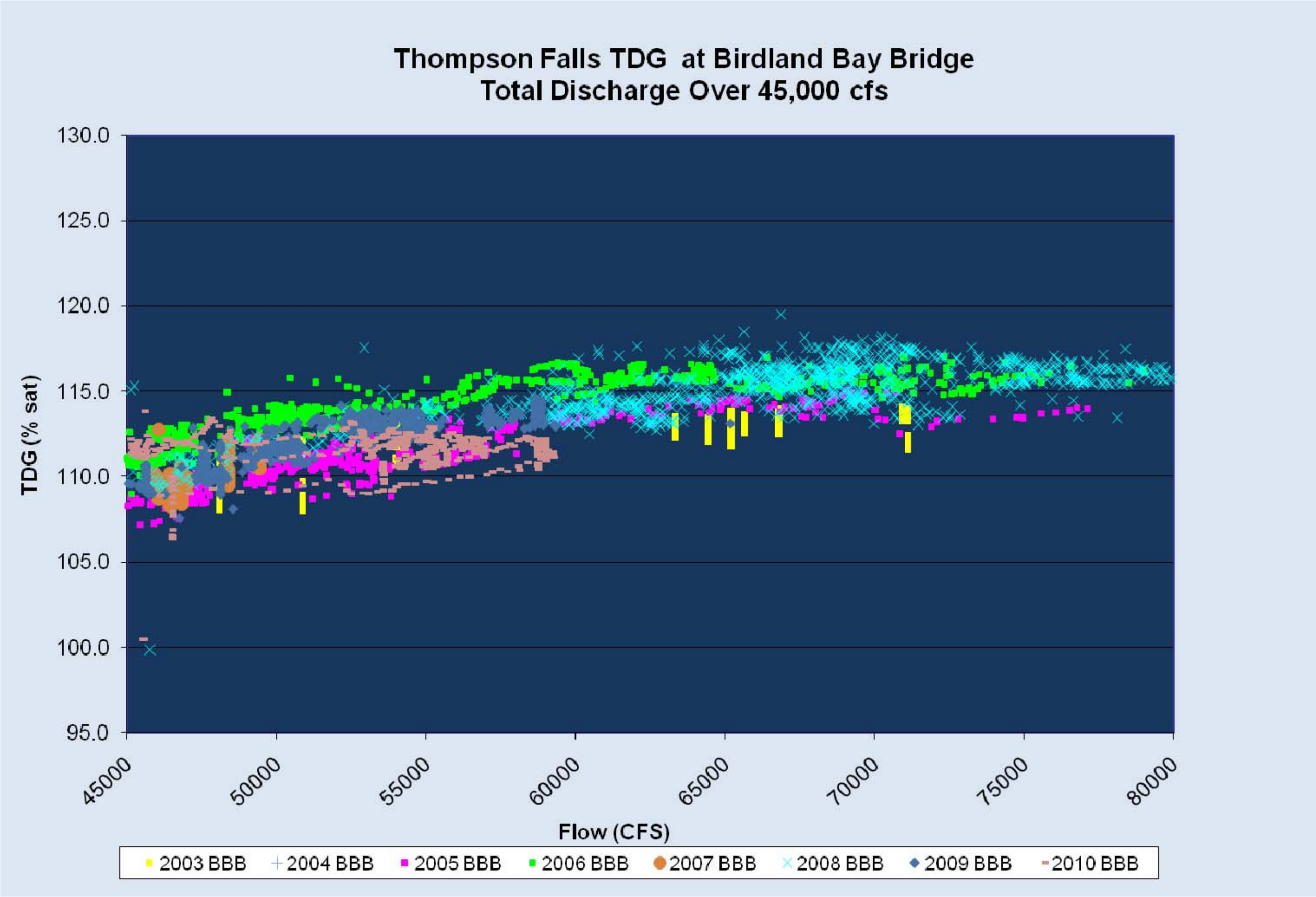
Operational plan for the Main Dam spillway when the “non-fish” spill schedule is in place. Each lift bay contains 6 panels. Opening a panel releases ~235 cfs. As river flow increases, panels are opened balance flow between the right and left bank.

Figure 3-11.



TDG in percent saturation at discharge (cfs) in 2003, 2004, 2005, 2009, in red, the “non-fish” spill schedule. Blue is TDG at discharge in 2006, 2007, and 2008, the “fish” spill schedule. TDG measured at the Birdland Bay Bridge.

Figure 3-12.



TDG as measured at the Birdland Bay Bridge, in all years. Showing discharge between 45,000 cfs and 80,000 cfs. “Fish” spill schedule was used during 2006, 2007, and 2008. The “Non-fish” schedule was used during 2003, 2004, 2005, and 2009. 2010 was unique because of the constraints of construction of the fish ladder and the Dry Channel spillway was used first.

In order to more thoroughly investigate the issue, PPL Montana compared the percentage TDG at various levels of total flow (Table 4). These data seem to confirm that TDG levels are higher than average during the years when the “fish” spillway schedule was implemented when total flow exceeds 40,000 cfs, but not at lower levels of flow. However, it is difficult to draw firm conclusions because data are limited. In some years (2004 and 2007), peak discharge did not exceed 50,000 cfs. Therefore, there are only 2 years when the “fish” spill schedule was implemented and peak flow exceeded 70,000 cfs. It should also be noted that 2006 and 2008 were years with high peak flow. The apparent higher levels of TDG during the “fish” operating years may actually be a result of the higher runoff.

Table 4.

Total Flow	2003	2004	2005	2006	2007	2008	2009	2010	Average
<23,000	N/A	102.75	103.69	99.45	103.11	N/A	101.58	101.64	102.31
>23,000, <30,000	102.14	103.55	103.57	103.56	102.46	102.22	102.59	101.98	102.81
>30,000, <40,000	104.75	105.05	107.06	106.71	105.22	105.65	105.15	106.58	105.73
>40,000, <50,000	109.46	107.49	110.41	110.62	109.05	110.63	109.16	110.93	109.94
>50,000, <60,000	111.01	N/A	112.68	114.34	N/A	114.92	112.98	111.61	113.62
>60,000, <70,000	112.92	N/A	114.15	115.74	N/A	115.99	113.11	N/A	115.21
>70,000, <80,000	113.17	N/A	113.99	115.68	N/A	115.90	N/A	N/A	114.77

Mean TDG, measured at the Birdland Bay Bridge, at various levels of total flow, by year. The “Fish” spillway operating procedures were implemented in 2006, 2007, and 2008 (blue). The non-fish spillway operations were implemented in 2003, 2004, 2005, and 2009 (green). Spillway operations in 2010 were dictated by the needs of the fish ladder construction, and the Dry Channel Dam spillway was used more extensively than in any other year.

3.3.3 Radial Gate Operation

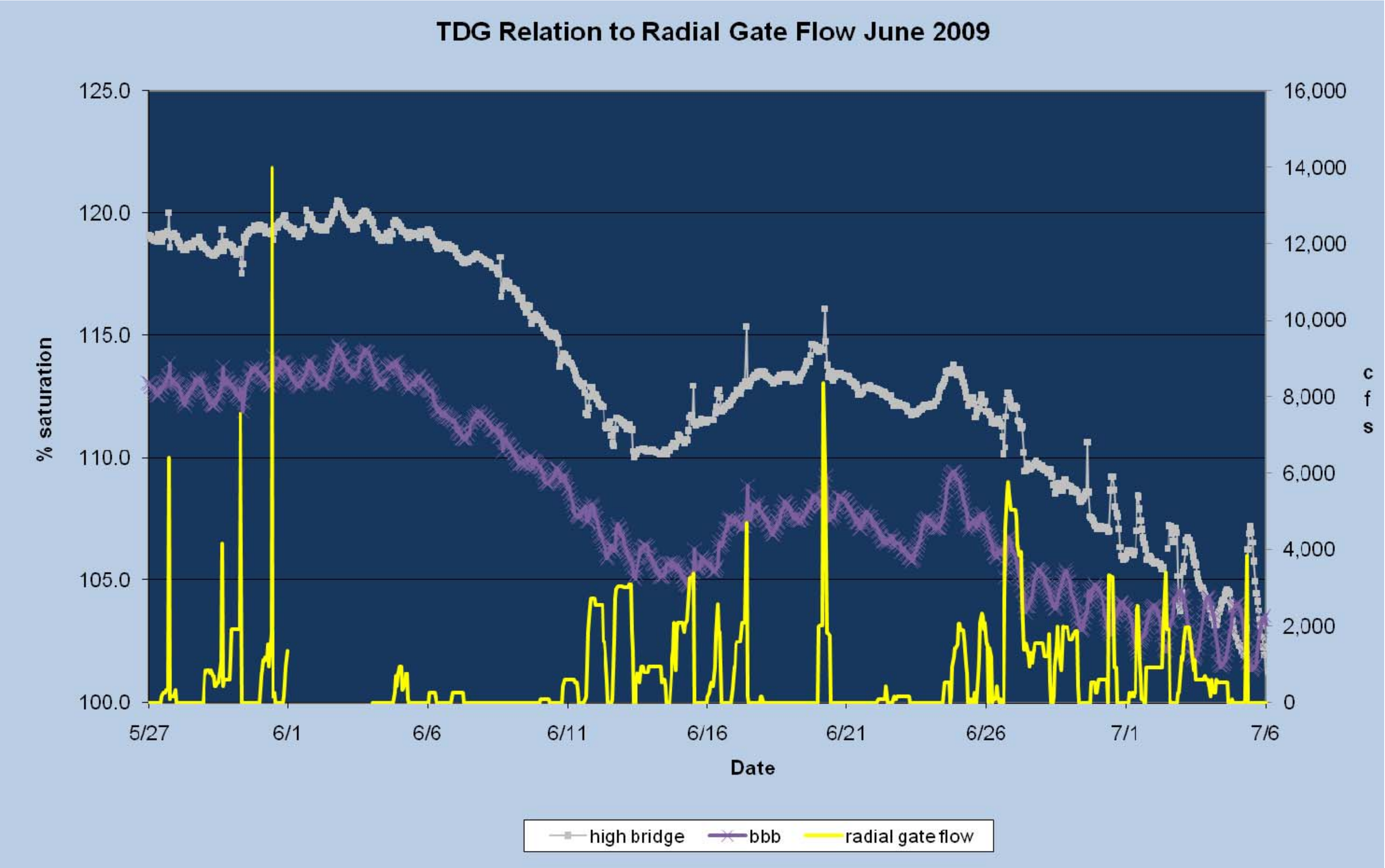
Main Dam spillway gates 16 and 17 are radial gates which are controlled by computer to open at a full reservoir elevation set point. The set point is approximately elevation 2,396 feet during the spring runoff.

Radial gate operation is necessary for dam structural integrity and reservoir level control. Radial gate automation allows water to be spilled safely when flow exceeds the dam spill capacity. Dam spill capacity changes with the number of panels removed from the top of the dam. As flow changes during the spring freshet, spill panels are removed and inserted to maintain spill capacity approximately equal to inflow. The radial gates fine-tune the dam spill capacity for short-term changes in flow. All spill changes are made to maintain a stable reservoir level.

When the radial gates open, a surge of water is released. As shown on Figure 3-13, this seems to create a momentary increase in TDG downstream, most noticeable at the High

Bridge station. Small openings of the radial gates do not appear to affect TDG downstream. When spikes in TDG occur simultaneously with radial gate opening, the spike is generally about 1-2%, and is generally detected for 15 to 30 minutes before declining to previous levels.

Figure 3-13.



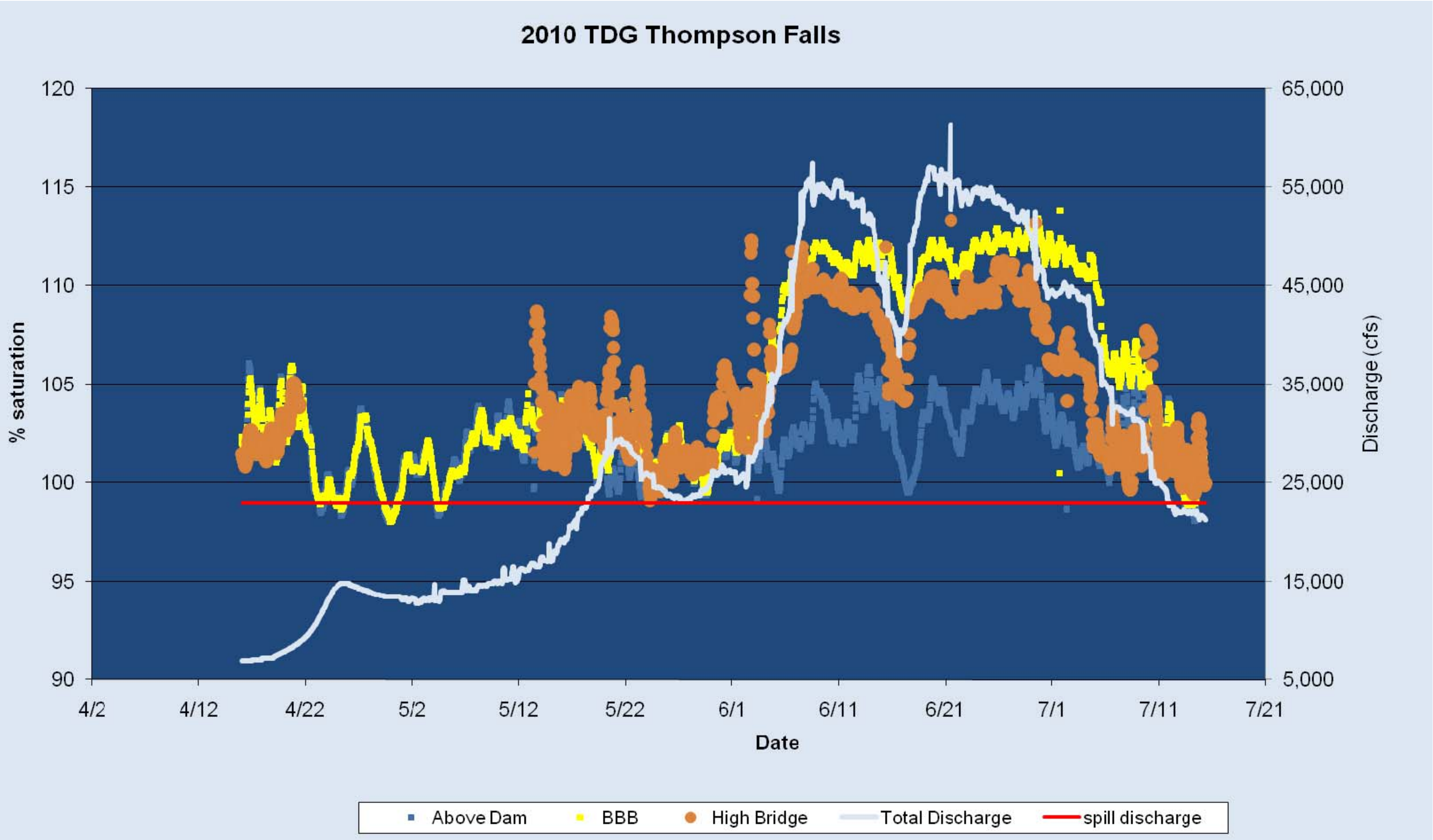
Discharge (cfs) from the Main Dam radial gates in June 2009. TDG is also shown, as measured at the High Bridge and also at the Birdland Bay Bridge at the same date and time.

3.4 2010 Total Dissolved Gas Monitoring

In 2010, the fish ladder at the Main Dam was under construction during the spring runoff period. Because there was construction equipment on site at the Main Dam, it was a priority to minimize spill at the Main Dam. For this reason, the Dry Channel spillway was used first to handle total river discharge in excess of powerhouse capacity. Normally, the Dry Channel spillway is only used in high flow years, after the Main Dam spillway has been fully opened. TDG monitoring was conducted upstream of the Project, in the Dry Channel, at the High Bridge, and at the Birdland Bay Bridge. The Dry Channel sensor washed downstream in the high flows and has not yet been recovered.

Figure 3-14. TDG at the Thompson Falls Hydropower Project in 2010.

BBB = Birdland Bay Bridge

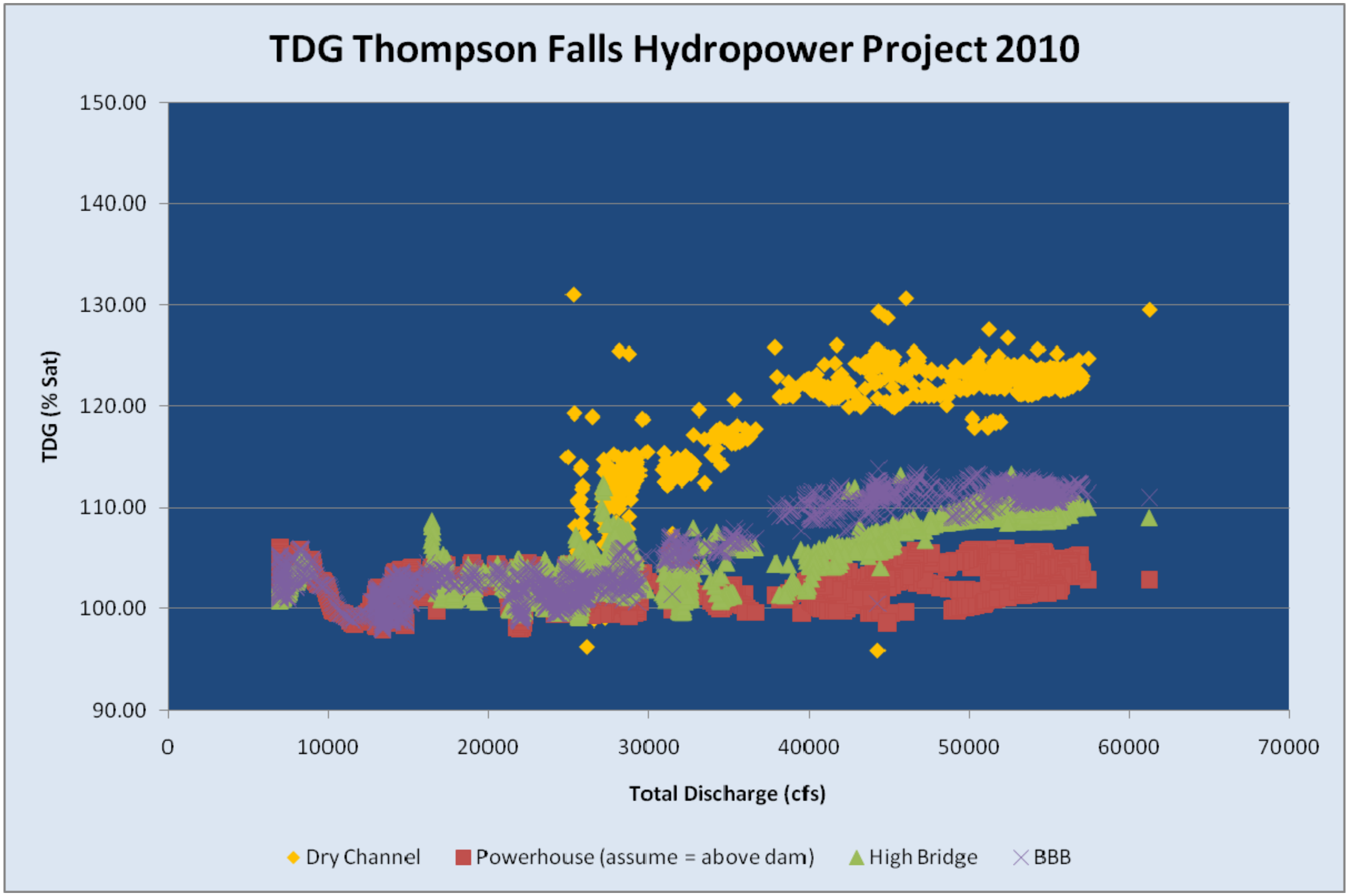


The High Bridge monitoring site collects data on TDG in the Clark Fork River below the Main Dam, but is upstream of the confluence with the Dry Channel. As a result, TDG monitored at the High Bridge was lower in 2010 than in previous years, because flow over the Main Dam was lower in 2010 than in previous years. This is the only year when TDG levels at the High Bridge were lower than at the Birdland Bay Bridge. In order for TDG to be higher at the Birdland Bay Bridge than at the High Bridge, the Dry Channel must be the source of the additional TDG.

The quantity of TDG added to the river at the Dry Channel cannot be directly assessed until the Dry Channel sensor is recovered. However, it possible to calculate the quantity of TDG added at the Dry Channel Dam using a mass balance approach because the discharge and TDG level is known at the other flow pathways (High Bridge, Above Dam, and Birdland Bay Bridge). In making these calculations it was assumed that the TDG in water passing through the powerhouse was equal to the TDG entering the project site as measured at the above dam location. Total river discharge and discharge through the powerhouse were measured by PPL Montana on an hourly basis. Discharge over the Main Dam and Dry Channel Dam was calculated based on records kept by PPL Montana project operators of the number of bays and panels that were opened on the spillways. The Main Dam spillway was assumed to pass 235 cfs for each panel that was opened.

The results of these calculations of Dry Channel TDG are depicted in Figure 3-15, along with TDG levels at the Birdland Bay Bridge, High Bridge, and powerhouse.

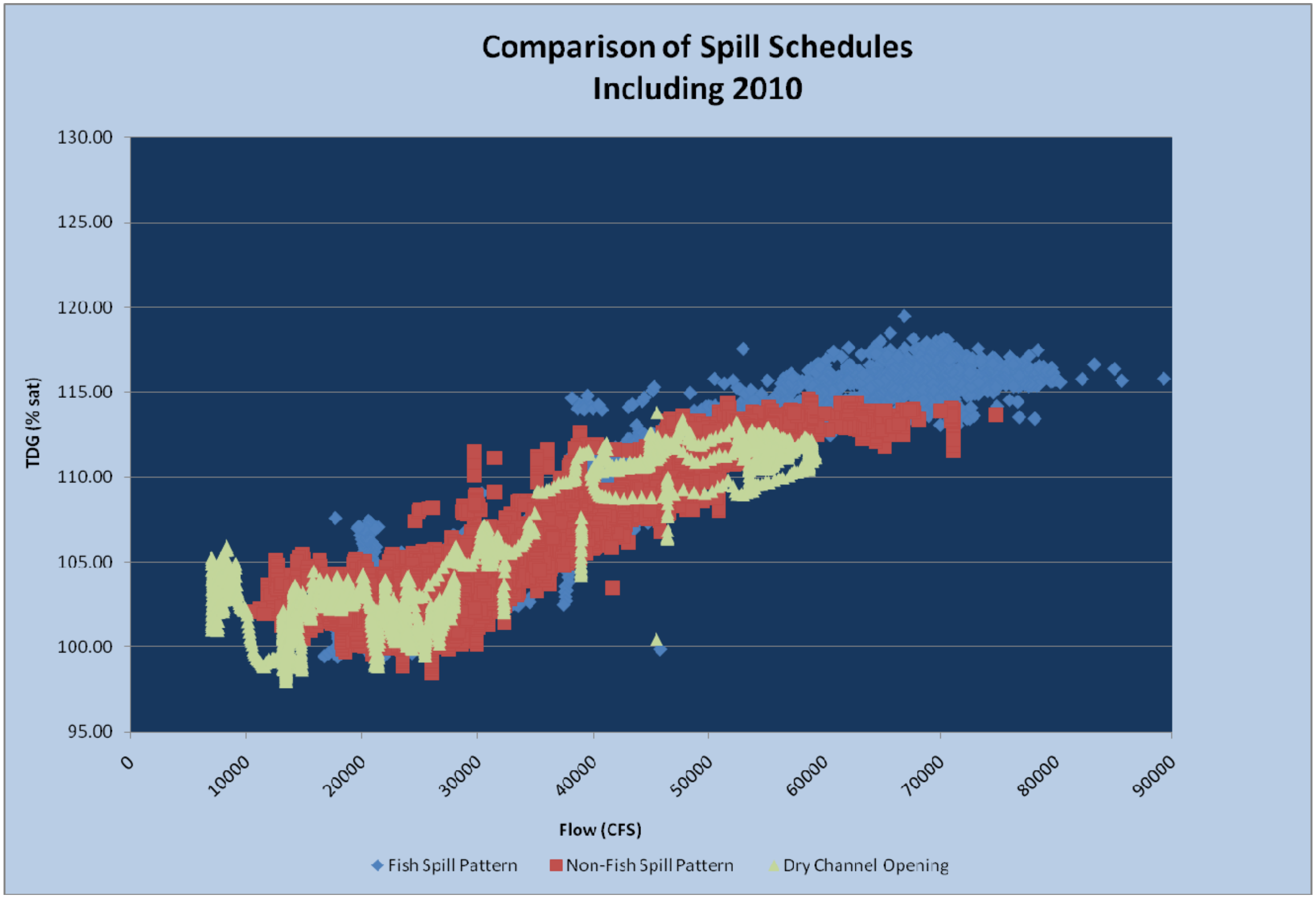
Figure 3-15. TDG at Thompson Falls Hydroelectric Project in 2010. TDG at the Dry Channel Spillway and powerhouse were estimated based on calculations described in the text.



It is clear that TDG was added by passing water over the Dry Channel spillway. Calculated TDG levels at the Dry Channel ranged from approximately 115% when total river discharge was about 27,000 cfs to approximately 123% when total river discharge was in excess of 40,000 cfs.

In order to assess the implications of this spillway operating scheme on TDG at the Birdland Bay Bridge, a comparison was made of TDG at Birdland Bay Bridge over the years of study (Figure 3-16). Opening the Dry Channel spillway first resulted in TDG levels at the Birdland Bay Bridge site that were comparable to previous years (Table 4). Runoff in 2010 was relatively low, so there are no data for flows in excess of 60,000 cfs total discharge, and relatively few data points for flows between 50,000 cfs and 60,000 cfs. This one year's experience provides a limited data set to evaluate the potential impacts of using the Dry Channel Spillway early in the spill season.

Figure 3-16



TDG in percent saturation at discharge (cfs) in 2003, 2004, 2005, 2009, in red, the "non-fish" spill schedule. Blue is TDG at discharge in 2006, 2007, and 2008, the "fish" spill schedule. Green is TDG during 2010, when the Dry Channel spillway was opened first. TDG measured at the Birdland Bay Bridge.

Changing the spillway operating plan to use the Dry Channel Spillway first does not appear to have had a significant impact on the amount of TDG measured downstream of the project site at the Birdland Bay Bridge, at least over the range of flows experienced during 2010. See also Table 4 for a calculation of the mean TDG at varying levels of total river discharge over the study period for a comparison of 2010 TDG levels with the long term average.

However, the Dry Channel Spillway is further downstream than the Main Dam Spillway. Therefore, using the Dry Channel Spillway reduces TDG in the reach of river between the Main Dam Spillway and the Dry Channel Spillway, a distance of approximately 700 m. Water passing over the Dry Channel Spillway mixes with water passing through the new powerhouse approximately 200 m downstream. Therefore, only 200 m of river is exposed to the undiluted levels of TDG passed over the Dry Channel Dam when the Dry Channel Dam is used to pass spill.

The impact of using the Dry Channel Spillway as the initial route to pass spill on fish passage at the newly constructed fish ladder at the Main Dam is not known at this time. Some questions to be examined are: would migrating fish be distracted by high flows from the Dry Channel Dam? Would this detrimentally affect their ability to locate the fish ladder at the Main Dam? In addition, when high flows are passed over the Dry Channel Dam, high velocity water crosses the Clark Fork River, potentially creating a velocity barrier to migratory fish (Figure 3-17).

Therefore, the relatively minor benefits of passing spill at the Dry Channel should be weighed against the potential detrimental impact on fish passage. This is an area that could be studied in future years.

Figure 3-17. Three photos taken during 2010, with water passing through the Dry Channel. Photos were taken July 2, 2010 when all 12 bays were pulled out on the Dry Channel Dam and total flow was about 45,000 cfs. The second photo shows the current from the Dry Channel Dam shooting across the main river channel to hit the far bank near where Prospect Creek empties into the Clark Fork.

3.5 Evaluation of Gas Bubble Trauma in Fish

Dissolved gas super-saturation can cause a variety of physiological symptoms known as gas bubble trauma (GBT), which can be harmful or fatal to fish and other aquatic organisms. In 2008 and 2009, PPL Montana and FWP captured fish during high flow and visually examined fish for signs of GBT.

Fish were sampled via electrofishing and evaluated for GBT six times between May 19 and June 23, 2008 and twice in 2009 (on May 28 and June 4). Electrofishing was conducted via boat using methods described in the 2009 Annual Report for the Fish Passage Project. Fish were sampled downstream of Thompson Falls Dam and upstream of the Highway 200 Bridge. River flows during fish sampling in 2008 varied from 55,197 cfs to 76,889 cfs. . River flows during fish sampling in 2009 varied from 54,880 cfs on May 28 to 57,154 cfs on June 4. Fish were captured and visually inspected for signs of GBT before being released. The gills, lateral line, dorsal fin, and caudal fin were visually examined for blistering, bubbling, boils, or discoloration of the gills.

In 2008 a total of 220 fish representing 16 species were collected between May and June 2008. Fish collected included one bull trout (*Salvelinus confluentus*), four westslope cutthroat trout (*Oncorhynchus clarki lewisi*), 13 brown trout (*Salmo trutta*), 52 rainbow trout (*Oncorhynchus mykiss*), one introgressed westslope cutthroat - rainbow trout, 29 mountain whitefish (*Prosopium williamsoni*), nine northern pikeminnow (*Ptychocheilus oregonensis*), 35 peamouth (*Mylocheilus caurinus*), one kokanee (*Oncorhynchus nerka*), two largemouth bass (*Micropterus salmoides*), 16 smallmouth bass (*Micropterus dolomieu*), two yellow perch (*Perca flavescens*), three northern pike (*Esox lucius*), 13 lake whitefish (*Coregonus clupeaformis*), 36 largescale suckers (*Catostomus macrocheilus)*, and three longnose suckers (*Catostomus catostomus*).

Of the 220 fish, one lake whitefish sampled on June 3, displayed visual signs of GBT. The signs documented included visual markings on the caudal fin, pelvic fins, dorsal fin, and anal fin, as well as signs of hemorrhaging and discoloration of the gills (darker than normal).

In 2009 a total of 276 fish representing 14 species were examined for visual signs of GBT. The gills, lateral line, dorsal fin, and caudal fin were visually examined for blistering, bubbling, boils, or discoloration of the gills. After visual examination of all 276 fish, there were no visual indications of any fish exhibiting GBT symptoms. Species totals were: 146 largescale sucker, 17 rainbow trout, four lake trout, six lake whitefish, three brown trout, 10 mountain whitefish, 49 smallmouth bass, six longnose sucker, 13 northern pikeminnow, 15 peamouth, four westslope cutthroat trout, one northern pike, one westslope cutthroat X rainbow trout hybrid, one sculpin (*Cottus* sp.).

In the Thompson Falls Project tailrace TDG exceeds 110% in most, but not all, years as measured at the Birdland Bay Bridge site. TDG is rarely in excess of 115% at the Birdland Bay Bridge site. This only occurred in 2006 and 2008. During the six years of data collection, the percentage of time when TDG exceeded 120% was very low, only during 2006 and only at the High Bridge Site. TDG has never exceeded 120% at the Birdland Bay Bridge site. Although the Clark Fork River exceeds the water quality standard of 110% saturation at the High Bridge and Birdland Bay Bridge sites during peak flow seasons in most years, no apparent impact on fishes in the Thompson Falls tailrace has been detected.

The risk to aquatic life from elevated levels of TDG increases with dosage and exposure (Weitkamp and Katz 1980). In addition, the level of TDG that salmonids can tolerate varies depending on species, body size, general physical condition, swimming depth and water temperature (Johnson et al 2005). In their 1980 review of dissolved gas supersaturation literature, Weitkamp and Katz concluded that a dramatic change occurs in both the number of deaths and the time to death at approximately 120% to 125% TDG in shallow water (1 m or less). At gas pressures below this general level, a low incidence of gas bubble disease will be found in juvenile salmonids, and deaths will occur at a low rate. Above 120 - 125% TDG, mortality due to GBD increases dramatically. More recent studies confirm these conclusions in natural waters. Weitkamp et al. 2003 evaluated the incidence of GBT below Cabinet Gorge Dam on the Clark Fork River and found that continuous supersaturation exceeding about 125–130% of saturation for prolonged periods produced GBT in at least some fish in the lower Clark Fork River. However, intermittent exposure to 120–130% TDG produced

GBT signs in a very small number of largescale suckers and yellow bullhead. Backman and Evans (2002) examined 4,667 adult chinook salmon *Oncorhynchus tshawytscha*, 1,878 sockeye salmon *O. nerka*, and 1,431 steelhead *O. mykiss* at Bonneville Dam for incidences of GBT at Bonneville Dam on the Columbia River. They found GBT symptoms were uncommon (<0.5%) among all species when TDG remained below 125%. The severity of GBT increased as TDG increased, but most symptoms were minor. Severe symptoms were observed only when TDG exceeded 126%

Fish depth plays a crucial role in the expression of GBT because hydrostatic pressure has a strong influence on the TDG exposure to individual fish. Each meter of depth exerts pressure that increases the solubility of dissolved gas to compensate for 10% of saturation. That is, a fish at 1 meter depth is exposed to 10% lower TDG than it would be exposed to if swimming at the surface. This may explain why so few fish are found with GBT when TDG is less than 120% saturation. Johnson et al (2005) found that adult spring and summer Chinook salmon spent a majority of the time at depths that would have provided adequate hydrostatic compensation for average conditions in the Columbia River. Weitkamp et al. 2003 also found salmonids in the Clark Fork River spent enough time at depth to reduce the incidence of GBT.

4.0 Recommendations

PPL Montana's plan, pending operational practicalities, will be to work toward a dual mode of spill control starting in 2011. Between 23,000 cfs and 45,000 cfs, the priority will be fish attraction to ladder. The "fish" spill schedule will be implemented and refined for the fish ladder. A new mode - TDG abatement will be implemented at discharge in excess of 45,000 cfs. The best possible TDG abatement scheme will be determined through experimentation. However, initially PPL Montana will use the "non-fish" spillway operating plan.

Specifically, the spillway panels will be opened in this order:

1. Remove three slide panels for fish attractant. Panels: 4, 8, and 12
2. Pull out eight bays of slide panels, Bays: 29-36, on the far side of the Main Dam
3. Pull out two bays of slide panels, Bays: 10 and 11
4. Pull out two bays of slide panels, Bays: 27 and 28
5. Pull out two bays of slide panels, Bays: 8 and 9
6. Pull out two bays of slide panels, Bays: 25 and 26
7. Pull out two bays of slide panels, Bays: 6 and 7
8. Pull out two bays of slide panels, Bays: 23 and 24
9. Pull out two bays of slide panels, Bays: 4 and 5
10. Pull out three bays of slide panels, Bays: 20, 21, and 22
11. Pull out two bays of slide panels, Bays: 2 and 3
12. Pull out two bays of slide panels, Bays: 18 and 19
13. Pull out the last remaining bay of slide panels, Bay: 1

Next, start to pull the Dry Channel Dam.

As changing conditions like weather, runoff and operational/maintenance demands pose different concerns, changes in this schedule may occur.

This schedule is illustrated in Figure 3-16. This schedule is tentative, pending review by the TAC and Thompson Falls Project operators. It is based on the assumption that once a panel is opened, it will not be closed again unless discharge is declining.

The operational mode will switch back to fish attraction when flows recede to allow fish to use ladder.

During radio telemetry studies of fish behavior at the Main Dam, fish left the Main Dam tailrace when discharge exceeded 40,000 cfs (Figure 3-16). Therefore, PPL Montana does not anticipate that making TDG abatement a priority during the spring freshet, when discharge exceeds 45,000 cfs, will have a significant impact on the efficiency of the fish ladder. However, experiments will continue in coming years to confirm this.

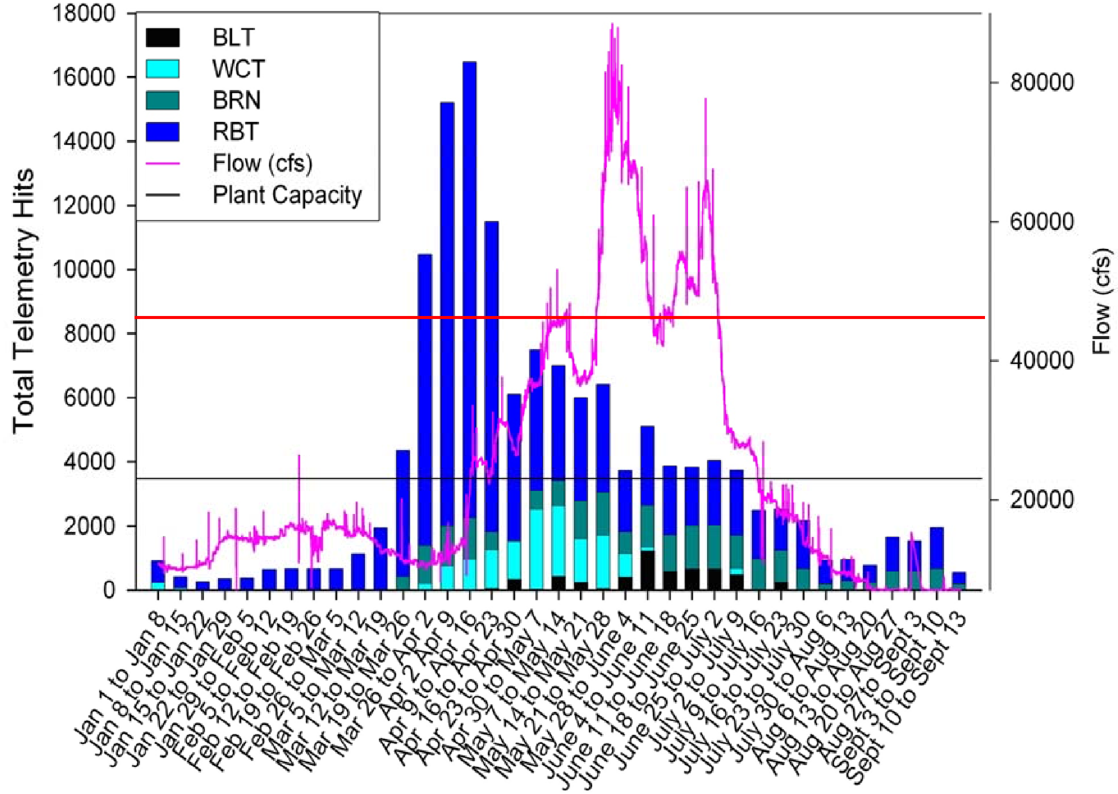
Figure 3-18. Example spill schedule that is initially designed for fish attraction (light blue rows), then to TDG abatement (green rows).

Thompson Falls Main Dam Spillway -"Dual Mode" Spill Schedule

BAY NUMBER																																				Lift Gates	Total Flow (cfs)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
			1				1				1																									3	23,705
			1				1				1																	6	6	6	6	6	6	6	6	51	34,985
			1				1		6	6	1																	6	6	6	6	6	6	6	6	63	37,805
			1				1		6	6	1															6	6	6	6	6	6	6	6	6	6	75	40,625
			1				6	6	6	6	1															6	6	6	6	6	6	6	6	6	6	86	43,210
			1				6	6	6	6	1													6	6	6	6	6	6	6	6	6	6	6	6	98	46,030
			1		6	6	6	6	6	6	1													6	6	6	6	6	6	6	6	6	6	6	6	110	48,850
			1		6	6	6	6	6	6	1											6	6	6	6	6	6	6	6	6	6	6	6	6	6	122	51,670
			6	6	6	6	6	6	6	6	1											6	6	6	6	6	6	6	6	6	6	6	6	6	6	133	54,255
			6	6	6	6	6	6	6	6	1								6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	151	58,485
	6	6	6	6	6	6	6	6	6	6	1								6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	163	61,305
	6	6	6	6	6	6	6	6	6	6	1						6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	175	64,125
6	6	6	6	6	6	6	6	6	6	6	1						6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	181	65,535
DRY CHANNEL SPILLWAY (12 Bays)																																					
6	6	6	6	6	6	6	6	6	6	6	6																									72	82,455
Radial Gates (Bays 16 and 17)																																					
													Both - Full-Open - 11,000 cfs per bay																								104,455

Notes:
1. Numbers under each bay represent the six lift gates in each spill bay
2. Each bay should have all six lift gates opened, before opening lift gates from another bay
3. Closing sequence is opposite of the opening sequence
4. Bays 13 through 15 should never be opened
5. Bays 16 and 17 are radial gates, to be operated in a pre-set manner by operations for forebay elevation control, and load rejection purposes
6. This is a living document, and can be changed as necessary to depict past, non-fish Project spill operations

Figure 3-19.



Total number of “hits” of fish in the Thompson Falls Project tailrace, by date, during 2006. The red horizontal line shows the level when discharge is 45,000 cfs total flow.

References

Backman, T.W.H. and A. F. Evans. 2002. Gas Bubble Trauma Incidence in Adult Salmonids in the Columbia River Basin. North American Journal of Fisheries Management 22: 579-584.

Johnson, E.L. and 6 others. 2005. Migration Depths of Adult Spring and Summer Chinook Salmon in the Lower Columbia and Snake Rivers in Relation to Dissolved Gas Supersaturation. Transactions of the American Fisheries Society 134:1213-1227.

Weitkamp, D.E. and M. Katz. 1980. A Review of Dissolved Gas Supersaturation Literature. Transactions of the American Fisheries Society 109:659-702.

Weitkamp, D.E., R. D. Sullivan, T. Swant, and J. DosSantos. 2003. Gas Bubble Disease in Resident Fish of the Lower Clark Fork River. Transactions of the American Fisheries Society 132: 865-876

Appendix A

Technical Memorandum on TDG at Thompson Falls, Prepared by Steve Rainey, GEI Consultants, Inc. May 14, 2007.

Geotechnical
Environmental &
Water Resources
Engineers

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 ≤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, <u>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.</u> 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.

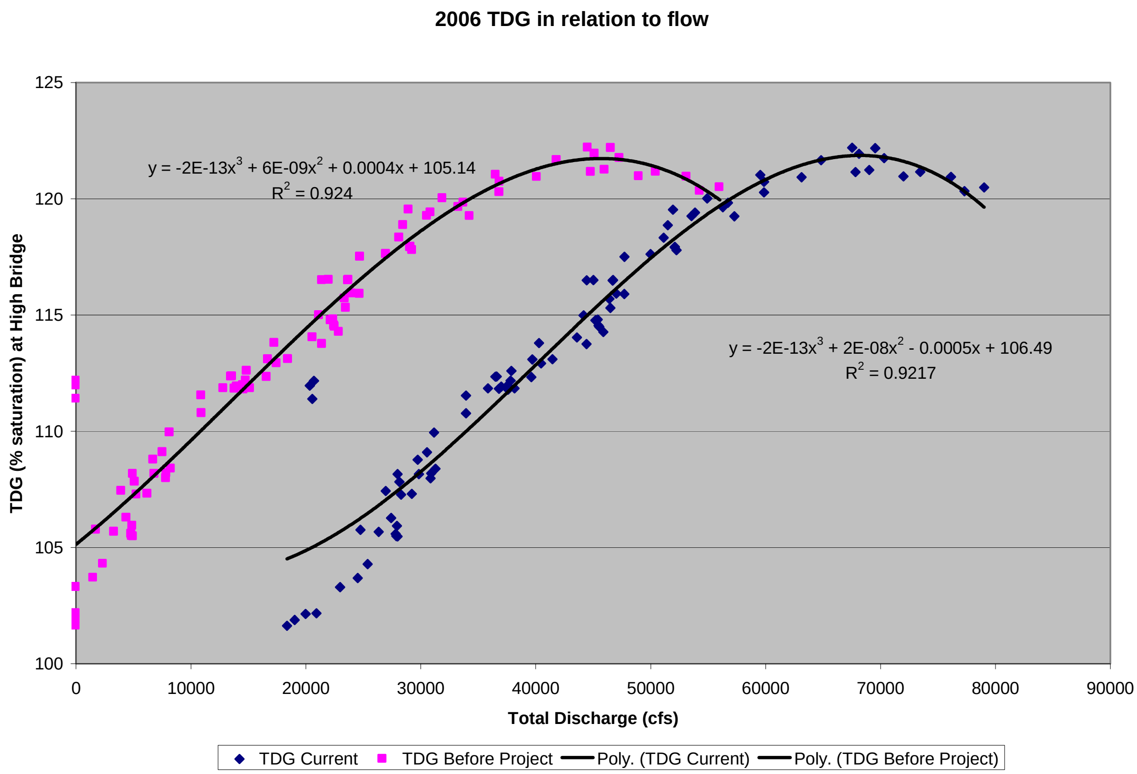

Figure 1 – Total Dissolved Gas Levels at the Thompson Falls High Bridge Monitoring Station, before and after hydro development (see above explanation).

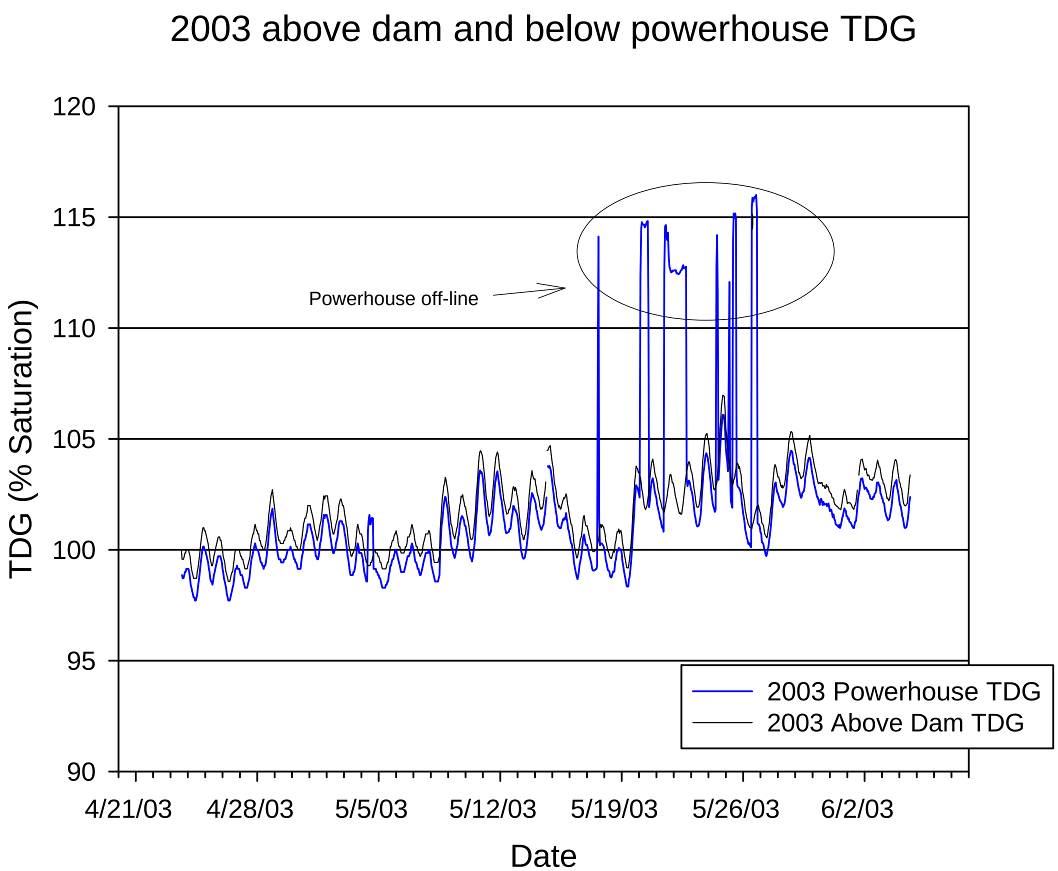

Figure 2 – TDG as measured above the dam and below the new powerhouse in 2003.

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.

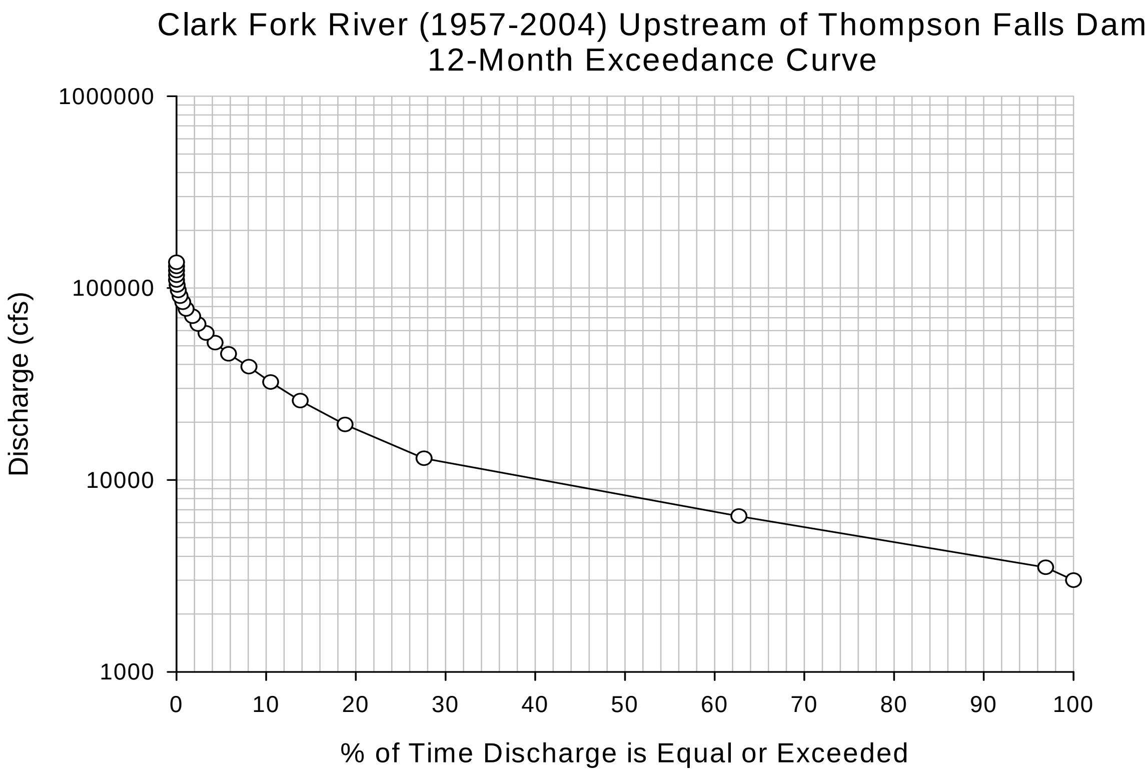

Figure 5 – River Discharge Exceedence Curve.

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.

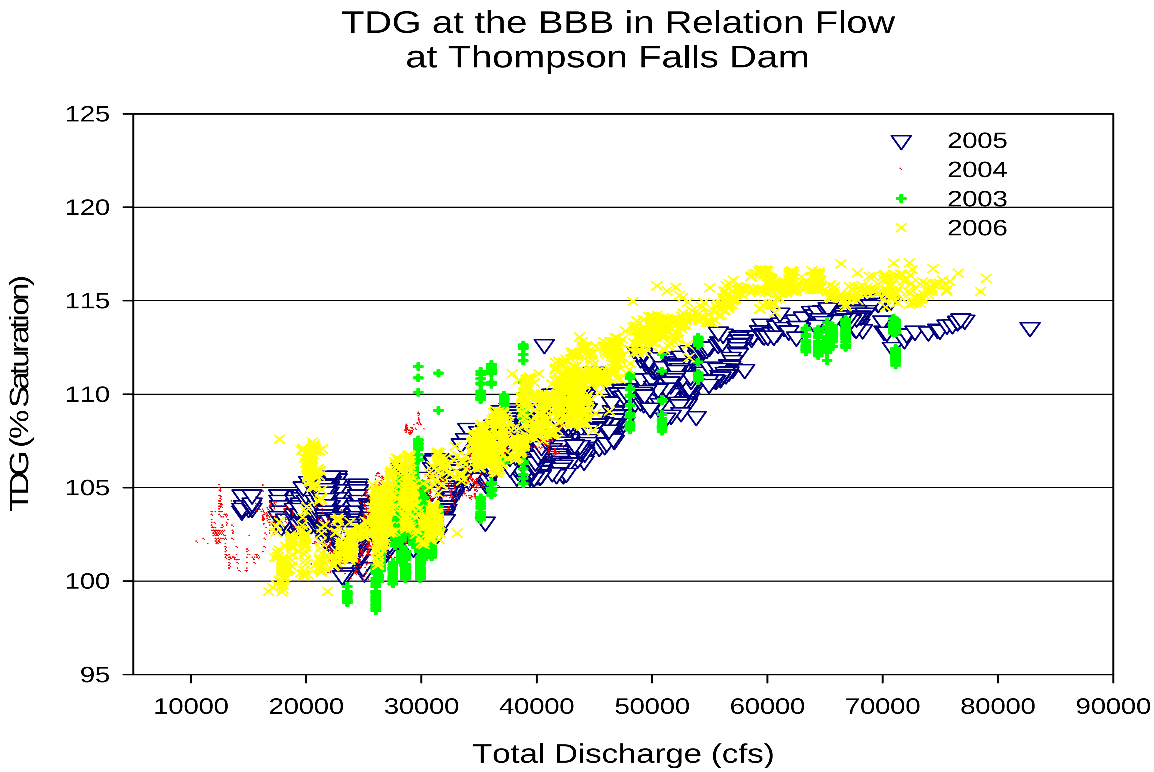

Figure 6 – TDG at the Birdland Bay Monitoring Station, 2003 - 2006

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 $\leq$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

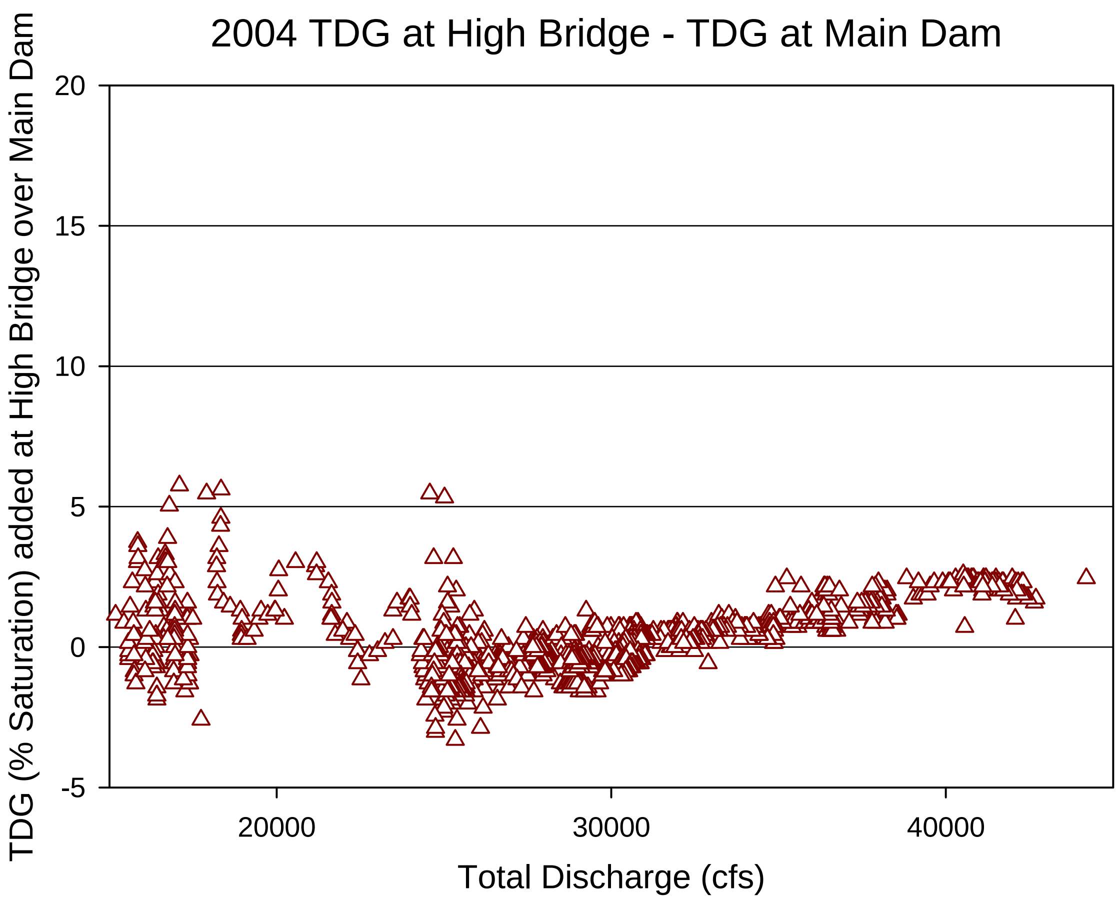

Figure 7 – Apparent TDG component of the 2004 HB TDG reading contributed by the falls.

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.

Appendix B – Calibration Checklist

Checklist for Thompson Falls Hydrolab Logging Run Maintenance

Site ____________ Date ___________ Time ___________ Tech ___________
DS# ___________

1. Remove DataSonde ……………………………………………… Time ___________

2. Clean DataSonde exterior and probes ……………………………… ___________

3. Connect to PC or Surveyor

4. Remove and Replace TDG Sensor …………………………………. ___________
   Check TDG Sensor holds pressure …………………………………. ___________

5. Check/Calibrate Specific Conductance from __________ to ___________

6. Check/Calibrate pH 7 from ___________ to ___________ temp ___________
   pH 10 from ___________ to ___________ temp ___________

7. Check/Calbrt DO % sat from ___________ to ___________ temp_________
   mg/l from ____________ to ___________

8. Check/Calibrate Turbidity from ____________ to ___________

9. Download Logging file to C drive or SUV ………………………… ____________
   Name of file and computer ____
   Reprogram Logging file if necessary ……………………………… _____________

10. Check/Cal Depth and Barometric Pressure ………………………. ____________

11. Remove/Replace C Batteries …………………………………………… ____________

12. Check Internal Voltage (at or above 12 volts) ………………….. ____________

13. Check Date and Time ……………………………………………………. ____________

14. Read/record water temperature ……………………………………. ____________

15. Reinsert DataSonde Time …………………………………………… ____________

16. Photos ____