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Mitigation for the Construction and Operation of Libby Dam

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MITIGATION FOR THE CONSTRUCTION AND OPERATION OF LIBBY DAM

ANNUAL REPORT
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By:

James Dunnigan, Brian Marotz, Jay DeShazer, Larry Garrow, and Tom Ostrowski

Montana Fish, Wildlife and Parks
475 Fish Hatchery Road
Libby, MT 59923

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Division of Fish and Wildlife
P.O. Box 3621
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Ron Morinaka, COTR
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Chapter 4

Kootenai River Fisheries Monitoring Results From the Spill Events at Libby Dam, June-July 2002

Abstract

Spill at Libby Dam has been an infrequent event since the fourth turbine unit went online in 1976. As a result of infrequent spill, subsequent information regarding the gas exchange processes, particularly dissolved gas production from spill releases and dissolved gas dissipation downstream from the project are limited. Additional knowledge related to gas production dynamics in the Kootenai River below Libby Dam could help water managers make critical decisions during events that require spill. Therefore the U.S. Army Corps of Engineers proposed to conduct a comprehensive test of total dissolved gas resulting from a range of releases at Libby Dam during June 2002 that were designed to systematically vary the spillway flow over time while monitoring downstream water quality and fish. However, warm weather and high inflows into a nearly full reservoir required forced spill at Libby Dam beginning on June 25 and lasting 13 days until July 7, and then commencing again for another 7 days from July 11 to July 17. Fish monitoring during the spill activities at Libby Dam in the summer of 2002 used three general approaches including the examination of captive fish and fish captured via electrofishing for signs of gas bubble disease, and radio telemetry to assess fish displacement and behavior changes. Signs of gas bubble disease developed rapidly in the captive fish, and quickly escalated to 100% incidence, relative to fish captured via nighttime electrofishing. Approximately 86% of the rainbow trout *Oncorhynchus mykiss*, 80% of the bull trout *Salvelinus confluentus* and 31% of the mountain whitefish *Prosopium williamsoni* collected during the peak total discharge and spill at Libby Dam exhibited signs of gas bubble disease. We developed 2 indices of exposure to saturated water that used total volume of spill water and the proportion of spill water to correlate with observations of gas bubble disease. Results from the radio telemetry work suggests that most radio tagged rainbow trout (n= 7; 100%), bull trout (n = 3; 75%) and mountain whitefish (n = 2; 67%) did not move substantially during the spill activities at Libby Dam, and remained within the general vicinity of Libby Dam (RM 221.7) downstream to Dunn Creek (RM 219.8), with the center of gravity more near Libby Dam. Spill activities at Libby Dam during the summer of 2002 created relatively rapid response of total dissolved gas concentrations with relatively small amounts of spill water, and impacted resident fish of the Kootenai River below the dam. Therefore, the use of spill as a regular management activity at Libby Dam appears to have limited practical application under the current dam configuration.

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Introduction

Spilling water at hydroelectric projects can cause supersaturated gas conditions in waters downstream. Water and air become mixed when water passes over the spillway, and can be carried to substantial depths in the plunge basin where hydrostatic pressure increases the solubility of the atmospheric gases. The air can then pass into solution in sufficient quantities to promote supersaturated conditions with respect to surface or atmospheric pressure. These conditions can cause gas bubble disease in aquatic organisms. Bouck (1980) defines gas bubble disease as "a noninfectious, physically induced process caused by uncompensated, hyperbaric total dissolved gas pressure, which produces primary lesions in blood (emboli) and in tissues (emphysema) and subsequent physiological dysfunctions. Emboli and gas bubbles can form only when the sum of the dissolved gas pressures or cavitation pressure exceeds the sum of the hydrostatic and other compensating pressures." Workers first reported supersaturation associated with hydroelectric projects in Sweden in the 1940s and 1950s (Jarnefelt 1948 and Lindroth 1957, respectively). The problem was also well documented on the Columbia and Snake rivers during the 1960's (Ebel 1969).

During the construction phase at Libby Dam, operators exclusively used the sluiceways and/or spillway to pass water beginning in March 1972 until August 1975 when the first turbine unit went online. The fourth turbine unit at Libby Dam went online in March 1976. River operations during this period caused supersaturated conditions in the Kootenai River below the dam that adversely impacted mountain whitefish (*Prosopium williamsoni*) and westslope cutthroat trout (*Oncorhynchus clarkii*), the two dominant game fish species in the Kootenai River at that time (May and Huston 1976; May and Huston 1973; May 1973). Since then, sluiceways and spillway have been infrequent methods of passing water at Libby Dam, and subsequent information regarding the gas exchange processes, particularly dissolved gas production from spill releases and dissolved gas dissipation downstream from the project are limited. Additional knowledge related to gas production dynamics in the Kootenai River below Libby Dam could help water managers make critical decisions during 3 potential future events. The 2000 U.S. Fish and Wildlife Service (USFWS) Biological Opinion on the operation of the Federal Columbia River Power System, which includes Libby Dam, calls for spill at Libby Dam to augment powerhouse discharges to benefit sturgeon in the Kootenai River (USFWS 2000). An alternative flood control operation called VARQ, could slightly increase the probability of involuntary spill at Libby Dam (ACOE 2002). Extraordinarily rare flow conditions or discharge forecasting errors may require spill. Therefore the U.S. Army Corps of Engineers proposed to conduct a comprehensive test of total dissolved gas (TDG) resulting from a range of releases at Libby Dam during June 2002. The spill test schedule was designed to systematically vary the spillway flow over time while monitoring downstream water quality and fish. The study was a cooperative effort with the U.S. Army Corps of Engineers as the lead agency responsible for operations and gas monitoring within the river and Montana Fish, Wildlife and Parks as the lead agency responsible for fish monitoring.

May and Huston (1976) concluded that during the construction period of Libby Dam, game fish populations 17 or more miles below Libby Dam were not substantially impacted by supersaturated conditions in the Kootenai River. In fact, it seems logical to conclude that the greatest potential for supersaturated waters from Libby Dam to impact aquatic life would occur directly below the dam. This is especially true given that the spillway is located on the left (east) bank and the turbines are located on the right (west) bank and that an unknown time interval and travel distance would be required for spill and turbine waters to be fully mixed. Montana Fish, Wildlife and Parks was especially concerned about the tailrace area because of the unique fishery that exists there. The lower 3 miles of river directly downstream of Libby Dam supports a unique abundance of world-class rainbow trout (*Oncorhynchus mykiss*) and bull trout (*Salvelinus confluentus*), that likely congregate in this location due to the abundant rich food source of kokanee salmon (*Oncorhynchus nerka*) that are entrained through Libby Dam.

Gas bubble disease (GBD) can cause a variety of signs and lesions, and identification of the disease requires familiarity with the symptoms and careful examination of fish. Exopthalmia or pop eye is a common outward symptom of GBD. However, the absence or presence of exopthalmia alone cannot be considered conclusive evidence of either the presence or absence of the disease, respectively since not all fish ailing from GBD exhibit this symptom and exopthalmia can result from other diseases or infections (Weitkamp and Katz 1980). A much more common symptom of GBD is the presence of bubbles or blisters under the skin, frequently present between fin rays, on the head and in the lining of the mouth (Marsh and Gorham 1905; Weitkamp 1974; 1976; Dawley et al. 1976). Bubbles are most frequent on the unpaired fins, but may occur on the paired fins, head, jaws, and mouth, generally after the appearance of bubbles in the unpaired fins first (Weitkamp 1976). The appearance of gas emboli along the lateral line is generally the first external symptom of the disease to appear in juvenile salmonids, but these bubbles are usually small and difficult to observe, which accounts for the absence in most descriptions of the disease (Schiewe and Weber 1976; Weber and Schiewe 1976). Scattered bubbles (covering less than 15%) along the lateral line have also been observed in fish not exposed to supersaturated water (Dawley et al. 1976). Therefore, this symptom should not be considered an indication of GBD unless extensive portions of the lateral line contain gas emboli (Weitkamp and Katz 1980). Hemorrhages at the base of the paired fins are a frequent sign of the disease in cases of chronic exposures (Meekin and Turner 1974). Fish with gas bubble disease have also been shown to exhibit abnormal behavior including loss of equilibrium (Marsh and Gorham 1905; Wyatt and Beiningen 1971), inability to maintain position in current and avoid obstacles (Wyatt and Beiningen 1971), and reduced growth with chronic exposure (Dawley and Ebel 1975; Meekin and Turner 1974). The most pertinent and conclusive physical external sign of GBD is probably the presence of gas emboli in the gill blood vessels (Dawley et al. 1976; Wyatt and Beiningen 1971; Weitkamp and Katz 1980). Fish mortality due to gas bubble disease is generally attributed to anoxia resulting from stasis in the blood. Sufficient quantities of gas in the circulatory system can lead to accumulations of gas in the heart, preventing blood movement through the vascular system (Marsh and Gorham 1905). Lesser quantities of gas in the circulatory system can result in emboli only in the gills, that can cause blood stasis in the gill arterioles, causing death (Woodbury 1941; Renfro

1963; Dawley et al. 1976). Stroud et al. (1975) also noted that other sublethal effects such as blindness, stress, and diminished lateral line sensitivity can lead to death through secondary causes such as increased vulnerability to predation. Gas bubble disease can also increase the susceptibility to other diseases, such as secondary fungal, and bacterial infections (Weitkamp 1976).

The tolerance to supersaturated water varies by fish life stage. Fish eggs are perhaps the most tolerant life stage to supersaturated water (Rucker and Kangas 1974; Meekin and Turner 1974). A review of supersaturation tolerance by life stage by Weitkamp and Katz (1980) concluded that tolerance by life stage follows two consecutive trends. Tolerance to supersaturation in the early life stages decreases from high tolerance in the egg stage to very low tolerance in the early juvenile life stages. The tolerance of post juvenile life stages tends to increase, with adults being generally most tolerant of supersaturation.

Fish can recover from gas bubble disease. Several authors have found that after a recovery period of 2 weeks in water at equilibrium, fish no longer exhibited external signs of the disease (Dawley and Ebel 1975; Dawley et al. 1976; Meekin and Turner 1974). Recovery can be promoted using equilibrated water, hydrostatic pressure, or artificially produced pressure. Wietkamp (1976) used increased depth to recover juvenile chinook salmon (*Oncorhynchus tshawytscha*) exposed to 118-126% total gas pressure for 10 to 20 days. He observed about 10% mortality, and concluded that most fish that died had developed secondary fungal infections. Meekin and Turner (1974) reported a similar mortality rate of juvenile chinook salmon during recovery. Seven of 67 (10.5%) fish died within the first 24 hours after being placed in equilibrated water. Secondary infections were not identified as an issue related to mortality in this study.

Fish can escape the effects of supersaturated water by either avoiding it, if the choice exists, or by sounding to compensate for supersaturated conditions at surface pressures. However, Weitkamp and Katz (1980) report that it is generally accepted that fish are not able to detect supersaturated conditions and avoid them. A study by Ebel (1971) supports this statement. He found that juvenile chinook salmon held in volitional 0-4.5 m deep cages suffered higher mortality than fish forced to remain in deep (3-4 m) cages. Ebel (1971) concluded that these fish were unable to detect or not willing to avoid saturated water. However, several studies contradict this generalization and suggest that the ability to detect and avoid saturated water may be species specific. Blahm et al. (1976) found that juvenile chinook salmon were able to detect and avoid supersaturated water when given a choice, but that juvenile steelhead (*Oncorhynchus mykiss*) were not able to detect supersaturation. Dawley et al. (1976) concluded that both juvenile steelhead and chinook salmon were able to detect and avoid supersaturated water by sounding. Meekin and Turner (1974) found that juvenile chinook salmon were able to detect and avoid supersaturated water when given the choice, but that steelhead were not. However, temperature differences during this study limit its inferential power. Bentley et al. (1976) also demonstrated that northern pikeminnow (*Ptychocheilus oregonensis*) may be able to detect and avoid supersaturated conditions given the opportunity. Nevertheless, Weitkamp and Katz (1980) concluded that insufficient information exists to conclude whether or not fish are able to detect and avoid supersaturated water.

Methods

The primary objective for conducting the spill test in June 2002 was to increase the understanding of gas exchange processes within the Kootenai River during spill operations, particularly dissolved gas production, mixing and dissolved gas dissipation downstream from Libby Dam. However, another important objective was to ensure that aquatic life was not harmed during the collection of these data. Montana Fish, Wildlife and Parks was the lead agency in a cooperative effort to monitor fish in the Kootenai River for signs of gas bubble disease during the scheduled spill test. Fish monitoring during the spill activities at Libby Dam in the summer of 2002 used three general approaches. Sentry fish were held in cages and checked for signs of gas bubble disease, fish were captured using electrofishing gear and examined for signs of gas bubble disease, and finally radio telemetry was used to investigate fish movement or displacement during spill activities. In order to ensure that supersaturation did not impact fish in the Kootenai River three threshold criteria were established that would stop the spill test at Libby Dam. Spill was to be suspended if any of the three criteria were realized. A real time TDG monitoring station was established approximately one mile downstream of Libby Dam. Spill was to be terminated under two criteria established for this monitoring station. The criteria were exceeding either a three-hour average of TDG saturation of 120%, or an hourly average of TDG saturation exceeded 125%. The final criterion was the identification of signs of gas bubble disease in either the captive fish or fish captured via electrofishing. Estimating fish mortality was not an intended objective because the criteria for stopping spill activities during the test period were considered conservative to the point that spill would be stopped before mortality was prevalent.

Captive Fish

Captive fish were held in hoop traps at three locations on the left bank approximately 0.4, 0.8 and 1.7 miles below Libby Dam (sites 1-3, respectively; Figure 1) throughout the spill duration. A total of 9 spill events were scheduled for the 3-day spill test (Table 1). However, warm weather and high inflows into a nearly full reservoir required forced spill at Libby Dam beginning on June 25 and lasting 13 days until July 7, and then commencing again for another 7 days from July 11 to July 17.

Three hoop traps measuring 2 foot diameter, approximately 6-8 feet in length with ¾ inch net mesh (Figure 2) were located at each of the three sites (9 total hoop nets) in 3-6 feet of water. Large weights attached to each hoop trap prevented downstream movement. The protocol had intended to stock each hoop trap with 5 mountain whitefish and 5 rainbow trout. However, species composition within individual hoop nets varied depending upon the electrofishing catch. Fish were captured using nighttime electrofishing by jetsled using a Coffelt model Mark 22 electrofishing unit, operating with an electrical output ranging from 200-350 volts at 5-8 amps. Captured fish were examined for external signs of gas bubble disease prior to being placed in hoop nets. Captive fish were stocked in the hoop nets on three separate occasions during the spill event (Table 2), because investigators were concerned that handling mortality may be substantial and could potentially confound the results. Captive fish from one hoop net at

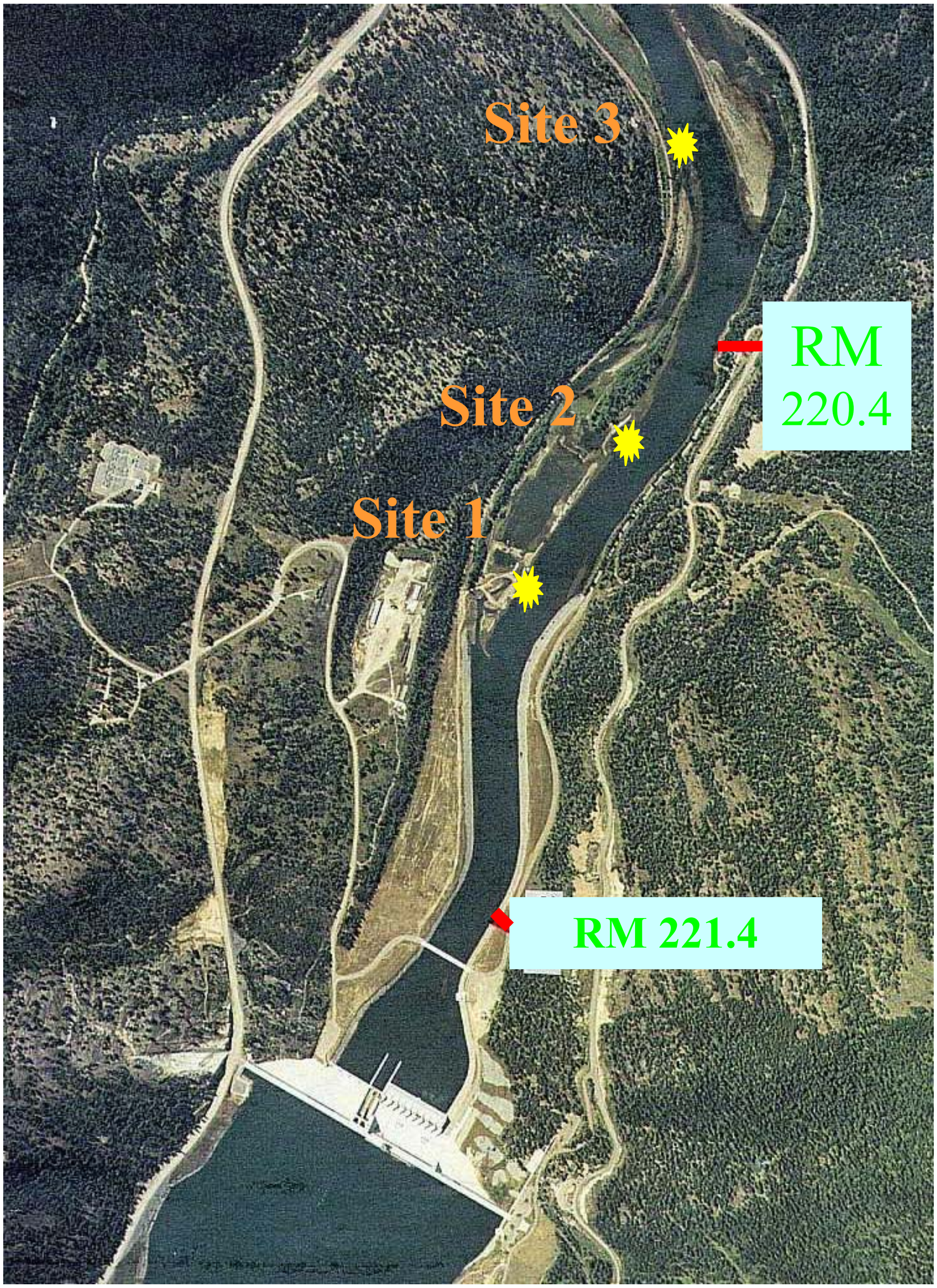


Figure 1. Aerial photograph of Libby Dam, looking downstream. The three locations marked with yellow symbols on the photograph represent the approximate location of three hoop traps used to hold captive fish during the spill activities. River mile (RM) locations are shown for reference. Thee hoop traps were located at each location at depths ranging from 3-6 feet.

Figure 2. Investigators, Brian Marotz, Monty Benner (Montana FWP), Pat Dwyer (consultant), and Evan Lewis (USACOE) checking mountain whitefish and rainbow trout held in a hoop trap during spill activities at Libby Dam.

Table 1. Scheduled spill events, duration, and powerhouse, spill and total flows at Libby Dam.						
Event	Date	Time	Number Hours	Powerhouse Flow (Kcfs)	Spill Flow (Kcfs)	Total Flow (Kcfs)
1	6/25	0700-1030	3.5	23	2	25
2	6/25	1100-1430	3.5	22	3	25
3	6/25	1500-1830	3.5	21	4	25
	6/25-26	1830-0700		25	0	25
4	6/26	0900-1230	3.5	20	5	25
5	6/26	1300-1630	3.5	19	6	25
6	6/26	1700-2030	3.5	18	7	25
	6/26-27	2030-0900		25	0	25
7	6/27	0900-1230	3.5	17	8	25
8	6/27	1300-1630	3.5	16	9	25
9	6/27	1700-2030	3.5	15	10	25

Table 2. Date and times that hoop traps were stocked with fish (S), fish examined for signs of gas bubble disease (E), and examined for signs of gas bubble disease and released (ER) during the spill event at Libby Dam in June and July 2002. Fish were held in three hoop traps on the left bank at three sites approximately 0.4, 0.8 and 1.7 miles below Libby Dam (sites 1-3 respectively).

	Site 1			**Site 2**			**Site 3**		
Date	**Trap 1**	**Trap 2**	**Trap 3**	**Trap 1**	**Trap 2**	**Trap 3**	**Trap 1**	**Trap 2**	**Trap 3**
6/24	S (23:00)	S (23:00)	S (23:00)	S (23:00)	S (23:00)	S (23:00)	S (23:00)	S (23:00)	S (23:00)
6/25	E (9:35) E (17:45) ER (23:25)	E (13:45) ER (22:30)		E (9:53) E (18:00) ER (22:40)	E (14:00) ER (22:45)		E (10:15) E (18:15) ER (22:55)	E (14:15) ER (23:00)	
6/26	S (00:30) E (10:05) E (18:35)	S (00:30) E (15:35)		S (00:30) E (10:22) E (19:00)	S (00:30) E (15:45)		S (00:30) E (10:41) E (19:15)	S (00:30) E (15:55)	
6/27	ER (23:21)	ER (23:40)	ER (24:00)	ER (22:26)	ER (22:43)	ER (23:00)	ER (21:12)	ER (21:29)	ER (21:58)
6/28	S (00:20)	S (00:22)	S (00:25)				S (00:50)	S (00:55)	S (01:00)
7/1	ER (23:50)						ER (23:00)		
7/3		ER (15:20)						ER (14:54)	
7/8			ER (14:00)						ER (14:20)

each site were examined between each spill event (Table 2) up until forced spill occurred. Monitoring intensity of captive fish was reduced once spill operations shifted from test conditions to forced spill (Table 2). During each examination period, fish were removed from the hoop nets, anesthetized using an aqueous non-buffered solution of MS-222, and then externally examined for signs of gas bubble disease. Investigators examined the fins, eyes, and head using either an ophthalmoscope manufactured by Welch Allyn or a hand held loup 5X magnifying glass for the presence of gas emboli, and then recorded the total proportion of each fin or anatomical feature that contained emboli.
Because we replaced the captive fish in the hoop nets throughout the duration of the spill activities, it was necessary to attempt to quantify the amount (dose) of potentially saturated water fish were exposed to, and relate that exposure to the presence of signs of gas bubble disease observed. We derived two indices of exposure time to correlate to signs of gas bubble disease. The first index was cumulative hourly spill discharge (CSpill) a particular group of fish was exposed to, and was calculated using the following equation.

$$CSpill_j = \sum_i HSD$$

Where $Cspill_j$ = The cumulative hourly spill discharge for fish group j at time of examination, and HSD (Hourly Spill Discharge) = the sum of i hourly spill discharge measurements (kcfs) that fish group j was exposed to until examination. For example, if a fish were exposed to 5 kcfs spill for 10 hours, the cumulative hourly spill discharge would be 50. The second index of exposure (CSpWtd) was similar to the previous index, but differed in that it utilized a weighting factor based on the proportion of the spill discharge relative to total discharge. We calculated cumulative spill weighted discharge ($CSpWtd_j$) for fish group j using the following equation.

$$CSpWtd_j = \sum_i (HSD) * (\frac{HSD}{TD})$$

Where HSD (Hourly Spill Discharge) is the hourly spill (kcfs), and TD is the total discharge at Libby Dam (kcfs) for the i^{th} hourly periods. For example, if a fish were exposed to 5,000 cfs spill with at a total discharge of 10,000 cfs for 10 hours, the cumulative spill weighted discharge would be 25. We used nonlinear regression to correlate our two indices of captive fish saturated water exposure to fish response. We used the proportion (percent) of fish in an individual hoop net that were identified with signs of gas bubble disease as the response variable in the nonlinear regression. Individual regression analyses were completed using the proportion of mountain whitefish, rainbow trout and all fish species pooled, exhibiting signs of gas bubble disease as the response variable. We used r^2 values from competing models to determine which model provided the best fit to the data.

Electrofishing

We used electrofishing to capture free-swimming fish below Libby Dam for examination of signs of gas bubble disease in the Kootenai River. Fish were captured using nighttime electrofishing by jetsled using a Coffelt model Mark 22 electrofishing unit, operating with an electrical output ranging from 200-350 volts at 5-8 amps. Sampling occurred on evenings of June 25, July 1, July 8, and July 24 from directly below Libby Dam (river mile; RM 221.7) downstream to the confluence of Alexander Creek (RM 220.5), and was generally restricted to the left bank, with the exception of sampling on July 1, when both left and right banks were sampled and reported separately. Electrofishing was generally confined to the left bank because the spill water had not thoroughly mixed across the river channel at this location, in order to maximize our ability to detect symptoms of GBD. We attempted to net all salmonids encountered during electrofishing. We anesthetized captured fish using an aqueous non-buffered solution of MS-222, and then externally examined each fish for signs of gas bubble disease. Investigators examined the fins, eyes, and head using either an ophthalmoscope manufactured by Welch Allyn or a hand held loup 5X magnifying glass for the presence of gas emboli, and then recorded the total proportion of each fin or anatomical feature that contained emboli. Fish were held in vessels circulating with fresh river water and then released on the left bank at RM 221.0 once fully recovered.

We used nonlinear regression to quantify the amount (dose) of potentially saturated water fish were exposed to, and related that exposure to the presence of signs of gas bubble disease observed in the electrofishing catch. We used the same two indices of exposure time used for captive fish, cumulative hourly spill discharge (CSpill), and cumulative spill weighted discharge ($CSpWtd_j$). We used the proportion (percent) of fish captured on a particular evening that were identified with signs of gas bubble disease as the response variable in the nonlinear regression. Individual regression analyses were completed using the proportion of rainbow trout, bull trout, mountain whitefish and all fish species pooled exhibiting signs of gas bubble disease as the response variable. We used r^2 values from competing models to determine which model provided the best fit to the data.

Radio Telemetry

We used radio telemetry to assess the movement and behavior of fish below Libby Dam during the spill activities. We used electrofishing to capture and then surgically implant radio tags into 5 bull trout, 8 rainbow trout, and 3 mountain whitefish. Fish were captured via nighttime jetsled electrofishing using a Coffelt model Mark 22 electrofishing unit, operating with an electrical output ranging from 200-350 volts at 5-8 amps on the evening of June 18 (one week prior to spill activities). Collection occurred from directly below Libby Dam (RM 221.7) downstream to the confluence of Alexander Creek (RM 220.5). We examined fish for marks, tags, and injuries, and then we anesthetized captured fish using an aqueous non-buffered solution of MS-222, measured them, and surgically implanted the radio tag. Tagged fish were released in the general vicinity of capture. We used 9.5 g tags manufactured by Advanced Telemetry Systems, Inc. that were powered by a single 3.6 V lithium battery and had a minimum life span of 80 days and a burst rate of 45 pulses per minute. Each transmitter had a 29 cm flexible external whip antenna attached to one end. Each tag transmitted on a unique frequency ranging from 49.105 to 49.811 kHz, allowing individual fish identification. We used telemetry receivers manufactured by Lotek Engineering (Model SRX-400) for mobile monitoring activities. Each mobile monitoring unit consisted of a radio receiver, data processor, internal clock, and a tuned loop antenna. We determined the location of tagged fish using mobile tracking that consisted of a combined effort of fixed wing aircraft and jetsled observations. Field crews conducted observations 3 times per day during the first 2 days of spill activities below Libby Dam and then approximately 2-4 days per week until July 7. Field crews manually recorded the location description of each fish identified. Fish movement and visual observations were used as the primary as indicators of live fish.

Results

As a result of warm weather and high inflows (with a peak in excess of 70,000 cfs) into a nearly full reservoir, the spill test was superseded after the first day as dam operations shifted to flood control. Forced spill continued until July 16 and at substantially higher levels than those that had been intended for the spill test. The planned spill activities are presented in Table 1, and the actual spill events that occurred at Libby Dam are presented in Table 3. If forced spill had not occurred at Libby Dam, the spill test would have been stopped when one of the three criteria established to protect aquatic life in the Kootenai River were met. The 125% one-hour average numeric criterion was exceed for 3 hours on July 1 13:30-16:30 while the 120% three-hour criterion was exceeded from June 26 10:45 to July 6 13:00 as measured near the left bank (spillway side of channel) at the USGS gauging station (Schneider and Carroll 2002). The criterion for observations of gas bubble disease in fish is discussed below.

Captive Fish

Signs of gas bubble disease manifested, as emboli, were first identified in the eyes of rainbow trout and mountain whitefish in the late evening of June 25. Two of the three hoop traps at each of the three sites were examined and released at approximately June 25 22:00 (Table 4). Approximately 5% of the mountain whitefish examined at this time had gas emboli in at least one eye, and 10% of the captive rainbow trout had gas emboli in at least one eye (Table 4). Each of the 6 hoop traps was restocked with fresh fish collected from downriver. These observations on June 25 would have warranted stopping the spill test, but forced spill for flood control continued. The size of the rainbow trout and mountain whitefish used for the captive fish studies were similar (rainbow trout mean total length 268 mm; range 152-406 mm, and the mean total length of mountain whitefish 290.4 mm; range 152-406 mm). The severity of the symptoms of gas bubble disease observed in both rainbow trout and mountain whitefish increased with the duration of exposure to saturated water (Figure 3). Mortality of the captive fish was generally low (less than 10% overall) during the spill activities. Mortalities were only included in estimates of the incidence of signs of gas bubble disease if they had recently died, as evidenced by red gills.

Signs of gas bubble disease developed rapidly in the captive fish, and quickly escalated to 100% incidence, relative to the duration of spill activities at Libby Dam in the summer of 2002 (Figures 4 and 5; Table 4). The nonlinear regression model that provided the best fit utilized cumulative hourly spill weighted discharge as the independent variable and proportion of all fish (mountain whitefish and rainbow trout combined) that exhibited signs of gas bubble disease as the response variable ($r^2 = 0.875$; Figure 4). The nonlinear regression model that used cumulative hourly spill discharge and the proportion of all fish that exhibited signs of gas bubble disease, produced similar results as the previous model, but was the was the third best model ($r^2 = 0.870$; Figure 5). Competing models using cumulative hourly spill weighted discharge and proportion of mountain whitefish that exhibited signs of gas bubble disease, cumulative hourly spill discharge and

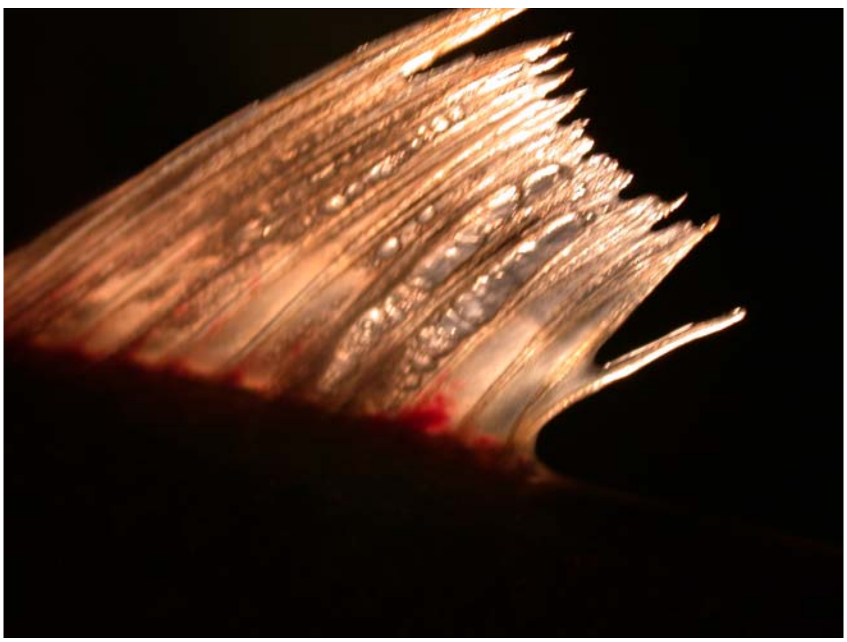


Figure 3. Examples of severe signs of gas bubble disease observed in the eyes and head of a rainbow trout (top photograph) and the dorsal fin of a mountain whitefish (bottom photograph) at the peak of spill activities at Libby Dam on July 1, 2002. Fish in these photographs were captive fish held in hoop traps.

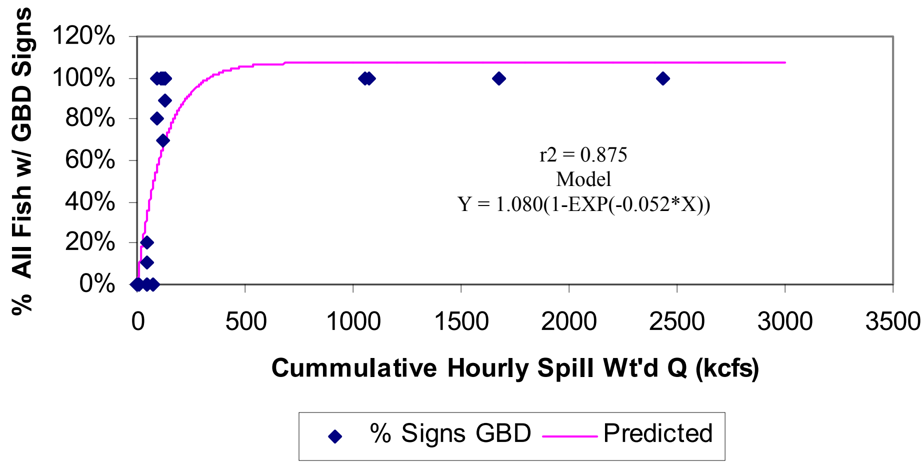


Figure 4. The relation between the cumulative hourly spill weighted flow (Q; kcfs) and the proportion of all captive fish (rainbow trout and mountain whitefish combined) observed exhibiting signs of gas bubble disease (GBD) during spill activities in the Kootenai River below Libby Dam in the summer of 2002.

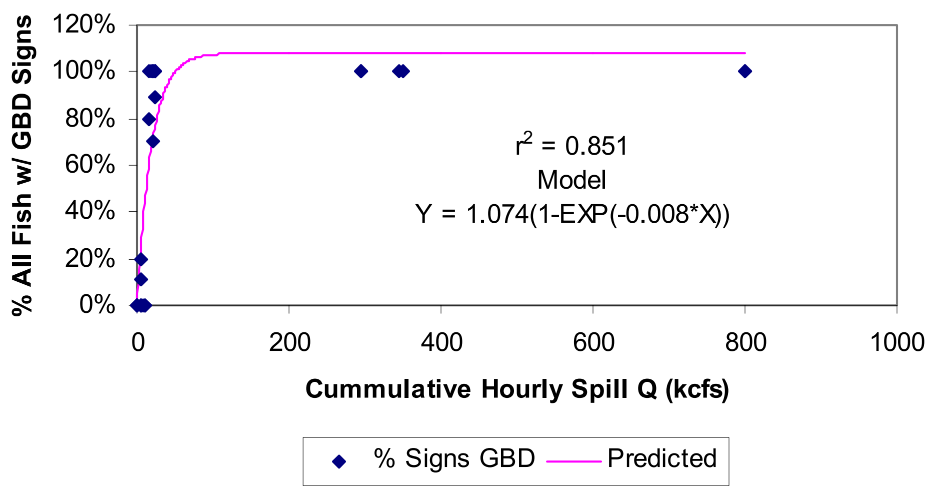


Figure 5. The relation between the cumulative hourly spill flow (Q; kcfs) and the proportion of all captive fish (rainbow trout and mountain whitefish combined) observed exhibiting signs of gas bubble disease (GBD) during spill activities in the Kootenai River below Libby Dam in the summer of 2002.

Table 3. Summary of the spill events at Libby Dam during June and July, 2002 including start and stop date and time, duration (hours), total discharge (thousand cubic feet per second; kcfs), spill discharge, and turbine discharge.

Event Number	**Starting Date and Time**	**Ending Date and Time**	**Duration (hr:min)**	**Total Discharge (kcfs)**	**Spill Discharge (kcfs)**	**Turbine Discharge (kcfs)**
1	6/25 7:00	6/25 9:45	2:45	23.5	0.7	22.8
2	6/25 11:45	6/25 13:45	2:00	23.8	3.0	20.8
3	6/25 15:00	6/25 17:45	2:45	29.0	6.0	23.0
4	6/25 18:00	6/26 8:45	14:45	29.0	4.0	25.0
5	6/26 9:00	6/26 15:45	6:45	30.0	5.0	25.0
6	6/26 16:00	6/28 7:45	39:45	32.0	7.0	25.0
7	6/28 10:00	6/28 13:45	3:45	32.0	7.4	24.6
8	6/28 14:00	6/28 15:45	1:45	33.0	8.4	24.6
9	6/28 16:00	6/30 10:45	42:45	35.0	10.6	24.4
10	6/30 11:00	6/30 12:45	1:45	36.0	11.6	24.4
11	6/30 13:00	6/30 14:45	1:45	37.0	12.6	24.4
12	6/30 15:00	7/1 11:45	20:45	38.0	13.6	24.4
13	7/1 12:00	7/1 13:45	1:45	39.0	14.6	24.4
14	7/1 14:00	7/3 9:45	43:45	40.0	15.6	24.4
15	7/3 10:00	7/3 12:45	2:45	39.0	14.6	24.4
16	7/3 13:00	7/4 9:45	20:45	38.0	13.6	24.4
17	7/4 10:00	7/4 12:45	2:45	37.0	12.6	24.4
18	7/4 13:00	7/4 15:45	2:45	36.0	11.6	24.4
19	7/4 16:00	7/5 10:45	18:45	35.0	10.6	24.4
20	7/5 11:00	7/5 13:45	2:45	32.5	8.1	24.4
21	7/5 14:00	7/6 11:45	21:45	30.0	5.6	24.4
22	7/6 12:00	7/7 9:45	21:45	28.0	3.6	24.4
23	7/7 10:00	7/7 12:45	2:45	26.0	2.0	24.4
24	7/11 10:00	7/12 11:00	25:00	25.8	2.0	23.8
25	7/12 11:00	7/12 12:00	1:00	24.5	0.7	23.8
26	7/12 12:00	7/14 22:00	58:00	27.0	3.2	23.8
27	7/14 22:00	7/15 17:00	19:00	28.0	4.2	23.8
28	7/15 17:00	7/15 18:00	1:00	29.5	5.7	23.8
29	7/15 18:00	7/16 13:00	19:00	30.0	6.2	23.8
30	7/16 13:00	7/17 11:00	22:00	27.0	3.2	23.8

Table 4. A summary of the results of the examination of captive fish held in hoop traps along the left bank below Libby Dam during spill activities. The first number represents the sample size followed by the percent exhibiting signs of gas bubble disease in parentheses. The locations of hoop trap sites 1-3 are shown in Figure 1.

Date and Time	Site #	Net #	Rainbow Trout	Mountain Whitefish
6/25 9:35	1	1	0	12 (0)
6/25 9:53	2	1	5 (0)	5 (0)
6/25 10:15	3	1	3 (0)	5 (0)
6/25 13:45	1	2	4 (0)	5 (0)
6/25 14:00	2	2	4 (0)	5 (0)
6/25 14:15	3	2	3 (0)	7 (0)
6/25 22:00	2	1	5 (0)	5 (0)
6/25 22:10	1	1	0	12 (0)
6/25 22:20	1	2	3 (0)	5 (0)
6/25 22:30	3	1	5 (10%)	4 (0)
6/25 22:40	3	1	3 (33%)	7 (14%)
6/26 10:00	1	1	2 (0)	7 (0)
6/26 10:22	2	1	3 (0)	6 (0)
6/26 15:30	2	2	1 (0)	7 (0)
6/26 15:35	1	2	2 (0)	5 (0)
6/26 16:00	3	2	3 (0)	5 (0)
6/26 18:35	1	1	2 (100%)	3 (67%)
6/27 21:12	3	1	0 (0)	3 (100%)
6/27 21:12	3	2	3 (100%)	5 (100%)
6/27 22:26	2	1	3 (100%)	4 (100%)
6/27 22:43	2	2	1 (100%)	7 (100%)
6/27 23:00	2	3	4 (25%)	6 (100%)
6/27 23:00	1	1	2 (100%)	7 (100%)
6/27 23:00	1	2	2 (100%)	5 (100%)
6/27 23:50	3	3	2 (100%)	7 (86%)
6/27 23:56	1	3	5 (100%)	5 (100%)
7/1 23:00	3	1	3 (100%)	5 (100%)
7/1 23:00	1	1	0	10 (100%)
7/3 14:54	1	2	0	10 (100%)
7/3 15:15	3	2	0	8 (100%)
7/8 12:00	1	3	0	4 (100%)
7/8 12:30	3	3	0	8 (100%)

proportion of mountain whitefish that exhibited signs of gas bubble disease, cumulative hourly spill weighted discharge and proportion of rainbow trout that exhibited signs of gas bubble disease, and cumulative hourly spill discharge and proportion of rainbow trout that exhibited signs of gas bubble disease, all yielded similar results (r^2 = 0.870, 0.845, 0.797, and 0.766, respectively).

Electrofishing

Our electrofishing activities to capture fish for examination of signs of gas bubble disease occurred less frequently than examination of captive fish. The lower frequency limited our ability to estimate the precise time when signs of gas bubble disease first appeared in free-swimming fish in the Kootenai River below Libby Dam. The first electrofishing survey in the Kootenai River below Libby Dam was conducted on June 26. No signs of gas bubble disease were observed in any fish captured via electrofishing on June 26 (Table 5). Signs of gas bubble disease were first identified in the electrofishing catch on the evening of July 1, 2002. At that time signs of gas bubble disease were common in all salmonid species examined (Table 5). Approximately 86% of the rainbow trout, 80% of the bull trout and 31% of the mountain whitefish collected from the electrofishing along the left bank and examined on July 1 exhibited signs of gas bubble disease. Gas emboli in the eyes were the most common sign of gas bubble disease identified by observers. Spill at Libby Dam peaked in terms of volume (kcfs) and the proportion of spill relative to total discharge peaked during this period (Table 3). Spill discharge peaked during spill event number 14 (July 1 15:00 – July 3 9:45) at 15.6 kcfs, and represented approximately 39% of the total discharge passing Libby Dam. We also collected fish from the right bank on the evening of July 1. Although the proportion of rainbow trout, bull trout and mountain whitefish exhibiting signs of gas bubble disease differed between left and right bank (Table 5), these differences were not significant ($P > 0.05$), but the power of the three tests was low (0.46, 0.35, and 0.21 respectively, for alpha = 0.05).

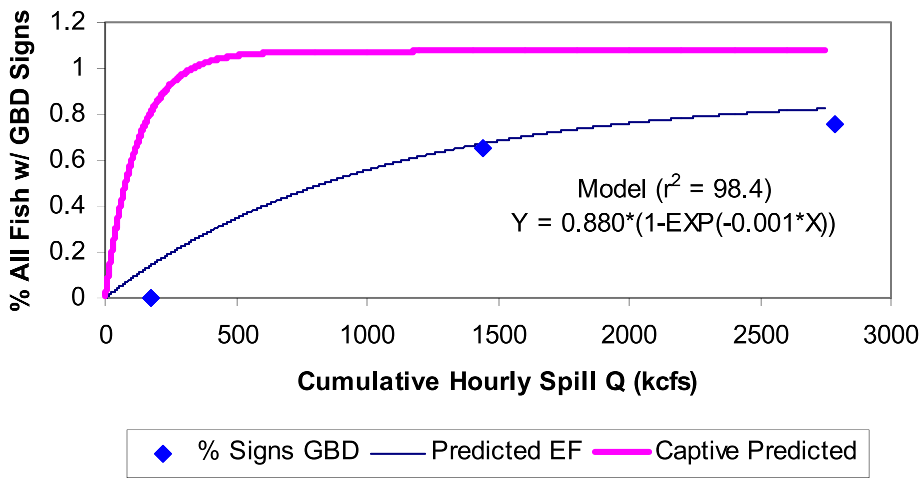
The only survey conducted prior to the July 1st survey was conducted 4 days prior on the evening of June 26. We intentionally maintained a low frequency of electrofishing within the area directly below Libby Dam to minimize impacts to the large salmonids inhabiting this section of the river. The next collection of fish via electrofishing below Libby Dam occurred on July 8. Signs of gas bubble disease were prevalent during the July 8 sampling period also with approximately 67% of the rainbow trout, 71% of the bull trout, and 83% of the mountain whitefish examined exhibiting signs of gas bubble disease (Table 5). Spill activities at the time of collection and examination on July 8 had been suspended for approximately 22 hours after continuous spill activities at Libby Dam lasting 12.2 days ranging from 0.7 – 15.6 kcfs. Our last electrofishing survey was conducted on July 24, approximately 7.5 days after the final spill event. We did not observe gas emboli in any of the 4 salmonid species examined at that time (Table 5). However, a substantial proportion of these fish had split fins. Field crews estimated that approximately 56% of the rainbow trout, 50% of the bull trout and 88% of the mountain whitefish below Libby Dam had at least one split fin on the evening of July 24. We did not estimate the proportion of fish that had split fins on any of the other observation dates, but we recall that this was not a noticeable infliction on prior sampling dates.

Table 5. A summary of the results of nighttime electrofishing surveys below Libby Dam to examine fish species for signs of gas bubble disease. The first number represents the sample size followed by the percent exhibiting signs of gas bubble disease in parentheses.

Species	**6/26 Left Bank**	**7/1 Left Bank**	**7/1 Right Bank**	**7/8 Left Bank**	**7/24 Left Bank**
Rainbow Trout	6 (0)	14 (86%)	5 (80%)	12 (67%)	16 (0)
Bull Trout	11 (0)	10 (80%)	9 (44%)	7 (71%)	8 (0)
Mountain Whitefish	4 (0)	13 (31%)	3 (67%)	18 (83%)	8 (0)
Suckers (all spp.)	0 (0)	7 (0)	1 (0)	5 (40%)	0 (0)
Kokanee	0 (0)	1 (0)	3 (100%)	10 (100%)	3 (0)
Columbia River Chub (*Mylocheilus caurinus*)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
Northern Pikeminnow	0 (0)	0 (0)	3 (0)	0 (0)	0 (0)
Redsided Shiner (*Richardsonius balteatus*)	0 (0)	2 (100%)	0 (0)	0 (0)	0 (0)
Burbot (*Lota lota*)	0 (0)	0 (0)	0 (0)	1 (100%)	0 (0)

Cumulative hourly spill weighted discharge compared to cumulative hourly spill discharge consistently provided a better regression fit to the data sets of the proportion of rainbow trout, bull trout, mountain whitefish, and all species combined exhibiting signs of gas bubble disease. The nonlinear model using cumulative hourly spill weighted discharge as the independent variable and the proportion of all species combined exhibiting signs of gas bubble disease provided the best fit for the fish captured via electrofishing ($r^2 = 0.993$; Figure 6). The nonlinear models for rainbow trout and bull trout were similar to the model using all species pooled when either cumulative hourly spill weighted discharge or cumulative hourly spill discharge was used as the independent variable (Figures 6-8). Linear regression provided a better fit to the mountain whitefish data set than did nonlinear regression (Figure 9).

The rate of fish response to supersaturated water in terms of the proportion of captive fish and fish captured via electrofishing appeared to be substantially different (Figure 6). Differences appeared to include both the rate in which signs of gas bubble disease affected each group and the maximum proportion observed exhibiting symptoms. Fish captured via electrofishing seldom exhibited incidence rates of 100%, even though the condition was common for captive fish (Figure 6). However, statistical analyses were not performed to evaluate whether nonlinear regressions significantly differed between captive fish and fish captured via electrofishing.



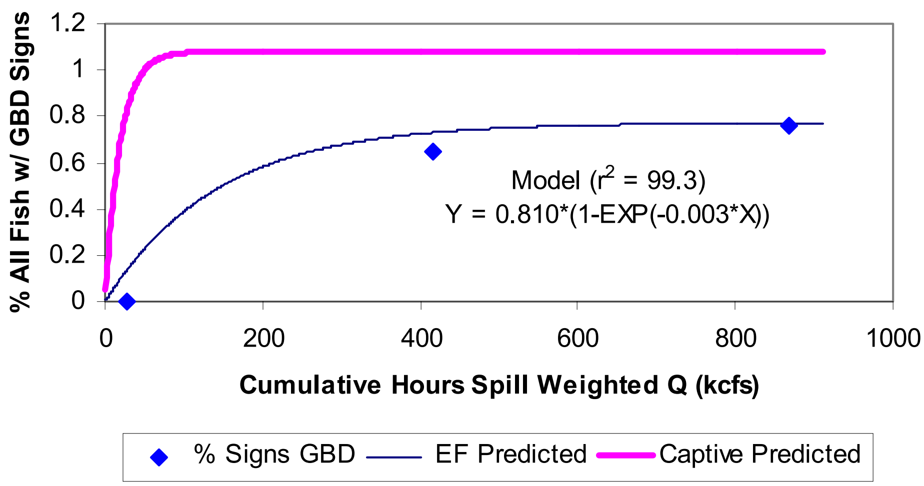
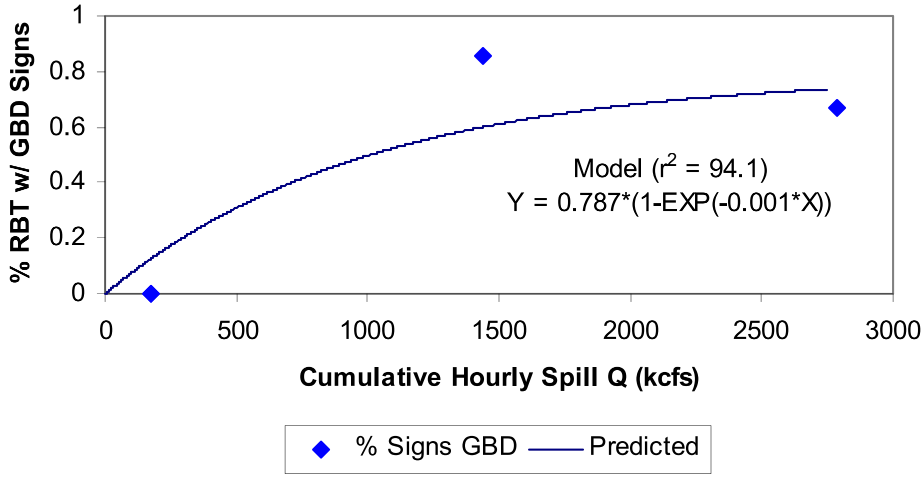


Figure 6. The relation between the cumulative hourly spill flow (top graph), cumulative hourly spill weighted flow (bottom graph), and the proportion of all fish (rainbow trout bull trout, and mountain whitefish combined) captured via electrofishing observed exhibiting signs of gas bubble disease (GBD) during spill activities in the Kootenai River below Libby Dam in the summer of 2002. The blue solid line represents the predicted relationship for fish captured via electrofishing and the pink solid line represents the predicted relationship for captive fish (all species pooled) for comparison. The model and r^2 value describe the relationship for fish captured via electrofishing.



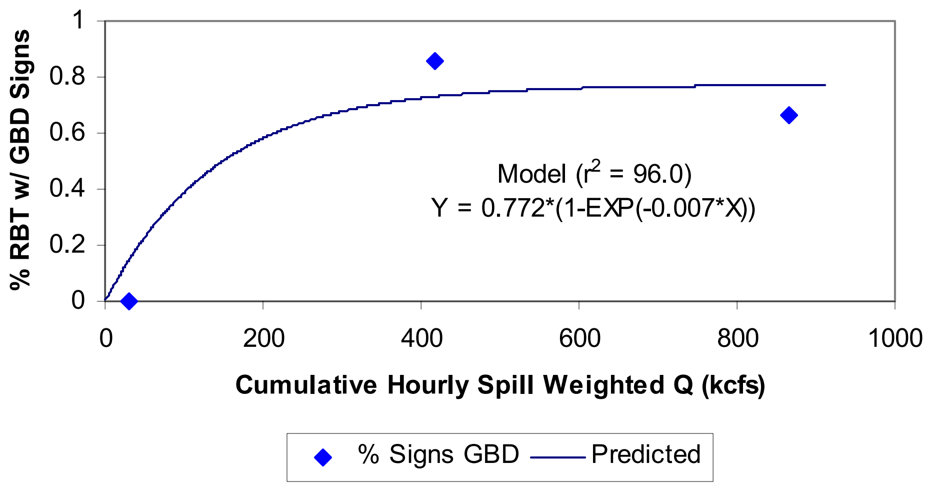
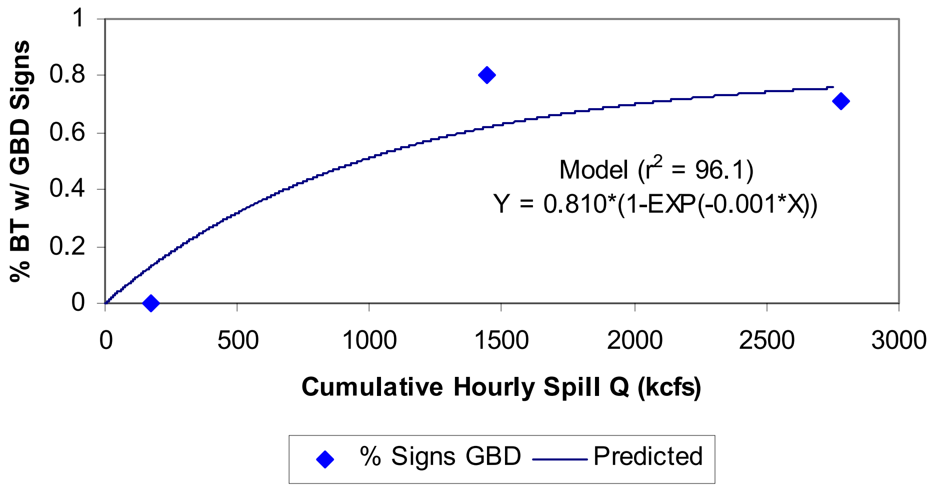


Figure 7. The relation between the cumulative hourly spill flow (top graph), cumulative hourly spill weighted flow (bottom graph), and the proportion of rainbow trout (RBT) captured via electrofishing observed exhibiting signs of gas bubble disease (GBD) during spill activities in the Kootenai River below Libby Dam in the summer of 2002.



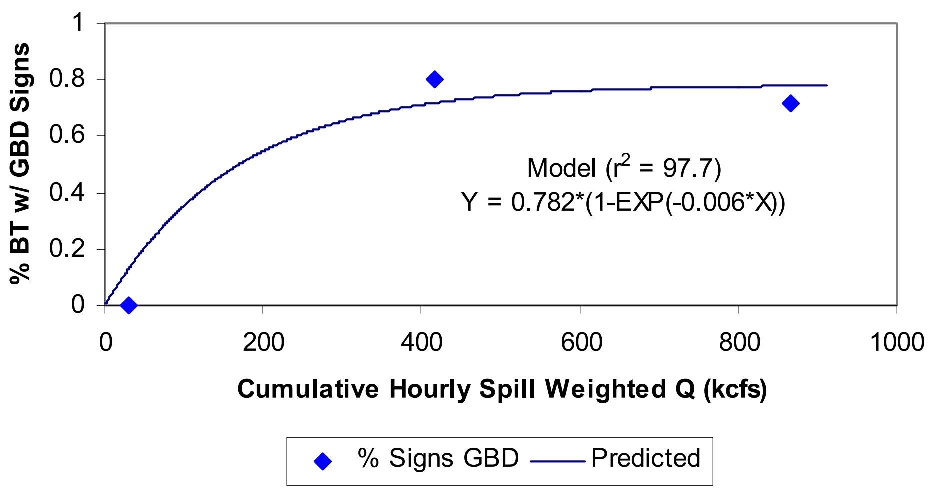
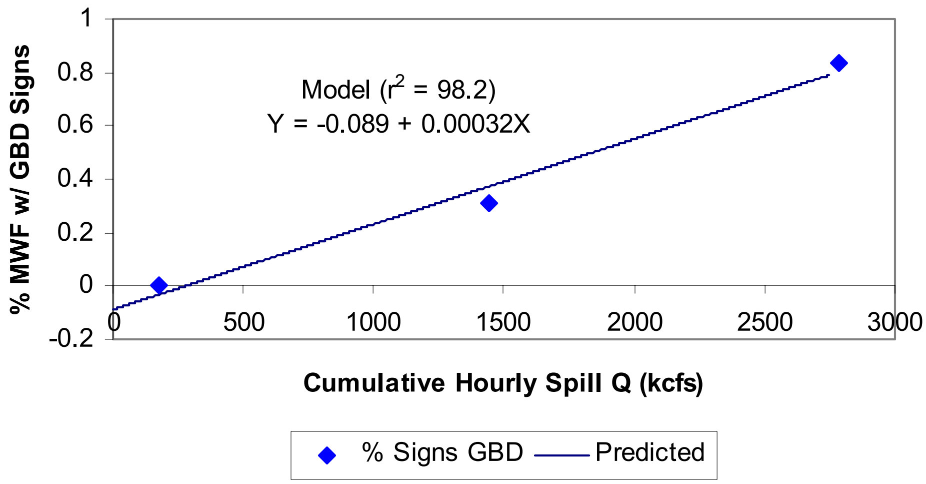


Figure 8. The relation between the cumulative hourly spill flow (top graph), cumulative hourly spill weighted flow (bottom graph), and the proportion of bull trout (BT) captured via electrofishing observed exhibiting signs of gas bubble disease (GBD) during spill activities in the Kootenai River below Libby Dam in the summer of 2002.



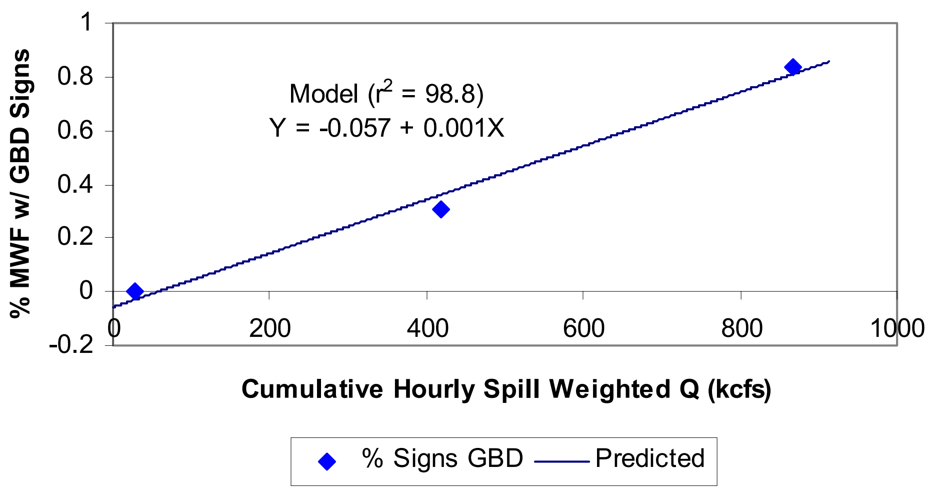


Figure 9. The relation between the cumulative hourly spill flow (top graph), cumulative hourly spill weighted flow (bottom graph), and the proportion of mountain whitefish (MWF) captured via electrofishing observed exhibiting signs of gas bubble disease (GBD) during spill activities in the Kootenai River below Libby Dam in the summer of 2002.

Radio Telemetry

We were able to locate all the radio tagged fish at least once with the exception of 1 rainbow trout and 1 bull trout (Table 6). Radio tagged fish were located an average of 7.9 times during our mobile tracking occurring 1 day prior to spill to 33 days after the last spill event at Libby Dam. The 3 radio tagged mountain whitefish were located an average of 9.7 times per fish, and bull trout and rainbow trout were located an average of 7.0 and 7.8 times per fish, respectively, but were not significantly different (P = 0.717).

Table 6. Summary of radio tag frequencies, total length and total number of observations (detections) for 8 rainbow trout, 5 bull trout and 3 mountain whitefish radio tagged and mobile tracked during the spill activities at Libby Dam.

Species	Radio Frequency (kHz)	Total Length (mm)	Total Observations
Rainbow Trout	49.105	510	11
Rainbow Trout	49.341	368	13
Rainbow Trout	49.541	406	2
Rainbow Trout	49.591	384	11
Rainbow Trout	49.711	375	6
Rainbow Trout	49.751	457	10
Rainbow Trout	49.801	394	0
Rainbow Trout	49.811	435	9
Bull Trout	49.531	711	0
Bull Trout	49.551	710	7
Bull Trout	49.571	813	9
Bull Trout	49.651	686	12
Bull Trout	49.741	610	7
Mountain Whitefish	49.601	440	11
Mountain Whitefish	49.611	406	13
Mountain Whitefish	49.771	403	5
Average			**7.9**

I believe that all the radio tagged fish that were detected at least once during the spill activities at Libby Dam were alive, based on repeated upstream movements during mobile tracking activities. Of those radio tagged fish that were detected at least once, most rainbow trout (n= 7; 100%), bull trout (n = 3; 75%) and mountain whitefish (n = 2; 67%) did not move substantially during the spill activities at Libby Dam, and remained within the general vicinity of Libby Dam (RM 221.7) downstream to Dunn Creek (RM 219.8), with the center of gravity more near Libby Dam. This information suggests that spill activities at Libby Dam did not cause substantial geographic fish displacement. We detected substantial movement of 1 mountain whitefish and 1 bull trout. We observed mountain whitefish, tag number 49.611 in the vicinity of the Libby Dam afterbay from 6/25 – 6/27 (9 observations total). The next detection was near the confluence of Rainy

Creek (RM 209.9) on 7/2. The final detection dates for this fish were 7/8 and 8/19 in the vicinity of the Libby Dam afterbay. Bull trout number 49.741 was detected near Canoe Gulch (RM 216.7) on 8/19, which was the last observation date for this fish. However, the second to last observation was in the lower Alexander Creek side channel (RM 220.3) on 6/26. Since we don't have any location information between 6/26 and 8/19, we don't know if the downstream movement occurred during the spill activities.

A gradient of supersaturated water occurred across the river channel in the tailrace of Libby Dam during the spill activities (Schneider and Carroll 2002; Figure 10). This mixing zone and associated cross sectional gradient of supersaturated water extends downstream from Libby Dam at least 6.1 miles (Schneider and Carroll 2002). We examined the radio telemetry data collected prior to and during the spill activities to attempt to determine if the tagged fish detected and avoided the supersaturated water along the left bank below Libby Dam. used a paired t-test to assess whether the number of detections for radio tagged fish were consistently higher along the left or right banks below Libby Dam, on a fish by fish basis during spill activities. We detected over twice as many radio tagged fish along the left bank below Libby Dam as those detected along the right bank (mean number of detections per fish = 3.4 and 1.6, respectively). However, differences were not significantly different either for a single-tailed or two-tailed test ($P = 0.064$ and 0.128, respectively). The power of these two tests were 0.560 and 0.709, respectively for alpha = 0.05. Radio tagged fish also moved across the river channel during the spill activities. We detected at total of 6 fish that changed bank orientation at least once, these included 3 rainbow trout, 2 mountain whitefish, and 1 bull trout. Radio tagged fish were also infrequently observed inhabiting the mid-river channel. We observed 4 different radio tagged fish in the mid-river channel, including 2 rainbow trout, 1 bull trout and 1 mountain whitefish. Each of these fish was only observed in the mid-river channel once.

Figure 10. This photograph was taken from the top of Libby Dam looking downstream during the first spill event at Libby on June 25, 2002. Spill discharge was approximately 700 cfs, total dam discharge was 22.8 kcfs. The lack of mixing of spill and turbine water across the channel created a gradient of total dissolved gas concentrations across the river channel for several miles downstream.

Discussion

Spill activities at Libby Dam during June and July, 2002 impacted resident fish in the Kootenai River, including bull trout, a species listed as threatened under the Endangered Species Act. This field studies indicated that signs of gas bubble disease were common for fish held in cages and fish collected from the river, and that symptoms generally developed rapidly (within 2-3 days) relative to the duration of spill activities. Observations for these field studies were limited to an area within 1.7 miles downstream of Libby Dam, and likely represent the worst-case scenario of potential impacts to fish in the lower Kootenai River because the highest TDG concentrations in the Kootenai River during the spill activities were observed in close proximity to Libby Dam (Schneider and Carroll 2002).

Our field study did not estimate mortality caused by gas bubble disease or other factors associated with the spill activities at Libby Dam. This was in part because the original intent of the study was to provide real time monitoring information that would identify early signs of gas bubble disease in fish and stop spill activities. Although we did observe mortality of captive fish, we were not able to extrapolate mortality rates of captive fish to the population at large in the river due to several confounding factors. The stress associated with electrofishing and handling likely contributed to mortality of captive fish held in the hoop traps. Captive fish also likely experienced additional stress due to confinement at densities that were many times higher than those existing in the Kootenai River. Due to the narrow range of depths available within the hoop traps (2 feet diameter) and relatively shallow positioning of the hoop traps (3-6 feet), captive fish had little opportunity for hydrostatic compensation. Many studies have demonstrated that hydrostatic pressure increases with water depth and can compensate for the effects of supersaturation exerted on a fish (Marsh and Gorham 1905; Blahm et al. 1973; Blahm 1974; Blahm et al. 1976; Ebel 1969; Ebel 1971; Meekin and Turner 1974; Weitkamp 1976). Hoffman et al. (2002) found that adult rainbow trout preferred habitat on the Kootenai River was characterized by water depths of 3-5 feet, mean velocities (mean velocities of 20% and 80% depth) of 1-3 feet/second, and large cobble and larger substrates. In the same study, mountain whitefish tended to prefer slightly deeper water, with suitability values peaking at depths of 4-7.5 feet, similar focal velocities ranging from 1.5-3.5 feet/second, and slightly smaller substrate ranging from large gravel to large cobble. We were not able to locate similar information for bull trout. However, given the habitat preferences for rainbow trout and mountain whitefish and the velocity and depths conditions that actually occurred over the range of observed discharges during the spill activities (23.5 – 38 kcfs), rainbow trout and mountain whitefish might have inhabited deeper water than that which the captive fish were held. If this were the case, hydrostatic compensation may help explain why we observed different responses to supersaturated water exposure time for captive and fish captured via electrofishing (Figure 6). We acknowledge that the response curves for fish captured via electrofishing (Figures 6-9) were developed with three data points each, and that the relatively low number of observations contributed to the relatively high regression r^2 values. However, we believe these data accurately represent conditions that existed in the Kootenai River directly below Libby Dam. We base our conclusions on the consistency of similar results across the three fish species for the three sampling periods, and the similarity in the general shape of the response curves between the captive fish and the fish captured via electrofishing.

The majority of the bull trout, rainbow trout and mountain whitefish captured via electrofishing below Libby Dam on July 24, one week after the final spill event at Libby Dam, exhibited fin damage (Table 5). This damage was presumably caused by necrosis of the fin tissue between the fin rays that was ultimately caused by gas emboli between within the fins. This observation suggests that many fish survived the initial spill period and were beginning to heal. However, the injuries we observed might have resulted in an increased susceptibility to fungal and bacterial infections, that could have resulted in delayed mortality. Weitkamp (1976) found fungal infections were responsible for delayed mortality of juvenile chinook exposed to supersaturated water that caused lesions and hemorrhages near the base of the caudal fin. We did not however observe any fungal infections associated with the damaged fins observed on the evening of July 24.

This field study provided insufficient evidence to conclusively decide whether or not bull trout, rainbow trout or mountain whitefish were able to detect the elevated TDG concentrations below Libby Dam during the spill activities. In a review by Weitkamp and Katz (1980), they concluded that the ability to detect and avoid supersaturated may be species specific, but that in general too little information exists to draw definitive conclusions on the subject. Although mobile radio telemetry tracking efforts suggested that radio tagged fish preferred the left bank, the differences were not statistically significant. These results for rainbow trout are consistent with those of Blahm et al. (1976), who found that juvenile steelhead did not avoid supersaturated water. We were unable to find published information regarding whether or not bull trout or mountain whitefish were able to detect supersaturated water.

The Montana Clean Water Act is the foundation that the Montana Department of Environmental Quality used to establish surface water quality standards, including limits on total dissolved gas concentrations. This standard is 110% (MT DEQ 2001), and was established to protect aquatic gill breathing organisms from the harmful effects of gas supersaturation. The federal standard set by the Environmental Protection Agency is also 110%. The Montana Department of Environmental Quality granted a short-term exemption from the 110% TDG standard during the spill test at Libby Dam. The standard was exceeded below Libby Dam early during the spill activities at Libby Dam, where TDG exceeded 120% approximately 250 feet below the stilling basin during the second spill event (Schneider and Carroll 2002). Approximately 3.0 kcfs passed over the spillway at Libby Dam during the second spill event, comprising approximately 12.6% of the total discharge passing Libby Dam at that time. The 110% standard was exceeded for the remainder of the spill activities at Libby Dam at this sampling location (Schneider and Carroll 2002). TDG concentrations peaked in the stilling basin below Libby Dam during spill event 16, exceeding 134% (Schneider and Carroll 2002). Therefore, given the relatively rapid response of TDG concentrations to relatively small amounts of spill water and the findings of this field study, the use of spill as a regular management activity at Libby Dam appears to have limited practical application. Libby Dam managers may seek to explore the feasibility and cost efficiency of making structural modifications at Libby Dam that could potentially reduce spill water plunge into the stilling basin, and reduce TDG concentrations or increase powerhouse capacity to allow higher dam discharges without spilling water.

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