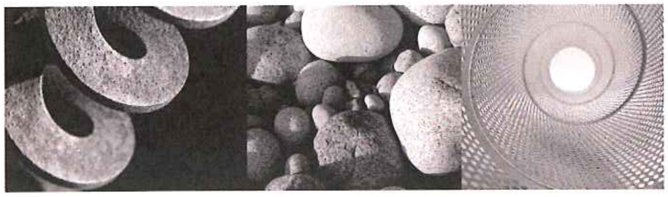

GEI Consultants

Geotechnical
Water Resources
Environmental and
Ecological Services

Literature Review of Downstream Fish Passage Issues at Thompson Falls Hydroelectric Project

Submitted to:
PPL Montana
45 Basin Creek Road
Butte, MT 59701

Submitted by:
GEI Consultants, Inc.
Chadwick Ecological Division
127 East Front Street, Suite 216
Missoula, MT 59802

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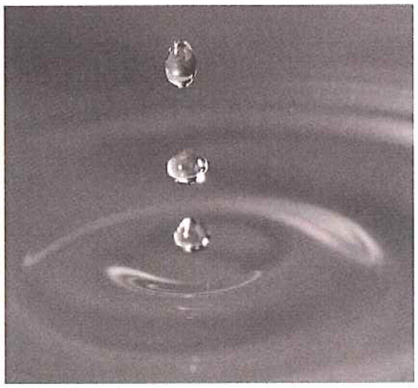
Project 060080



Ginger Gillin

Ginger Gillin
Environmental Scientist

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Executive Summary

The Thompson Falls Power Company began construction of the Thompson Falls Dam Project (Project) on the Clark Fork River in Montana in 1912. The original license expired in 1975. The current license was issued to Montana Power Company (now PPL Montana) in 1979 and is scheduled to expire on December 31, 2025. In 1999 the bull trout (*Salvelinus confluentus*) was federally listed under the Endangered Species Act (ESA) as a threatened species (Federal Register, 1999); and critical habitat was designated in 2005 (Federal Register, 2005). Petitions were made to list the westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) as well, but the U.S. Fish and Wildlife Service (USFWS) determined that ESA listing was unnecessary (Federal Register, 2000 and 2003). PPL Montana is the designated non-federal representative for the consultation with the USFWS on compliance with ESA. As a part of this informal consultation, the USFWS has requested that PPL Montana address the issue of downstream fish passage risk at the Thompson Falls Project.

The Thompson Falls Project is a run-of-the-river hydropower facility in northwestern Montana. The Project is the upstream-most dam in a series of three hydroelectric dams on the lower Clark Fork River. Fish upstream of Thompson Falls Dam have unimpeded access to 357 miles of mainstem habitat within four different rivers. This number will soon increase to 601 miles when Milltown Dam is removed, and access to the Upper Clark Fork and Blackfoot Rivers is restored. Immediately downstream of the Project are two dams and reservoirs owned and operated by Avista Corporation, Noxon Rapids Dam and Reservoir and Cabinet Gorge Dam and Reservoir.

The Thompson Falls Project is comprised of two dams (Main and Dry Channel) and two powerhouses (old and new). The turbine/generator configuration in the old powerhouse (Nos. 1-6) consists of six similar Francis units rated at 5 megawatts (MW) each, each with hydraulic capacities of 1,700 cubic feet per second (cfs) and a total turbine capacity of 10,200 cfs. The new powerhouse is immediately upstream of the old powerhouse, and has one large 62 MW Kaplan turbine (Unit 7) with a capacity of approximately 13,000 cfs. Unit 7 is among the most modern of Kaplan type turbines with four adjustable blades. The runner is large, 262" (28 feet or 8.5 m) in diameter, and it rotates at a speed of 94.7 rotations per minute (rpm).

When total river discharge is less than plant capacity, the new powerhouse is generally preferentially operated to maximize peak efficiency of the project, with between 50 and 70 percent of the river flow typically going through Unit 7. Two units, typically Nos. 1 and 3, operate as auxiliary power to No. 7 to maintain heat in the old powerhouse and to exercise these other units during low flows. Generally, Units 2, 4, 5, and 6 are operated at high flows, as they are the least efficient and smallest units at the project.

One of the major environmental issues for hydroelectric power plants is fish mortality due to turbine passage. When the dam is spilling, fish can migrate downstream via spillway, outlet works or through the turbines. During non-spill periods, the primary means of downstream passage is through the turbines. Any form of dam passage poses some quantifiable risk of injury or mortality to migrating fishes. Studies done on anadromous fishes have generally indicated that passage via spill poses less risk than via turbine. Mortality is typically 0-2 percent for standard spill bays and 5-15 percent for turbine passage at most hydropower plants. However, mortality at a specific facility can vary depending on the specific configuration of the turbines and spillways and type and timing of fish being passed.

In the past decade there has been a considerable increase in downstream fish passage research; this is in large part due to the need to explore all reasonable means of conserving declining salmon and steelhead stocks. Turbine-passage survival is a complicated function of runner diameter, head, turbine type, runner speed (rpm), fish size, trajectory of the entrained fish relative to flow streams through the turbine, spatial clearance between structural components, such as wicket gates, number of runner blades or buckets, peripheral runner blade speed, flow, and angle of water flow through the turbine. In addition to turbine design and operational modifications, turbine intake screens, surface flow bypass (SFB) systems, bar racks, louver arrays, and light or sound based guidance systems have been employed at various hydropower projects to minimize fish mortality.

In general, at any given time throughout the year, approximately 50 to 70 percent of the Clark Fork River at Thompson Falls flows through the Kaplan unit. Based on an assumed 1:1 ratio of fish-to-flow, we assume that 50 to 70 percent of the migrants that pass through the turbines at the Project pass through the new Kaplan unit during non-spill time periods. If spillway efficiency is 1:1, the number of migrants passing the dam in spill is similar in proportion to water being spilled. Based on combined survival estimates for passage through the Francis turbines, the Kaplan turbine and the spillway, the average downstream passage survival at the Project for trout measuring greater than 100 millimeters (mm) is likely 91 to 94 percent.

Numerous costly efforts have been undertaken to address the issue of safe downstream fish passage at hydropower projects. Many of these efforts have not been evaluated for effectiveness, and some are so new that their benefit has yet to be established. Most of these projects have been done in rivers with anadromous fishes, which must migrate downstream in order to complete their life-history. Measures that are warranted for anadromous fishes may not be logical or reasonable for rare non-anadromous fishes.

At the two dams directly downstream of the Thompson Falls Project, a trap-and-haul approach is being used to address downstream passage. An evaluation of this approach is underway, but it may be years or even decades before the effectiveness can be determined. While bull trout in the Clark Fork River upstream of Thompson Falls may migrate downstream past the Thompson Falls Project, they can complete their life history without making this migration. Since the habitat for bull trout is arguably better upstream of Thompson Falls Dam than downstream (given the presence of additional dams and reservoirs), a trap and haul approach may not make sense at this Project.

An alternative approach for the Project that would have higher likelihood of benefiting bull trout, and incidentally westslope cutthroat trout, is off-site mitigation. Avista Corp. recently completed a review of current conditions for native salmonids in tributaries to the lower Clark Fork River drainage. This report covers several of the tributaries to the Clark Fork River upstream of the Thompson Falls Project and outlines areas where restoration or enhancement efforts should focus. This approach may be more sensible, less costly, and have a greater beneficial impact on bull trout and other lower Clark Fork River fishes than any type of downstream trap and transport, or fish screening and bypass at the Project.

1.0 Introduction

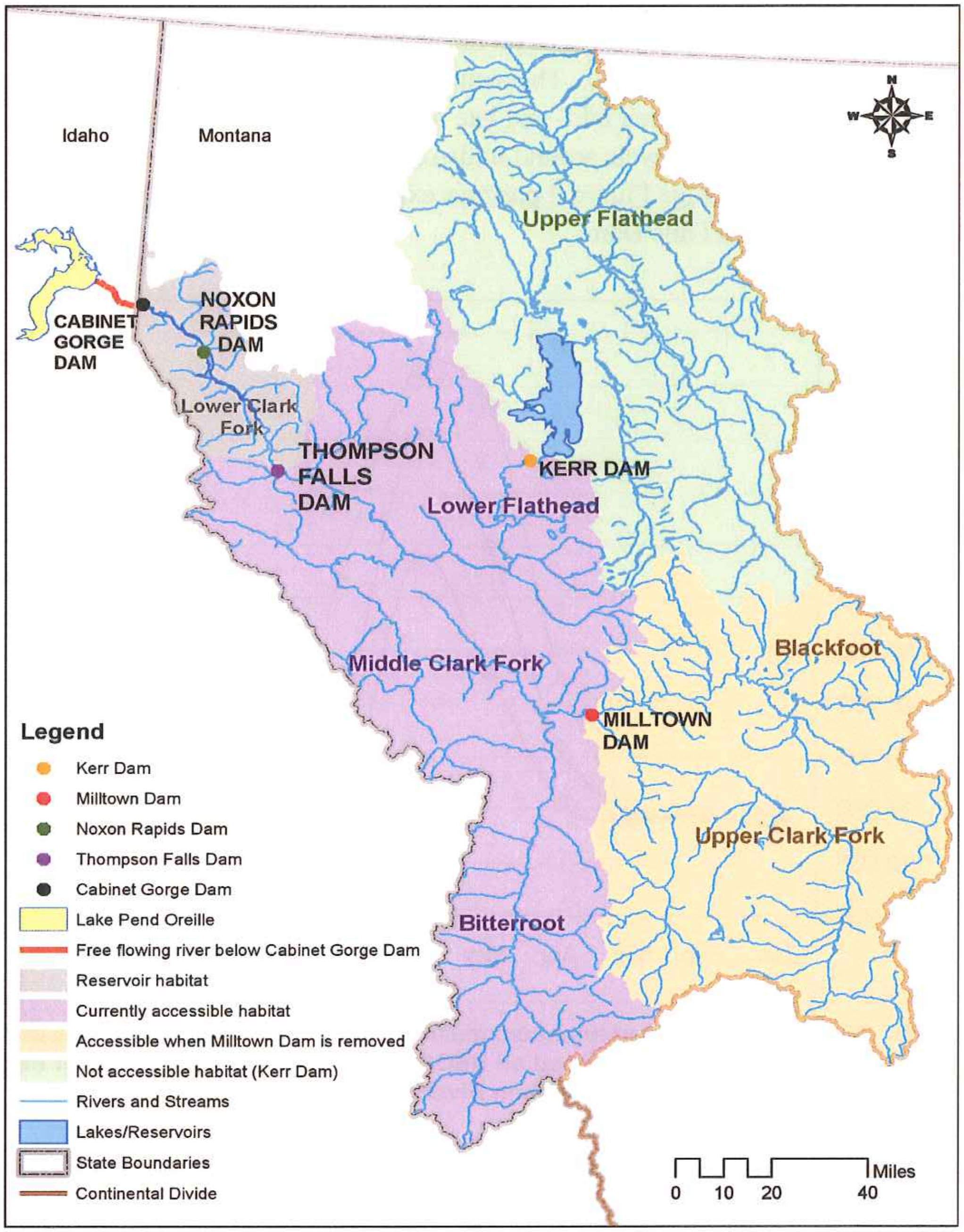
1.1 Background of Project

The Thompson Falls Power Company began construction of the Thompson Falls Dam Project (Project) on the Clark Fork River in Montana in 1912. The original license expired in 1975. The current license was issued to Montana Power Company (now PPL Montana) in 1979 and is scheduled to expire on December 31, 2025. A major order amending the license was issued in 1990 allowing for construction of an additional powerhouse and generating unit. That project was completed in 1995. In 1999 the bull trout (*Salvelinus confluentus*) was federally listed under the Endangered Species Act (ESA) as a threatened species (Federal Register, 1999); and critical habitat was designated in 2005 (Federal Register, 2005). Petitions were made to list the westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) as well, but the USFWS determined that ESA listing was unnecessary (Federal Register, 2000 and 2003).

In a biological assessment of Thompson Falls Hydroelectric Development prepared by PPL Montana in 2003, the potential risks that the hydropower project poses to downstream migrating bull and westslope cutthroat trout were described (Pizzimenti and Gillin, 2003). It was recognized that any form of dam passage poses some quantifiable risk of injury or mortality to migrating fishes. PPL Montana is the designated non-federal representative for the consultation with the USFWS on compliance with ESA. As a part of this consultation, the USFWS has requested that PPL Montana address the issue of downstream fish passage risk at the Thompson Falls Dam Project specific to bull trout. We have included westslope cutthroat trout in this review as well, because of their status as a sensitive species and a Montana Species of Special Concern.

1.2 Site Description

The Project is a run-of-the-river hydropower facility in northwestern Montana. The Project is the upstream-most dam in a series of three hydroelectric dams on the lower Clark Fork River, at RM 63 (Figure 1).



Data Source: NRIS
Datum: North American 1983
December 19, 2006

Figure 1 Clark Fork subbasin, showing location of Thompson Falls Dam in relation to the free-flowing Clark Fork and Flathead rivers, and downstream dams and reservoirs.

The annual hydrograph of the Clark Fork River just upstream of Thompson Falls Dam from 1957 to 2004 is shown in Figure 2. The hydrograph shows the minimum, mean, and maximum monthly mean flows over a 48 year period based on addition of flows taken from U.S. Geological Survey (USGS) gages on the Clark Fork River near Plains (#12389000) and the Thompson River (#12389500). The annual hydrograph indicates the ascending limb of the hydrograph begins between mid- and late March, peaks between late May and mid-June, and descends to base flow levels around mid-August. Of course these trends may vary in dry or wet years, but on average Figure 2 portrays expected hydrology in the Clark Fork River upstream of Thompson Falls Dam.

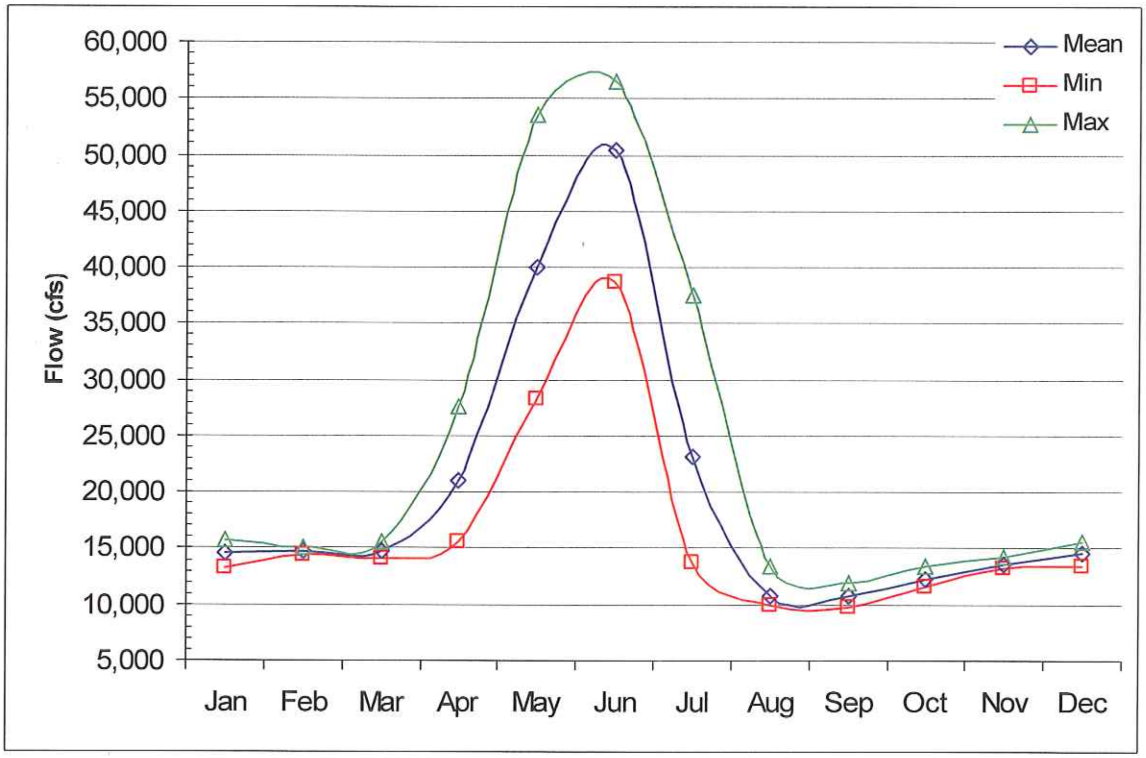


Figure 2 **Maximum, mean, and minimum mean monthly flow in the Clark Fork River at Thompson Falls Dam based on USGS gages on the Clark Fork River near Plains (#12389000) and the Thompson River (#12389500).**

Plant capacity at the Project is approximately 23,000 cfs. River flow in excess of this amount is routed over the spillways. Typically, spill begins in late April, peaks in early June, and ends in mid-July (Figure 3).

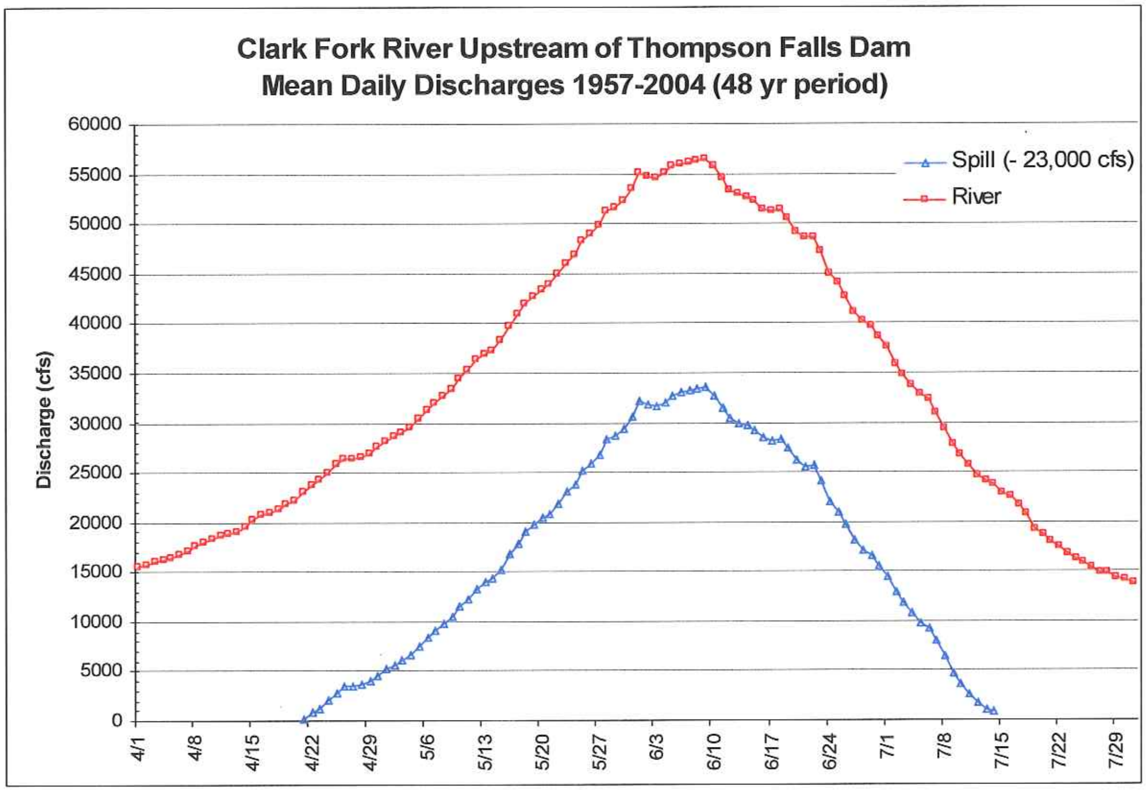


Figure 3 **Mean of daily river discharges (cfs) and spill discharges (cfs) between April 1 and July 30 from 1957-2004.**

Upstream of Thompson Falls Dam there are approximately 157 miles of free-flowing Clark Fork River. The only other fish passage barrier on the Clark Fork River upstream of Thompson Falls is Milltown Dam, located at RM 220. This dam is scheduled for removal in 2007. At the present time, fish in the Clark Fork River upstream of the Project have free access to 157 miles of the Clark Fork River, 77 miles of the Flathead River, 84 miles of the Bitterroot River, 39 miles of St Regis River, and thousands of miles of suitable tributary streams (total 357 mainstem river miles). Once Milltown Dam is removed, the number of miles of accessible habitat on the Clark Fork River will increase to 274 miles. The Blackfoot River, mainstem of 127 miles, and all of its tributaries will also become accessible to fish migrating from downstream areas (Figure 1).

The Flathead River is a major tributary to the Clark Fork River, and enters the Clark Fork just upstream of the town of Paradise, Montana. Kerr Dam, located at RM 77 on the Flathead River, will be the only fish passage barrier on a major river upstream of Thompson Falls Dam once Milltown Dam is removed. Therefore, there are 357 miles of mainstem river that are currently accessible to fluvial bull trout, and this number is soon to increase to 601 miles.

Immediately downstream of Thompson Falls Dam, there are a series of two dams/reservoirs: Noxon Rapids Reservoir and Cabinet Gorge Reservoir. Downstream of Cabinet Gorge Dam there are approximately 7 miles of free flowing river, before the Clark Fork River enters Lake Pend Oreille. Lake Pend Oreille is a natural lake with lake levels controlled by the Albeni Falls Hydroelectric Dam.

Very small numbers of bull trout and westslope cutthroat trout inhabit all three reservoirs on the lower Clark Fork River. There are also large numbers of non-native fish such as northern pike, largemouth bass, smallmouth bass, walleye, and yellow perch as well as native northern pikeminnow, peamouth and largescale sucker. The reservoirs provide limited useable habitat for bull trout and westslope cutthroat trout because of the dominance of large predators and warm summer water temperatures.

1.3 Overview of Downstream Passage Issues

Hydroelectric power supplies approximately 10 percent of the electrical energy generated in the United States, and nearly 20 percent of the world's energy (Cada et al. 1999). Hydropower is a non-polluting, renewable energy resource that does not contribute to global warming. However, there are some undesirable ecological effects associated with hydropower projects, like disrupting fish migration. In this report we examine how hydroelectric dams in general, and the Thompson Falls Project in particular, affect the downstream movement of bull and westslope cutthroat trout.

While dams may completely block upstream movement, downstream fish passage remains viable at hydropower facilities. When the dam is spilling, fish can migrate downstream via spillway, outlet works or through the turbines. During non-spill periods, the primary means of downstream passage is through the turbines. While any form of dam passage poses some quantifiable risk of injury or mortality to migrating fishes, generally passage via spill poses less risk than via turbine (Muir et al. 2001).

2.0 Bull and Westslope Cutthroat Trout

2.1 Status and Life History

There are two fish species present in the project area that the state of Montana lists as Species of Special Concern. Bull trout (*Salvelinus confluentus*) and westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) are both native to the western United States. The current distribution and population of each species are fractions of what they were in the past. In 1999 bull trout were federally listed as a threatened species (Federal Register, 1999) and critical habitat was designated in 2005 (Federal Register, 2005). The westslope cutthroat trout is not a federally listed species (Federal Register, 2000 and 2003).

In Montana, both species are potamodromous (migrate but stay within freshwater) and exhibit three life history patterns: resident, fluvial, and adfluvial (Liknes and Graham, 1988; Behnke, 1992; McIntyre and Rieman, 1995). All three patterns use smaller tributaries to spawn. Resident fish will spend their lives entirely in the natal tributaries. Fluvial fish reside in larger rivers where their young will join them to mature. Adfluvial fish reside in lakes and reservoirs to which their young will eventually migrate. The young of both species will typically spend 1 to 4 years in their natal stream before migrating (Fraley and Shephard, 1989). All three life-history types may occur in a single drainage (Rieman and Apperson, 1989).

2.1.1 Bull Trout

The Clark Fork River basin supports very low numbers of bull trout (Schmetterling, 2003, Schmetterling and McEvoy, 2000). PPL Montana has been sampling fish in the tailrace of Thompson Falls Dam since 1999. In 2006, four bull trout were collected out of 151 fish sampled using electrofishing and trapping, or 2.6 percent of the fish sampled. Table 1 lists the date and size of every bull trout handled by the sampling program in the tailrace of Thompson Falls Dam since 1999. Even with multiple collection techniques, including trapping, electrofishing, and angling, a total of only 26 bull trout have been collected in 8 years (between one and seven per year). In a survey conducted by Schmetterling and McEvoy (2000) on fish attempting to migrate past Milltown Dam, the percentage of bull trout caught (n=2) relative to the total number of trout species caught (n=1,360) was 0.15 percent. Actual numbers may be a bit higher though; Schmetterling (2003) estimated that Milltown Dam impedes the spawning of 75 bull trout annually. We have no comparable estimate of the number of bull trout attempting to pass the Thompson Falls Project.

In the Lower Clark Fork River, bull trout begin their long-distance upstream spawning migration during the rising limb of the hydrograph in the spring. April is the month when the most bull trout have been collected in the tailrace of Thompson Falls Dam (15 out of 26 bull trout handled). It should be noted that it is impossible to safely sample this environment during high water, and trapping and electrofishing efforts are stopped when water temperatures are high in the summer to reduce the risk of injury to bull trout. The adults will generally spawn in the September – October, and shortly thereafter will return to their primary habitat to overwinter. Bull trout are known to migrate as much as nearly 110 km on average (Schmetterling 2003). In 2001, two adult bull trout were radio tagged and transported upstream of Thompson Falls Dam. Both of these fish ascended the Thompson River. Total upstream movement averaged 26.5 km, and the bull trout moved at an average rate of 0.3 km/day.

Table 1 Bull trout collected in the tailrace of Thompson Falls Dam, 1999 – 2006. A = angling, EF = electrofishing, T = trapping.

Date	Length (mm)	Weight (gram)	Sampling Method
5/7/1999	505	1247	A
5/18/1999	395	400	EF
5/3/2000	517	1180	A
4/11/2001	323	264	A
6/1/2001	545	1390	T
7/20/2001	644	2275	T
5/3/2002	414	568	A
8/7/2002	780		T
4/3/2003	274	182	EF
3/29/2004	109	n	EF
4/7/2004	487	1225	T
4/13/2004	523	1483	T
4/19/2004	372	393	EF
4/19/2004	535	1275	EF
4/19/2004	718	3660	EF
5/5/2004	505	1185	T
4/11/2005	118	13	EF
4/11/2005	102	9	EF
4/12/2005	167	30	EF
4/12/2005	162	31	EF
4/21/2005	730	5021	EF
4/21/2005	300	202	EF
3/9/2006	245	103	EF
4/6/2006	341	560	T
4/13/2006	485	1115	EF
5/3/2006	775	3941	EF

Migratory (fluvial and adfluvial) bull trout are significantly larger than their resident counterparts (150 to 300 mm) (Rieman and McIntyre 1993). Their large size may make them more prone to injury when passing through hydroelectric facilities. However, at this time it is assumed that most of the bull trout passing downstream through the Project are juvenile bull trout outmigrating from tributaries. Adult bull trout may pass downstream through the Project occasionally, if they are exploring or pioneering new habitats or food sources.

Bull trout are bottom-oriented fish and require cold temperatures (≤ 15°C or 59°F) (Montana Bull Trout Restoration Team [MBTRT], 2000). Many of the screens and bypass facilities constructed on the Columbia River system have been designed to pass juvenile salmon swimming near the surface. The effectiveness of these devices for a substrate oriented fish has not been tested.

2.1.2 Westslope Cutthroat Trout

The westslope cutthroat is one of two subspecies of native cutthroat trout found in Montana. The other is the Yellowstone cutthroat trout, which is not native to the Clark Fork basin. The decline of westslope cutthroat populations can be attributed to hybridization, notably with rainbow and Yellowstone cutthroat trout, and habitat loss. Accurate information about the status of westslope cutthroat trout can be difficult to acquire because of the difficulty in distinguishing pure westslope cutthroat trout from introgressed rainbow/westslope/ Yellowstone cutthroat. While pure westslope cutthroat appear to be uncommon in the Clark Fork River, fish with the appearance of westslope cutthroat trout are more common than bull trout. In 2006, 13 fish identified as westslope cutthroat trout were collected downstream of Thompson Falls Dam (8.6 percent of the fish collected).

In the lower Clark Fork River, westslope cutthroat begin migrating to spawning tributaries during the rising limb of the hydrograph in the spring. Spawning generally occurs during the falling limb of the hydrograph between May and June (Schmetterling, 2001b). In 2001, 13 cutthroat trout (average length 366 mm) were radio tagged and transported upstream past the Project. Four of these fish made upstream migrations in excess of 100 km. Tributaries used by these radio tagged fish included Combest Creek, Cherry Creek, Thompson River, Fishtrap Creek, St. Regis River, and Cedar Creek. Minimally, cutthroat trout appear to have wide ranging movements, utilizing habitats from Thompson Falls, Montana to Superior, Montana.

Westslope cutthroat do not grow as large as bull trout but can measure over 400 mm for migratory forms, and more commonly 150 to 300 mm for resident fish.

2.2 Downstream Passage

Much attention has been paid to downstream fish passage in the Columbia River system, which supports anadromous salmon and trout. Bull and cutthroat trout life histories in Montana differ from that of anadromous Pacific salmon in that they do not migrate to the ocean, they do not die after spawning, and both migratory and non-migratory life history patterns are expressed.

Therefore, the downstream passage issue is different for salmonids in Montana than for anadromous fish in the Columbia River. For anadromous fishes, outmigration of juveniles to the ocean is an obligatory component of the life history - juveniles must successfully pass downstream through a hydropower system in order to survive to adulthood. Fishes in Montana often migrate, but they can also be non-migratory. In either case, they stay within the freshwater system, and may never migrate to a large lake or reservoir. Therefore, the need to provide downstream juvenile passage at the dams in Montana is less clear.

Thus, until recently, there have been limited efforts to provide downstream passage of adults through the Columbia hydropower system. Trout in Montana do not die after spawning, and can spawn more than once in a lifetime. Therefore, adults may move both upstream and downstream within a river system.

2.2.1 Bull Trout

There are limited data pertaining to the effects of run-of-the-river dams on inland fisheries (Cada and Sale, 1993). Fortunately, a comprehensive study regarding bull trout movement in the mid-Columbia River hydropower system was conducted from 2001 to 2004. Seventy-nine bull trout were tagged from 2001 to 2002 on the mid-Columbia River to study the operational effects of multiple hydropower projects on adult bull trout (BioAnalysts, 2004). Of the 79 tagged bull trout tracked from 2001 to 2003, 8 individuals moved downstream after exiting the fish ladders at Rocky Reach and Wells Dams. However, 11 total downstream events were documented, thus indicating multiple upstream and downstream passages. For example, the five downstream passage events documented in 2002 at Rocky Reach Dam were undertaken by three individuals. The downstream route was not obtainable for each event, but both spillway and turbine passage were documented. No fish were significantly harmed during their downstream movements (BioAnalysts 2004; Rocky Reach Bull Trout Management Plan [RRBTMP], 2006). Researchers concluded that the operations of the hydropower projects on the mid-Columbia River do not negatively affect adult bull trout survival (BioAnalysts 2004).

Avista Corporation, owner and operator of the two dams on the Clark Fork River downstream of Thompson Falls, is involved in a trap-and-haul fish passage program for bull trout. Adult bull trout are captured downstream of Cabinet Gorge Dam and, depending on the results of genetics testing to determine the likely natal stream, released upstream of either Cabinet Gorge Dam or Noxon Rapids Dam. Many of these fish are radio tagged and their movements tracked. Lockard et al. (2004) report that 15 of these transported adult bull trout passed back downstream through Cabinet Gorge Dam. While the fate of all 15 of these fish has not been documented, at least eight have been recaptured and, therefore, survived passage through the dam (Lockard et al. 2004).

At this time there are no site-specific data to indicate the degree to which the Thompson Falls Project is an impediment to downstream passage of adult bull trout. Neither of the two bull trout which were passed upstream over the Project in 2001as part of the radio telemetry study is known to have returned downstream past the dam. However, it should be noted that fish were tracked for an average of 100 days during the 2001 radio telemetry study. Some radio tagged fish may have moved downstream past the dam after the batteries died in the radios. For example, one of the radio tagged bull trout was last tracked on August 3, 2001, before the start of the bull trout spawning season and well before downstream post-spawning movements would be expected to occur.

No site-specific information on the timing of juvenile bull trout outmigration through Thompson Falls Reservoir is available. In other areas of the lower Clark Fork basin, bull trout seem to have a bimodal outmigration pattern. In the Bull River, juvenile bull trout outmigrate in the spring (approximately March – July) and with rain events in the fall (October and November). In Fishtrap Creek, tributary to the Thompson River, the spring pattern is unknown, but outmigration in the fall generally occurs with rain events from the end of September through early November (Katzman, Montana Fish, Wildlife and Parks, personal communication, July 2002).

In 2004, the Avista Corporation captured 84 juvenile bull trout (< 300 mm) moving downstream in the East Fork Bull River. Although a few of these fish were collected in the spring (April – May), most were collected in the July – October time period. September had the highest number of outmigrating juvenile bull trout (n=16). Recent studies in Trestle Creek, tributary of the Lake Pend Oreille, also found two pulses of outmigration for bull trout. The timing of the pulses was again spring (April – June) and fall (September-November). The two pulses accounted for 92 to 93 percent of the total outmigrants sampled in the April – November time period (Downs, Idaho Fish and Game, personal communication, November 2002).

Further upstream on the Clark Fork River, juvenile bull trout have been found to pass downstream through Milltown Reservoir during a relatively short window during high water in May. This migration has been detected through monitoring of the stomach contents of northern pike in Milltown Reservoir (Schmetterling, 2001a). Therefore, juvenile bull trout moving downstream through Thompson Falls Reservoir could conceivably be entering Thompson Falls Reservoir before, during, or after the spill season.

2.2.2 *Westslope Cutthroat Trout*

Of the 13 westslope cutthroat radio tagged and transported upstream of Thompson Falls Dam in 2001, five were documented to pass back downstream through Thompson Falls Dam (Table 2). An angler captured one of these cutthroat trout after passing through the dam, indicating that the fish survived downstream passage through the dam. Another cutthroat moved into Noxon Rapids Reservoir and moved in both upstream and downstream directions after passing through that dam. This indicates that the fish survived passage through the Project. One adult radio tagged rainbow trout also passed back downstream through the dam in 2001 (Table 2). It was also caught by an angler in Noxon Rapids Reservoir, indicating survival after passage.

Table 2 Downstream movements of radio-tagged fish transported upstream of Thompson Falls Dam in 2001. BLT = bull trout, WCT = westslope cutthroat trout, RBT = rainbow trout

Species (n)	Date Captured	Date Last Located	Days Tracked	Date Most Upstream	Date Most Downstream	Days to Move Downstream	Km Moved Downstream	Rate Moved Downstream (km/day)	Last Location	Comments
BLT (n = 2)	11-Apr	3-Aug	114	6-Jul	13-Jul	7.0	2.9	0.4	Thompson R	
	1-Jun	5-Oct	127	31-Aug	28-Sep	28.0	2.7	0.1	Thompson R	
Mean						17.5	**2.8**	0.3		
SD						**14.8**	**0.1**	**0.2**		
RBT (n = 6)	21-Mar	3-Oct	196	27-Jun	5-Jul	8.0	1.3	0.2	Heron nest, Jocko R	
	26-Mar	25-May	60	25-May	25-May	0.0	0.0	0.0	Flathead River	
	26-Mar	23-Jun	89	13-Apr	2-May	19.0	18.7	1.0	Thompson Reservoir	Tracked in Reservoir for 52 days
	26-Mar	3-Aug	130	2-Apr	14-Jul	103.0	6.9	0.1	Prospect Ck mouth	Tracked in Reservoir for 5 days Caught by angler Aug 3
	26-Mar	20-Apr	25	20-Apr	20-Apr	0.0	0.0	0.0	Clark Fork above Flathead	
	17-Apr	20-Apr	3	20-Apr	20-Apr	0.0	0.0	0.0	Clark Fork above Flathead	
Mean						**21.7**	**4.5**	**0.2**		
SD						**40.5**	**7.5**	**0.4**		
WCT (n = 13)	21-Mar	25-May	65	25-May	25-May	0.0	0.0	0.0	Miller Ck/Combest Ck	
	22-Mar	24-Aug	33	23-Mar	14-Jul	113.0	19.6	0.2	mouth of	Tracked in Reservoir

Species (n)	Date Captured	Date Last Located	Days Tracked	Date Most Upstream	Date Most Downstream	Days to Move Downstream	Km Moved Downstream	Rate Moved Downstream (km/day)	Last Location	Comments
									Graves Ck	for 51 days
	22-Mar	11-Oct	203	22-May	11-Oct	142.0	0.2	0.0	Cherry Cr	
	31-Mar	19-Aug	142	22-Jun	19-Aug	58.0	61.2	1.1	mouth Marten Ck	Caught by angler on Aug 19.
	3-Apr	15-Jun	73	29-May	14-Jun	16.0	49.9	3.1	mouth Graves Ck	
	5-Apr	10-May	35	10-May	10-May	0.0	0.0	0.0	Thompson R	
	11-Apr	18-Oct	190	25-May	14-Jul	20.0	144.3	7.2	mouth Graves Ck	
	17-Apr	29-Jun	73	26-Jun	29-Jun	3.0	0.8	0.3	Thompson R (dead)	
	17-Apr	17-Jul	61	1-Jun	28-Jun	28.0	131.5	4.7	Thompson Reservoir	Tracked in Reservoir for 19 days
	19-Apr	15-Jun	57	25-Apr	14-Jun	50.0	10.3	0.2	Below T Falls Dam	
	23-Apr	22-Sep	152	2-May	11-Jun	40.0	34.3	0.9	Thompson Reservoir	Tracked in Reservoir for 103 days
	23-Apr	3-Oct	163	21-Jun	21-Sep	92.0	1.4	0.0	St. Regis R	
	25-Apr	16-Aug	113	15-Jun	16-Aug	62.0	0.2	0.0	St. Regis R	
Mean						**48.0**	**34.9**	**1.4**		
SD						**44.9**	**50.2**	**2.3**		
All species (n = 21)			100			**37.6**	**23.2**	**0.9**		
						42.6	**41.9**	**1.9**		

The dates when these fish passed downstream of Thompson Falls Dam are listed in Table 3. In 2001, the Project spilled intermittently from approximately May 15 until June 13. By comparing the dates of spill with the dates when the fish passed the dam, it is possible to determine, in some cases, whether the fish passed through the turbines. Of the six radio-tagged fish known to have passed downstream through the dam, two passed during a time period when the dam was not spilling (Table 3). Therefore, these fish must have passed through the turbines and survived.

Table 3 **Dates and conditions during downstream passage through Thompson Falls Dam, 2001. RBT = rainbow trout, WCT = westslope cutthroat trout**

Species	Size (mm)	Date Passed Downstream of Dam	Passed During Spill or Non-Spill	Alive After Downstream Passage?
RBT	364	April 29 – May 17	Unknown	yes
WCT	255	April 29 - July 14	Unknown	unknown
WCT	384	June 24 - Aug 19	Non-spill	yes
WCT	350	June 5 - June 14	Spill	unknown
WCT	393	June 21- July 14.	Non-spill	yes?
WCT	408	May 2 - June 14	Unknown	unknown

The largest radio-tagged fish that are known to have passed through the turbines at Thompson Falls Dam was a 393 mm cutthroat trout. Therefore, the trash racks are passable to fish that are of a girth size equal or less than a 393 mm cutthroat. However, the upper size limit for fish passage through the trash racks is unknown. Bull trout often reach sizes substantially larger than 393 mm.

We do not have data on the numbers of bull trout that may be passing downstream of Thompson Falls Dam. Gill net samples collected in Thompson Falls Reservoir during the fall of 2004 to 2006 found relatively small numbers of fish of any species, and no salmonids whatsoever (Table 4). In all 3 years, the most abundant species collected was black bullhead, comprising about 56 percent of the fish collected. This is evidence that the numbers of salmonids passing downstream through Thompson Falls Dam may be small. It should be noted that this gill net data is collected in October. We do not have data on the composition of fishes in Thompson Falls Reservoir at other times of the year.

Table 4 **Summary of fish collected gill-netting in Thompson Falls Reservoir in October, 2004 to 2006**

Species	2004 total	2005 total	2006 total	2004 # /net	2005 # /net	2006 # /net
Northern Pike	8	18	17	1.3	1.8	1.7
Largemouth bass	1	0	0	0.2	0	0
Smallmouth bass	2	1	0	0.3	0.1	0
Yellow perch	10	7	1	1.7	0.7	0.1
Pumpkinseed	2	1	2	0.3	0.1	0.2
Northern pikeminnow	1	3	5	0.2	0.3	0.5
Largescale sucker	4	13	7	0.7	1.3	0.7
Peamouth	0	1	1	0	0.1	0.1
Black bullhead	17	34	83	2.8	3.4	8.3
TOTAL	**45**	**78**	**116**	**7.5**	**7.8**	**11.6**

3.0 Downstream Passage

Passage through the turbines poses risks of direct (immediate) mortality from mechanically induced injuries such as blade strike or mortality induced from such forces as shear, cavitation, turbulence, or high pressure gradients (Pizzimenti, 1991a; 1991b). Indirect (delayed) effects of turbine passage include physiological stress, disorientation and increased susceptibility to predation (Kleinschmidt Associates and Sverdrup Civil, 1997; Coutant and Whitney, 2000). Indirect injuries may result in damage to the immune system or other protective systems; and subsequent death from these types of injuries is not easily correlated with turbine-passage (Pavlov et al. 2002).

Downstream fish passage through spillways is generally considered to be less risky than passage through turbines. However, spillway passage can also result in physical injury to fish and indirect mortality. Fish mortality is typically 0-2 percent for standard spill bays and 5-15 percent for turbine passage, with Kaplan turbines generally at the lower end of this mortality range and Francis turbines generally greater (Whitney et al. 1997).

3.1 Causes of Turbine-Induced Injuries

Turbine passage potentially poses numerous problems for fish. The relative importance of the various injury mechanisms (shear, turbulence, etc.) depends on the species, size, and life stage of this fish (Coutant and Whitney, 2000). In general, higher rates of survival are obtained with small fish going through larger openings over lower heads, and slower moving units with more laminar flow. Conversely, higher rates of mortality result from large fish passing through small openings at high heads in a rapidly moving mechanical environment with high turbulence. The surface orientation of juvenile anadromous salmonids has been well documented (Coutant and Whitney, 2000; Johnson et al. 2005), therefore turbine entry is a last resort for these species. If an alternative at a shallower depth is available, a smolt will preferentially take it (Coutant and Whitney, 2000). However, bull trout, and to a lesser extent westslope cutthroat trout, are bottom-oriented and may be more prone to entrainment than smolt.

The critical factors that appear to influence turbine-passage survival are: runner diameter, head, turbine type, runner speed (rpm), fish size, trajectory of the entrained fish relative to flow streams through the turbine, spatial clearance between structural components, such as wicket gates, number of runner blades or buckets, peripheral runner blade speed, flow, and angle of water flow through the turbine (Coutant and Whitney, 2000). Some of these factors are highly correlated and no direct causation is necessarily applied to any one factor.

3.1.1 Shear and Turbulence

Shear and turbulence occur when two different water velocities collide. Depending on the velocity and magnitude of directional change, shear and turbulence may cause a fish to become momentarily disoriented, lose its scales, or be bruised or cut. Shear stresses in the turbine may exceed 4 kilopascal (kPa) (Cada et al. 1997).

3.1.2 Cavitation

Cavitation occurs when the pressure in the runner blades goes down to the vapor pressure, thereby causing boiling and vaporization of the liquid. Bubbles may be instantaneously filled with fluid, thus resulting in a local fluid-induced shock of up to 10,000 kPa. These underwater "explosions" primarily damage swim bladders, liver and multiple blood vessels (Pavlov et al. 2002). Shock wave-related injuries are similar to those induced by rapid pressure changes.

Specific data on the effects of cavitation are limited because it is difficult to model cavitation conditions on a laboratory scale (Pavlov et al. 2002) and thus it challenging to elicit conclusions about its consequences. Nevertheless, Cada et al. (1997) suggested that turbine designs should be aimed at minimizing pressure reductions to no greater than 60 percent of ambient in order to eliminate cavitation. On the other hand, some laboratory-scale experiments have shown that the cavitation zones themselves may be limited and easily avoided by most entrained fish.

3.1.3 Pressure Changes

The extent to which pressure changes affect a fish is determined, in part, upon whether the fish is physostomous (open swim bladder) or physoclistous (closed swim bladder). Salmonids, like bull and westslope cutthroat trout, are physostomes and are able to take in or release air from their mouths to accommodate for rapid changes in pressure. Closed bladder fishes are more vulnerable to swim bladder rupture because they are unable to quickly release the air in their bladder during decompression (Cada et al. 1997).

The effects of pressure change also depend upon the difference between the adaptation depth of the fish prior to entering the turbine and after exiting the turbine (Pavlov et al. 2002). For example, open bladder fishes that are acclimated to deep water may experience a near instantaneous decrease in pressure when passing through a turbine. In this case, an open bladder fish may suffer from swim bladder rupture because the rate at which the swim bladder increases exceeds the fish's ability to release excess gas (Cada et al. 1997; Turnpenny et al. 1992). Even if rapid decompression does not kill a fish, it may become momentarily stunned and more susceptible to predation in the tailrace (Cada et al. 1997). It has been suggested that the maximum possible pressure change for migratory fish should not exceed the pressure value associated with headwater depth (Pavlov et al. 2002).

"Gas bubble trauma" is caused by rapid decompression and is characterized by the release of gas bubbles (primarily nitrogen) into blood and tissues. Bubbles are most often seen where membranes are the most gas permeable, such as in gills, eyes, and skin. The bubbles may clog blood vessels and cause rupture or poor circulation (Pavlov et al. 2002). Common symptoms are swimming upside down or vertically, and sometimes gasping for air at the surface (FishBase, 2006).

3.1.4 Strike and Grinding

Strike and grinding occur from physical contact with the turbine blades and runner. The most common injuries are hematomas, deep cuts, loss of scales and body parts, and spine fractures (Pavlov et al. 2002). Primary turbine characteristics that affect the rate of blade strike are: the number and length of blades, rotational speed, clearance (gap) between runner blades, and clearance between wicket gate blades and runner blades (Pavlov et al. 2002; Deng et al. 2005). The primary biological parameters that affect the potential for strike injuries are: fish length, mass, stiffness, fish species, and age (Deng et al. 2005). The ability of a fish to detect and avoid obstacles in a turbine is questionable, especially when considering the rapid rate at which fish encounter obstacles (Coutant and Whitney, 2000).

Pavlov et al. (2002) noted that fish below 20 g contacted the runner blade 13.7 percent of the time while fish greater than 200 g contacted the blade 75 percent of the time. It is reasonable to accept that larger, adult fish are significantly more susceptible to mechanical injury than smaller, young fish (Cook et al. 2003; Franke et al. 1997; Coutant and Whitney 2000). However, shear, turbulence, and cavitation are more jeopardous for small fish than for large fish (Ferguson et al. 2006).

3.2 Turbine-Induced Mortality

There are various predictive models available for determining the probability of turbine-induced mortality (Pavlov et al. 2002; Deng et al. 2005). Turbine passage survival is a probabilistic event influenced by a number of variables; but is mainly determined by the size of the fish relative to the passageway through which it moves (Normandeau Associates [Normandeau], 2006).

Almost all of the available information on turbine-passage survival comes from studies on juvenile fish, especially salmon smolts, and very little is known regarding turbine-passage survival of adults (Cada, 2001; Ferguson et al. 2005). Modifications to dams and dam operations have emphasized juvenile salmonid survival (Wertheimer and Evans 2005).

Fallback (fish that migrate upstream past a dam, and then move back downstream again) is known to result in reduced escapement, but there are a variety of explanations for this, including increased metabolic cost of re-ascending the dams. Additional studies like those conducted by Mendel and Milks (1997) would be useful. They found that during non-spill periods at Lower Snake River dams, the estimated mortality for adult fall Chinook salmon due to fallback was 26 percent and 14 percent in 1993 and 1994 (Mendel and Milks, 1997). Ferguson et al. (2005) concluded that survival estimates of adult salmonids that do not fall back at dams range from 3 percent to 5 percent higher than for those that do fall back. However, a significant portion of this fallback is believed to occur via spillways.

Data from migrating steelhead kelts (post-spawned adults) indicate kelts predominately choose spill and sluiceway routes when available and migrate faster with higher flows and flow augmentation (Ferguson et al. 2005; Wertheimer and Evans, 2005). Turbine passage, the primary alternative route during nonspill periods, may be a substantial source of kelt mortality. Migration success rates of steelhead kelts in the Columbia River were poorer during the low-flow nonspill conditions of 2001 (4.1 percent) than in the more typical flow year of 2002 (15.6 percent) (Wertheimer and Evans, 2005). We were unable to locate data specific to kelt survival through turbines. There is still a need in the industry to further investigate the specific effects of turbine passage on adult fish in particular (Ferguson et al. 2005).

Bickford and Skalski (2000) performed a meta-analysis of smolt survival studies in the Snake and Columbia rivers. All the dams covered in their review had Kaplan turbines. Based on 102 paired release survival estimates (where smolts were released both upstream and downstream of the dams, then recaptured at a single site downstream), survival averaged 87.3 percent ± 1.7 percent (95 percent C.I.). Direct turbine survival on the Columbia and Snake was estimated with balloon tags and averaged 93.3 percent ± 0.8 percent (95 percent C.I.), which is closer to the values cited by the other reviewers. The difference between these estimates suggests that as much as 6 percent additional subacute or chronic mortality may be associated with turbine passage (Bickford and Skalski, 2000).

Ferguson et al. (2005) also reviewed survival estimates for turbine passage at the Federal Columbia River Power System (FCRPS). A table summarizing these results is reproduced in Appendix A.

Indirect mortality can be caused by physiological stress and disorientation (Kleinschmidt Associates and Sverdrup Civil, 1997; Coutant and Whitney, 2000). Sublethal impacts to fish sensory systems may cause delayed mortality because of vulnerability to predation in the tailrace (Ferguson et al. 2006). Predation is the primary cause of indirect or delayed mortality associated with turbine passage (Cada and Rinehart, 2000; Ferguson et al. 2006) for anadromous fish. A specific instance of this are that fish, oriented to a depth greater than that of the tailrace, will be positively buoyant and will float until equilibrated. This makes them highly vulnerable to predation by birds, a commonly observed occurrence with outmigrating smolts (Coutant and Whitney, 2000).

Mortality may result from the synergistic effects of multiple stresses (Cada et al. 1997). For example, a fish that is already stressed by high water temperatures may be more likely to die when exposed to levels of shear thought to be sublethal from laboratory studies (Cada et al. 1997). All of the above mentioned turbine-induced injuries affect the fish simultaneously and it is difficult to figure out which factor caused mortality (Pavlov et al. 2002).

Although mortality may appear to be relatively low through one hydropower project, the cumulative effect of passing multiple projects in sequence is large for anadromous fish that must pass all the hydropower projects that they encounter on their migration to the ocean (Coutant and Whitney, 2000). Bioenergetic exhaustion may be a limiting factor for survival of anadromous smolts (Wertheimer and Evans, 2005). Cumulative mortality may be a less significant factor for downstream migrating bull and westslope cutthroat trout. These fish may pass all three dams on the lower Clark Fork, or they may pass none of them. Passage through the Thompson Falls Project does not necessarily indicate that the trout will pass the other dams in turn.

3.3 Spillway Survival

The survival rate of fish passing a dam in spill depends upon the forces that are exerted as the fish goes over the crest of the dam and into the river on the other side. It should logically vary by the height of the dam and the configuration of the spillway, however no mathematical model exists to predict spillway passage survival (Normandeau, 2006). In general, fish encountering laminar flow with no shear forces (currents crossing at different velocities) should have high survival. Spill is generally assumed as being a more benign means of passing fish compared with passage through turbines and is the preferred means of passing smolt in the Columbia River hydropower system (Coutant and Whitney, 2000; Cada and Rinehart, 2000). However, some of the same mechanisms of injury present in turbine passage are present in spillway passage. Extremely high velocity of water over a spillway can create severe shear stress, turbulence, and disorientation (Cada and Odeh, 2001). The volume of spill may also have a direct effect on survival (Normandeau, 2006).

Specific data on tailrace conditions during spill are difficult to collect due to dangerous field conditions, which limit research capabilities. Therefore, we have very limited information on the actual effects of spillway discharges on fish (Cada and Odeh, 2001). Comparisons between hydropower projects is also difficult because there are substantial differences in hydraulic and physical conditions among dam spillways, which can affect both spill effectiveness and fish survival (Cada and Rinehart, 2000).

The vast majority of studies focus on direct mortality and few have investigated delayed mortality (Cada and Rinehart, 2000, Cada, 2001). Direct mortality studies indicate that the probability of survival is often higher for spillway passed fish than for turbine-passed fish, however subsequent losses due to predation and disease could potentially reduce these differences (Cada and Rinehart, 2000). Some factors may be enough to kill a fish immediately but more often they leave the fish highly susceptible to tailrace predation. This susceptibility is due to loss of equilibrium and disorientation, which are commonly observed in spillway-passed fish but their effects are still poorly understood (Cada and Odeh, 2001). These sublethal effects may lead to predation; the most significant source of indirect mortality to downstream migrating smolts (Cada and Rinehart, 2000).

Flow deflectors have been installed at a number of projects to direct spill water along the surface of the tailrace. These deflectors are concrete projections which prevent or reduce gas supersaturation in the tailrace waters. Some concern exists about the potential detrimental effects of flow deflectors on spillway-passed fish. Normandeau et al. (1996c) concluded that flow deflectors do not have a significant adverse effect on spillway passed fish. These deflectors may even increase survivability. Bickford and Skalski (2000) found that average survival over deep plunge spillways without flow deflectors (84 percent) was lower than survival over all other spillway types (103 percent) (Survival estimates can exceed 100 percent because of the paired-release methodology employed). On the other hand, Muir et al. (2001) estimated passage survival of Chinook salmon and steelhead to be highest through spill bays without flow deflectors (98.4 – 100 percent), followed by spill bays with flow deflectors (92.7 – 100 percent), bypass systems (95.3 – 99.4 percent), and turbines (86.5 – 93.4 percent). Grant County had lower levels of survival after they installed flow deflectors to improve gas supersaturation at Priest Rapids Dam on the Columbia River (Harza Engineering Company [Harza] 1998).

Ferguson et al. (2005) summarized the spillway survival data for the FCRPS. This summary is included in Appendix B, but results varied from 75 percent survival at The Dalles of subyearling Chinook to 102 percent survival at Little Goose for yearling Chinook (Ferguson et al. 2005). They concluded that fish survival through spillways at the FCRPS dams is influenced by stilling basin depth and turbulence, hydraulic patterns in the basin, spillbay location within the spillway relative to the spill pattern being used, deflector elevation relative to tailwater elevation and then total river flow, gate opening, and fish location when passing through the spillbay and under the control gate. Efforts to further explore the relationships between these factors are ongoing.

The average survival through spillways on the Snake and Columbia rivers is estimated to be 100.5 percent ± 6.5 percent (95 percent C.I.) (Bickford and Skalski, 2000). They found that survival through most spillway types is near 100 percent, except for some estimates of survival for steelhead. Most of the studies with lower than 100 percent survival were conducted in spillways that contained exposed rebar, pitted concrete, or exposed rocks (Bickford and Skalski, 2000). Survival estimates ranges from 95.5 percent to 99.3 percent for the Dalles spillbay (Normandeau et al. 1996b), and 92.0 percent to 99.6 percent for the Wanapum Dam (Normandeau et al. 1996a). When projects with greater than 90 feet of head were eliminated from the analysis, Normandeau (2006) found that survival for fish passing through tainter-type spillgates ranged from 85.1 percent to 100 percent.

The within season variability observed for spillway survival studies was 19 percent, roughly twice the estimate for turbine survival studies (Bickford and Skalski, 2000). Sources for this relatively large within-season variability are unknown and probably reflect variation in spillways as well as discharge. Additionally, it is known that temperatures, predation, fish physiology, nitrogen saturation and uniqueness of spillway configurations, may also affect spillway survival compared with survival through turbines. No spillways have been studied under identical conditions for more than 1 year, so estimates of between-year survival variability are unavailable (Bickford and Skalski, 2000).

3.4 Downstream Passage Improvements

A number of operational and structural options have been employed at various hydropower projects to benefit smolt passage (Cada and Sale, 1993). Most of the research and development of downstream passage improvements at hydropower projects has been focused on anadromous fish.

3.4.1 Intake Screens

Narrow-mesh intake screens are often used to prevent turbine entrainment (Cada et al. 1999), as well as to direct fish to the SFB system. These screens are expensive to install and maintain, and there are limited data regarding their benefits to fish populations (Bell 1991; Francfort et al. 1994). Their effectiveness is further limited by high flows and large amounts of debris, both of which are common at the Thompson Falls Project. Bell (1991) reported that intake screens appear to be ineffective for blocking small fish (smolt) from entrainment. They may be useful, however, for preventing entrainment of larger fish (>50 mm) (Pavlov et al. 2002), although Wertheimer and Evans (2005) noted that intake screen systems provided poor steelhead kelt guidance. Studies have also indicated that intake screens may actually be a source of physical damage to downstream-migrating salmon (Nestler and Davidson, 1995).

3.4.2 Surface Flow Bypass

SFB systems are complicated and extremely cost-prohibitive in many cases. The effectiveness of surface guidance systems for passing substrate oriented fish is likely to be limited. The bypass at Rocky Reach Hydro Project cost over $110 million, however, the Chelan County Public Utility District expects to save $400 million over 15-years (www.chelanpud.org). The savings is due to the fact that the dam will no longer have to purposely spill water in order to pass juvenile salmonids. Thus, the gain in power generation will more than recoup the construction costs. SFB systems will also consequently reduce the dissolved gas concentrations in the tailrace. For some of these reasons, regional managers and policymakers are recommending the development of additional SFB systems for juvenile salmonids (Johnson et al. 2005).

Certain SFB innovations, like removable spillway weirs, may enhance overall passage effectiveness at spillways (Wertheimer and Evans, 2005). An additional benefit may come from the flow nets associated with the SFB system. These nets create a gradual increase in water velocity that mimics a river in the forebay (Johnson et al. 2005), and creates the flow needed by fish to migrate downstream.

3.4.3 Bar Racks and Louver Arrays

Angled bar racks are the most frequently utilized device for minimizing entrainment of downstream migrating or resident fish (Cada and Sale, 1993), as well as for SFB guidance. Angled bar racks are basically trash racks with closely spaced bars (~2.0 cm apart) that are set at an angle (≤ 45 degrees) to the water flow (Francfort et al. 1994; Figure 4). Fish behavior at bar racks is poorly understood (Kynard and Horgan, 2001). Louver arrays are a series of bars spaced similarly to bar racks, but are oriented 90 degrees to the water flow. The entire array is then positioned at an 11 to 20 degree angle to flow (Electric Power Research Institute [EPRI]) 1986 [as cited in Kynard and Horgan, 2001]; Figure 4). Superior guidance efficiency for sturgeon (total length ranged from 174 to 315 mm) was achieved with a louver array (96 to 100 percent) than with angled bar racks (58 to 80 percent) (Kynard and Horgan, 2001).

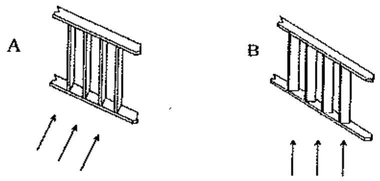


Figure 4 Drawing of a bar rack (A) and louver array (B). Bar rack slats are oriented parallel to water flow while louver array slats are oriented perpendicularly (Kynard and Horgan 2001).

3.4.4 Light and Sound

Strobe lights can be used as a behavioral barrier to prevent entrainment while avoiding the high cost and maintenance problems associated with intake screens and bar racks. Also in contrast to the physical barriers mentioned, strong evidence exists on fish avoidance of strobe lights (Winchell et al 1994; Maiolie et al. 2001). Ploskey and Johnson (2001) demonstrated marked salmonid avoidance using newly designed lights for underwater use along with sequenced flashing arrays and electronic controls. The use of sound avoidance has also been extensively studied. Carlson and Popper (1997) provides in-depth information regarding acoustic deterrence for fish protection at hydropower projects. While these technologies are relatively simple compared with some of the others mentioned in this paper, site-specific variations make employment challenging and experts may be hard to find. We are not aware of tests of these systems for bull trout.

3.4.5 Advances in Turbines

One of the major environmental issues for hydroelectric power plants is fish mortality due to turbine passage (Cada and Rinehart, 2000). In the past decade there has been a considerable increase in downstream fish passage research; this is in large part due to the need to explore all reasonable means of conserving declining salmon and steelhead stocks while maintaining an important renewable power source.

There are major ongoing efforts by the U.S. Department of Energy (DOE) to develop fish-friendly turbines. In 1994, the DOE established the Advanced Hydropower Turbine System (AHTS) Program as a partnership with the hydropower industry. The targeted research areas include greater survival of turbine-passed fish, higher dissolved oxygen in tailwaters, and more beneficial flow regimes downstream of powerhouses (Sale et al. 2000). These studies are supported by a multitude of organizations including, but are not limited to, the U.S. Army Corps of Engineers, Bonneville Power Administration, National Marine Fisheries Service, USGS, Alden Research Laboratory, Inc., and Voith Hydro, Inc.

Under the AHTS Program, two companies recently developed innovative conceptual designs for advanced turbines. The Alden Research Laboratory, Inc./Northern Research and Engineering Corporation (ARL/NREC) concept was a brand new type of turbine runner designed to minimize fish injury and mortality. The new runner minimizes the number of blade leading edges, minimizes clearance between the runner and runner housing, and maximizes the size of flow passages (Cook et al. 2003). These design changes were accomplished with minimal loss to turbine efficiency. The Voith Hydro, Inc. concept investigated the modification of existing turbines, both Kaplan and Francis types, to both improve efficiency and reduce environmental effects (Franke et al. 1997). The advanced turbine design developed by Voith is called the Minimum Gap Runner (MGR).

In 2005, one of the 10 Kaplan turbines at Wanapum Dam was replaced with the MGR. Cada et al. (2006) conducted fish survival tests using juvenile summer Chinook salmon to compare passage mortality associated with the old (Kaplan) turbine and the new (MGR) turbine. Postpassage survival rates for both turbines were greater than 94 percent. This is comparable to estimates in other studies on passage survival through Kaplan turbines (Cada et al. 1997). In addition, Cada et al. (2006) found no overall difference in mortality between the Kaplan turbine and the MGR turbine. The overall injury rates were also low, 1.5 percent for the MGR and 2.5 percent for the Kaplan turbine (Cada and Rinehart, 2000).

Cook et al. (2003) conducted pilot-scale tests of the ARL/NREC turbine. Their tests included over 40,000 fish of six species studied over 2 years. Survival rates in their experiments were highly correlated with fish length and the most common injury was bruising. Minor incidences of lacerations were observed and the researchers concluded that strike with the leading edge of the runner blade was the primary cause of immediate mortality. They regarded the effects of shear and pressure changes as minor. The predicted passage survival for fish 150 to 200 mm in length entrained in a full-scale ARL/NREC turbine would be 96 percent (Cook et al. 2003).

3.4.6 Discretionary Spill

Discretionary or managed spill is often induced to aid in smolt migration (Coutant and Whitney 2000; Johnson et al. 2005). However, an increase in spill means a loss in power production. Other limits to excess spill may include the reduction in survival that occurs when an excessively large volume of water is discharged. Spill has the potential to harm fish and other aquatic life by elevating total dissolved gas levels (gas supersaturation) downstream of the dam (Johnson et al. 2005).

Use of discretionary spill to enhance survival of substrate oriented species such as bull trout has not been attempted. The cost in terms of lost power production can be very significant for a small potential gain in survival, primarily for surface oriented fishes.

3.4.7 Trap and Haul

Avista Corporation owns and operates the two hydroelectric projects downstream of Thompson Falls, Noxon Rapids Dam and Cabinet Gorge Dam. Avista is currently engaged in a research program testing the feasibility of downstream transport of juvenile bull trout past Avista's dams on the Clark Fork River. Juvenile bull trout leaving Montana tributary streams and migrating to Lake Pend Oreille, Idaho, must swim through a corridor that includes Noxon Rapids Reservoir, Cabinet Gorge Reservoir, and the lower Clark Fork River below Cabinet Gorge Dam. The Aquatic Implementation Team (an interagency group that manages fisheries protection, mitigation, and enhancement (PM&E) measures for the Avista projects) has concluded that decreased survival is likely for downstream migrating juvenile bull trout leaving Montana tributaries due to increased predator vulnerability in the reservoirs and the Clark Fork River, as well as dam spill or turbine induced injuries, or other reasons (Lockard, Weltz, and Stender-Wormwood, 2005).

Therefore Avista is funding a program of capturing juvenile bull trout from Montana tributary streams and subsequently releasing them into Lake Pend Oreille. A multi-year draft evaluation plan was developed and provides guidelines for the implementation of the program. Bull trout are transported to Idaho following an approved set of protocols. All downstream migrating bull trout captured in screw traps or weir traps between 75 and 250 mm in length are PIT tagged. About one-half of the juvenile bull trout are transported to Idaho, while the remainder are released on site (DosSantos et al. 2004). The premise of the study design is that it allows fisheries managers to isolate the benefit of transport by comparing the proportion of adult returns from two groups of fish – juveniles that were transported and those that migrated downstream volitionally (Kleinschmidt Energy and Resource Consultants and Skalski, 2003). It may require 10 years to gather enough statistically valid data to test the hypothesis (Lockard, Weltz, and Stender-Wormwood, 2005).

Recapture of the juvenile bull trout after they have matured to adulthood is attempted through electrofishing in the Clark Fork River and by operation of a fish ladder and trap at the Cabinet Gorge Fish Hatchery. Recapture of adults is also attempted in some years in the tributaries (Lockard, Weltz, and Stender-Wormwood, 2005).

Figure 5 illustrates the numbers of downstream migrating juvenile bull trout collected in Montana tributaries in 2000 – 2004. A total of 1,095 juvenile bull trout have been captured since the program began. The total number of juvenile bull trout transported has been 394. One juvenile bull trout (255 mm in length) captured and released in the Vermilion River in 2001 was recaptured as an adult in 2004. However, this fish was too large at the initial tagging to meet the definition of "juvenile-sized" bull trout used in the evaluation procedures for assessing the juvenile bull trout transport program.

Since inception of the program, only one fish that was tagged as a defined juvenile has been recaptured. This particular fish was trapped as a juvenile in the Bull River and released back into the Bull River in 2002. In 2006, this fish was recaptured downstream of Cabinet Gorge Dam (LaDana Hintz, Avista Corporation, as cited in USFWS, 2006), thus indicating that this fish, and presumably others, are able to successfully pass the dam on their own and survive to adulthood. It is apparent, however, that many more years of data collection will be needed to determine if transport to Lake Pend Oreille provides higher or lower survival than release of juveniles within their natal stream.

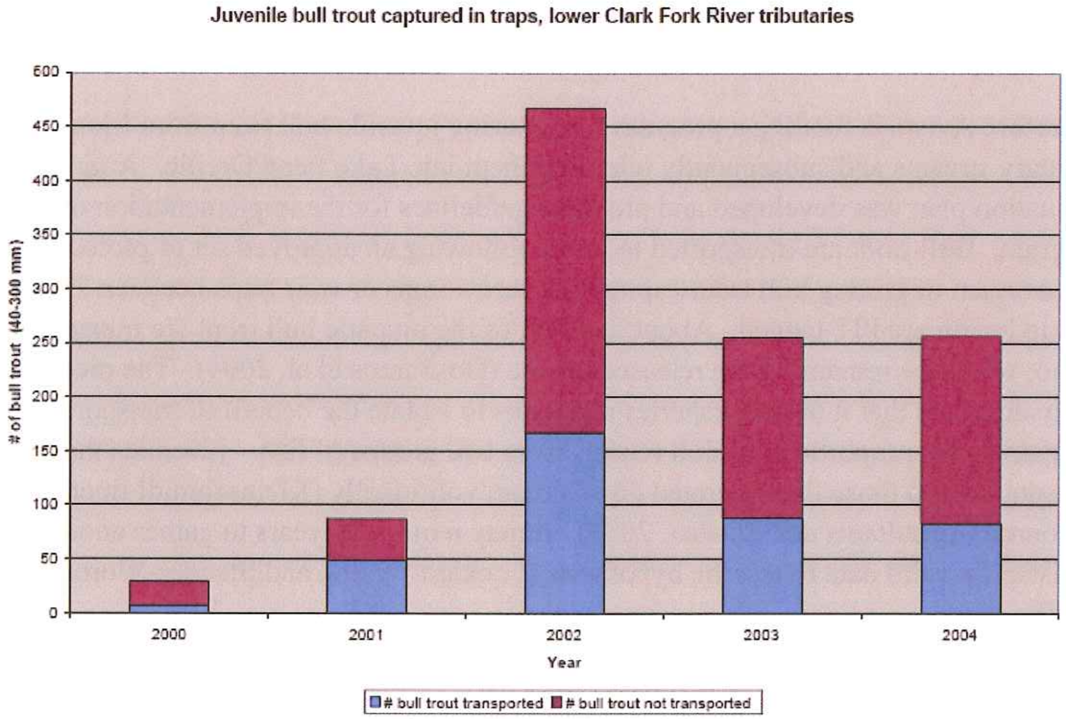


Figure 5 **Downstream migrating bull trout captured in lower Clark Fork tributaries from 2000-2004.**

For most of the alternative mitigation measures mentioned above, except light and sound, there is a lack of effectiveness monitoring (Cada and Sale, 1993). Performance objectives at nonfederal hydropower plants were not even specified for the majority of the projects investigated in Cada and Sale (1993). They also noted that the lack of information regarding effectiveness is a particular problem for downstream passage measures, where designs are more recent and varied, and operating experience is less than that for devices such as fish ladders. There is currently no existing national program to develop and test innovative downstream passage technologies (Federal Energy Regulatory Commission [FERC], 2004), and knowledge is gained only by experience and exchange of information.

4.0 Thompson Falls Hydroelectric Project

4.1 Description of Project Configuration

In general, the Thompson Falls Hydropower Project is comprised of two dams (Main and Dry Channel), and two powerhouses (old and new) (Photo 1). Together, the powerhouses are capable of producing 92.6 MW of electricity. Specifically, the Project consists of: (1) a concrete gravity arch main dam, approximately 1,016 feet long and 54 feet high; 2) a concrete gravity auxiliary dam known as the Dry Channel Dam, approximately 449 feet long and 45 feet high; 3) a 1,446- acre, 12-mile-long reservoir with a usable storage capacity of 15,000 acre-feet (ac-ft); 4) a 450-foot-long, 80-foot-wide intake channel cut through rock; 5) a steel framed and masonry powerhouse containing six generating units with a total capacity of 40 MW; 6) an additional powerhouse, built in 1994, containing one generating unit with a capacity of 52.6 Mw; 7) a 75-foot-wide, 300-foot-long intake channel; 8) a 1,000-foot-long tailrace channel, 9) a 1,000-foot access road; and 10) a 360-foot-long bridge (FERC, 1990; FERC, 1994).

Photo 1 Arial View of Thompson Falls Dam Project

The existing facilities enable water to be released from four major locations - two spillways (the Main Dam and the Dry Channel Dam) and two powerhouses (old and new). These releases change at different times of the day, season, and year; and are variable from year to year depending on runoff volume and snowmelt timing, as well as power demands and tradeoffs between the two powerhouses. The project operates at about 62 feet of maximum head with headwater at 2,397 and tailwater at 2,335, depending on discharge and flashboard/reservoir conditions. More typical operating heads are around 59 feet (PPL Montana Operators).

4.2 Powerhouse Turbines

There are no site-specific data on fish survival during downstream passage at Thompson Falls Dam. The turbine/generator configuration in the old powerhouse (Nos. 1-6) consists of six similar Francis units rated at 5 MW each, each with hydraulic capacities of 1,700 cfs and a total turbine capacity of 10,200 cfs. The Francis runners are 11 feet (3.4 m) in diameter, have 13 buckets, and rotate at a speed of 100 rpm. The wicket gate at the old powerhouse is 4 feet (1.2 m) tall and has a spacing of 14 inches when fully open (Bonnes, PPL Montana, personal communication, November 18, 2002).

The new powerhouse is immediately upstream of the old powerhouse, and has one large 62 MW Kaplan turbine (Unit 7) with a capacity of approximately 13,000 cfs. Unit 7 is among the most modern of Kaplan type turbines with four adjustable blades. The runner is large, 262" (28 feet or 8.5 m) in diameter, and it rotates at a speed of 94.7 rpm. The wicket gate at the new powerhouse is 8.5 feet (2.6 m) tall and has a 36-inch spacing when fully open.

Operational scenarios may be altered depending on the time of year and flow rates (Bill Beckman, PPL Montana, personal communication, December 19, 2006). When total river discharge is less than 23,000 cfs, the new powerhouse is preferentially operated to maximize peak efficiency of the project, with between 50 and 70 percent of the river flow typically going through Unit 7. Two Francis units, typically Nos. 1 and 3, operate as auxiliary power to No. 7 to maintain heat in the old powerhouse and to exercise these other units during low flows. Generally, Units 2, 4, 5, and 6 are operated at high flows, as they are the least efficient and smallest units at the project.

New governors exist on the newest units (No. 1, No. 3, and No. 7) and these units are automated to maintain constant reservoir elevation during normal run of river operations. During peaking operations, the plant is operated at full gate for the number of hours that will enable the reservoir to refill within a 24-hour period and stay within the restricted headwater elevations of 2,393-2,397 feet. The powerhouse intakes at the old powerhouse are about 16 feet square and the invert is about 35 feet below forebay surface elevation. The top of the intake is about 20 feet below the surface. The intakes are guarded by a steel trash rack with openings of 2-5/8 inches between the bars in the old powerhouse and 5½ inch spacing in the new powerhouse.

4.2.1 Francis Versus Kaplan Type Turbines

Kaplan units are significantly safer for fish than Francis type turbines (Franke et al. 1997). The differences may be due to the fact that Francis units spin faster, have more blades and more confined hydraulic passages compared to Kaplan turbines. Francis type turbines may be made safer for fish by increasing the clearance between the wicket gate blades and the runner blades (Monten, 1985).

We compared the old powerhouse with six other projects with similar Francis units at other hydroelectric installations with fish survival data (Table 5). The turbine passage survival at these comparable projects varied from 61 percent to 98 percent among the different tests on mostly salmonids ranging in size from 110 to 317 mm (Table 5). The Thompson Falls Project is most similar to EJ West in configuration, thus, we would expect fish passage survival to be in the 65 – 96 percent range.

In Table 6, we compare the Kaplan unit at Thompson Falls to other similar units where survival estimates have been made. The large size of the Kaplan unit means much larger hydraulic openings for water and fish. We note that the trash bar openings are 5½ inches compared to the 2-5/8 inch openings of the old powerhouse. The wicket gates have 3-foot by 8.5-foot-wide openings compared to 14-inch by 4-foot openings in the old powerhouse Francis units. It is a modern, high efficiency unit with adjustable blades and a relatively flat efficiency curve over the entire range of discharge operations. The unit can operate from 10 Mw to 50 Mw.

The range of survival found in these studies for salmonids ranged from 86 – 100 percent. The runner speed at Thompson Falls is quite low compared to many other comparable units, but the blade tips travel at comparable speeds due to the large radius (Table 6). At 61 feet of operating head and with the large diameter, the Thompson Falls Kaplan unit is more similar with projects in the Columbia River Basin like Big Cliff, than projects in the mid-west or east coast where heads are relatively lower (Table 6).

In the past it was generally believed that units with higher efficiencies are more fish friendly than units with lower efficiencies as loss of efficiency is usually accompanied by turbulence and cavitation, factors known to injure fish (Bell, 1991). Inefficient turbine operation is a result of a poor blade-to-wicket gate relationship, where efficiency drops due to turbulence that results from the rotating machinery (hub and blades) being misaligned with the hydraulic flow field coming off the stationary but adjustable wicket gates. However, a statistical relationship between turbine efficiency and fish survival has not been observed (Ferguson et al. 2005)

Table 5 Selected Turbine Survival Data for Francis Units Similar to the Units at Thompson Falls Dam (Franke et al. 1997)

Station	Ref	Method	Species	Test and Control (N)	Length (mm)	Survival (%)	Dischg (cfs)	Type	Blades or Buckets (#)	Head (ft)	Diameter (ft)	RPM
Ruskin	1	Fyke net	Sockeye	12125	86	89.5	3990	FRAN	-	130	12.4	120
Rogers	2	Net	Rainbow Trout	30	108	89.9	381	FRAN	15	39	5	150
				30	317	61.2						
E J West	3	Net	Salmonids	280	<100	65.2	2700	FRAN	15	63	10.9	113
				160	175	90.6						
				160	> 250	95.6	2700					
Alcona	4	Net	Rainbow Trout	40	108	100	1667	FRAN	16	43	8	90
				40	317	89						
Mineto	5	Net	Salmonids	397	<100	92	1501	FRAN	16	17	12	72
				291	175	91						
				337	>250	92						
Stevens Creek	6	Hi-Z	Bluegill	220	122	95	1000	FRAN	14	28	11	75
			B.B.Herring	251	203	95						
			Sucker/Perch	240	165	98						
Thompson Falls Nos. 1-6	**--**	**--**	**Trout**	**--**	**--**	**--**	**1850 each**	**FRAN**	**13**	**61**	**11**	**100**

Reference: 1 –Eicher 1987; 2 –LMS 1991, 3 – KA 1996, 4 – Lawler, Matusky and Skelly (1991), 5 – Kleinschmidt Associates, 1996a, and 6 – RMC (1994) all cited in Franke et al. 1997.
Sample Methods: Net = tailrace netting; Hi-Z = balloon tags

Table 6 Selected Turbine Survival Data for Kaplan Units Similar to the Units at Thompson Falls Dam (Franke et al. 1997)

Station	Ref	Method	Species	Test and Control (N)	Length (mm)	Survival (%)	Dischg (cfs)	Type	Blades or Buckets (#)	Head (ft)	Diameter (ft)	RPM
Big Cliff	1	Net	Chinook	37,500	100	90-95	2292	KAP	6	71-91	12	164
Lower Monumental	4	PIT Tag	Chinook	-	-	86.5	18000	KAP	6	94	26	90
Lower Granite	4	PIT Tag	Chinook	3200	151	92.7	18000	KAP	6	98.	26	90
Herrings	2	Net	Salmonids	165	100	96	1201	KAP	4	19	9	138
				167	175	99						
				188	250	99						
Townsend	3	Hi-Z	Rainbow Trout	106	139	94	802	KAP	3	16	9	152
				103	344	87						
				21	139	100	1501					
Thompson Falls No.7	--	--	Trout	--	--	--	Max 13,000	KAP	4	61	28	95

Reference: 1 – Oligher and Donaldson (1966); 2 – Kleinschmidt Associates, 1996, 3 – RMC (1994), 4- Muir et al (1995) all cited in Franke et al. 1997.

4.3 Dam Spillways

The Project is operated as a daily peaking power facility about 4 months of the year and as a run-of-the-river facility during the high flow and winter months. When river discharge exceeds the combined hydraulic capacity of both powerhouses (23,000 cfs), two tainter gates each enable automatic spill operations up to 10,000 cfs. The tainter gates have openings of 41 feet wide and 14 feet high when fully open. As the runoff proceeds, 4 by 8 foot spillway panels on the east side (toward the left bank) on the main dam are removed for additional spill capacity. As flows increase, more panels are removed to balance flows across the length of the main dam spill section until all 228 panels have been removed. In most years, when the peak flood discharge is less than 70,000 cfs, spill is restricted to the Main Dam section. If flows exceed 70,000 cfs, there are 72 Dry Channel Dam spill panels (each 4 by 8 feet) available to increase spill capacity. Operation of the Dry Channel Spillway occurs infrequently according to dam operators.

Thompson Falls Dam is an intermediate high head dam (61 feet or 18.6 m) that should have relatively high survival for fish passing the dam via spill. However, personal observations of spill at Thompson Falls during the 2002 runoff (Pizzimenti, personal communication, 2002) suggest hydraulically violent conditions exist at some locations more than others at least during high flow events (Photos 2 to 5). Spill over the Dry Channel Dam passes via a complex set of downstream rapids and much of the energy is dissipated against the rocky substrate for a distance of up to 400 feet depending on location of passage (Photos 4 to 8). Survival over this spillway is unknown, but may be less than at other, less turbulent, spillways. Bickford and Skalski (2000) noted that the spillways in the Columbia River with survival less than 100 percent contained exposed rebar, pitted concrete, or exposed rocks. The Thompson Falls Project spillway contains exposed steel I-beams and large boulders.

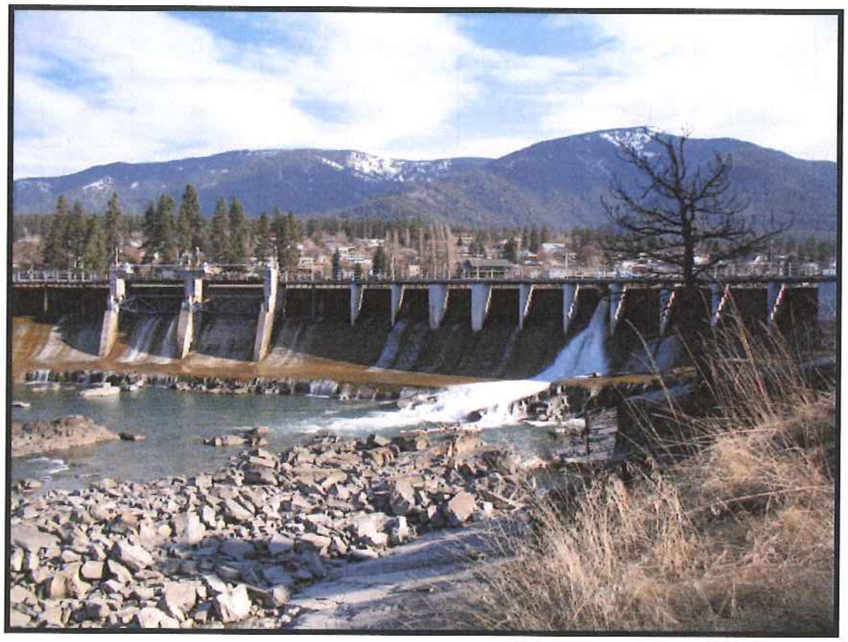


Photo 2 Main Dam at Thompson Falls, low flow (March 20, 2006)

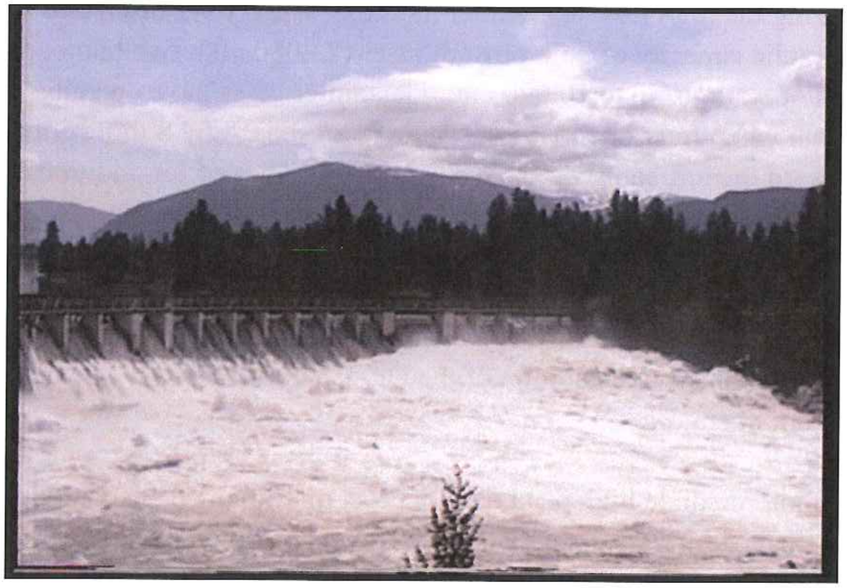


Photo 3 Main Dam at Thompson Falls, high flow (June 10, 2002, total river flow approximately 77,000 cfs)

Photo 4 Dry Channel Dam at Thompson Falls, low flow

Photo 5 Dry Channel Dam at Thompson Falls, high flow (June 10, 2002, total river flow approximately 77,000 cfs)

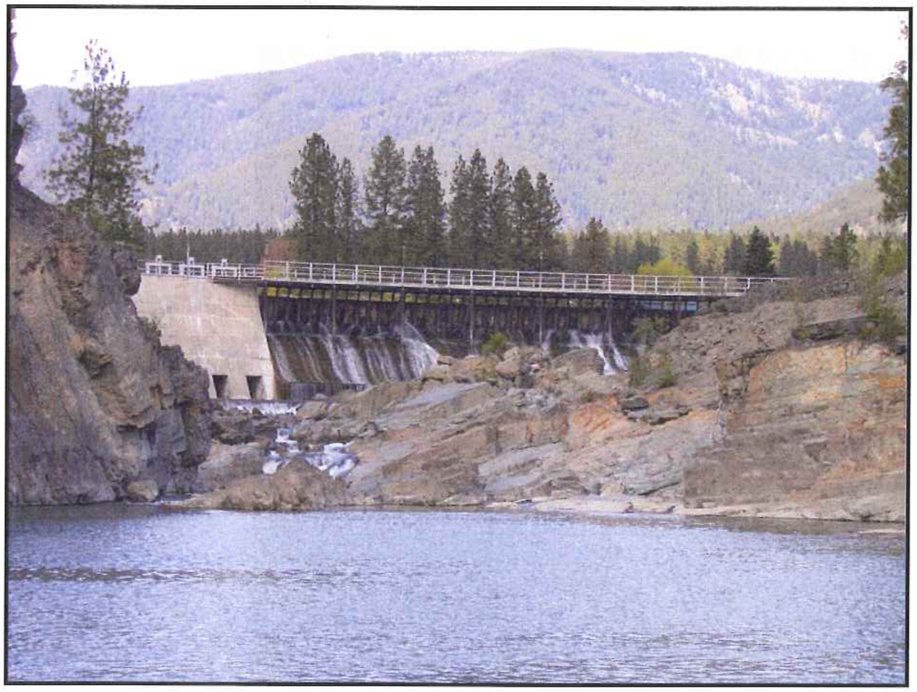


Photo 6 Dry Channel spillway, looking upstream

Photo 7 Dry Channel spillway, from above

Photo 8 Dry Channel spillway, looking downstream

4.4 Estimated Survival at the Thompson Falls Project

In order to estimate overall survival for downstream trout passage through the Project, we made the following assumptions:

- Spillway effectiveness is 1:1 so fish will pass the Project in numbers proportional to flow. That is, if 50 percent of the flow is through the spillway then 50 percent of the fish will pass over the spillway
- Fish will also pass the two powerhouses in proportion to flow
- assumed survival estimates are: Kaplan 94 percent, Francis 85 percent, and Spillway 98 percent

We selected 98 percent as the estimated spillway survival based on Ferguson et al. (2005), who noted that fish survival through spillways can be very high (near 1.00) and is often higher than turbine or bypass system survival when spill passage conditions are optimal. However, as noted in Section 3, survival through spillways with deflectors or shallow basins or exposed rocks and rebar can be considerably less.

Based on the comparison to similar projects with Francis turbines in Table 5, we selected 85 percent as the estimate of survival through the Francis turbines at Thompson Falls. Based on the comparison to similar projects with Kaplan turbines in Table 6, we selected 94 percent as the estimate of survival through the Kaplan turbines at Thompson Falls.

We calculated overall survival by month based on the above assumption (Table 7). Overall, we estimate that downstream passage survival at Thompson Falls Hydroelectric Project should be approximately 91 - 94 percent.

Table 7 Immediate downstream passage survival estimates at Thompson Falls Dam Project.

Month	Monthly mean Flow *(cfs)	% Flow Kaplan	% Flow Francis	% Flow Spillway	Estimated % Survival
January	12,155	70.0	30.0	0.0	91.3
February	12,043	70.0	30.0	0.0	91.3
March	12,201	70.0	30.0	0.0	91.3
April	20,026	70.0	30.0	0.0	91.3
May	45,406	28.6	22.0	49.3	94.0
June	55,403	23.5	18.0	58.5	94.7
July	25,987	50.0	38.5	11.5	91.0
August	11,239	70.0	30.0	0.0	91.3
September	9,811	70.0	30.0	0.0	91.3
October	10,696	70.0	30.0	0.0	91.3
November	11,647	70.0	30.0	0.0	91.3
December	12,264	70.0	30.0	0.0	91.3

We assumed a spillway effectiveness (spillway passage/percent spill flow) of 1:1 because of a lack of site specific data to indicate otherwise. However, on the Columbia and Snake rivers, spillway effectiveness is > 1:1 when the spillway is downstream of the powerhouse, and < 1:1 when spillway is upstream of powerhouse (Rainey, personal communication, 2006). Since the Project spillway is upstream of both powerhouses, the Project spillways would be expected to have an effectiveness < 1:1. In addition, bull trout are substrate oriented fish and may be less likely than anadromous smolts to pass the Project via spill. Our estimates for downstream survival during spill (May and June) may be overestimated.

However, since the new powerhouse is upstream of the old one, it would be expected to pass a greater percentage of fish than the old powerhouse. Also, during time periods when less than 25 percent of the flow is passing through a given route, studies in the Columbia and Snake rivers have found a higher percentage of the fish tend to go with the greater (bulk) flow (Rainey, personal communication, 2006). On average, 30 percent of the flow passes the old powerhouse, but amount varies and at times can be less. Therefore, during times when less than 25 percent of the flow is passing the old powerhouse, the new powerhouse (with its higher estimated survival) may be passing >90 percent of fish. Therefore, our estimates for downstream survival during non-spill periods may be underestimated.

5.0 Recommendations

It is clear that downstream fish passage through the Thompson Falls Project is occurring, at least to some degree. However, it is not clear if passage should be considered desirable. Fish upstream of Thompson Falls Dam have unimpeded access to 357 miles of habitat within four different rivers. This number will soon increase to 601 miles when Milltown Dam is removed, and access to the Upper Clark Fork and Blackfoot Rivers is restored. In addition, these mainstem figures do not include the thousands of miles of tributaries that flow into these rivers. Downstream of the dam there are a series of reservoirs that are less than desirable habitat for trout. The Noxon Rapids Dam has over 150 feet of head and the Cabinet Gorge Dam has over 100 feet of head, along with notable gas supersaturation (Harza, 2000). Unlike the situation where anadromous fish are present, bull and westslope cutthroat trout may actually benefit from being deterred from passing downstream of the Project. Therefore, downstream fish passage through or over Thompson Falls Dam may actually be undesirable as it puts fish at risk when they pass the facility, and it results in the fish being in the downstream reservoir system with limited access to desirable habitat upstream.

No field studies have been documented to estimate downstream passage survival through the Project, but based on a review of the literature we roughly estimated survival to be 91 – 94 percent. We do not recommend expending additional effort to more accurately estimate survival. Given the small numbers of salmonids in Thompson Falls Reservoir, it could be very difficult to even undertake a study of downstream passage past the dam. Rather, we suggest future activities be focused on improving habitat conditions for bull and westslope cutthroat trout in the project area.

Constructing screens and bypass channels at this facility, as is done on hydroelectric dams on the Columbia, would be enormously expensive and provide relatively little benefit. These systems are constructed for surface-oriented fish that must migrate to the ocean. Bull and westslope cutthroat trout are not surface-oriented and it is very unlikely that they would utilize such systems. The new "fish friendly" turbines that have been developed have shown very modest increases in survival, if any, and are installed at great expense.

Modifying operations to increase the amount of flow that passes the Project in spill may have little or no benefit for a substrate oriented species. In addition, the spillways at the Project may have lower-than-average survival because of the hydraulically violent conditions that are present.

Avista's Tributary Trapping and Downstream Juvenile Bull Trout Transport Program does not provide an appropriate model for action at the Thompson Falls Project. If a downstream trap and transport program were to be initiated for tributaries above the Project, it is unclear what destination would be selected to deposit these fish. Lake Pend Oreille is a long distance downstream of the Project. Many of the outmigrating juveniles from tributaries such as the Thompson River may not be destined for this lake. This is particularly true given the availability of free flowing river habitat upstream of the Project.

An alternative approach that would benefit bull and westslope cutthroat trout is off-site mitigation. Avista Corp recently completed a review of current conditions for native salmonids in tributaries to the Lower Clark Fork River drainage (Gillin, 2005). Some biologists have indicated that focus on unhealthy stocks could be a major impediment to managing healthy stocks, thus restoration priorities should focus on populations with the greatest chance of recovery (Huntington et al. 1996). So, based on current information, and using a philosophy of "protect the best first", Gillin (2005) developed a list of subwatersheds that they consider the highest priority for protection of native salmonids. This review may provide a starting point for developing an off-site mitigation strategy for Thompson Falls Dam.

Avista's review included two subwatersheds upstream of Thompson Falls Dam, the West Fork of the Thompson River and Fishtrap Creek. Both of these streams are tributaries to the Thompson River and both are known to contain important bull and westslope cutthroat trout habitat. Both of these watersheds were ranked in the top tier (highest priority) for protection and enhancement of habitat for native salmonids. The West Fork Thompson River ranked fourth and Fishtrap Creek ranked fourteenth priority out of the 40 watersheds and subwatersheds assessed.

The Problem Assessment report lists potential projects for each watershed. A watershed assessment of Fishtrap Creek prepared by Land and Water Consulting in 2000 recommended installation of large woody debris in the lower reach of Fishtrap Creek to improve fish habitat. In addition, road densities in the Fishtrap Creek watershed are high. There are a total almost 938 km of roads within the watershed, the greatest of any of the watersheds in the Lower Clark Fork River drainage. One-third of the roads are on sensitive or unstable land types, which may provide a source of sediment to the stream. Road rehabilitation may be a worthwhile endeavor in this watershed. Land acquisition is another strategy that has been proposed for Fishtrap Creek, although the majority of private land in the watershed is already protected by a conservation easement (parcels owned by Plum Creek Timber Company).

A watershed assessment of the West Fork Thompson River prepared by Land and Water Consulting in 2001, did not recommend any large-scale habitat restoration projects. However, they did note that installation of large woody debris structures could improve fish habitat by increasing habitat complexity. The Forest Service road adjacent to the stream may pose the greatest threat to stream habitat in the watershed. Road rehabilitation or relocation may be a viable aquatic habitat restoration measure in the West Fork Thompson River. Land acquisition is not an option in this watershed as the watershed is U.S. Forest Service System Lands.

An additional possibility may be habitat improvement in the immediate Project area. Predation by fish, birds and mammals is a major cause of indirect mortality for downstream migrating fish, whether they pass through the turbines or over the spillway (Muir et al. 2001). As indicated in gill net surveys in Thompson Falls Reservoir, there are a significant number of predacious fish. Control of known bull and westslope cutthroat trout predators, such as northern pike, may potentially be beneficial to the persistence of these threatened species. Avian predation, if significant, can be reduced with bird wires across the tailrace. Further study would be warranted to determine if predation is a real problem in the Project area before measures to reduce predation are instituted.

Other off-site mitigation opportunities may exist in other watersheds not addressed in the Avista report. A collaborative effort with the stakeholder groups would be needed to determine the opportunities. However, this approach may be more sensible, less costly, and have a greater beneficial impact on lower Clark Fork River fishes than any type of downstream trap and transport, or fish screening and bypass.

The particular circumstances of this Project warrant creative solutions to provide real benefits to bull and westslope cutthroat trout. The strategies devised for anadromous fish at hydropower projects may not be applicable here. Habitat improvements off-site and, potentially, in Thompson Falls Reservoir may have more direct benefit for these species. We recommend the continuation of the collaborative, problem-solving approach that has been established at this Project to define effective solutions.

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Appendix A

Summary of turbine survival at the Federal Columbia River Power System Dams. From Ferguson et al (2005).

These dams are all six-bladed vertical axis Kaplans, except for Bonneville Dam turbines which have five blades.

Appendix A

Summary of turbine survival at the Federal Columbia River Power System Dams. From Ferguson et al (2005).

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Table 12. Turbine passage survival estimates for Snake and Columbia River dams. Abbreviations: PIT = Passive Integrated Transponder, B = Balloon, C = Coded-wire tag, R = Radio, SHT = steelhead, SYCS = subyearling Chinook salmon, YCS = yearling Chinook salmon, S = Single release, P = Paired release.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
Lower Granite Dam									
1988	Giorgi et al. 1988	PIT	P	YCS	Point; turbine intake	Downstream from Unit 3 turbine boil	Normal load response	Not estimated	0.831 (95% CI, 0.741–0.922)
1993	Iwamoto et al. 1994	PIT	P	YCS	Point; turbine intake	Lower tailrace midriver off juvenile bypass outfall	Normal load response	Not estimated	0.823 (SE 0.025)
1994	RMC Environmental et al. 1994	B	P	YCS	Point; turbine intake elevation 623 ft msl	Draft-tube exit	Normal load response	0.946 (90% CI, 0.955–0.992) 1 hr survival	Not estimated
1995	Normandeau Associates et al. 1995	B	P	YCS	Point; turbine intake elevation 603 ft msl	Draft-tube exit	18 kcfs Discharge	0.975 (90% CI, 0.955–0.992) 1 hr survival	Not estimated
					Point; turbine intake elevation 603 ft msl			0.975 (90% CI, 0.955–0.992) 1 hr survival	
					Point; turbine intake elevation 603 ft msl			0.953 (90% CI, 0.928–0.973) 1 hr survival	
					Point; turbine intake elevation 603 ft msl			0.972 (90% CI, 0.949–0.989) 1 hr survival	
					Point; turbine intake elevation 603 ft msl		13.5 kcfs Discharge	0.946 (90% CI, 0.922–0.965) 1 hr survival	
					Point; turbine intake elevation 603 ft msl		19 kcfs Discharge	0.949 (90% CI, 0.925–0.979) 1 hr survival	
					Pooled			0.961 (90% CI, 0.951–0.969) 1 hr survival	
1997	Muir et al. 2001	PIT	P	YCS	Point; turbine intake	Lower tailrace mid-river downstream of juvenile bypass outfall	Normal	Not estimated	0.927 (SE 0.027)
Little Goose Dam									
1993	Iwamoto et al. 1994	PIT	P	YCS	Point; turbine intake	Lower tailrace mid-river off juvenile bypass outfall	Normal load response	Not estimated	0.920 (SE 0.025)
1997	Muir et al. 1998	PIT	P	SHT	Point; turbine intake	Lower tailrace mid-river downstream of juvenile bypass outfall	Normal load response	Not estimated	0.934 (SE 0.016)
1997	Muir et al. 1998	PIT	P	YCS	Point; turbine intake	Lower tailrace mid-river off juvenile bypass outfall	Normal load response	Not estimated	0.920 (SE 0.025)

Table 12. Continued. Turbine passage survival estimates for Snake and Columbia River dams. Abbreviations: PIT = Passive Integrated Transponder, B = Balloon, C = Coded-wire tag, R = Radio, SHT = steelhead, SYCS = subyearling Chinook salmon, YCS = yearling Chinook salmon, S = Single release, P = Paired release.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
Lower Monumental Dam									
1997	Muir et al. 2001	PIT	P	YCS	Point; turbine intake	Lower tailrace mid-river downstream of juvenile bypass outfall	Normal load response	Not estimated	0.865 (SE 0.018)
Ice Harbor Dam									
1968	Long et al. 1968	--	P	Coho	Units 1–3	Frontroll	Normal load response	0.810–0.900	Not estimated
2003	Absolon et al. 2003a	PIT	P	YCS	Unit 1	Frontroll	Normal load response	Not estimated	0.89 (95% CI, 0.84–0.94)
2003	Absolon et al. 2003a	PIT	P	YCS	Unit 3	Frontroll	Normal load response	Not estimated	0.86 (95% CI, 0.81–0.90)
2003	Absolon et al. 2003a	PIT	P	SYCS	Unit 1	Frontroll	Normal load response	Not estimated	0.89 (95% CI, 0.85–0.94)
McNary Dam									
1955	Schoeneman et al. 1961	Tattoo	P	YCS	Hose-unit not specified	Control-not specified	0.80% wicket gate opening	Not estimated	0.87
1956	Schoeneman et al. 1961	Tattoo	P	YCS	Hose-unit not specified	Control-not specified	0.75% wicket gate opening	Not estimated	0.92
1999	Normandeau Associates et al. 1999	B	P	YCS	Turbine intake upstream of wicket gate	Stay vane- mid runner blade	12.0 kcfs	0.98 (90% CI, 0.955–1.005), 1hr survival	Not estimated
					Stay vane-runner tip			0.98 (90% CI, 0.955–1.005), 1 hr survival	
					Stay vane-runner hub			0.978 (90% CI, 0.952–1.004), 1 hr survival	
2002	Normandeau Assoc. et al. 2003	B	P	YCS	Point release all three intake bays	Draft-tube exit	8.0 kcfs	0.944 (90% CI, 0.914–0.977), 1 hr survival-April	Not estimated
							11.2 kcfs	0.955 (90% CI, 0.931–0.982), 1 hr survival-April 0.930 (90% CI, 0.900–0.970), 1 hr survival-May 0.944 (90% CI, 0.914–0.977), 1 hr survival-April	
							16.4 kcfs	0.945 (90% CI, 0.945–0.964), 1 hr survival-April 0.953 (90% CI, 0.915–0.994), 1 hr survival-April	

Table 12. Continued. Turbine passage survival estimates for Snake and Columbia River dams. Abbreviations: PIT = Passive Integrated Transponder, B = Balloon, C = Coded-wire tag, R = Radio, SHT = steelhead, SYCS = subyearling Chinook salmon, YCS = yearling Chinook salmon, S = Single release, P = Paired release.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
McNary Dam (Continued)									
2002	Absolon et al. 2002	R	P	YCS	Unit 9 point release all three intake bays	Tailrace 2 km below dam;	11.2 kcfs	Not estimated	To 15 km downstream: 0.871 (SE 0.016) To 46 km downstream: 0.858 (SE 0.034)
							16.4 kcfs		To 15 km downstream: 0.856 (SE 0.011) To 46 km downstream: 0.814 (SE 0.037)
2003	Peery and Bjornn 2003	R	P	SYCS	Unit 9 point release	Frontroll	Normal load response	Not estimated	0.816 (95% CI, 0.755–0.877
John Day Dam									
2002	Counihan et al. in prep. a	R	P	SHT	Rock Creek	Tailrace 1 km downstream from dam	Normal load response	Not estimated	Powerhouse 0.90 (95% CI, 0.81–0.97) Spill: 30 day/ 30 night 0.93 (95% CI, 0.85–1.00) Spill: 0 day/60 night
2002	Counihan et al. in prep. a	R	P	SYCS	Rock Creek	Tailrace 1 km downstream from dam	Normal load response	Not estimated	Powerhouse 0.97 (95% CI, 0.89–1.03) Spill: 30 day/30 night Powerhouse 0.87 (95% CI, 0.80–0.93) Spill: 0 day/60 night
2002	Counihan et al. in prep. a	R	P	YCS	Point; turbine intake U15	Tailrace 1 km downstream from dam	Normal load response	Not estimated	0.778 (SE 0.051) Spill: 0% day/ 60% night 0.832 (SE 0.042) Spill: 30% day/30% night
2003	Counihan et al. in prep. b	R	P	YCS	Point; turbine intake U4 and U15	Tailrace 1 km downstream from dam	Normal load response	Not estimated	0.820 (SE 0.043) Spill: 0% day/60% night 0.764 (SE 0.046) Spill: day/45% night
				SYCS					0.719 (SE 0.024) Spill: 0% day/60% night 0.722 (SE 0.024) Spill: 30% day/30% night

Table 12. Continued. Turbine passage survival estimates for Snake and Columbia River dams. Abbreviations: PIT = Passive Integrated Transponder, B = Balloon, C = Coded-wire tag, R = Radio, SHT = steelhead, SYCS = subyearling Chinook salmon, YCS = yearling Chinook salmon, S = Single release, P = Paired release.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
The Dalles Dam									
2000	Counihan et al. 2002	R	P	YCS	Point; several turbine intakes	Downstream of dam at proposed bypass outfall	Normal load response	Not estimated	0.869 (95% CI, 0.718–1.020)
2000	Absolon et al. 2002	PIT	P	YCS and Coho	Point; several turbine intakes	Downstream of dam at proposed bypass outfall	Normal load response	Not Estimated	0.790 (95% CI, 0.748–0.834) day 0.830 (95% CI, 0.785–0.878) night
				SYCS					0.791 (95% CI, 0.703–0.890) day 0.889 (95% CI, 0.790–1.000) night

Table 12. Continued. Turbine passage survival estimates for Snake and Columbia River dams. Abbreviations: PIT = Passive Integrated Transponder, B = Balloon, C = Coded-wire tag, R = Radio, SHT = steelhead, SYCS = subyearling Chinook salmon, YCS = yearling Chinook salmon, S = Single release, P = Paired release.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
Bonneville Dam First Powerhouse									
1939-1945	Holmes 1952	Fin Clip	P	SYCS	Various, upstream OR, WA, spillway, turbine	Various tailrace locations	Normal load response	Not estimated	0.88
1999-2000	Normandeau Associates et al. 2000	B	P	YCS	Stay vane-blade tip	Draft-tube exit	Original	0.947 (SE 0.0164)	Not estimated
					Stay vane-mid-blade		Kaplan	0.964 (SE 0.0144)	
					Stay vane-blade hub		6.2 kcfs	0.986 (SE 0.019)	
					Stay vane-blade tip	Draft-tube exit	Original	0.933 (SE 0.0166)	
					Stay vane-mid-blade		Kaplan	0.959 (SE 0.0137)	
					Stay vane-blade hub		7.0 kcfs	1.009 (SE 0.077)	
					Stay vane-blade tip	Draft-tube exit	Original	0.963 (SE 0.0145)	
					Stay vane-mid-blade		Kaplan	0.986 (SE 0.0106)	
					Stay vane-blade hub		10.5 kcfs	0.968 (SE 0.0106)	
					Stay vane-blade tip	Draft-tube exit	Original	0.909 (SE 0.0189)	
					Stay vane-mid-blade		Kaplan	0.968 (SE 0.0139)	
					Stay vane-blade hub		12.0 kcfs	1.004 (SE 0.0063)	
					Stay vane-blade tip	Draft-tube exit	MGR	0.955 (SE 0.0155)	
					Stay vane-mid-blade		Kaplan	0.981 (SE 0.0116)	
					Stay vane-blade hub		6.2 kcfs	0.986 (SE 0.018)	
					Stay vane-blade tip	Draft-tube exit	MGR	0.949 (SE 0.0149)	
					Stay vane-mid-blade		Kaplan	0.963 (SE 0.0134)	
					Stay vane-blade hub		7.0 kcfs	0.974 (SE 0.0144)	
					Stay vane-blade tip	Draft-tube exit	MGR Kaplan 10.5 kcfs	0.977 (SE0.0122)	
					Stay vane-mid-blade			0.977 (SE 0.0123)	
					Stay vane-blade hub			0.986 (SE 0.0119	
					Stay vane-blade tip	Draft-tube exit	MGR	0.947 (SE 0.0153)	
					Stay vane-mid-blade		Kaplan	0.977 (SE 0.0124)	
					Stay vane-blade hub		12.0 kcfs	0.980 (SE 0.0132)	
2002	Counihan et al. 2003	R	P	YCS	Point; turbine intake MGR unit	Tailrace downstream of turbine discharge frontroll	Normal load response	Not estimated	1.06 (95% CI, ± 0.057)
						Tailrace downstream of PH2 JBS outfall		Not estimated	1.01 (95% CI, ± 0.031)

Table 12. Continued. Turbine passage survival estimates for Snake and Columbia River dams. Abbreviations: PIT = Passive Integrated Transponder, B = Balloon, C = Coded-wire tag, R = Radio, SHT = steelhead, SYCS = subyearling Chinook salmon, YCS = yearling Chinook salmon, S = Single release, P = Paired release.

Year	Report	Tag type	Survival model	Test fish	Treatment release type/location	Reference release type/location	Turbine operation	Direct survival	Total survival
Bonneville Dam Second Powerhouse									
1988, 1989	Ledgerwood et al. 1990	CWT and Cold Brand	P	SYCS	Upper turbine — 1 m below gate slot	Tailrace 2.5 km downstream	Normal load response	Not estimated	0.91
					Lower turbine — 1 m below tip of STS				0.91
					Upper turbine — 1 m below gate slot	Frontroll			0.98
					Lower turbine — 1 m below tip of STS				0.97

Appendix B

Summary of spillway survival at the Federal Columbia River Power System Dams. From Ferguson et al (2005).

Table 1. Location, species and run type, study year, fish-marking method, spillbay, test conditions, and survival estimates for spillway passage at dams on the lower Snake and Columbia rivers. Dam abbreviations: LGR-Lower Granite; LGO-Little Goose; LMO-Lower Monumental; IHR-Ice Harbor; MCN-McNary; JDD-John Day; TDA-The Dalles; BON-Bonneville.

Dam	Species/run type	Year	Method	Flow deflector	Location	Conditions	Survival	Reference
LGR	Steelhead	1996	PIT tags	no	Bay 1	3.9 kcfs	1.01	Smith et al. 1998
LGR	Yearling Chinook salmon	2003	Radiotelemetry	yes	Bays 2–8	BiOp night	0.931	Plumb et al. 2004
LGO	Steelhead	1997	PIT tags	no	Bay 1	4.9–10.0 kcfs	1.004	Muir et al. 1998
LGO	Steelhead	1997	PIT tags	yes	Bay 3	4.9–10.0 kcfs	0.972	Muir et al. 1998
LGO	Yearling Chinook salmon	1993	PIT tags	yes	Bay 3	3.8 kcfs	1.021	Iwamoto et al. 1994
LMO	Coho salmon	1973	Freeze brands	yes*	Bay 2	4.5 kcfs	0.970	Long and Ossiander 1974
LMO	Coho salmon	1973	Freeze brands	yes	Bay 4	4.5 kcfs	1.100	Long and Ossiander 1974
LMO	Steelhead	1974	Freeze brands	yes	Bay 7	4.5 kcfs	0.978	Long et al. 1975
LMO	Steelhead	1974	Freeze brands	no	Bay 8	4.5 kcfs	0.755	Long et al. 1975
LMO	Subyearling Chinook salmon	1972	Freeze brands	yes*	Bay 2	13.1 kcfs	0.831	Long et al. 1972
LMO	Subyearling Chinook salmon	1972	Freeze brands	yes*	Bay 2	2.8 kcfs	0.840	Long et al. 1972
LMO	Yearling Chinook salmon	1994	PIT tags	yes	Bay 7	4.4–4.8 kcfs	0.927	Muir et al. 1995a
LMO	Yearling Chinook salmon	1994	PIT tags	no	Bay 8	4.4–4.8 kcfs	0.984	Muir et al. 1995a
LMO	Yearling Chinook salmon	2003	Radio, PIT tags	yes	Bays 4, 7	2.0–11.5 kcfs	0.900	Hockersmith et al. in prep.
IHR	Yearling Chinook salmon	2000	PIT tags	yes	Bays 3, 5, 7	BiOp night	0.978	Eppard et al. 2002a
IHR	Subyearling Chinook salmon	2000	PIT tags	yes	Bays 3, 5, 7	BiOp night	0.885	Eppard et al. 2002a
IHR	Yearling Chinook salmon	2002	PIT tags	yes	All bays	BiOp	0.892	Eppard et al. 2002b
IHR	Subyearling Chinook salmon	2002	PIT tags	yes	All bays	BiOp	0.894	Eppard et al. 2002b
IHR	Yearling Chinook salmon	2003	Radiotelemetry	yes	All bays	BiOp	0.948	Eppard et al. 2003
IHR	Yearling Chinook salmon	2003	Radiotelemetry	yes	All bays	50% spill	0.928	Eppard et al. 2003
MCN	Subyearling Chinook salmon	1955	Tattoo	no	Not specified	Not specified	0.980	Schoeneman et al. 1961
MCN	Subyearling Chinook salmon	1956	Tattoo	no	Not specified	Not specified	1.00	Schoeneman et al. 1961
MCN	Yearling Chinook salmon	2002	Radiotelemetry	yes	All bays	BiOp	0.976	Axel et al. in prep. a
MCN	Yearling Chinook salmon	2003	Radiotelemetry	yes	All bays	BiOp	0.928	Axel et al. in prep. b
MCN	Yearling Chinook salmon	2003	Balloon tag	yes	Bay 5	Various	>0.98	Heisey et al. 2003
JDD	Subyearling Chinook salmon	1979	Freeze brands	no	Bay 16	4.3 kcfs	0.98–1.2	Raymond and Sims 1980
JDD	Yearling Chinook salmon	2000	Radiotelemetry	no	All bays	0/60% spill	0.986	Counihan et al. 2001
JDD	Yearling Chinook salmon	2000	Radiotelemetry	no	All bays	30/60% spill	0.937	Counihan et al. 2001
JDD	Steelhead	2000	Radiotelemetry	no	All bays	0/60% spill	0.988	Counihan et al. 2001
JDD	Steelhead	2000	Radiotelemetry	no	All bays	30/60% spill	0.905	Counihan et al. 2001
JDD	Yearling Chinook salmon	2002	Radiotelemetry	no	All bays	0/54, 30/30	.993, 1.000	Counihan et al. in prep. a

Table 1. Continued. Location, species and run type, study year, fish-marking method, spillbay, test conditions, and survival estimates for spillway passage at dams on the lower Snake and Columbia rivers. Dam abbreviations: LGR-Lower Granite; LGO-Little Goose; LMO-Lower Monumental; IHR-Ice Harbor; MCN-McNary; JDD-John Day; TDA-The Dalles; BON-Bonneville.

Dam	Species/run type	Year	Method	Flow deflector	Location	Conditions	Survival	Reference
JDD	Subyearling Chinook salmon	2002	Radiotelemetry	no	All bays	0/54, 30/30	.985, 1.003	Counihan et al. in prep. a
JDD	Steelhead	2002	Radiotelemetry	no	All bays	0/54, 30/30	.958, .938	Counihan et al. in prep. a
JDD	Yearling Chinook salmon	2003	Radiotelemetry	no	All bays	0/45, 0/60	.939, .934	Counihan et al. in prep. b
JDD	Subyearling Chinook salmon	2003	Radiotelemetry	no	All bays	0/60, 30/30	.901, .955	Counihan et al. in prep. b
TDA	Subyearling Chinook salmon	1997	PIT tags	no	All bays	64% spill	0.92	Dawley et al. 1998b
TDA	Coho salmon	1997	PIT tags	no	All bays	64% spill	0.87	Dawley et al. 1998b
TDA	Subyearling Chinook salmon	1998	PIT tags	no	All bays	64% spill	0.75	Dawley et al. 2000a
TDA	Subyearling Chinook salmon	1998	PIT tags	no	All bays	30% spill	0.89	Dawley et al. 2000a
TDA	Coho salmon	1998	PIT tags	no	All bays	64% spill	0.89	Dawley et al. 2000a
TDA	Coho salmon	1998	PIT tags	no	All bays	30% spill	0.97	Dawley et al. 2000a
TDA	Subyearling Chinook salmon	1999	PIT tags	no	All bays	64% spill	0.96	Dawley et al. 2000b
TDA	Subyearling Chinook salmon	1999	PIT tags	no	All bays	30% spill	1.00	Dawley et al. 2000b
TDA	Coho salmon	1999	PIT tags	no	All bays	64% spill	0.93	Dawley et al. 2000b
TDA	Coho salmon	1999	PIT tags	no	All bays	30% spill	0.96	Dawley et al. 2000b
TDA	Yearling Chinook salmon	2000	PIT tags	no	All bays	BiOp	0.91	Absolon et al. 2002
TDA	Yearling Chinook salmon	2000	Radiotelemetry	no	All bays	BiOp	0.92	Counihan et al. 2002
TDA	Subyearling Chinook salmon	2000	PIT tags	no	All bays	BiOp	0.897	Absolon et al. 2002
TDA	Subyearling Chinook salmon	2000	Radiotelemetry	no	All bays	BiOp	0.826	Counihan et al. 2002
TDA	Yearling Chinook salmon	2002	Balloon tags	no	Bays 4, 9, 13	40% spill	98.4, 98.9, 95.6	Normandeau Assoc. Inc. 2003
TDA	Subyearling Chinook salmon	2002	Balloon tags	no	Bays 4, 9, 11	40% spill	93.6, 93.3, 92.6	Normandeau Assoc. Inc. 2003
TDA	Chinook salmon	2002	Balloon tags	no	Bay 2	4.5,12 kcfs	0.949, 1.00	Normandeau Assoc. et al. 2004
TDA	Chinook salmon	2002	Balloon tags	no	Bay 4	4.5,12 kcfs	0.965, 0.995	Normandeau Assoc. et al. 2004
TDA	Chinook salmon	2003	Balloon tags	no	Bay 2	9–21 kcfs	0.931, 1.00	Normandeau Assoc. et al. 2004
TDA	Chinook salmon	2003	Balloon tags	no	Bay 4	9–21 kcfs	0.966, 0.999	Normandeau Assoc. et al. 2004
BON	Subyearling Chinook salmon	1974	Freeze brands	no	Bay 11	13 kcfs	0.958	Johnsen and Dawley 1974
BON	Subyearling Chinook salmon	1974	Freeze brands	yes	Bay 14	13 kcfs	0.868	Johnsen and Dawley 1974
BON	Subyearling Chinook salmon	1989	CWT/freeze brand	yes	Bay 5	6.8 kcfs	0.9604	Ledgerwood et al. 1990
BON	Yearling Chinook salmon	2002	Radiotelemetry	yes	All bays	75 kcfs/cap	0.969	Counihan et al. 2003
BON	Yearling Chinook salmon	2002	Radiotelemetry	yes	All bays	24-hour cap	0.98	Counihan et al. 2003

*Flow deflector included dentates.