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Assessment of Total Dissolved Gas in the Spokane River at Upriver and Little Falls Dams

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Assessment of Total Dissolved Gas in the Spokane River at Upriver and Little Falls Dams

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Table of Contents

List of Figures

Abstract

Total dissolved gas (TDG) monitoring in the Spokane River from 1999-2003 was evaluated to determine whether Upriver Dam and Little Falls Dam are contributing to elevated TDG levels that exceed Washington State water quality criteria.

TDG is generated by the natural waterfalls at Post Falls, Idaho, and the bypass of flows through Avista's Post Falls power plant has likely reduced TDG levels. The pool behind Upriver Dam reduces dissipation of TDG produced by Post Falls, but not enough for TDG to exceed natural levels. Upriver Dam does not appear to be increasing TDG above the 110% criterion nor is it increasing TDG above natural conditions when TDG levels are above 110%.

At Little Falls, elevated TDG can be entirely attributed to Long Lake Dam operations; no evidence can be found that Little Falls contributes additional TDG.

Based on this analysis, a TDG Total Maximum Daily Load (TMDL) for the Spokane River is not necessary. The 401 certification process for Federal Energy Regulatory Commission (FERC) hydropower relicensing should serve as a pollutant control plan sufficient to address TDG impairments in the Spokane River. Future Washington State 303(d) listings for TDG in the Spokane River should be moved from Category 5 (*TMDL required*) to:

- Category 2 (*waters of concern*) from Mirabeau Park to Upper Falls, pending additional monitoring and the relicensing of Upriver Dam.
- Category 4B (*has a pollutant control plan*) from the Idaho state line to Mirabeau Park and from Upper Falls to the Spokane Arm of Lake Roosevelt, once the Avista FERC license is issued and the 401 certification is in effect.

TMDL development should be set at the lowest priority until the 303(d) listing changes described above can be completed.

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- Staff and consultants at Avista Corporation for providing data, monitoring support, and other valuable information.
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Introduction

Setting

This report presents the findings of an analysis of total dissolved gas (TDG) generation and dissipation in the Spokane River in the vicinity of Upriver Dam (between the Idaho-Washington state line and the City of Spokane) and Little Falls Dam (between Long Lake Dam and the Spokane Arm of Lake Roosevelt). The purpose of the analysis is to determine whether these two projects, the only projects on the Spokane River not covered under the Federal Energy Regulatory Commission (FERC) license for Avista's hydropower facilities, are contributing to the impairment of water quality standards by elevating TDG or preventing the dissipation of TDG.

The Spokane River Watershed drains over 6,000 square miles of land in Washington and Idaho (Figure 1). Most people in the watershed live in the Spokane metropolitan area. However, the populated areas of Liberty Lake east of Spokane and Coeur d'Alene and Post Falls in Idaho are growing in population. The Spokane River starts as the outflow from Lake Coeur d'Alene, flows into Washington and through the city of Spokane, ultimately reaching the Columbia River where it becomes the Spokane Arm of Lake Roosevelt.

Applicable Criteria

Washington State's water quality standards regulations establish a TDG criterion of 110% of saturation for the protection of aquatic species. The standards also specify that when a water-body cannot meet a criterion due to natural conditions, those conditions are effectively the water quality criteria for that waterbody.

This project was initiated because the state of Washington had received information that showed that TDG levels exceed state water quality standards in multiple reaches of the Spokane River in Washington State (CH2M Hill, 2002). These reaches have been placed on Ecology's draft 2002/2004 303(d) list. Additional studies (Golder, 2003; 2004) have confirmed that supersaturated TDG can be found not just in these reaches but throughout the Spokane River in Washington. Therefore, the Spokane River downstream of the Idaho state line is considered impaired for TDG. In addition, a TDG TMDL has being approved for Lake Roosevelt (Pickett *et al.*, 2004), in which pollutant allocations were assigned to the Spokane Arm of Lake Roosevelt.

In 2002, the Washington State Department of Ecology (Ecology) established its annual priority list of waterbodies impaired by pollutants for which Total Maximum Daily Load (TMDL) studies would be conducted. The list included a TMDL for TDG in the mainstem Spokane River from the Idaho border to its confluence with the Columbia River. In 2003, Ecology issued a Quality Assurance (QA) Project Plan for TDG monitoring and TMDL development (Pickett, 2003).

Portions of the Spokane River are waters of the Spokane Tribe of Indians and of the state of Idaho. EPA has a trust responsibility for Tribal waters and has been coordinating among Washington, Idaho, and the Spokane Tribe.

In its 2002 Integrated Report, Idaho did not included TDG in the Spokane River on its 303(d) list and assessed the Spokane River as “not impaired” by excess TDG. This assessment was based, in part, on the Idaho Department of Environmental Quality’s (DEQ) understanding that TDG levels are at, or below, natural levels as a result of the Post Falls Hydroelectric Development. Idaho also based their assessment on an evaluation of the impairment of beneficial uses, which found no adverse effects from elevated TDG on fish below Post Falls (Idaho DEQ, 2005).

TDG Generation Processes

Elevated TDG levels are commonly caused by spill events at hydroelectric projects on a river. Water pouring over the spillway of a dam and plunging into tailrace waters entrains air bubbles. When these are carried to depth in the dam’s stilling basin, the higher hydrostatic pressure forces air from the bubbles into solution. The result is water supersaturated with dissolved nitrogen, oxygen, and the other constituents of air. As the bubbles rise in the aerated zone of the tailrace, some of the gas leaves solution. However, as the bubbles dissipate and the water enters the downstream reach, the remaining TDG will remain unless wind- or channel-induced turbulence causes more degassing.

Water that passes a dam through the powerhouse usually has the same TDG as upstream. However, at some dams under certain conditions, TDG can be elevated if air is present in the turbines.

TDG may also be increased or decreased by natural phenomena:

- High biological primary productivity can cause diurnal variation of dissolved oxygen which is also reflected in TDG levels.
- Rising and falling water temperatures can cause increases and decreases of TDG pressure and percent saturation, even with constant dissolved gas concentrations.
- The percent saturation of TDG can rise if atmospheric barometric pressure drops, simply because percent saturation is a function of ambient equilibrium pressure. These effects are generally stronger when travel time is slower.
- Natural waterfalls and cascades can either increase or decrease gas levels. In general, plunging waterfalls generate gas, while cascades passing over rock surfaces can cause degassing.

Fish in water with high TDG levels may not display signs of difficulty if higher water pressures at depth offset high TDG pressure passing through the gills into the blood stream. However, if the fish inhabit supersaturated water for extended periods, or rise in the water column to a lower water pressure at shallower depths, TDG may come out of solution within the fish, forming bubbles in their body tissues. This gives rise to gas bubble trauma (GBT), which has symptoms that include bubbles in the fins and lateral lines, bulging eyes, and mortality at high levels.

Methods are available to quantify these symptoms to determine the impacts of elevated TDG on fish.

Spill flows can occur at any time when reservoir inflows exceed powerhouse capacity ("involuntary" spills) and available reservoir storage is not sufficient to hold excess flows. There are three main reasons for involuntary spills:

- The powerhouse can't pass flood flows.
- The powerhouse is off-line due to lack of power demand.
- The powerhouse is off-line for maintenance or repair.

There are seven hydroelectric projects in the TMDL area (Figure 1):

- Post Falls Dam (Avista, in Idaho).
- Upriver Dam (City of Spokane, in Washington).
- Upper Falls Project (Avista, in Washington).
- Monroe Street Project (Avista, in Washington).
- Nine Mile Dam (Avista, in Washington).
- Long Lake Dam (Avista, in Washington).
- Little Falls Dam (Avista, half Washington/half Spokane Reservation).

With the exception of Long Lake and Post Falls dams, dams on the Spokane River are run-of-the-river dams with very little active storage capacity. The most common spills that generate high TDG levels occur during the spring months (March through June) when spring snowmelt raises flows above the capacity of hydroelectric plants. Avista Corporation, who operates the farthest upstream dam at Post Falls, reports that during spring runoff the dam is fully opened and conditions resemble the natural waterfall on which the dam was constructed. Effectively, Post Falls is operated as a run-of-the-river dam during the spring and as a storage dam in the summer. Staff at Idaho DEQ have confirmed this assessment (Idaho DEQ, 2005).

All of the dams except Little Falls and Upriver are covered by a single FERC license. Avista has applied for renewal of this license and is currently in the midst of the relicensing process, which includes a Section 401 certification from Ecology. Because five of the seven dams on the river are covered under one license, if the sources of TDG impairment can be shown to be caused by the facilities under that license and not by the two dams not under that license, then a TMDL may be unnecessary.

Ecology policy allows a 303(d) listing to be moved from a Category 5 (TMDL required) to a Category 4B (has a pollutant control plan) if a plan is in place that meets the following criteria:

- *Has enforceable pollution controls or actions stringent enough to attain the water quality standard or standard.*
- *Is problem-specific and waterbody-specific.*
- *Has reasonable time limits established for correcting the specific problem, including interim targets when appropriate.*

- *Has a monitoring component.*
- *Has adaptive management built into the plan to allow for course corrections if, necessary.*
- *Is feasible, with enforceable legal or financial guarantees, that implementation will occur.*
- *Is actively and successfully implemented and shows progress on water quality improvements in accordance with the plan.*

A 401 certification incorporated into a FERC license can meet these criteria.

Another listing category that might be an alternative to a Category 5 is Category 2 (waters of concern), which is defined as:

Waters where there is some evidence of a water quality problem, but not enough to require production of a TMDL at this time. There are several reasons why a water body would be placed in this category. A water body might have pollution levels that are not quite high enough to violate the water quality standards, or there may not have been enough violations to categorize it as impaired according to Ecology's listing policy. There might be data showing water quality violations, but the data were not collected using proper scientific methods. In all of these situations, these are waters that we will want to continue to test.

This category may be appropriate if data analysis indicates a project is not contributing to impairment, but a limited data set cannot fully address uncertainty and additional monitoring and analysis may be warranted in the future.

Upriver Dam

Background

The Spokane River begins at the outlet of Lake Coeur d'Alene in Idaho. The river flows about 10 miles to Post Falls Dam, which at low flows regulates river and lake levels and outflows. However during high spring flows when the spill gates are open, lake outflows are controlled not by the dam but by a natural sill at the lake outlet.

The Post Falls project (shown in Figure 2) is built on three channels of historic waterfalls. The center channel contains the powerhouse, and spill is released in the North and South Channels. The spill gates in the North and South Channels were built directly on top of the crest of the waterfalls, and when the spill gates are open flows fall over the historic waterfalls.

There are no non-natural sources of TDG in the Spokane River Watershed above Post Falls. Two years of monitoring upstream of Post Falls Dam has shown TDG levels above the 110% water quality criterion for only a few hours on three days in two years of monitoring (less than 1% of the readings), all with values less than 1% saturation above the criterion. (Golder, 2003; 2004). The reason for these high values is unclear but could be related to either a low air pressure event or high primary productivity and supersaturated dissolved oxygen.

Below Post Falls, the three channels join and the river flows about four miles to the Idaho-Washington state line at about river mile (RM) 96.2. This reach and the river in Washington to about Sullivan Road (RM 87.8) have been documented to be a "losing reach," i.e. the river is recharging groundwater. However, from Sullivan Road downstream there are significant flows entering the river from the Spokane Valley/Rathdrum Prairie aquifer.

Upriver Dam is located at about RM 80.2 and its pool backs up to a little below Mirabeau Park at RM 86. Below Upriver Dam, the river's next control is Avista's Upper Falls facility (RM 74.5).

Upriver Dam (shown in Figure 3) is owned by the City of Spokane, who uses the dam for the city water supply and for electrical power generation. The dam's first powerhouse was built in 1936 and contains three Kaplan turbines, while the second powerhouse was completed in 1984 and contains two Kaplan turbines. Total project hydropower capacity is 17.2 megawatts, and the hydraulic capacity is 7500 cubic feet per second (cfs). Upriver Dam is operated under a FERC license, which is scheduled to expire in 2031.

Avista has monitored the Spokane River for TDG as part of its relicensing work. TDG was monitored below Post Falls Dam from April 1999 through March 2002 (CH2M Hill, 2002). During the spill seasons of 2003 and 2004, a more detailed monitoring program was conducted (Golder, 2003; 2004). Monitoring locations for these two years are shown in Figures 4 and 5.

Monitoring in 2003 included:

- Continuous monitoring at
  - Post Falls Dam forebay and tailrace (below the junction of the three channels)
  - Upper Falls forebay
- Spot monitoring in the North Channel below the spillway (PF1 in Figure 4)

Monitoring in 2004 included:

- The two Post Falls continuous monitors
- Spot monitoring at
  - North Channel (PF1 in Figure 5)
  - Stateline (PF2A)
  - North Bank/Buckeye Road (PF3)
  - Mirabeau Park (PF4)
  - Upriver Dam forebay (PF5)

Ecology conducted monitoring in 2003 at the Upriver Dam forebay and across from Mirabeau Park. The results of that monitoring are presented in the Appendix.

Discussion

There are two principal elements to evaluating the effect of Upriver Dam on TDG in the Spokane River. First, Upriver Dam may be reducing the dissipation of TDG by creating a slower, deeper pool where previously the river was swift and shallow. Second, Upriver Dam may be generating elevated TDG by its spill. Indirect effects, such as increased TDG pressures from water temperatures increased by the dam, are likely of minor importance compared to these two.

Figure 6 shows TDG data collected in 2003 from the Post Falls tailrace, the Upriver Dam forebay, and the Upper Falls forebay. This graph also shows total river flow measured below Spokane Falls and an estimate of Upriver Dam spill flows based on subtracting the hydropower plant capacity from flow. There are several key features in this graph:

- TDG from Post Falls significantly dissipates before reaching Upriver Dam.
- TDG in the Upriver forebay is sometimes higher than downstream at Upper Falls, but TDG rarely increases from Upriver to Upper Falls.
- A key period of interest in analyzing TDG is the peak TDG period from late March to mid-April when spill at Upriver Dam is above 4900 cfs.

Post Falls TDG Generation

It is useful to evaluate TDG generation at Post Falls Dam in order to understand TDG conditions from the Washington-Idaho state line to the Upriver Dam pool and the potential effect on TDG by Upriver Dam and its reservoir. The TDG production at Post Falls can be evaluated from Avista's continuous and spot monitoring and historical records.

Flows historically fell over all three channels, beginning with the North Channel and spilling over into the other two channels at higher flows. But under current operations, the powerhouse occupies the Middle Channel and spill occurs at the North Channel until maximum discharge capacity is reached, after which spill is increased in the South Channel. TDG from spill mixes with power plant flows from the Middle Channel below the channel confluences, and the Avista tailrace monitor measures these mixed flows.

Two methods of estimating TDG generation by the North Channel were evaluated. First, spot TDG measurements taken in the North Channel in 2003 and 2004 were compared to reported spill flows. All spot measurements were taken when spill only occurred in the North Channel, except for two measurements in April 2003 when the South Channel was in use as well.

Second, continuous monitoring TDG data from tailrace and forebay monitoring in 2004 were used to back-calculate spill TDG generation, assuming that total flow and TDG at the tailrace monitor represented total loading and that forebay TDG and the generation flows represented the generation loading. Only stable TDG readings were used (less than 2% saturation change between eight-hour periods). These backcalculated spill and TDG values would represent spill from both the North and South Channels.

The results are shown in Figure 7. Regressions using a semi-log equation were fit to the two data sets to project TDG generation to higher flows. Semi-log was chosen because it has been used with TDG data in other studies (for example: Schneider and Carroll, 1999) and fits the data well. The two dates with South Channel spills were removed from the regression for spot measurements, which removed a slight downward bias. The reason for differences between the curves is unclear; but, considering the size of the spot measurement data set and the errors inherent in the back-calculation, they can be considered to be reasonably similar.

The regressions suggest that maximum TDG generation in the spill channels at the 7-day 10-year recurrence (7Q10) high flow (approximately 32,000 cfs, with a spill flow of 27,000 cfs) could range as high as 130% saturation. Assuming that in the absence of the powerhouse all flow would generate TDG, then TDG levels at the tailrace location could be at least 3% saturation lower now than before the powerhouse was constructed, because of dilution by lower forebay TDG levels passed through the powerhouse. Because this is a rough estimate from extrapolating data for two spill seasons from low to average flow to 7Q10 flows, direct measurements under high flow conditions are necessary to more accurately evaluate TDG production.

TDG Dissipation from Post Falls to Upriver Dam

Continuous data collected in 2003 were compared as daily average values (Figure 8). This analysis shows that TDG can decrease by 2% to 7% saturation between Post Falls and Upriver Dam. Avista took spot TDG measurements in 2004 at several locations from Post Falls to Upriver Dam (Figure 9), which allows TDG dissipation by reach to be evaluated. Differences between the dissipation rates for different dates may be partially due to the monitoring schedule, which often was from downstream up, and may have sampled TDG under changing conditions. The pattern of dissipation is similar to 2003, with TDG levels dropping by 3% to 8% saturation.

To evaluate the effect of the Upriver Dam pool on degassing rates, the 2004 spot data were compared by three reaches:

- Post Falls to Mirabeau Park (PF4), the reach upstream of the Upriver Dam pool.
- Mirabeau Park (PF4) to Upriver Dam forebay (PF5), the Upriver Dam pool.
- North Bank/Buckeye Road (PF3) to Mirabeau Park (PF4) (the unimpounded reach just upstream of the Upriver pool reach).

Figure 10 shows the rate of reduction versus flow for these three reaches. A semi-log regression was chosen to fit the data from the three reaches because it provides a good fit and a conservative extrapolation. Several patterns in this figure are important:

- The overall rate from Post Falls to Upriver Dam is higher than the rates in the reaches above Upriver Dam.
- The reach just above the Upriver Dam pool has a dissipation rate higher than in the Upriver Pool but lower than the rate for the entire reach below Post Falls.
- The dissipation rate in the Upriver Pool is averaging less than 0.1% saturation per mile, a rate that is confirmed by the 2003 continuous TDG data (Figure 11). The reduction rate in the pool is negative at low flows, probably indicating a slight increase in TDG from temperature or productivity.
- Assuming that the TDG dissipation rates in the two reaches (in the Upriver Dam pool and just above the pool) would be similarly absent the effect of the dam, then the dissipation rate in the Upriver Dam pool appears to be lower than pre-project conditions by roughly 0.1% saturation per mile, for a total of less than 1% saturation over the reach.
- Figure 10 also shows projections of TDG dissipation for flows up to the 7Q10 flood flow. Although the magnitude of these extrapolations is highly uncertain, they suggest that the difference between impounded and unimpounded reaches remain small and fairly constant.

TDG Generation below Upriver Dam

TDG generation by Upriver Dam was estimated by back-calculating from 2003 forebay TDG levels, Upper Falls forebay TDG levels, and flows, assuming that forebay TDG levels pass through the powerhouse unchanged and Upper Falls represents mixed conditions. The analysis was limited to stable TDG readings (less than 2% saturation change between readings).

Figure 12 shows the estimated TDG generation when flows over the spillway are above 150 cfs or above 4900 cfs. TDG generation for 2003 conditions was below 110% saturation. An extrapolation of TDG generation for spills up to the 7Q10 flood flows suggests that the dam could potentially generate TDG up to 120 saturation. However, data collected at high flows will need to be collected to confirm this, since dissipation of TDG between Upriver Dam and Upper Falls forebay may result in an underestimate of TDG generation. Also, TDG generation at higher flows may be nonlinear. For example, if tailwater depths get deeper with increasing flows, TDG generation may first increase as the plunging depth increases but may then decrease as the distance from the spillway to the water surface is reduced. This pattern has been observed at other dams.

Since upstream TDG levels may be above standards when they arrive at Upriver Dam, it is also important to evaluate whether Upriver Dam is increasing TDG compared to upstream values. Figure 13 shows a comparison of TDG levels between Upriver Dam forebay and Upper Falls forebay in 2003. The three graphs show all flows, spill above 4900 cfs, and spill above 8000 cfs.

For all flows, it appears that TDG tends to be reduced between Upriver Dam and Upper Falls. This could be explained by TDG dissipation by shallow river depths during low flow. Focusing on the higher flows (spills over 4900 cfs), TDG levels remain unchanged below Upriver Dam. For the highest flows (spills over 8000 cfs), as TDG levels approach 110% TDG below Upriver Dam tends to shift from slightly higher levels towards similar or lower levels than upstream TDG. This may be occurring because Upriver Dam spill generates lower levels of TDG than upstream TDG levels.

Little Falls Dam

Background

Little Falls Dam is located on the Spokane River about five miles downstream of Long Lake Dam (Figure 14). Built in 1910, the dam was authorized by an act of Congress and is not covered by a FERC license. The generating plant has a design capacity of 32 megawatts and hydraulic capacity of 7000 cfs. The dam is built on historic waterfalls, and the spillway consists mainly of a cascade over the boulders of the original falls (Figure 15).

Currently, Little Falls Dam serves as a regulating facility and is managed jointly with Long Lake Dam. Long Lake Dam uses active storage to maximize generation at both dams, but spill usually occurs in the spring runoff season. Both dams have similar power plant hydraulic capacity, so both tend to spill at about the same level during the same flows.

Avista conducted monitoring below Little Falls Dam and Long Lake Dam from April 1999 through March 2002. Although 2001 was an extremely low-flow year, 2002 included a period of spill from the dams that produced TDG levels above the water quality criterion.

Discussion

For the three-years monitored, each TDG data point at Little Falls was paired with a data point from Long Lake that was the next earlier time. Figure 16 shows the relationship between the paired data below the two dams. What is immediately apparent is that the data show a virtual 1:1 relationship, with slightly lower TDG below Little Falls at higher TDG levels. The r^2 for the relationship is 0.975. When the paired data are lagged progressively in 1-hour increments, the relationship improves to an r^2 of 0.987 for a 3-4 hour lag.

This strong correlation suggests that spill at Long Lake is generating the TDG levels observed at both stations. Figure 17 shows TDG levels below Little Falls and the difference in paired values between Long Lake and Little Falls, both plotted against spill. This illustrates, again, that the TDG below Little Falls can be predicted by spill at Long Lake and that the higher the spill at Long Lake, the greater the reduction of TDG below Little Falls. Close examination of the data shows that most of the pairs, when Little Falls is greater than Long Lake, can be explained by time-of-travel and declining TDG levels.

A review of a period when TDG exceeded the criterion of 110% at Little Falls, April and May 2002, shows the relationship between the two stations even more clearly. Figure 18 shows the two-time series, with a 12-hour moving average of the two data sets. TDG patterns from upstream are replicated downstream, with a fairly consistent drop in TDG from upstream to downstream.

Conclusions and Recommendations

Conclusions

Upriver Dam

Total dissolved gas (TDG) levels generated by Post Falls appear to be primarily a natural phenomenon due to spill cascading over the historic waterfalls. The effect of Avista's development of the falls for hydropower on TDG generation cannot be determined with a high level of certainty. But most likely development is reducing TDG by several percentage points of saturation because flows are now diverted through the powerhouse that historically passed over the natural waterfalls.

The Idaho Department of Environmental Quality is responsible for issuing the 401 certification of Avista's Post Falls development as part of the FERC relicensing process. TDG water quality standards vary between Idaho and Washington, but the criteria are identical and the way the standards address natural conditions is similar. The Idaho 401 certification will ensure that Idaho standards are being met, which is likely to also meet Washington's standards. EPA has ultimate responsibility to ensure that both states' standards are met under the 401 certification.

Post Falls is the sole source of supersaturated TDG levels above Washington State water quality criteria from the Washington-Idaho state line to Mirabeau Park (the upper end of the Upriver Dam pool). The effect of the Upriver Dam pool on TDG dissipation rates appears to be small to negligible. It is unlikely that this effect is causing TDG levels above natural conditions, because any effect is most likely offset by TDG reduction from the Post Falls powerhouse bypass.

Although the spill at Upriver Dam did not supersaturate TDG levels above the 110% criterion during the 2003 season, extrapolation to higher flows suggests that the dam's spill will generate TDG above 110% at higher flows. However, the evidence indicates that TDG levels below Upriver Dam are not being elevated as compared to upstream levels.

In summary, in the Spokane River between Post Falls and Upper Falls, elevated TDG can be attributed to natural conditions. The evidence indicates that human activities either do not increase TDG above the 110% criterion or they do not increase TDG above natural conditions when background TDG levels are above 110%. There is some uncertainty involved in this conclusion because of the lack of data for high flows. However, this uncertainty can be addressed through future monitoring and through the next relicensing process for Upriver Dam.

Little Falls Dam

TDG levels measured for three years below Long Lake Dam and Little Falls Dam show a very strong relationship between upstream and downstream values. When TDG is elevated below Long Lake, the pattern is repeated below Little Falls with the values reduced. This evidence strongly suggests that TDG measured below Little Falls Dam above water quality criteria is generated at Long Lake Dam. Little Falls Dam appears to have little effect on TDG levels other than to reduce them. Therefore, Little Falls Dam is not contributing to the impairment of TDG in the Spokane River.

Recommendations

- The Spokane River from Mirabeau Park to Upper Falls should be placed in Category 2 (*waters of concern*) of the 303(d) listing due to no evidence of human-caused water quality impairment as compared to natural TDG conditions, but with uncertainty as to the effect of Upriver Dam. Following FERC relicensing of the Upriver Dam, this waterbody can be placed in Category 4B (*has a pollutant control plan*) based on the 401 water quality certification of the dam.

- The Spokane River, from the Idaho-Washington state line to Mirabeau Park and from Upper Falls to the Spokane Arm, should be placed in Category 4B during the 303(d) listing process following issuance of the new FERC license for Avista's Spokane River project. The FERC relicensing process and the associated 401 certification will address all sources of TDG impairment in these reaches of the Spokane River. The license and 401 certification are expected to meet all criteria for the Category 4B listing once they are in effect and legally enforceable. The Avista FERC license is currently scheduled for issuance in July 2007, at which time the 401 certification will become a mandatory condition of the license.

- Compliance of 401 certification conditions with the Category 4B listing criteria should be verified during 401 certification development. The 401 certification and 303(d) listing criteria should be included in the documentation for the re-listing of TDG in the Spokane River when the revised 303(d) list is sent to EPA for approval.

- Because of the previous recommendations, a TDG Total Maximum Daily Load (TMDL) for the Spokane River is not required. TMDL development should be set at the lowest priority until the 303(d) listing changes described above can be completed.

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Figures

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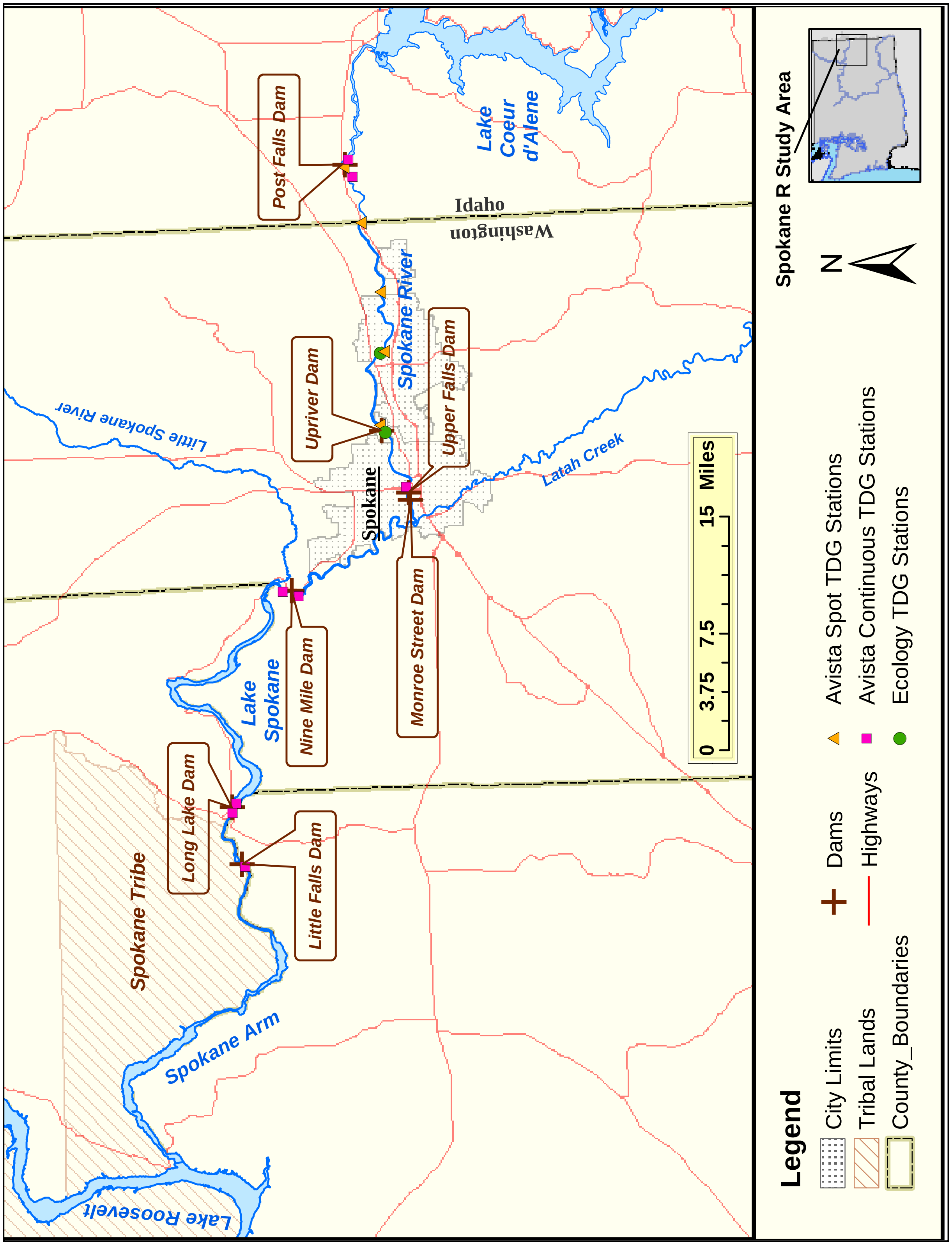
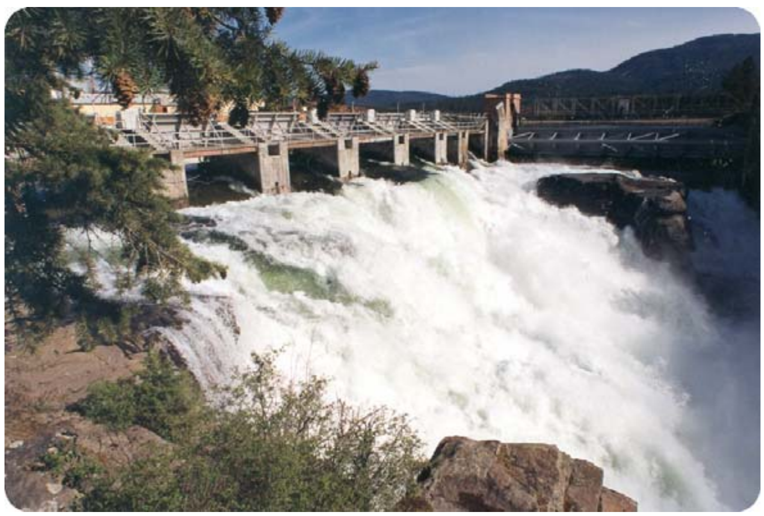


Figure 1. Spokane River Total Dissolved Gas TMDL Study Area

South Channel with Spill

South Channel without Spill



North Channel with Spill

Middle Channel with Powerhouse

Figure 2. Post Falls Dam (Photographs Courtesy of Avista Corporation)

Figure 3. Upriver Dam (Photograph Courtesy of City of Spokane)

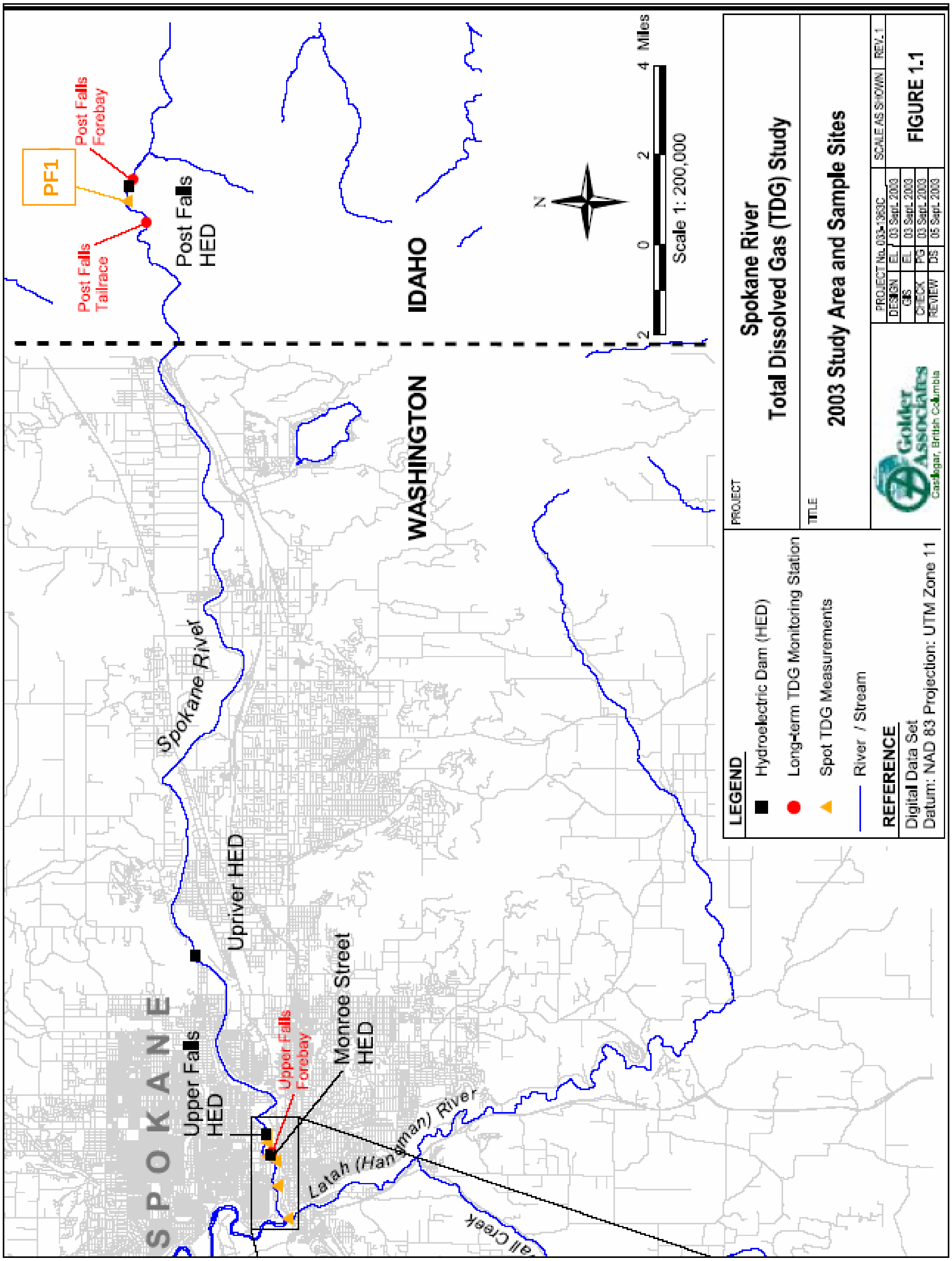


Figure 4. Avista Monitoring Locations – 2003 (from Golder, 2003)

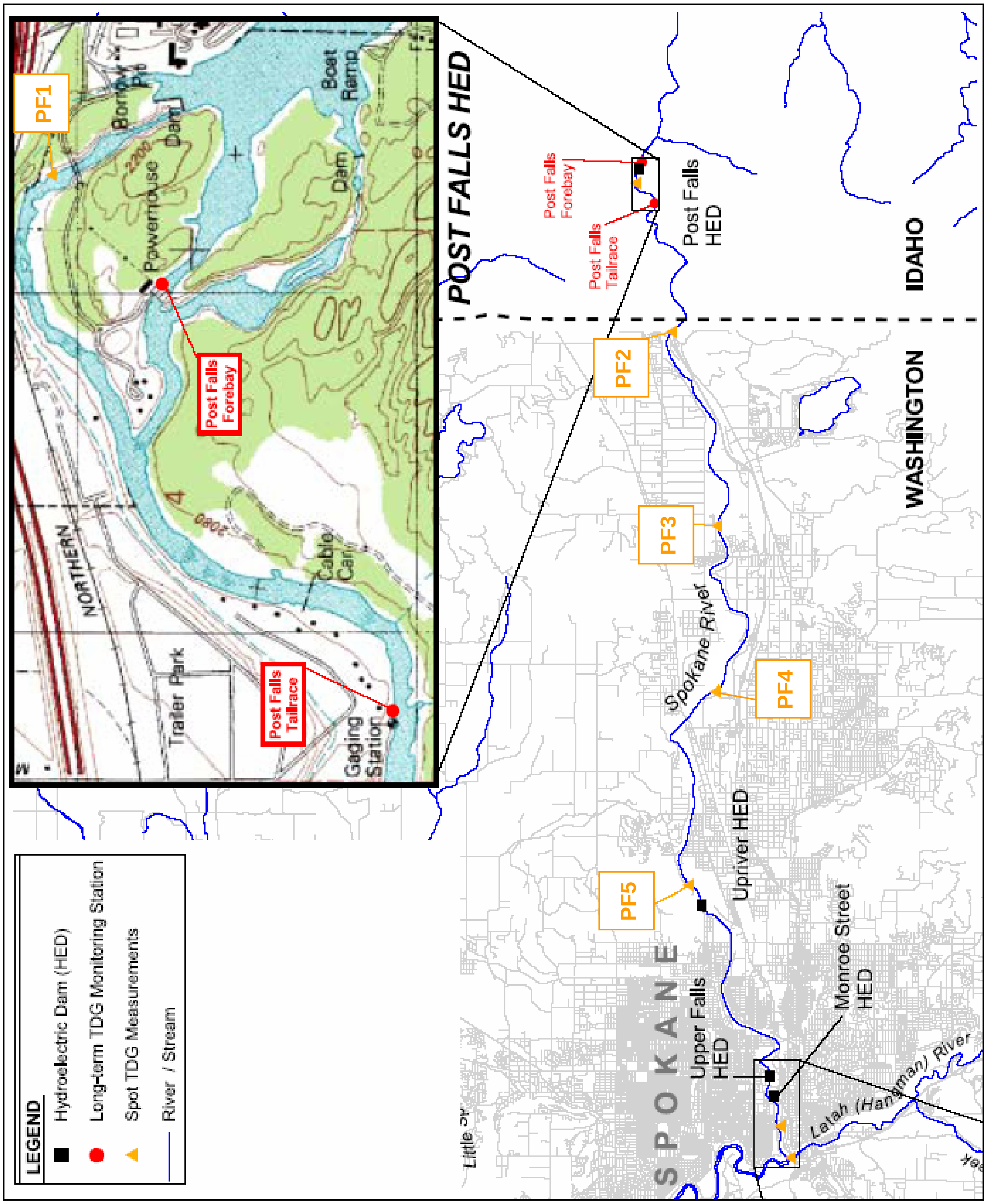


Figure 5. Avista Monitoring Locations - 2004 (from Golder, 2004)

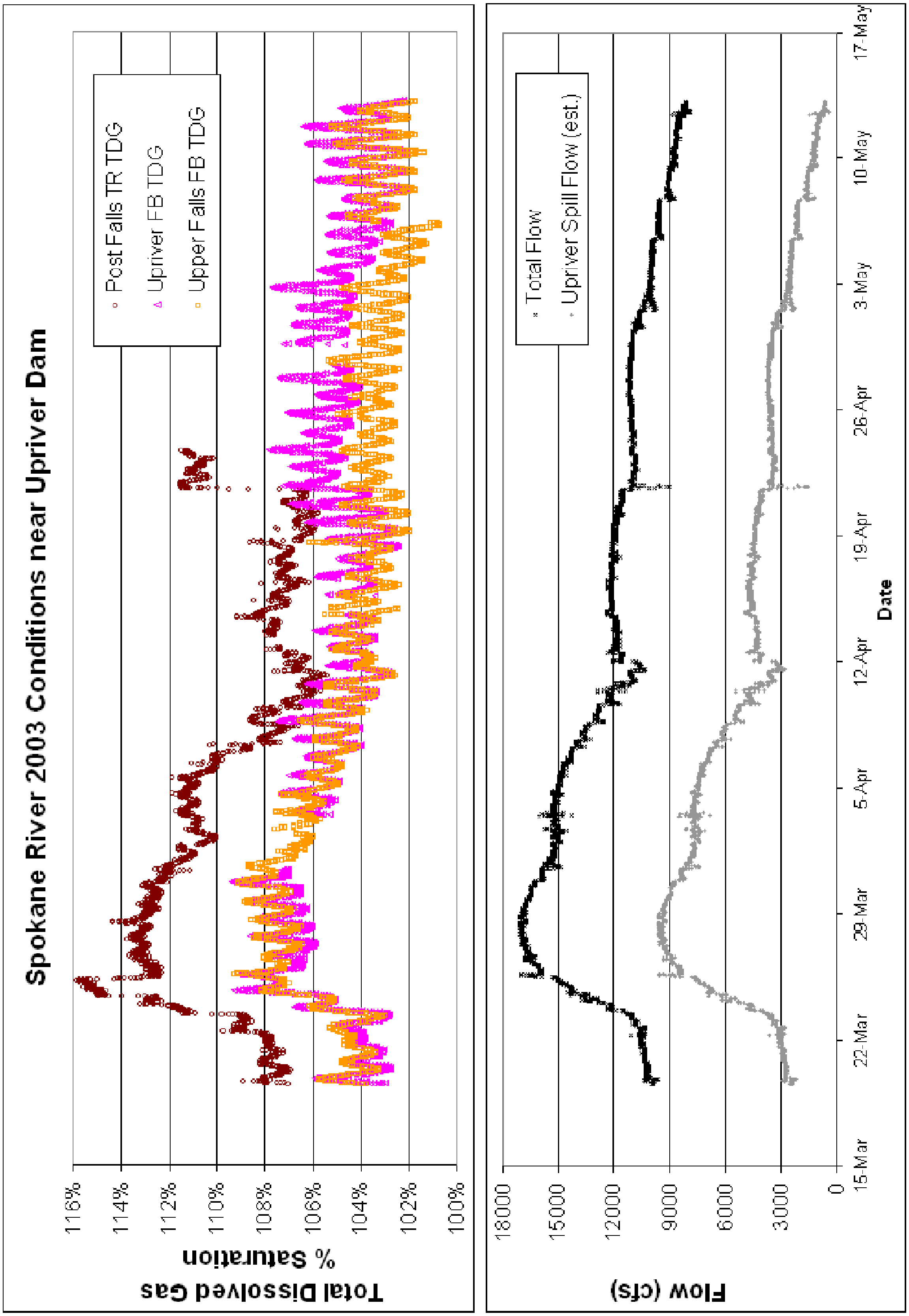


Figure 6. TDG and Flow at Upriver Dam and Upper Falls, 2003

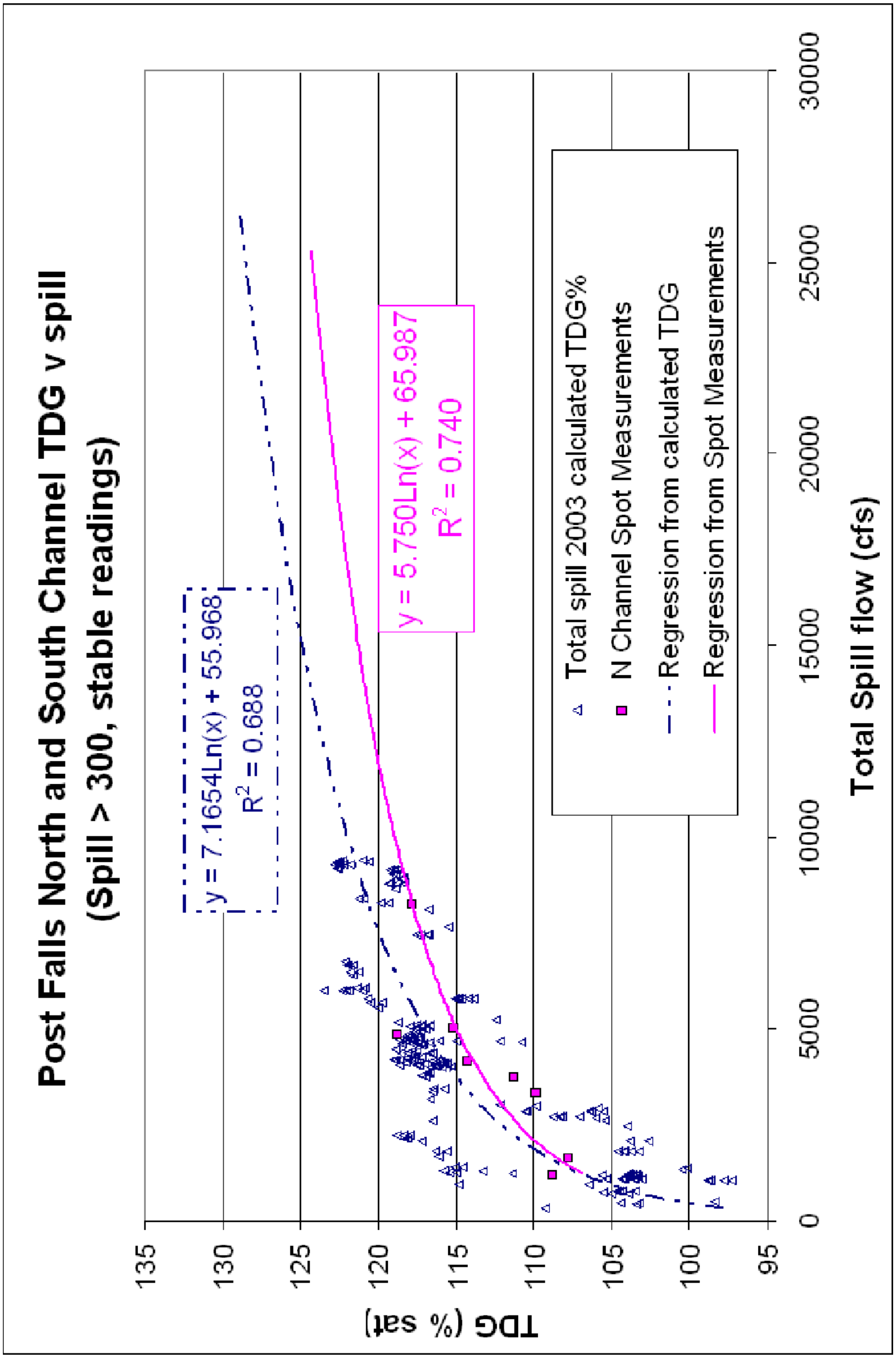


Figure 7. Post Falls Spill and TDG Generation

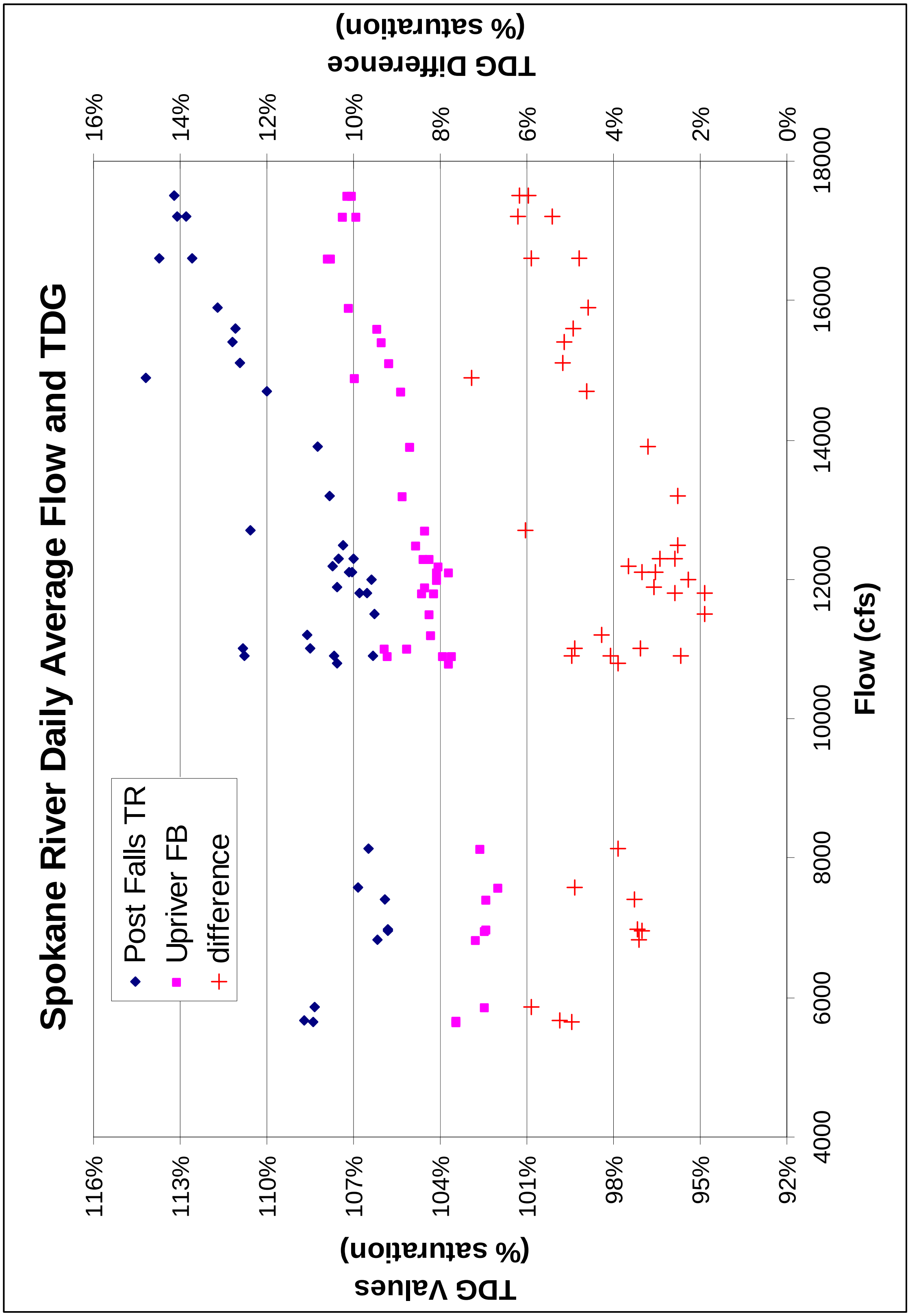


Figure 8. Post Falls Tailrace and Upriver Forebay 2003 Daily Average TDG

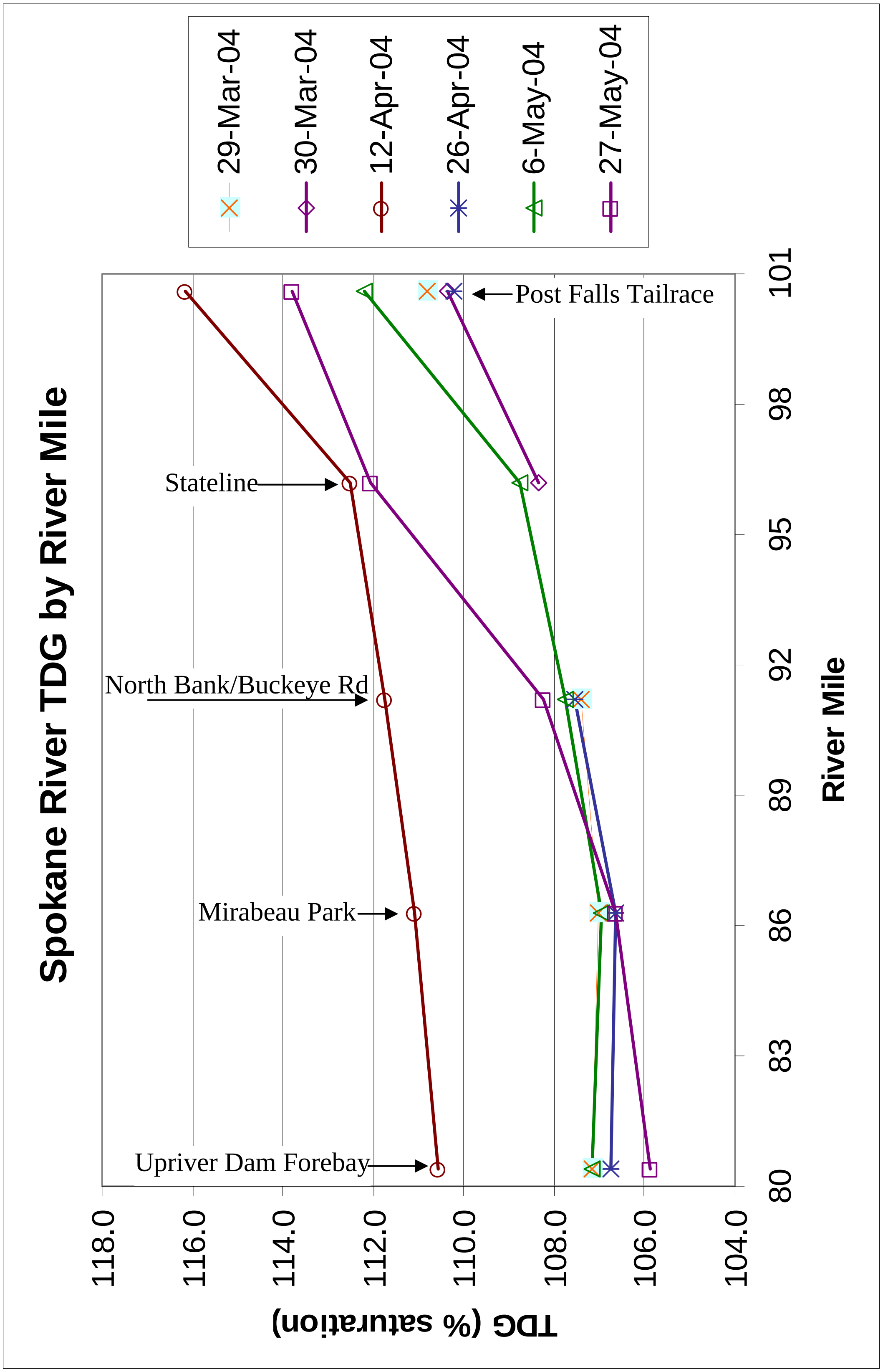


Figure 9. TDG Spot Measurements – Post Falls to Upriver Dam

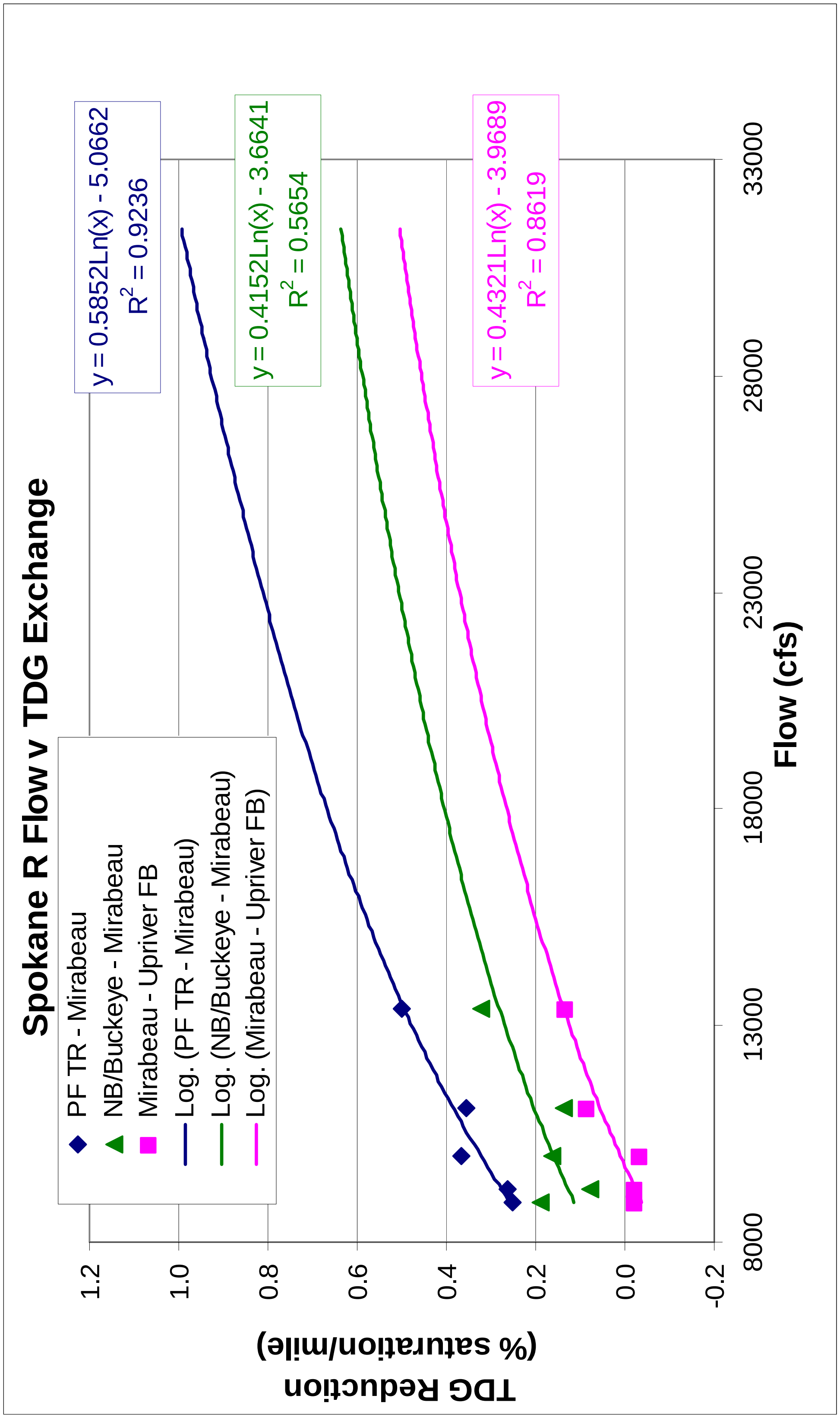


Figure 10. TDG Reduction in Spokane River by Reach, 2004 Spot Data

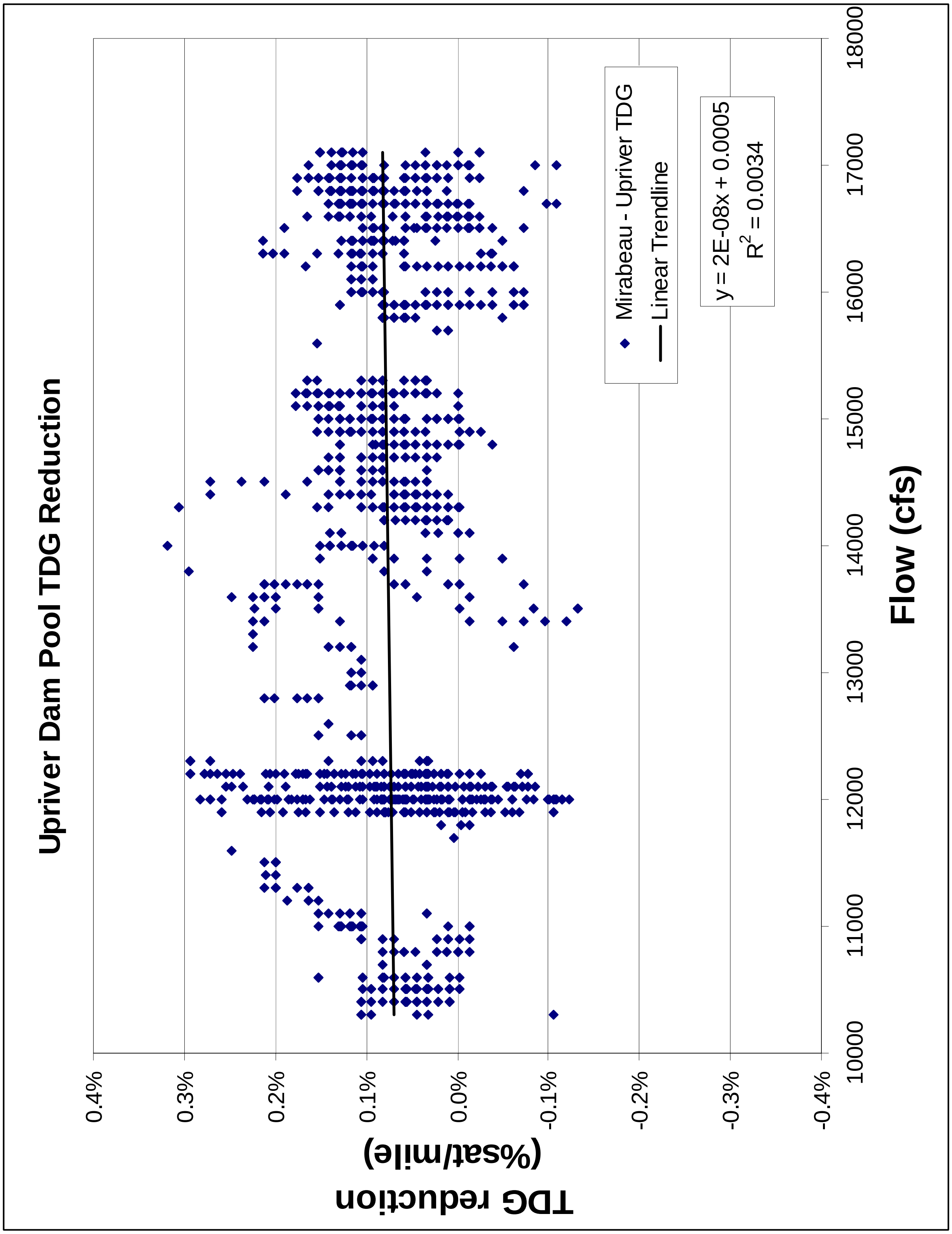
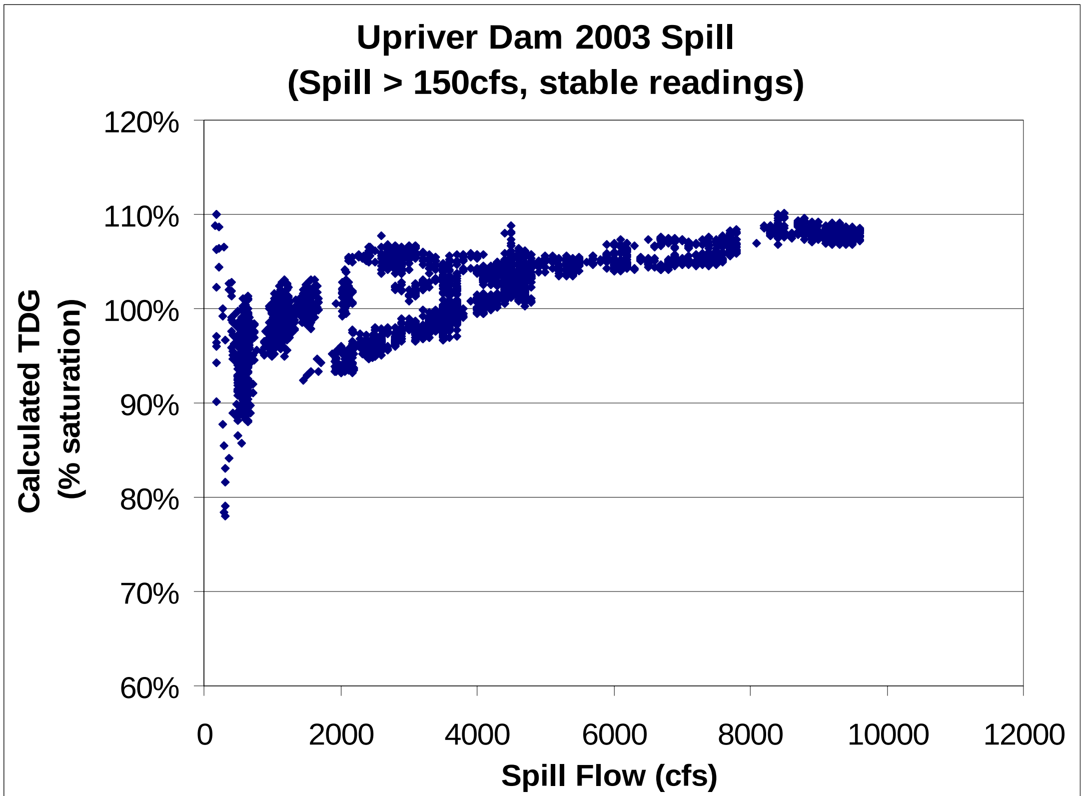


Figure 11. TDG Reduction, Mirabeau to Upriver Forebay, 2003 Continuous Data



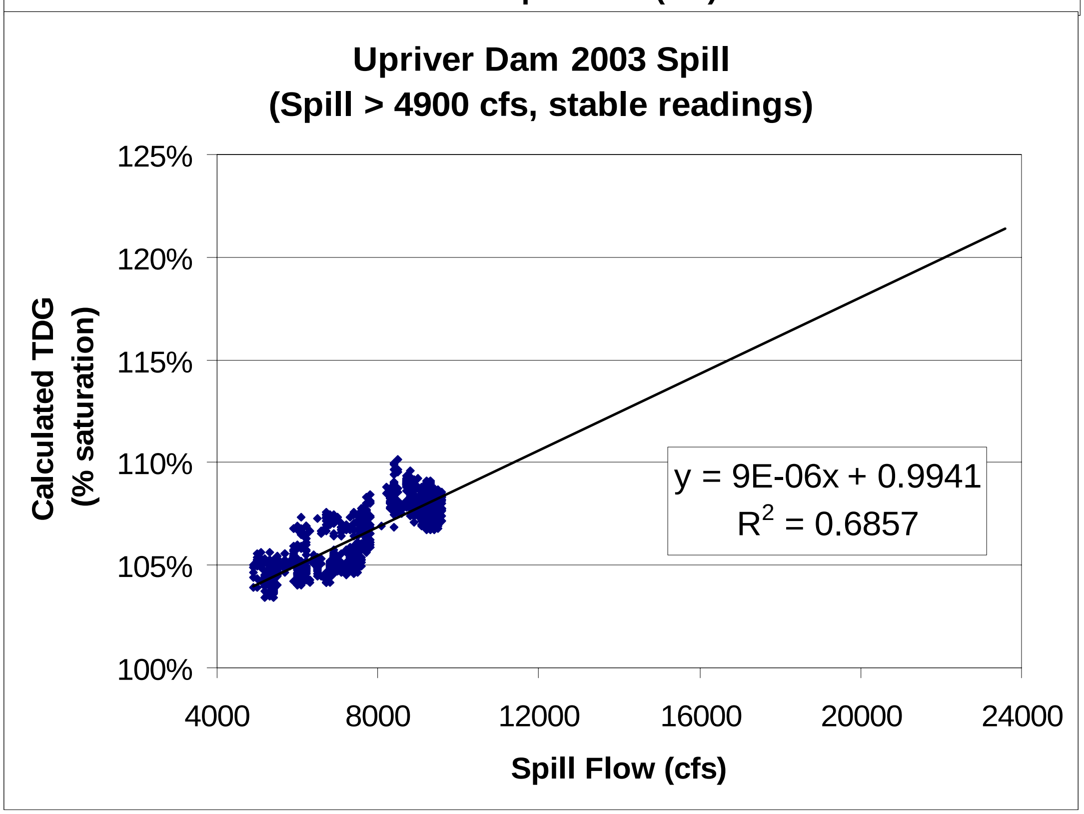


Figure 12. Calculated Upriver Dam Spill TDG Generation

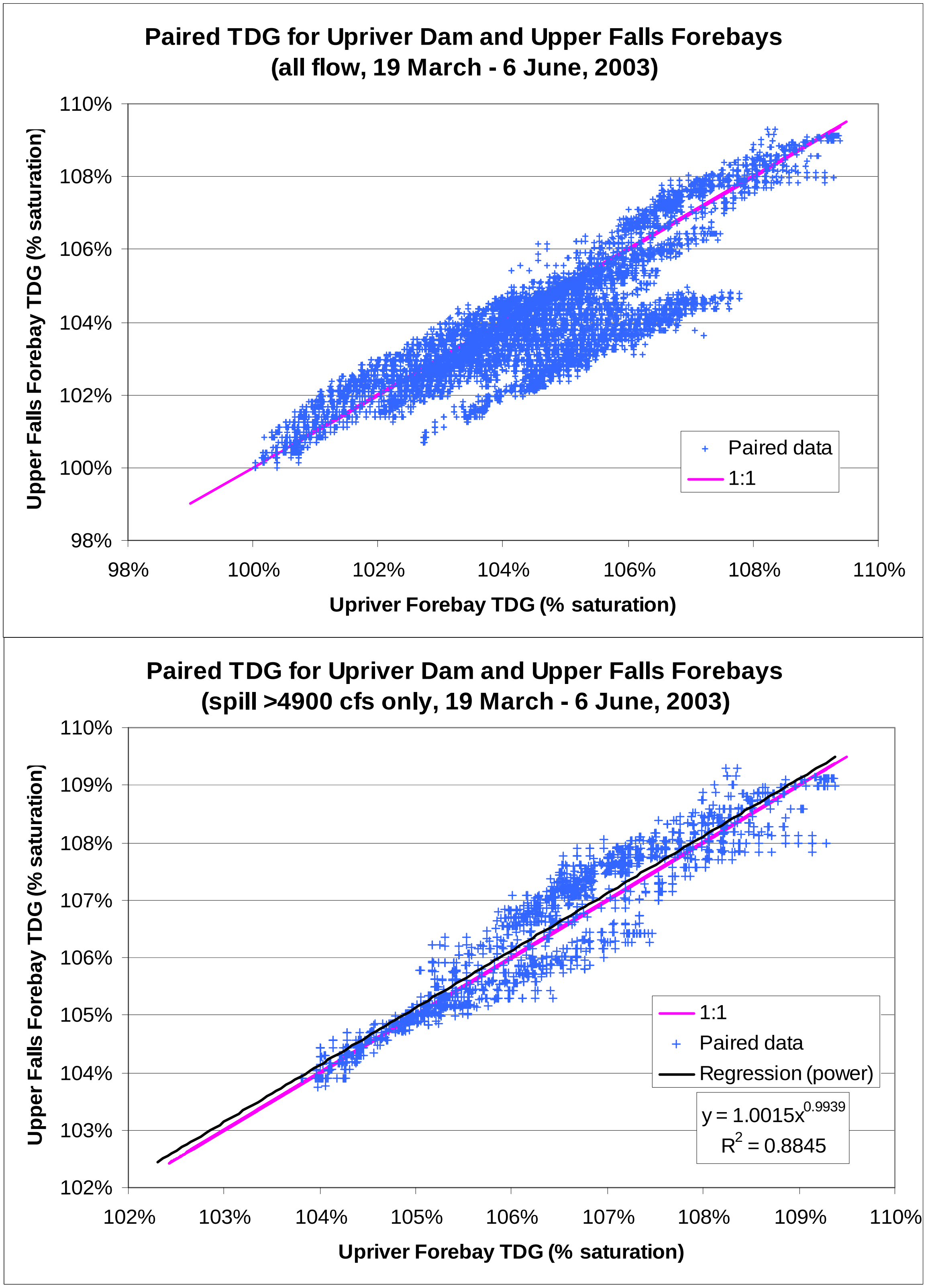


Figure 13. Paired TDG, Upriver Forebay and Upper Falls Forebay

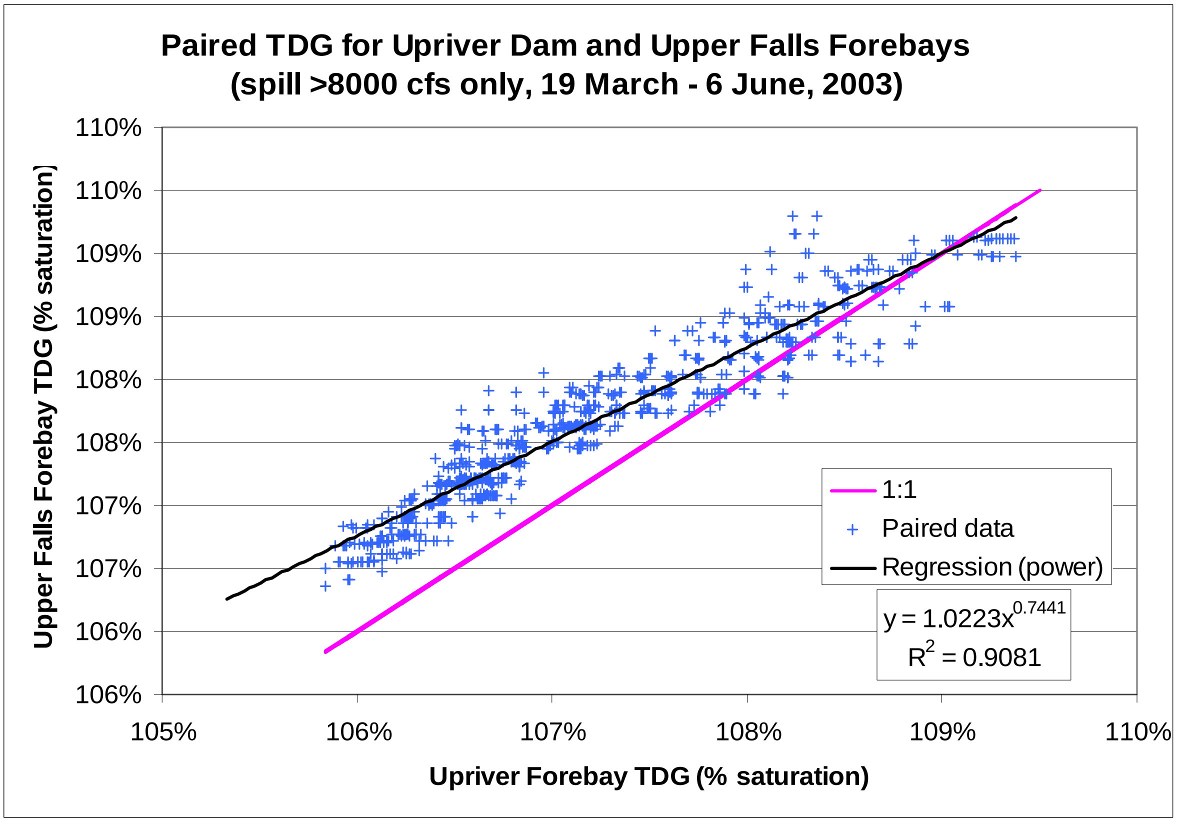


Figure 13, Continued. Paired TDG, Upriver Forebay and Upper Falls Forebay

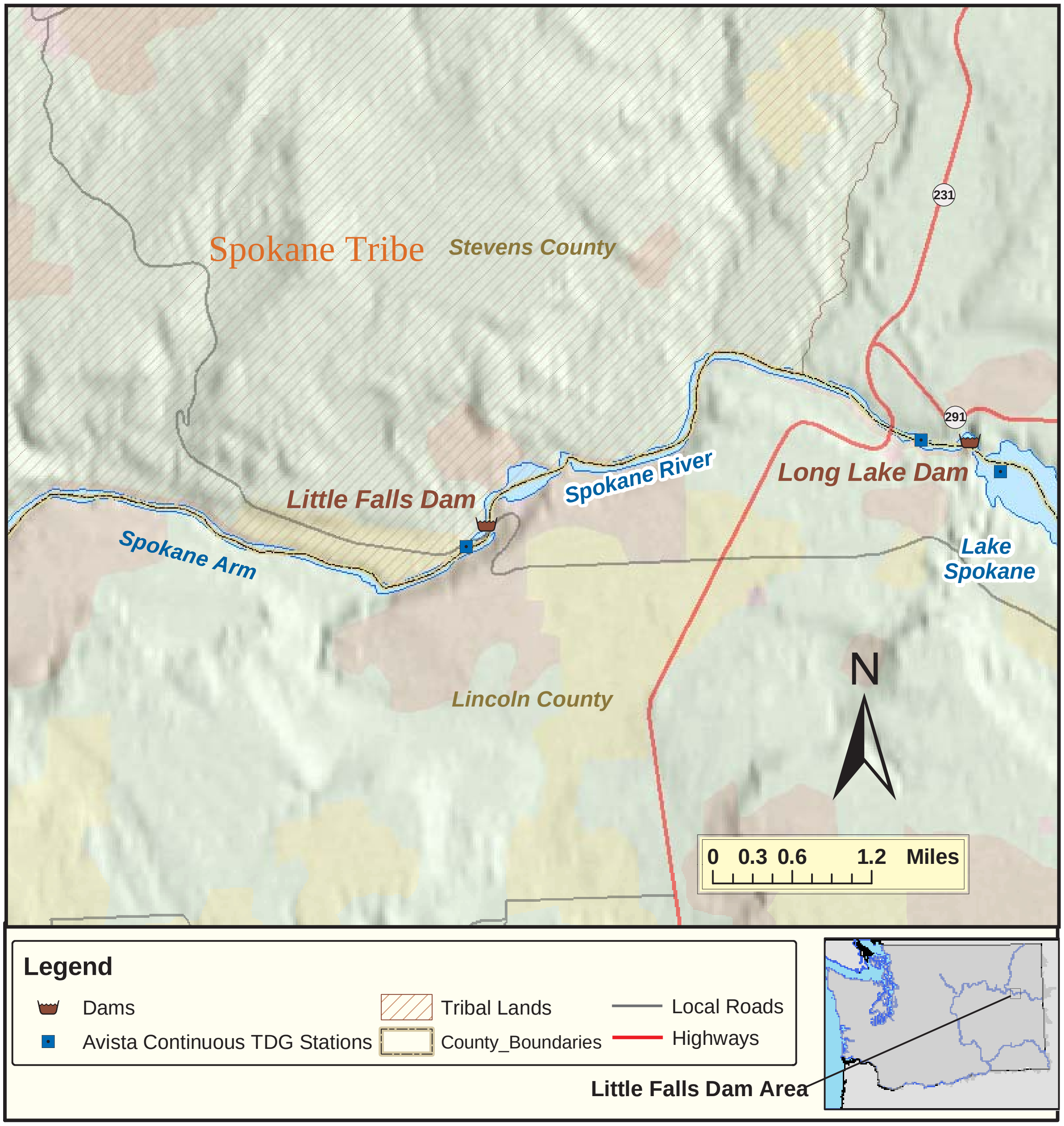


Figure 14. Little Falls Dam Vicinity Map

Figure 15. Little Falls Dam. (Photograph Courtesy of Avista Corporation)

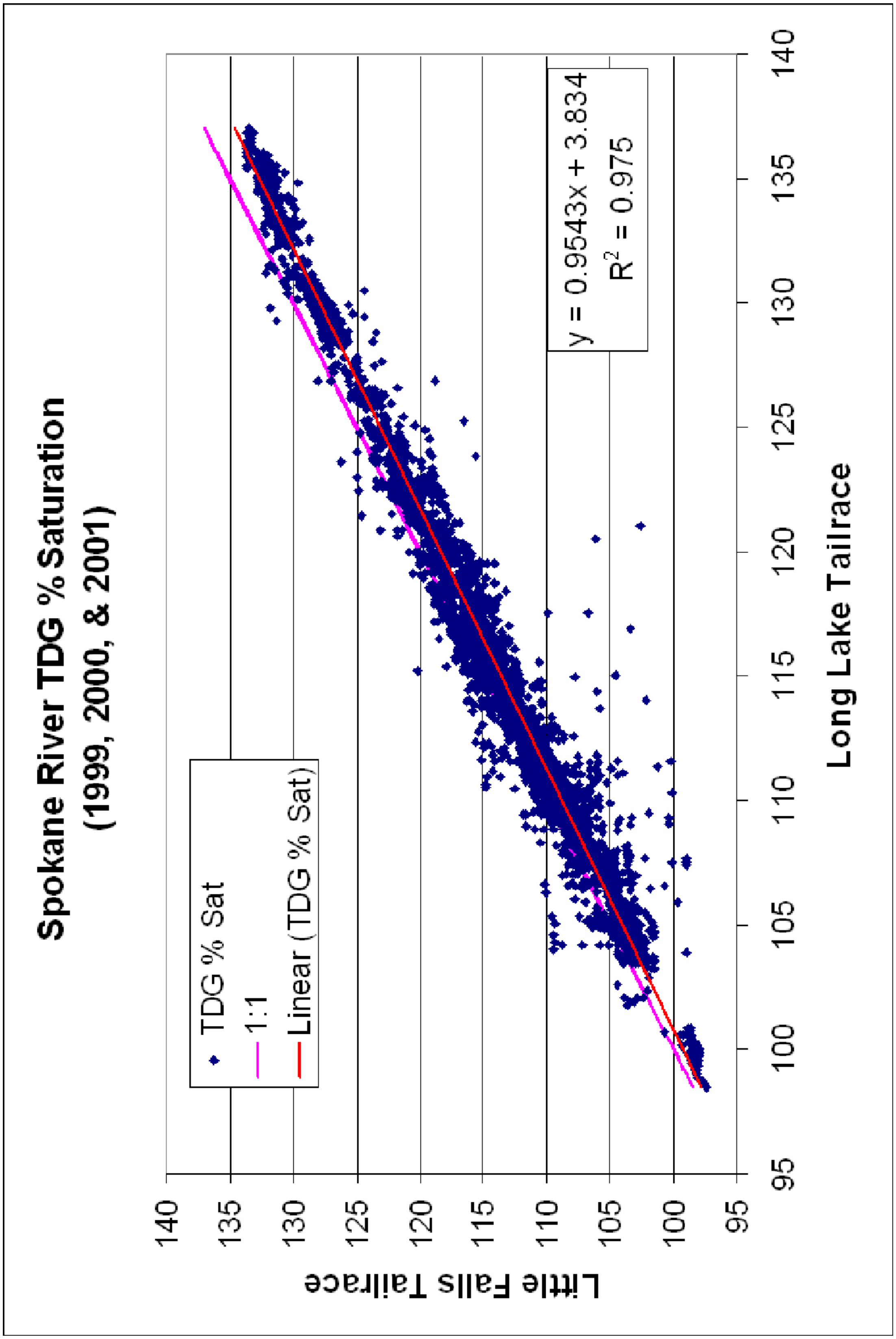


Figure 16. TDG Below Long Lake Dam and Little Falls Dam

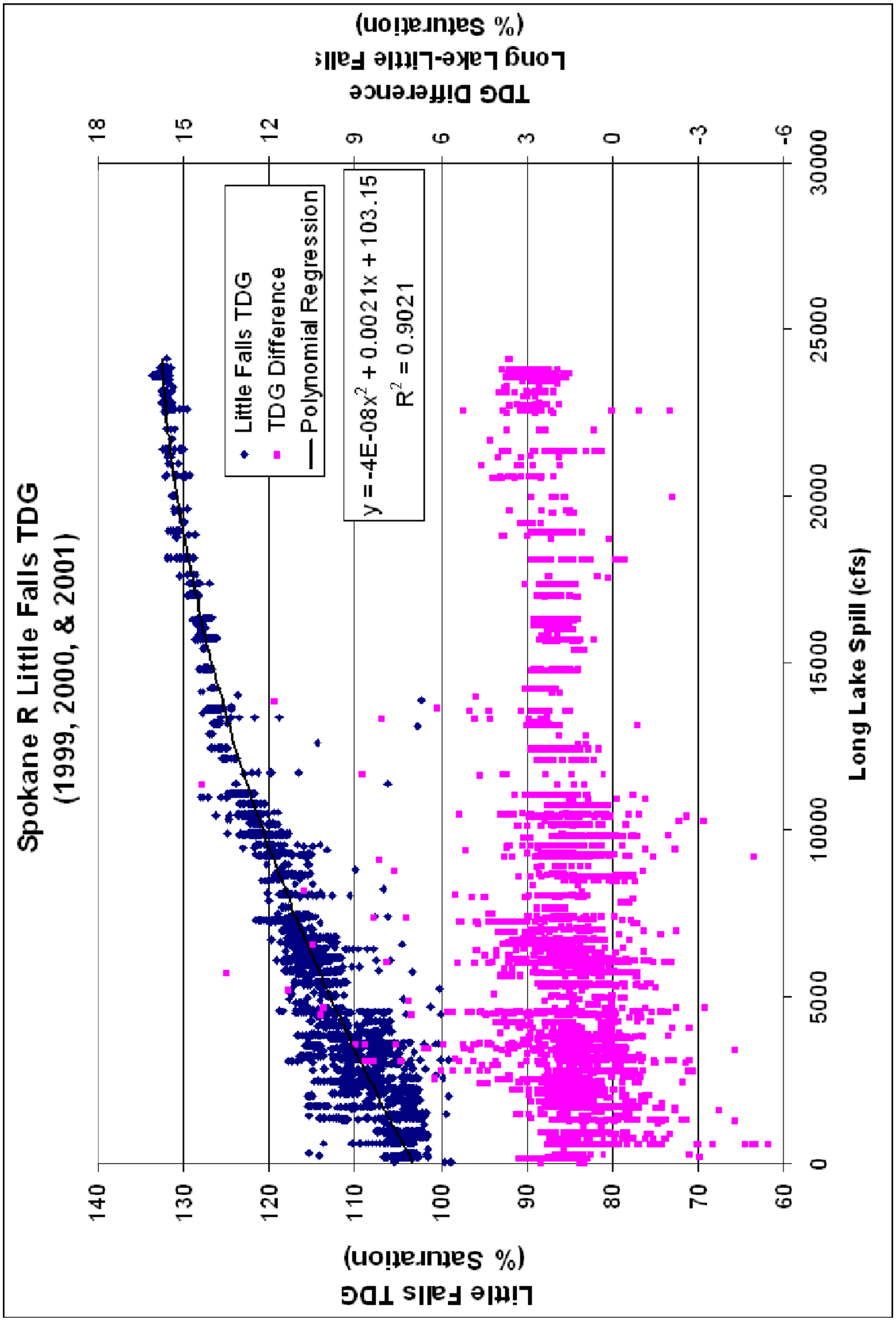


Figure 17. TDG Below Little Falls (Measurements and Difference from Long Lake Values) Versus Long Lake Spill

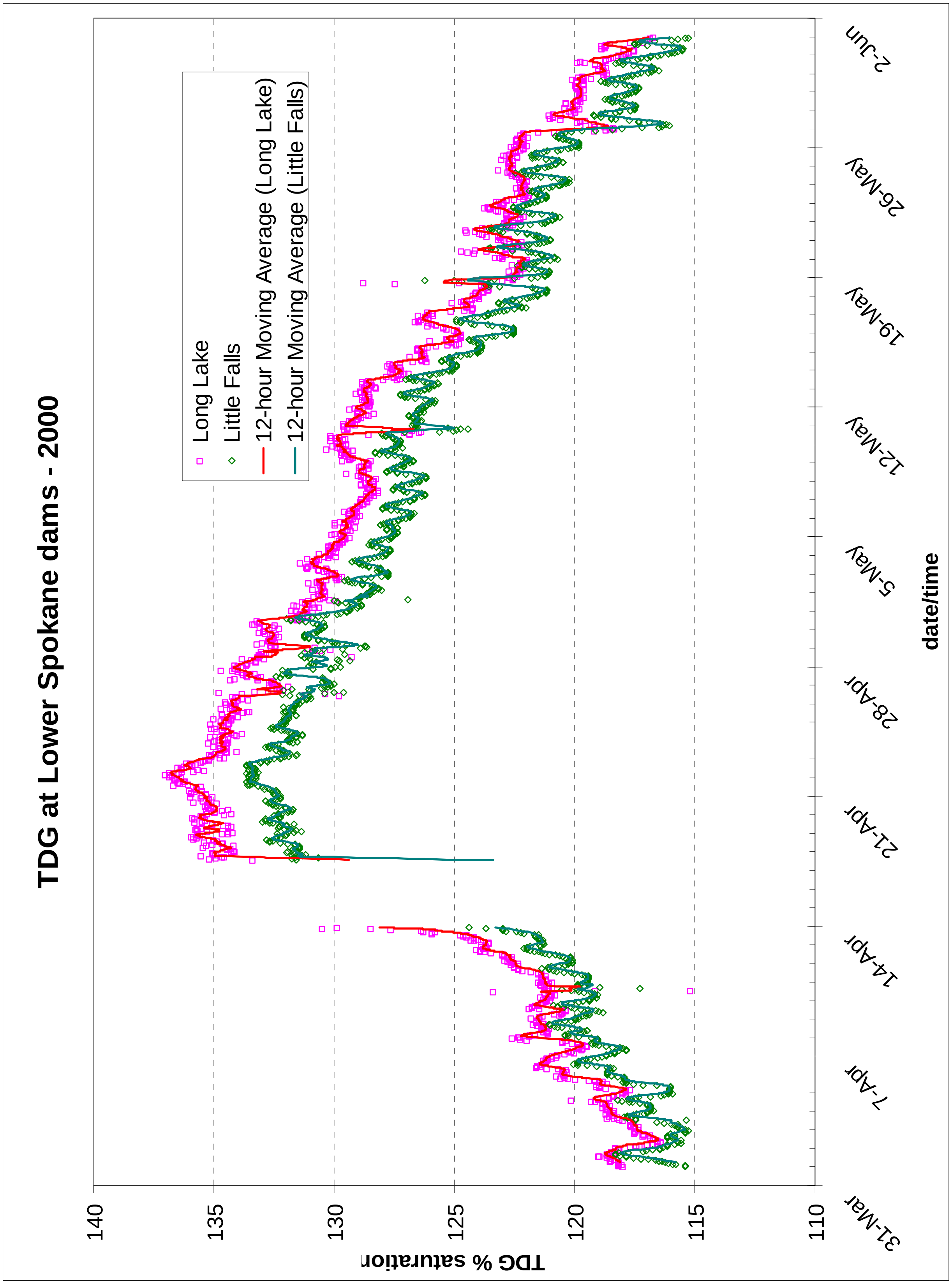


Figure 18. TDG Below Long Lake and Little Falls Dams, 2000 Peak Flow Conditions

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Appendix

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Total Dissolved Gas Monitoring Results, Spokane River, March - June 2003

Abstract

Total dissolved gas (TDG) was monitored in the Spokane River with data logging meters at Upriver Dam from March through June 2003 and near the Kaiser Trentwood plant (Mirabeau Park) from March through April 2003. Data will support the development of a Total Maximum Daily Load for TDG in the Spokane River. Data showed TDG changes over time at these two sites and allow comparisons to data upstream and downstream collected by other organizations.

Introduction

The Washington State Department of Ecology (Ecology) is determining the TMDL TDG in the Mainstem Spokane River from the Idaho border to its confluence with Lake Roosevelt. Ecology has reviewed data which show TDG levels above state water quality standards in multiple reaches of the Spokane River at levels that will likely result in listing the Spokane River on its 2002 303(d) list of impairment waters. The state of Washington will be issuing this TMDL and submitting it to the U.S. Environmental Protection Agency for its approval.

Spill events at hydroelectric projects and natural waterfalls (both of which are present on the Spokane River) can cause elevated TDG levels. For hydroelectric projects, water pouring over the spillway of a dam and plunging into tailrace waters entrains air bubbles. When these are carried to depth in the dam's stilling basin, the higher hydrostatic pressure forces air from the bubbles into solution. The result is water supersaturated with dissolved nitrogen, oxygen, and the other constituents of air.

As the bubbles rise in the aerated zone of the tailrace, some of the gas leaves solution at a relatively rapid rate. However, as the bubbles dissipate and the water enters the downstream reach, the remaining TDG will equilibrate with air pressure at the air-water interface at a relatively slow rate unless the process is enhanced by wind or channel-induced turbulence. At most dams, water passing through the powerhouse has virtually the same TDG levels as in the upstream forebay. (USACE, 2001)

Spills at hydroelectric projects can occur for several reasons:

- Powerhouse can't pass flood flows.
- Powerhouse capacity is not fully utilized due to lack of power demand.
- Powerhouse turbines are off line for maintenance or repair.

Although dams can spill at any time because of changes in power demand or turbine failure, typically the spill season occurs during the snowmelt-runoff season in late spring and early summer.

The TDG generation process at a natural waterfall is similar if the structure of the falls allows water to plunge to depth at the base of the falls. However, water cascading as shallow flow over rocks can have the opposite effect, allowing the stripping of supersaturated gas and rapidly establishing equilibrium with the atmosphere. Each waterfall is unique and has to be directly assessed to determine its effect on TDG levels.

A TDG TMDL for the Spokane River will be set by evaluating the effects of dams, hydroelectric projects, and natural features on TDG in the river. Consultants for the Avista Corporation collected TDG data in the Spokane River from spring 1999 through winter 2002 and during the 2003 runoff season for their project relicensing (CH2M Hill, 2002; Golder, 2003). Therefore, the TMDL will be developed mostly from analysis of this existing data.

Although Avista is collecting extensive data that will contribute to development of the TMDL, a few data gaps exist. Avista's monitoring plan included monitoring below Post Falls and above Upper Falls projects, but not in the reach in between which includes the City of Spokane's Upriver Dam. They also did not include Little Falls Dam in their 2003 monitoring. Therefore, Ecology conducted TDG monitoring upstream of Upriver Dam and provided support to the Spokane Tribe for TDG monitoring below Little Falls. The methods and results of Ecology's monitoring are described below.

Methods

The methods used for the TDG surveys followed the Quality Assurance (QA) Project Plan (Ecology, 2003) with the changes and exceptions noted below. Overall project planning was managed by Paul Pickett of Ecology's Environmental Assessment (EA) Program headquarters office in Olympia, while field operations were conducted by Jim Ross of Ecology's Eastern Regional Office in Spokane.

Figure 1 shows the TMDL study area including Spokane River dams and Ecology and Avista's 2003 long-term monitoring locations. Ecology's monitoring locations are described under *Results* and are shown at a smaller scale in Figure A-1. Monitoring was conducted at Upriver Dam from March through June 2003 and at the Kaiser Trentwood aluminum plant (across from Mirabeau Park) from March through April 2003. Daily average river flows prior to, during, and following the survey are shown in Figure A-2 (USGS Station 12422500, Spokane River at Spokane). The survey captured conditions during the 2003 spring freshet flows.

Data were collected by suspending each meter in a protective tube several meters below the surface, secured by cable or clamp from an existing structure. The meter at Upriver Dam was deployed in a protective tube attached to a footbridge crossing the powerhouse intake channel, which provided a representative measurement of river conditions above the dam. Gaps in the data occurred when the meter was serviced and during a period when the tube bent and floated up.

The meter at the Kaiser Trentwood plant was suspended by a steel cable from a bulkhead. Gaps in the data occurred during servicing and when the meter broke loose and floated downstream. The meter was recovered and returned by a local citizen. It appeared to be in good condition and was redeployed; but, major failure occurred within a couple weeks forcing the termination of monitoring at this site.

Meters were serviced four times during monitoring at Upriver Dam and twice at Kaiser. At each servicing, meter calibration was checked and data downloaded. The meters were also taken to the Avista TDG monitoring site at Long Lake Dam tailrace where paired measurements were taken.

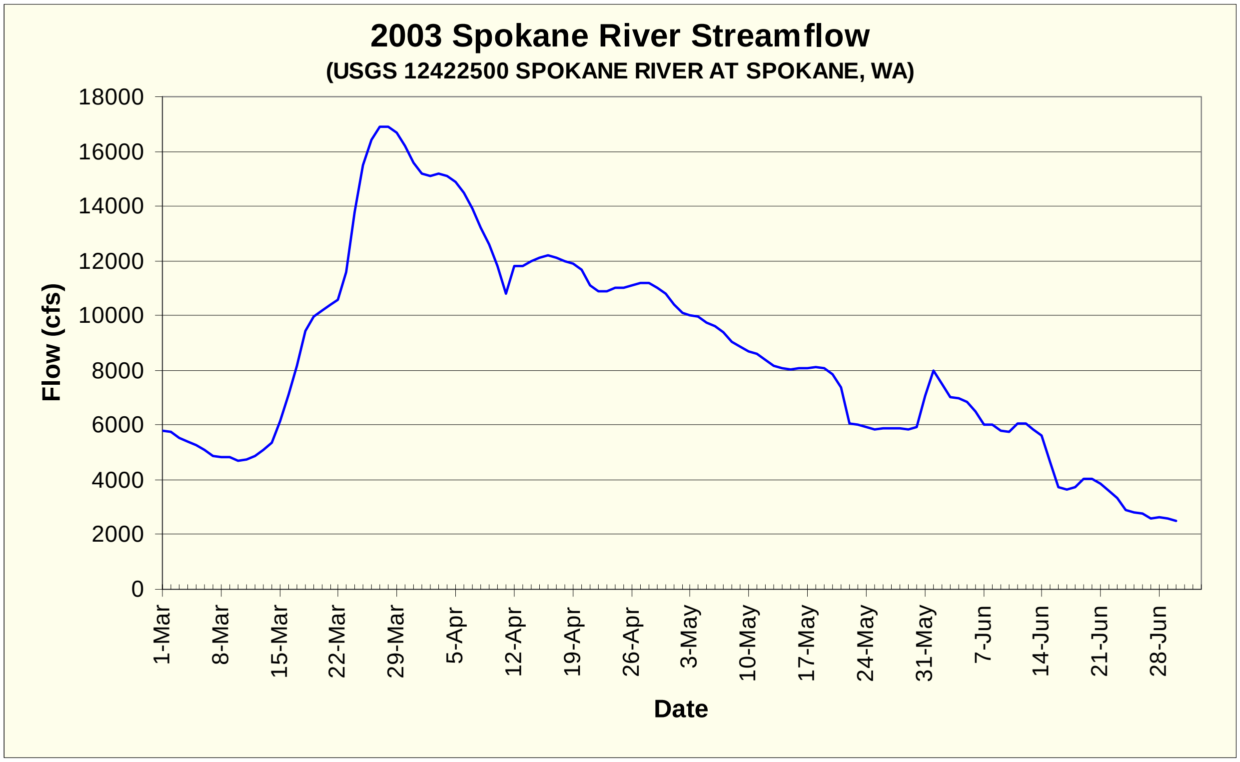

Figure A-2. Spokane River Flows During Monitoring Period

Spot measurements of barometric pressure were made during meter servicing using an aneroid barometer and the meters' pressure sensors with the TDG membrane removed. The National Weather Service station at Felts Field was relied upon as the main source of barometric pressure data because of its close proximity to the monitoring site. Felts Field station pressure was adjusted for elevation for each monitoring site.

Results

Data Quality

The analyses of monitoring data quality are shown in Tables 1 through 5. The root mean square error (RMSE) of measurements that meet MQOs are shown in bold, while RMSEs that exceed the MQOs are shaded.

Both meters met Measurement Quality Objectives (MQOs) for TDG during calibration and post calibration (+/- 5 mm Hg). The RMSE of paired Ecology meters ("Residual DS-DS" in Table 1) met the MQOs for both pressure and percent saturation, and the only pair that exceeded the MQO was pressures measured at different times during a period of rapidly changing TDG. The residuals between the meters and standard pressure during laboratory post calibration also met the MQO (Table 2). Therefore, the TDG data meets Data Quality Objectives (DQOs) and is considered acceptable for use in the TMDL.

Barometric pressure (BP) readings did not meet their MQOs in the field (Table 3). The approach planned in the QA Project Plan was to use Felts Field measurements (National Weather Service station "SFF") and convert them to local measurements by adding or subtracting a correction factor based on altitude. The factor would be determined by correlating Ecology spot measurements with a hand-held aneroid barometer to the SFF reported measurements.

To evaluate consistency with data collected by Golder (2003), barometric pressures calculated from Felts Field data were compared to pressures measured by Golder at the Upper Falls project. Figure A-3 shows this comparison. Factors developed from Ecology spot measurements under predict BP, both compared to Golder field data and to fundamental principles (pressures at lower elevations than Felts Field should be higher, but were not).

To improve BP estimates, a different factor for estimating local BP from Felts Field data and altitude was determined directly from Golder measurements. This approach improved the prediction, and was the method used to develop pressures for calculating percent saturation. Table 3 compares the two estimate methods.

BP estimates exceed the MQO. The BP MQO could have been met with direct measurements with the proper equipment, but resources were not available as part of this study to purchase the equipment. However, the BP MQO was much more stringent than the TDG pressure MQO (1 mm Hg versus 5 mm Hg). The observed RMSE of 2.7 mm Hg was still far below the TDG pressure MQO. Also, the variability in the BP estimates was small enough, in combination with TDG pressure measurement variability, to meet the MQO for percent saturation. Therefore, this BP estimation method (based on National Weather Service data and calibrated to Golder barometric data) is adequate for TMDL development purposes.

Golder's readings compared well with TDG readings conducted under this study ("DS-Golder" in Table 1). The RMSE differences met the MQOs, and the only individual paired reading that exceeded the MQO occurred at a time of rapidly changing TDG so a small difference in the internal clock times could account for some of the difference. Therefore, Ecology's and

Golder's TDG measurements appear to be comparable and can be used together for TMDL development.

DO data did not meet MQOs (Table 4), and problems were observed with calibration and with field measurements. DO data should be used with caution, probably only to track general tendencies. Golder DO readings were reported as pressure and were converted to mg/L using a table of conversion values (Colt, 1984). The resulting DO concentrations were significantly higher than the Ecology DO readings. DO readings between Golder and Ecology cannot be considered comparable.

Paired Ecology field temperature, pH, and conductivity readings met MQOs for all surveys (Table 5). However, laboratory calibration was not documented, and visual examination of the data shows problems with pH and conductivity readings due to outliers and blocks of spurious data. Temperature data are considered acceptable for use, but pH and specific conductance data should be used with great caution. Golder temperature readings met MQOs when paired with Ecology data, and can be considered comparable. Golder did not measure pH or conductivity.

Field Data

The TDG pressures measured in the Spokane River are shown in Figure A-4, while the TDG percent saturation values from monitoring are shown in Figure A-5. Pressures tend to track river flows, with the highest pressures and percent saturation associated with the maximum flows and the lowest values during the lowest flows. Maximum TDG levels remained below 110% saturation at both sites for all measurements.

Figure A-6 shows the pattern of temperature readings during monitoring. Values generally increased over time, as would be expected, and daily variation in temperature could also be observed.

A pattern of diurnal TDG variation can also be observed, with minimum levels in the morning and maximum levels in the evening. This could be associated with a number of processes including temperature variations, DO variations produced by instream productivity, or upstream hydroelectric operations.

To evaluate the effect of temperature and DO on TDG levels, a five-day period at the end of the monitoring period was chosen to analyze TDG levels (Figure A-7). The effect of changes in temperature and DO on TDG pressures was evaluated with a spreadsheet calculator based on the physical processes governing gasses in solution (Colt, 1984). First, TDG pressures were calculated from median daily conditions of temperature, percent saturation, and barometric pressure. Then maximum and minimum TDG pressures were estimated using maximum and minimum daily temperatures and DO. Since the measured DO values were unreliable, the observed range of DO around the median was added or subtracted from the median DO concentration calculated by the spreadsheet (on the assumption that the daily range might be reasonably accurate even if the absolute measurement was not). The results, shown in Table 6, suggest that the daily variation in TDG can be explained almost entirely by the daily fluctuations in temperature and DO.

The Upriver and Kaiser sites appear to have very similar TDG levels. When the distributions of the two sites are compared (Table 7), TDG levels were lower at the Upriver Dam site than at the Kaiser site about 75% of the time. The median difference between values at the two sites was 2 mm Hg pressure and 0.5% saturation. Since the temperatures at Upriver tended to be slightly higher than Kaiser, this indicates that TDG levels continue to move towards equilibrium (i.e. "degassing" is occurring) as the water moves between the sites.

Conclusions and Recommendations

Data for TDG and temperature collected by Ecology at Upriver Dam from March through June and from the Kaiser Trentwood plant in March and April are of good quality and are comparable to data collected by Golder at other sites on the Spokane River at the same time. Therefore, Ecology TDG and temperature data can be used in TMDL development combined with Golder data. Conductivity, pH and DO data are of poor quality and should be used with caution.

TDG levels correspond roughly to flow levels but do not exceed the state standard of 110% saturation. Daily patterns of TDG can be mostly explained by diurnal temperature and dissolved oxygen cycles, which are likely caused by solar heating and primary productivity.

Several recommendations are suggested for future Ecology TDG monitoring surveys:

- Methods should be explored for more accurate on-site measurement of barometric pressure.
- Methods to improve the quality of DO, conductivity, and pH measurements should be evaluated and implemented.

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Colt, J., 1984. Computation of Dissolved Gas Concentrations in Water as Functions of Temperature, Salinity, and Pressure. American Fisheries Society Special Publication 14.

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Tables

Table 1. Field Water Quality Monitoring QA/QC for TDG

TDG (mmHg)						
Date	Time	DS15	DS16	Golder	Residual DS-Golder	Residual DS-DS
18-Mar	9:40	737		735	1.6	
18-Mar	10:00		737	736	0.9	0.0
31-Mar	15:55	877		881	-4.0	
31-Mar	15:36		878	881	-3.0	-1.0
15-Apr	12:20	875		882	-7.0	
15-Apr	11:58		886	886	0.0	-7.0
21-May	10:00	764		766	-2.0	
6-Jun	11:24	776		778	-2.0	
Root Mean Square Error (RMSE) (Target = 5)					**3.3**	**4.1**

TDG (% Saturation)						
Date	Time	DS15	DS16	Golder	Residual DS-Golder	Residual DS-DS
18-Mar	9:40	101.0%		100.7%	-0.2%	
18-Mar	10:00		100.8%	100.7%	-0.1%	0.1%
31-Mar	15:55	122.3%		122.9%	0.6%	
31-Mar	15:36		122.5%	122.9%	0.4%	-0.1%
15-Apr	12:20	120.9%		121.8%	1.0%	
15-Apr	11:58		122.7%	122.7%	0.0%	-1.0%
21-May	10:00	104.7%		104.9%	0.3%	
6-Jun	11:24	106.6%		106.9%	0.3%	
RMSE (Target = 1%)					**0.5%**	**0.6%**

Table 2. Laboratory TDG Post Calibration QA/QC, mm Hg

Date	DS15 meter	DS15 standard	Difference (Target = +/- 5.0)	DS16 meter	DS16 standard	Difference (Target = +/- 5.0)
3/17	707	707	**0**	705	704	**1**
3/17	907	907	**0**	902	904	**2**
3/31	705	703	**2**	708	703	**5**
3/31	900	903	**-3**	900	903	**3**
4/15	707	704	**3**	707	704	**3**
4/15	906	904	**2**	906	904	**2**
4/29	704	703	**1**			
4/29	902	903	**-1**			
5/19	719	719	**0**			
5/19	918	919	**-1**			

Table 3. Field Barometric Pressure Monitoring QA/QC, mm Hg
(Estimate from Felts Field Readings Versus Golder Measurements [Upper Falls])

Regression to Ecology Readings		Regression to Golder Readings	
95th percentile	11.9	95th percentile	4.3
75th percentile	9.3	75th percentile	1.8
Median	7.7	Median	0.1
25th percentile	5.8	25th percentile	-1.7
5th percentile	4.3	5th percentile	-3.3
RMSE (Target = 1)	8.0	RMSE (Target = 1)	2.7

Table 4. Field Water Quality Monitoring QA/QC for DO

DO (mg/L)						
Date	Time	DS15	DS16	Golder	Residual DS-Golder	Residual DS-DS
18-Mar	9:40	9.9		11.4	-1.5	
18-Mar	10:00		9.3	11.5	-2.2	0.6
31-Mar	15:55	8.8		14.2	-5.4	
31-Mar	15:36		10.2	14.1	-3.9	-1.4
15-Apr	12:20	11.5		14.6	-3.1	
15-Apr	11:58		8.8	14.8	-6.0	2.7
21-May	10:00	9.8		11.1	-1.3	
6-Jun	11:24	9.4		10.5	-1.1	
RMSE (Target = 0.5)					3.5	1.8

Table 5. Field Water Quality Monitoring QA/QC for Temperature, pH, and Conductivity

Temperature (Deg C)						
Date	Time	DS15	DS16	Golder	Residual DS-Golder	Residual DS-DS
18-Mar	9:40	5.5		5.7	-0.2	
18-Mar	10:00		5.4	5.7	-0.3	0.1
31-Mar	15:55	6.1		6.3	-0.2	
31-Mar	15:36		6.0	6.2	-0.2	0.1
15-Apr	12:20	7.7		7.7	0.0	
15-Apr	11:58		7.7	7.7	0.0	0.0
21-May	10:00	11.8		11.7	0.1	
6-Jun	11:24	15.5		15.3	0.2	
RMSE (Target = 0.5)					**0.2**	**0.1**

pH (std Units)						
Date	Time	DS15	DS16			Residual DS-DS
18-Mar	9:40	7.9				
18-Mar	10:00		8.3			-0.4
31-Mar	15:55	7.8				
31-Mar	15:36		7.7			0.1
15-Apr	12:20	7.9				
15-Apr	11:58		7.9			0.0
RMSE (Target = 0.5)						**0.2**

Specific Conductance (uS/cm)						
Date	Time	DS15	DS16			Residual DS-DS
18-Mar	9:40	115				
18-Mar	10:00		114			1
31-Mar	15:55	69				
31-Mar	15:36		70			-1
15-Apr	12:20	75				
15-Apr	11:58		76			-1
RMSE (Target = 5)						**1**

Table 6. Analysis of the Effect of Temperature and DO on TDG

Median					
Date	TDG (mm Hg)	Temp (deg C)	DO Range (mg/L)	BP (mm Hg)	TDG (%sat)
1-Jun	732.0	16.0	+/- 0.4	714.2	102.5%
2-Jun	731.0	15.6	+/- 0.3	714.4	102.3%
3-Jun	730.0	15.5	+/- 0.3	714.6	102.2%
4-Jun	731.0	15.6	+/- 0.3	715.6	102.2%
5-Jun	733.0	15.9	+/- 0.2	714.9	102.5%

Maximum			
Date	Temp (deg C)	Pred TDG (mm Hg)	Obs TDG (mm Hg)
1-Jun	16.7	747.9	746.0
2-Jun	16.3	746.2	745.0
3-Jun	16.5	749.6	747.0
4-Jun	17.0	755.9	749.0
5-Jun	17.3	755.6	750.0

Minimum			
Date	Temp (deg C)	Pred TDG (mm Hg)	Obs TDG (mm Hg)
1-Jun	15.4	717.4	720.0
2-Jun	14.9	716.304	720.0
3-Jun	14.8	715.7	717.0
4-Jun	14.7	713.396	717.0
5-Jun	14.9	715.3	719.0

Table 7. Distribution of TDG Pressures at the Upriver Dam and Kaiser Sites, mm Hg

Pressure (mm Hg)			
	Upriver	Kaiser	Difference between Paired Values (Upriver-Kaiser)
Maximum	785	786	7
90th Percentile	777	776	1
75th Percentile	769	770	0
Median	758	756	-2
25th Percentile	745	744	-3
10th Percentile	736	738	-5
Minimum	730	733	-12

Percent Saturation			
	Upriver	Kaiser	Difference between Paired Values (Upriver-Kaiser)
Maximum	109.4%	109.6%	0.8%
90th Percentile	108.1%	108.3%	-0.1%
75th Percentile	107.2%	107.3%	-0.2%
Median	106.3%	106.3%	-0.5%
25th Percentile	104.7%	104.8%	-0.6%
10th Percentile	103.8%	104.1%	-0.9%
Minimum	102.4%	102.9%	-1.9%

Figures

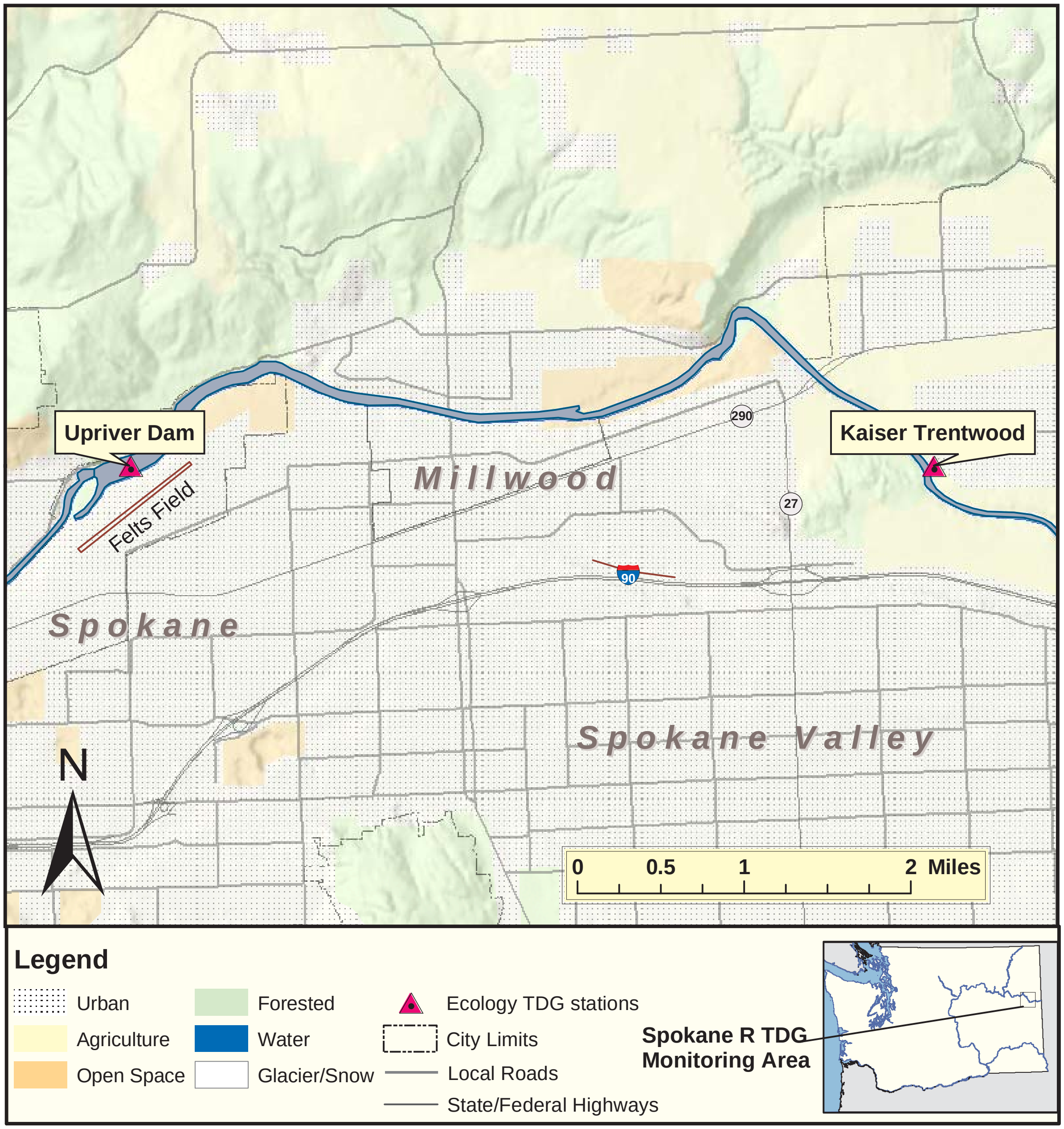

Figure A-1. TDG Monitoring Locations

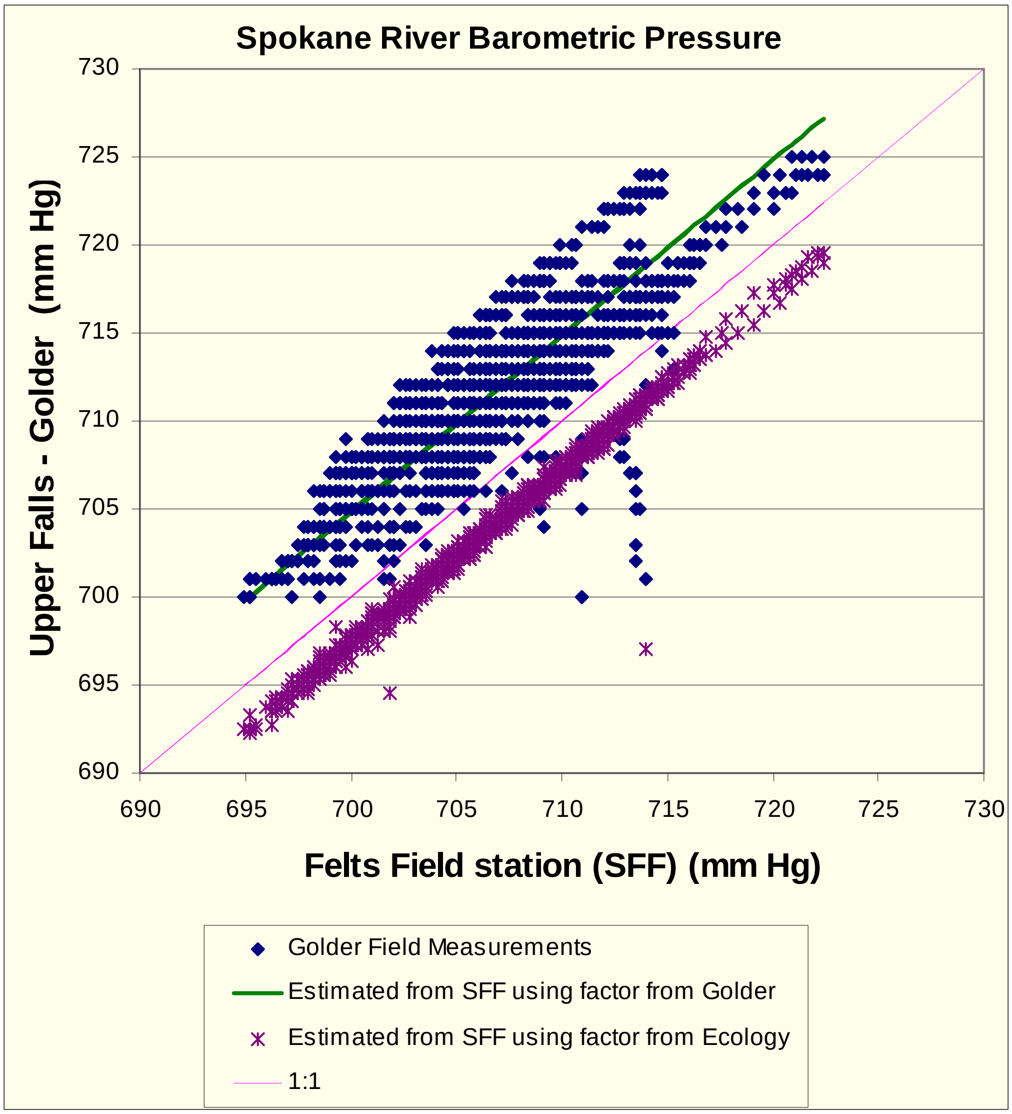

Figure A-3. Comparison of Barometric Pressure Estimation Methods

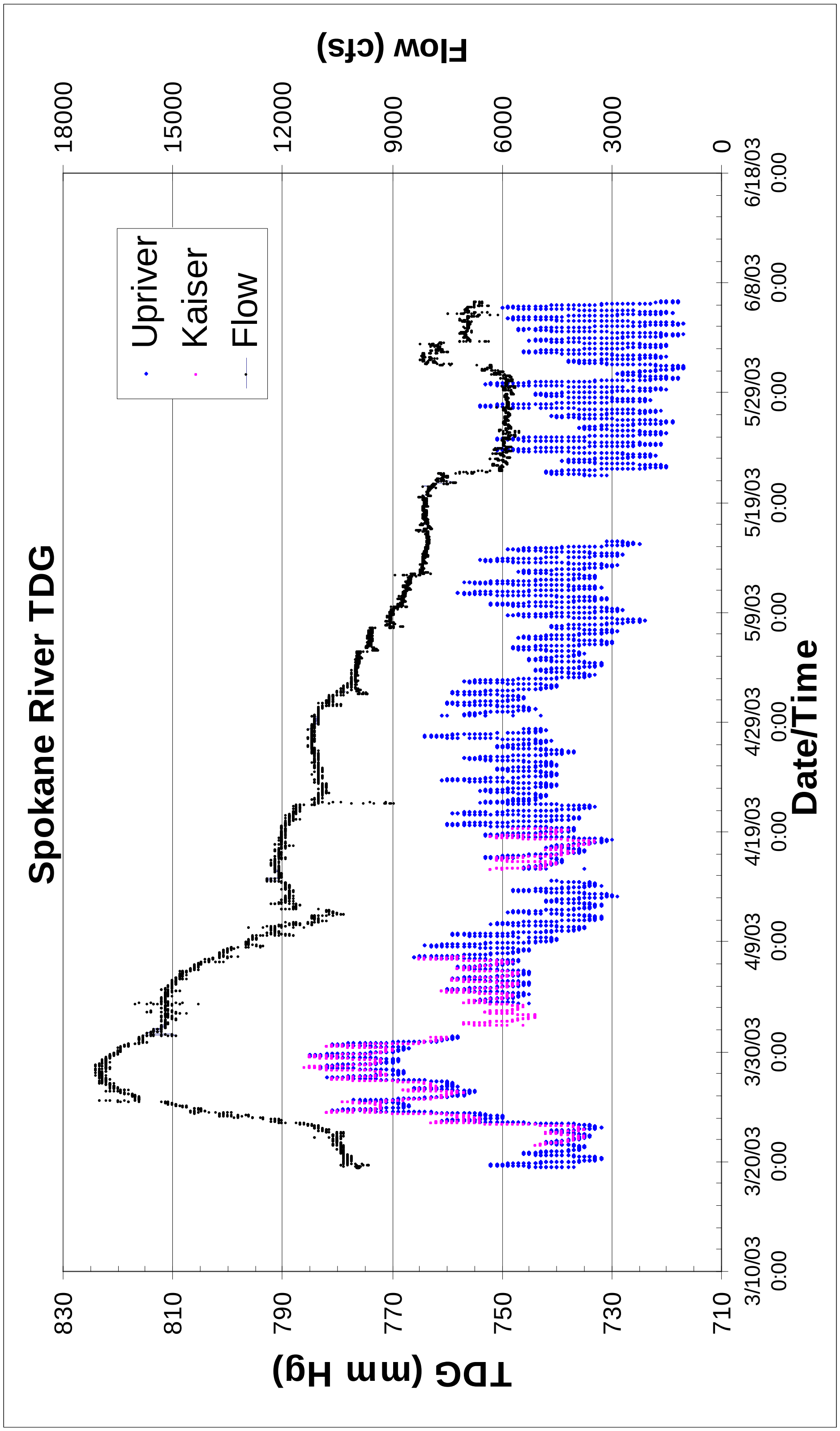

Figure A-4. Spokane River TDG Pressure

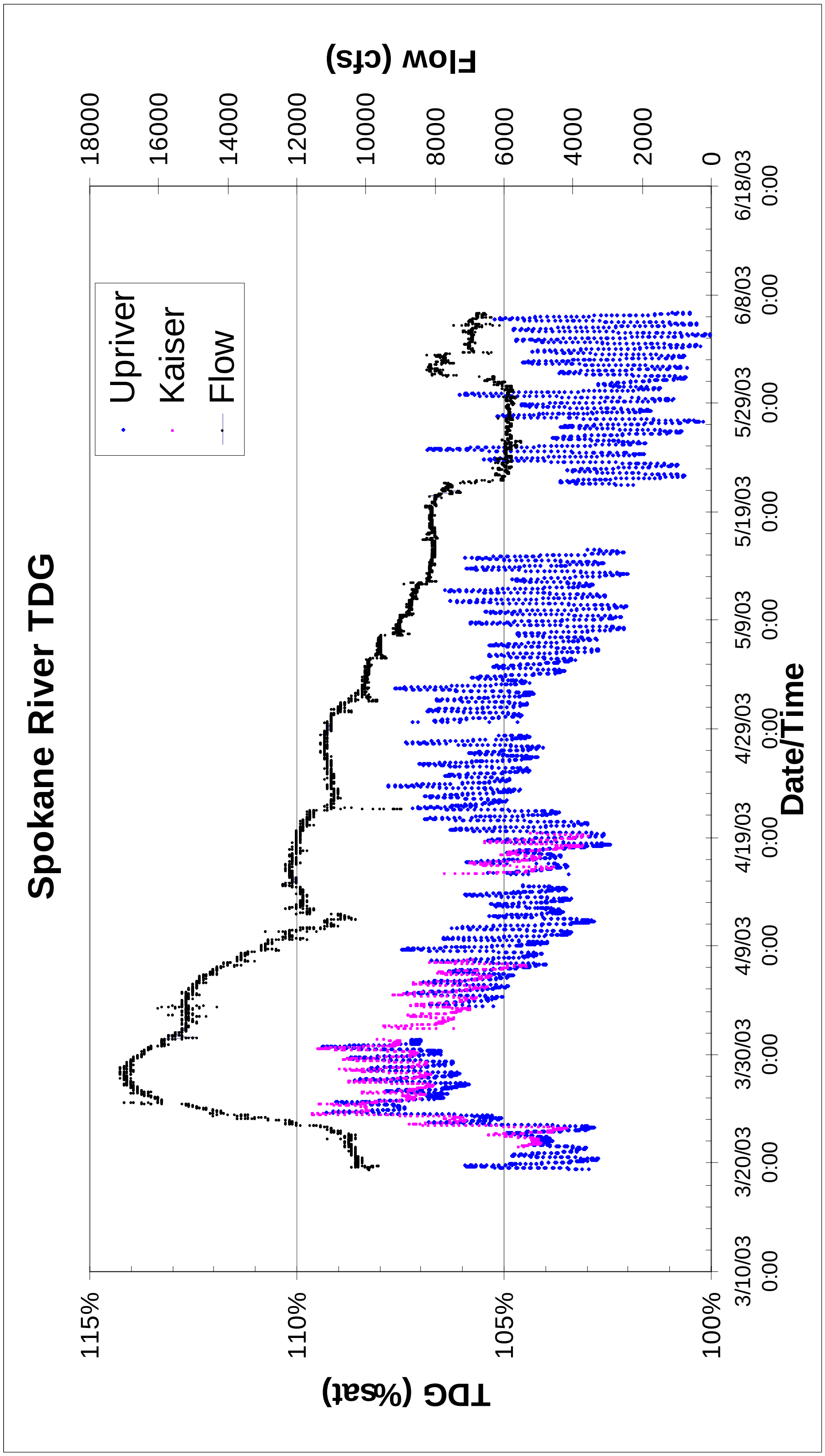

Figure A-5. Spokane River TDG Percent Saturation

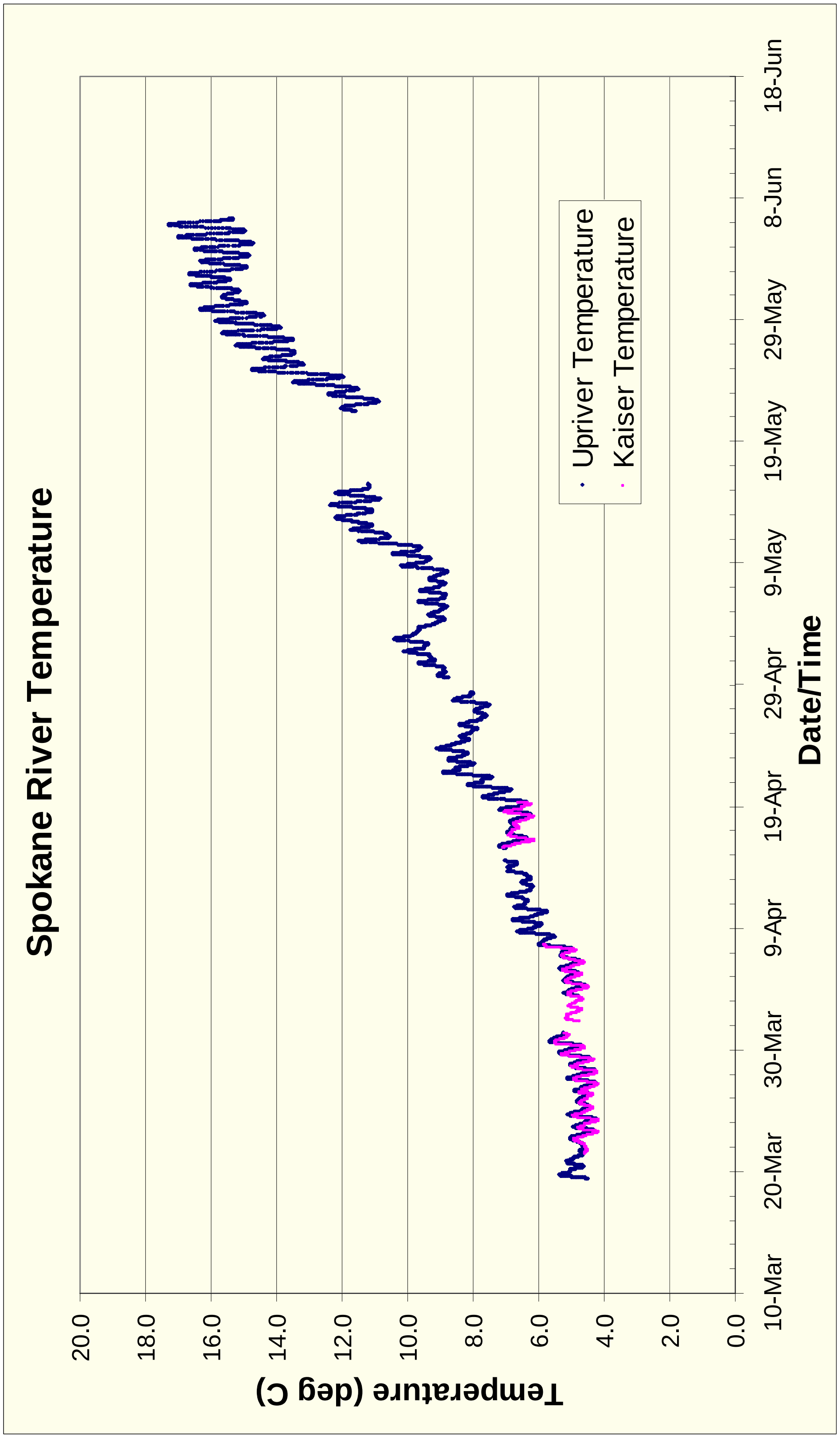

Figure A-6. Spokane River Temperature

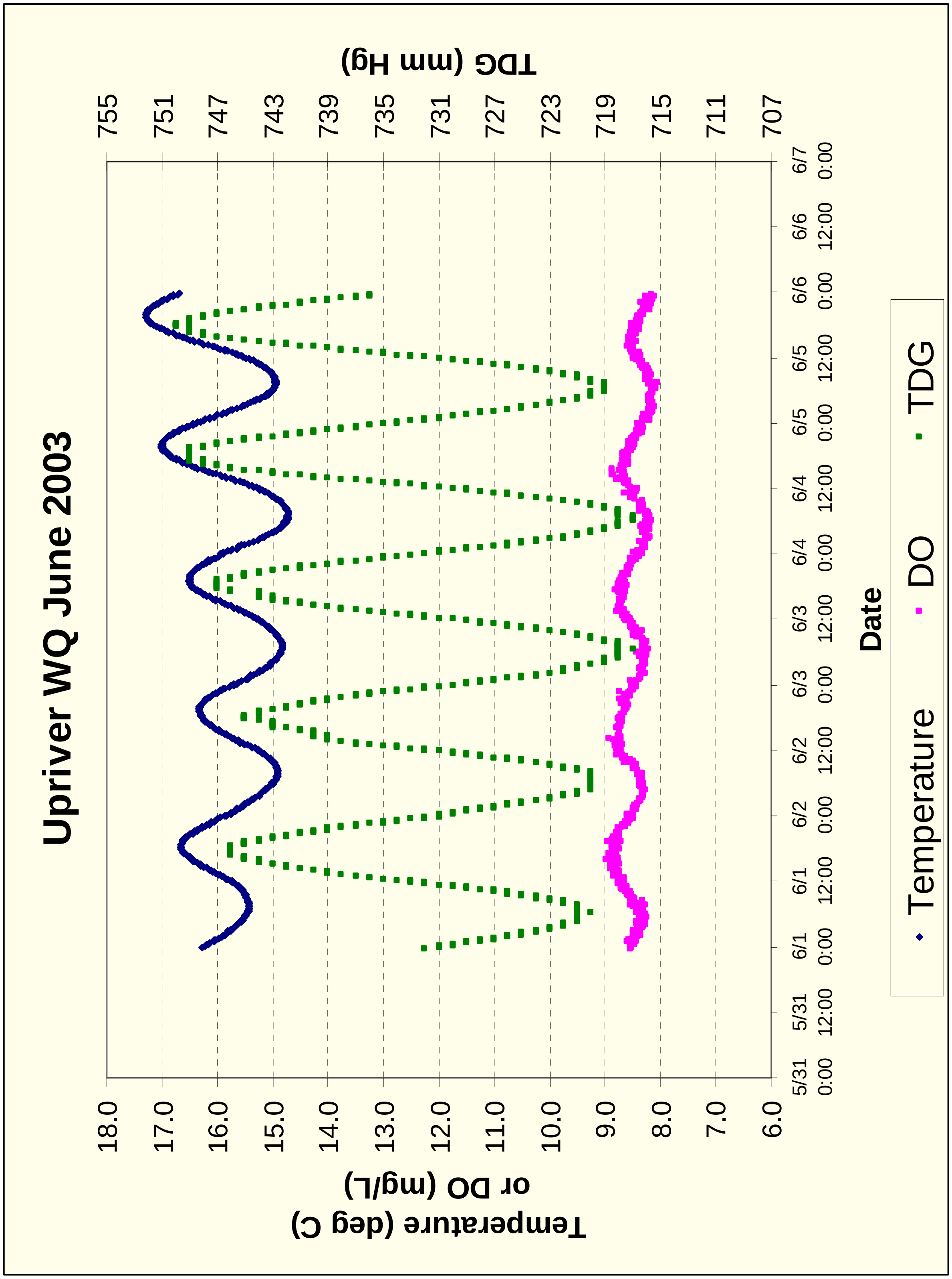

Figure A-7. Spokane River TDG, Temperature, and DO June 1-5, 2003