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MEMORANDUM

TO: Lance Keller (Chelan PUD)
Scott Hopkins (Chelan PUD)

FROM: Michele DeHart

DATE: September 25, 2018

SUBJECT: Results from Gas Bubble Trauma Monitoring Protocol at Rock Island Dam, 2018.

The purpose of this memorandum is to provide results from the modified Gas Bubble Trauma (GBT) protocol that was implemented in 2018 at Rock Island Dam (RIS). Specifically, we analyzed the data collected in 2018 under this modified protocol to determine whether we still see evidence that there is a difference in GBT incidence rates between "traditional" and "fresh" sampled fish. Below is a brief summary of our findings, followed by: 1) an overview of background information that led to this modified protocol, 2) a detailed description of the modified protocol, and 3) more detailed information on the analyses that were conducted for this memorandum.

- Data from 2018 continue to indicate that "fresh" fish can be captured and examined in a safe and efficient manner at RIS.
- The modified protocol that was implemented in 2018 demonstrated that it is possible to meet sample size requirements using exclusively "fresh" fish, at least for a portion of the season. "Traditional" fish will still be needed at times to assure sample size requirements are met, particularly at the beginning and end of the season.
- Based on fish collected and examined in 2018, "traditional" fish continue to have significantly higher GBT incidence rates than "fresh" fish.
- Results from 2018 are similar to those from our 2017 analysis (FPC 2017). Therefore, it appears that historic GBT rates at RIS are likely biased high and should be considered in the context of the sampling protocol in those years (i.e., "traditional" fish only).
- From the modified sampling protocols that were implemented in 2016-2018, it appears that using "fresh" fish in the GBT sample may reduce this bias and

potentially make results from RIS GBT sampling more representative of what is occurring to the run-at-large. However, the degree to which "fresh" fish are used in the GBT sample will influence the degree to which the bias is reduced.

- Based on these analyses, the FPC recommends continuing the 2018 GBT protocol in future years at RIS.

Background of Gas Bubble Trauma Monitoring Program and Sampling at Rock Island Dam

The objective of the Gas Bubble Trauma (GBT) monitoring program is to provide a measure of the exposure to harmful levels of total dissolved gas (TDG) experienced by migrating juvenile salmonids. The monitoring assesses both the incidence and severity of exposure, and provides an "early warning" of potentially harmful levels of TDG. The data are reported to the fisheries management entities and the water quality agencies of Washington and Oregon, and are available to other interested parties through FPC weekly reports and daily postings to the FPC website (http://www.fpc.org/smolt/gasbubbletrauma.html) during the season. The fisheries management entities review these data in-season to determine if modifications to spill are necessary based on the GBT monitoring.

Fish that are held at shallow depths for long periods of time may exhibit signs of GBT even at low TDG levels and, therefore, would not be representative of the migrating population (Weitkamp 2000). The GBT monitoring program is designed to minimize the holding time prior to examining fish. Fish to be examined for GBT are netted at the separator at Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), and McNary (MCN) dams, which greatly reduces the holding time at these sites. However, sampling at the separator is not possible at Bonneville (BON) and Rock Island (RIS) dams. Instead, fish at these sites are removed from the sample tank (BON) or sample trap (RIS). Over the years, SMP personnel at BON have reduced the amount of time that GBT sample fish are held in the sample tank to 2-3 hours by taking multiple draws from the sample tank on GBT exam days.

Rock Island Dam does not have a traditional bypass system. There are no screens that guide fish entering the powerhouse into a bypass system. Instead, a portion of the fish that enter the second powerhouse will swim through a series of submerged orifices into a bypass channel. While these submerged orifices are lighted to attract fish into the bypass channel, the process of swimming through the orifices is completely voluntary. Because of the voluntary nature of this collection system, it is unknown how much time fish may spend in the powerhouse prior to entering the bypass channel or how long fish are in the channel before being routed into the sample trap. In addition to the orifices and bypass channel that run parallel to the second powerhouse, some juvenile salmonids are also "opportunistically" collected from a screening system associated with an adult attraction pump that draws water from the forebay, just above the second powerhouse. Fish collected from this screening system are diverted to the bypass channel.

From the bypass channel, juveniles are routed to a sample trap that is located in the tailrace of the project where they are held for up to 24-hours before being processed for the SMP. The sample trap is relatively shallow (~2-3 ft). Just before 9:00 am, fish in the trap are crowded into a hopper and transported to a large sample tank in the sample room. Once fish are in the sample tank, they are enumerated for the SMP and returned to a recovery tank before ultimate release into the tailrace. On GBT sample days, a subset of 100 Chinook and steelhead (combined) are also examined for GBT prior to being returned to the recovery tank. This is what we refer to as the "traditional" method of GBT monitoring. Therefore, fish sampled under the "traditional" method, may have been held in the shallow sample trap for up to 24-hours prior to the exam, which increases the potential that incidences of GBT may be inflated.

Scheduling and budget constraints at RIS have made implementation of a protocol similar to the one used at BON more difficult. Since fish examined at RIS have been held in shallow depths for a longer period of time, the FPC staff has cautioned the fisheries managers that GBT data from RIS should be evaluated within the context of the sampling procedure. Since the values are likely biased high, the results are evaluated independently of the other monitoring locations.

In 2016 and 2017, FPC staff and Chelan County PUD Smolt Monitoring Program (SMP) personnel at RIS implemented a pilot GBT sampling protocol to reduce the amount of time that fish collected for GBT exams were held prior to being examined. Under the pilot protocol, SMP personnel at RIS attempted to collect fish for the GBT sample directly from the dewatering screens, as they entered the trap. This direct sampling occurred from the time the staff arrived at the project until approximately 9:00 am (approximately one to two hours). These "freshly sampled" fish were then prioritized for GBT exams. If the total number of "freshly sampled" fish fell short of the target sample size of 100 fish, SMP personnel would then examine fish from the daily collection (i.e., "traditional" method), until the target sample size for GBT was met. Each "fresh" fish from the GBT sample was flagged with a code for later identification. The 2016-2017 pilot protocol was conducted to address four primary questions. In October 2017, FPC staff conducted an analysis of the 2016 and 2017 data, in order to address these four questions (FPC 2017).

1) Can "fresh" fish be captured and examined in a safe and efficient manner at RIS? *Yes, "fresh" fish can be captured and examined in a safe and efficient manner at RIS.*
2) For how much of the season can "fresh" fish be captured at RIS? *"Fresh" fish can be sampled to some extent over the majority of the season, particularly when there is a commitment to do so.*
3) Can sample size requirements be met by exclusively using "fresh" fish? *Under the protocol that was implemented in 2016 and 2017, sample size requirements were never met by exclusively using "fresh" fish.*
4) Is there a difference in GBT incidence rates between "fresh" and "traditional" fish? *Based on the data collected in 2016 and 2017, "traditional" fish had significantly higher GBT incidence rates than "fresh" fish.*

Based on the results from the 2017 analysis, the FPC concluded that it appears that past GBT incidence rates at RIS are likely biased high and should be considered in the context of the sampling protocol in those years (i.e., 100% "traditional" fish). Using "fresh" fish may reduce this bias but the degree to which "fresh" fish are used in the GBT sample will influence the degree of this reduction. FPC staff recommended that every effort should be made to increase the use of "fresh" fish in future GBT samples at RIS and provided a few ideas of how this may be accomplished (FPC 2017).

Chelan County PUD SMP personnel revised the pilot protocol for 2018 in an effort to maximize the number of "fresh" fish that could be sampled, under current budget and scheduling constraints. The SMP sample at RIS runs from 0900 to 0900 and samples are generally processed at 0900 each day. GBT sampling at RIS generally occurs twice per week. Under the 2016 and 2017 pilot GBT protocol, "fresh" fish were only sampled for one to two hours in the morning, just before the sample was completed at 0900. The 2018 revised sampling protocol included two periods for collecting "fresh" fish: one in the late morning or afternoon prior and a second in the morning (just before the sample was completed at 0900). The duration of the "fresh" fish sampling periods varied and were dependent on several factors, including: staffing schedules, staff availability, and fish numbers. If the total number of "fresh" fish fell short of the target sample size of 100, SMP personnel would then examine fish in the "traditional" method until the target sample size for GBT was met. Each "fresh" fish from the GBT sample was flagged in the database with a code for later identification.

Methods: Comparing GBT Incidence Rates of "Traditional" and "Fresh" Fish in 2018

In 2018, 31 of the 32 GBT samples contained "fresh" fish in them. In addition, seven GBT samples had exclusively "fresh" fish and one GBT sample had exclusively "traditional" fish. The seven samples with exclusively "fresh" fish occurred in May and June while the one sample with exclusively "traditional" fish occurred on July 5th. A breakdown of all 32 GBT samples can be found in Appendix A, along with daily GBT incidence rates for the entire sample, the "traditional" sample only, and the "fresh" sample only (Table A.1). River flows in 2018 were above average throughout the Columbia River Basin and, as a result, TDG levels exceeded the 115% forebay waiver limits for most of May and June and the 120% tailrace waiver limits for most of May and early June. Due to the high TDG in the Upper Columbia, GBT incidences at RIS were frequent (29 of 32 samples had at least some signs of GBT) and high, with a maximum GBT incidence rate of 43.2% (Table A.1).

We conducted an analysis to compare GBT incidence rates between the two methods with two basic questions in mind: 1) Do "fresh" and "traditional" fish have different GBT incidence rates and 2) if yes, are they consistently higher or lower? To minimize seasonal variations, only days with both "traditional" and "fresh" sampling schemes were included in the analysis. In 2018, there were 22 total GBT samples that had a mixture of both "traditional" and "fresh" sampling schemes (Table A.1). For each of these GBT samples, we first calculated the GBT incidence rates of "traditional" and "fresh" fish and then calculated the difference between the two sampling schemes. After the paired-differences of all sampling days were obtained, the mean was calculated to estimate the overall difference in GBT rates between the two sampling types. Finally, we used a nonparametric bootstrap procedure with 5,000 iterations to estimate the standard errors (SE) and 95% confidence intervals (CI) around these means.

In addition, a permutation test was conducted to test for a difference in the GBT rates between "traditional" and "fresh" fish (Efron and Hastie 2016). The main idea of a permutation test was to create a hypothetical situation in which there was no difference in GBT incidence rate between the two sampling schemes. Thus, we simulated a distribution under such hypothesis, and compared it to the observed difference in GBT rates. If there was no difference in GBT rates between the two sampling schemes, the observed result would most likely fall close to the center of the simulated distribution. If there was a measurable difference between the GBT rates, the observed result would be far away from the center of the simulated distribution. To generate an approximate distribution to the null hypothesis, we first randomly reassigned GBT incidences to all fish regardless of sampling type, and calculated the difference between the new GBT rates for each batch sampling day. After the paired-differences of all sampling days were obtained, we calculated the mean for the overall difference in GBT rates between the two sampling types. The process was repeated to yield a permutation distribution of 5,000 simulated mean differences in GBT rates. We quantified how plausible the observed result was under the null hypothesis by calculating the portion of the simulated distribution that was greater than the observed value (i.e. p-value).

Results: Comparing GBT Incidence Rates of "Traditional" and "Fresh" Fish

The results from our paired comparison indicates that, on average, "traditional" fish had a higher GBT incidence rate than "fresh" fish. Considering only samples with both sampling schemes, the estimated mean GBT rate for "traditional: fish was 13.8% (95% CI: 7.8%-20.5%), whereas that for "fresh" fish was 7.9% (95% CI: 3.5%-13.1%). Therefore, the estimated mean difference was 5.9% (95% CI: 3.0%-13.1%).

From the permutation test, only 1 out of 5,000 simulated values was greater than the observed value. Therefore, the observed difference of 5.9% in GBT incidence rates was extremely unlikely under the null hypothesis (p< 0.001; Figure 1). This indicates that "traditional" fish had significantly higher GBT incidence rates than "fresh" fish.

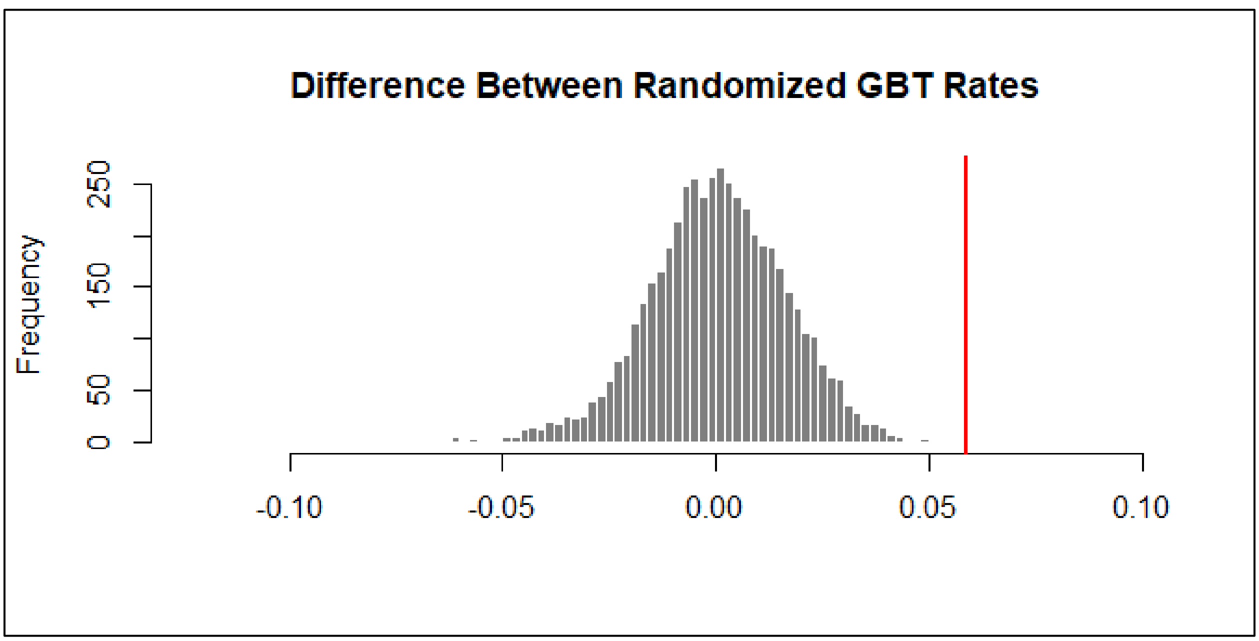

Figure 1. Histogram of permutation distribution for a paired-comparison of GBT rates between "traditional" and "fresh" fish. Red line indicates the observed difference from the 2018 sample.

Discussion

Results from 2018 are similar to those from our 2017 analysis (FPC 2017) and, therefore, we still conclude that historic GBT rates at RIS are likely biased high, as these were collected using only “traditional” fish. Therefore, these GBT rates should be considered in the context of the sampling protocol in those years. From the modified sampling protocols that were implemented in 2016-2018, it appears that using “fresh” fish in the GBT sample may reduce this bias and potentially make results from RIS GBT sampling more representative of what is occurring to the run-at-large. However, the degree to which “fresh” fish are used in the GBT sample will influence the degree to which the bias is reduced. For example, although the target sample size was met with exclusively “fresh” fish for seven samples in 2018, the majority (78%) of samples in 2018 still relied on some level of “traditional” fish to meet sample size requirements. Therefore, the estimates of overall GBT incidence rates may still be slightly biased on the high side due to the influence of “traditional” fish. Minimizing the influence of “traditional” fish is still desirable. It is worth noting that increasing the number of “fresh” fish to meet the sample size target of 100 fish may not completely eliminate the bias because it is still unknown how long fish spend in the powerhouse and bypass channel before being routed to the sample tank.

Based on our review of the results from the 2018 protocol, we would recommend that SMP personnel at RIS continue with this protocol in the future. We hope you find these analyses and suggestions useful to inform future GBT monitoring at RIS. The FPC staff looks forward to continuing discussions on how to improve the representativeness of GBT samples at RIS and are available to discuss these analyses and other potential solutions.

Literature Cited:

Efron, B. and T. Hastie. 2016. Computer Age Statistical Inference: Algorithms, Evidence, and Data Science. Cambridge University Press. New York, New York, USA.

Fish Passage Center. 2017. Recommendations on Gas Bubble Trauma Monitoring Protocol at Rock Island Dam. October 3, 2017 (http://www.fpc.org/documents/memos/45-17.pdf)

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Appendix A
GBT Exam Data for Rock Island Dam in 2018

Table A.1. Number examined and GBT incidence rates (%) of total GBT sample, "traditional" only fish, and "fresh" only fish at RIS during 2018. Grey highlighted rows indicate days where both sampling schemes were utilized and, thus, days that were included in the analysis comparing GBT incidence rates between "fresh" and "traditional" sampling schemes.

Date	Total Examined	Total GBT Incidence (%)	"Traditional" Examined	"Traditional" GBT Incidence (%)	"Fresh" Examined	"Fresh" GBT Incidence (%)
4/17/18	59	1.7%	58	1.7%	1	0.0%
4/19/18	100	0.0%	98	0.0%	2	0.0%
4/24/18	100	3.0%	93	3.2%	7	0.0%
4/26/18	100	2.0%	60	1.7%	40	2.5%
5/1/18	100	1.0%	---	---	100	1.0%
5/3/18	100	1.0%	---	---	100	1.0%
5/8/18	100	3.0%	---	---	100	3.0%
5/10/18	100	2.0%	---	---	100	2.0%
5/15/18	100	32.0%	61	39.3%	39	20.5%
5/17/18	100	36.0%	63	39.7%	37	29.7%
5/22/18	95	43.2%	84	44.0%	11	36.4%
5/24/18	88	31.8%	69	31.9%	19	31.6%
5/29/18	100	29.0%	71	32.4%	29	20.7%
5/31/18	100	30.0%	---	---	100	30.0%
6/5/18	100	14.0%	15	40.0%	85	9.4%
6/7/18	100	6.0%	---	---	100	6.0%
6/12/18	100	1.0%	---	---	100	1.0%
6/14/18	100	3.0%	16	12.5%	84	1.2%
6/19/18	75	4.0%	55	3.6%	20	5.0%
6/21/18	75	0.0%	73	0.0%	2	0.0%
6/26/18	11	0.0%	---	---	11	0.0%
6/28/18	100	5.0%	67	7.5%	33	0.0%
7/3/18	100	3.0%	56	5.4%	44	0.0%
7/5/18	100	4.0%	100	4.0%	---	---
7/10/18	100	4.0%	19	10.5%	81	2.5%
7/12/18	100	4.0%	38	5.3%	62	3.2%
7/17/18	100	1.0%	50	2.0%	50	0.0%
7/19/18	100	7.0%	62	9.7%	38	2.6%
7/24/18	100	3.0%	42	4.8%	58	1.7%
7/27/18	100	3.0%	87	2.3%	13	7.7%
7/31/18	89	5.6%	77	6.5%	12	0.0%
8/7/18	9	11.1%	---	---	9	11.1%